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Joint Optimization Of Maintenance and Reliability on Pedestal Crane Units to Improve Operational Efficiency

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A B S T R A C T

This research evaluates the maintenance and reliability of pedestal cranes in the Indonesian oil and gas industry, which is heavily affected by the harsh marine environment. The main objective is to improve operational efficiency through appropriate maintenance strategies. Based on operational data from January 2023 to October 2024, the initial reliability of the crane only reached 36.79%, with an MTBF of 272.89 hours. After implementing a lognormal distribution-based maintenance strategy, reliability increased to 42.88%, and Availability increased from 91.78% to 91.84%. This research identified the hydraulic system, running gear, and engine as the systems or components with the highest failure rates, accounting for more than 85% of the total downtime. Implementing a preventive maintenance strategy focused on critical components successfully reduced the MTTR from 24.44 hours to 24.25 hours. These results show a significant improvement in reducing downtime and extending the operational life of the crane.

1. INTRODUCTION

Pedestal cranes play an essential role in the oil and gas industry, especially in offshore drilling activities and logistics operations that support the supply chain. This type of crane is specifically designed for use in marine environments with harsh conditions, such as strong winds, high waves, and corrosive exposure to seawater. In offshore drilling operations, pedestal cranes lift and move heavy equipment and materials to and from the drilling platform, ensuring the workflow remains smooth and safe. In the oil and gas transportation and logistics sector, these cranes are also essential components in the loading and unloading process, both at offshore and onshore facilities, thus accelerating the material transfer process and increasing the efficiency of the supply chain [1].

However, pedestal crane maintenance in this environment is not easy. The harsh marine environment accelerates the corrosion rate of crane components, affecting component life and increasing the risk of mechanical failure. In addition, fluctuations in workload and high frequency of use increase the level of wear on the crane system. These conditions require companies to implement an effective maintenance program with the right preventive maintenance strategy to reduce the frequency of failures and expensive downtime [2, 3].

The operational reliability of pedestal cranes dramatically affects the overall process efficiency and worker safety. Crane failure can result in high downtime, disrupt production schedules, and increase operational costs. Furthermore, sudden component failure can endanger worker safety, especially in challenging operating conditions offshore. Therefore, optimal maintenance and appropriate reliability strategies are needed to ensure that cranes can operate continuously with minimal risk of failure. This research analyzes maintenance and reliability strategies that can be applied to pedestal cranes in the oil and gas industry, focusing on improving operational efficiency and occupational safety. In modern industries, reliability-centered maintenance (RCM) and reliability analysis have become essential elements to improve efficiency and reduce operational risks. Previous studies have discussed implementing reliability strategies in complex systems in diverse industrial environments. For example, Yang et al. (2023) focused on the overall line efficiency (OLE), which is the center of maintenance priority, by considering the operational reliability of the equipment [4]. Meanwhile, Zhang et al. (2023) studied a system with interdependent primary and supporting components and measured the influence of the relationships between these components on the system's overall reliability [5]. A similar approach was applied by Song et al. (2023), who used functional modeling to identify critical maintenance elements in the context of RCM in manufacturing systems [6].

Several other studies have focused more on silence and safety in the context of transportation systems. Igder et al. (2021) discussed improving the accuracy and safety of zero-emission ships through the RCM approach, which is relevant for the transportation industry, which is increasingly concerned about the desire [7]. On the other hand, Jafarpisheh et al. (2021) developed a hybrid RCM strategy for mining transportation machinery, focusing on operations in extreme mining environments [8].

Studies by Yang et al. (2022) and Koutsoyiannis (2022) adopted an accuracy-based mission and asset performance management (APM) approach to improve the effectiveness of RCM in multistate production systems and offshore production environments, in line with the extreme environmental challenges in the oil and gas industry [9, 10]. The analysis of performance performance in offshore environments was also studied by Cevasco et al. (2021), who focused on the trends of Availability, Availability, and maintainability (RAM) in offshore wind energy applications [11].

However, most of this literature focuses more on multistate systems, transportation equipment, or other offshore applications and does not focus on pedestal cranes in the oil and gas operational environment. More relevant research in the context of heavy conveying equipment in the oil and gas sector was conducted by Kumar et al. (2020), who reviewed the RAM analysis on draglines [12], and Ropero-Gaona and Lucas-Marmol (2023), who focused on mechanical pumping units in the oil extraction industry [13]. However, these studies have not included an in-depth analysis of pedestal cranes and the crucial maintenance factors in lifting operations in the oil and gas environment.

Meanwhile, research by Rebaiaia and Ait-Kadi (2022) developed an integrated maintenance strategy for optimizing maintenance costs of production systems [14], and Shahraki et al. (2020) and Vita et al. (2023) studied predictive maintenance to improve reliability in the context of stochastically dependent and distributed system components [15, 16]. However, there has been no approach that specifically examines pedestal cranes in the offshore oil and gas industry, which has unique maintenance challenges such as corrosion and high safety risks. This research aims to fill this gap by focusing on the maintenance and reliability of pedestal cranes in the oil and gas environment. This research is expected to provide comprehensive insights into improving operational efficiency and work safety in the offshore oil and gas industry by utilizing reliability analysis and reliability-based maintenance strategies.

2. THEORY

2.1 Reliability and failure distribution

Failure distributions are used to model the time to failure of components in a system, such as a pedestal crane, so that operators can understand and predict component failure patterns. The following are the main distributions that are often used [17, 18]:

a. Normal distribution

The normal or Gaussian distribution is generally applied when a component failure occurs due to symmetrically distributed wear around a specific time mean. This distribution may apply to components that exhibit slow and consistent degradation in a pedestal crane, such as structural components. The normal distribution is helpful for determining the optimal maintenance time based on the standard deviation of component failures [19].

b. Lognormal distribution

The lognormal distribution is often used for components whose failures increase over time. In this distribution, failures usually begin after a particular service life and increase rapidly. In the context of cranes, corroded cables or mechanical components may follow a lognormal distribution, as these components tend to degrade slowly at first but then experience significant failure [20].

c. Exponential distribution

Exponential distribution is often used for components with a constant failure rate over time. In this distribution, failure tends to be random, without the influence of age or time. Exponential distribution is often applied to electronic components on pedestal cranes that are not affected by material degradation or wear but by unexpected external factors [21].

d. Weibull distribution

The Weibull distribution is flexible and suitable for various failure patterns, whether experiencing early wear, stability, or wear in the final phase. The Weibull parameter, shape parameter (β), determines the shape of the failure curve [22, 23]:
If $\beta < 1$, the component experiences early failure.
If $\beta = 1$, failure occurs randomly (similar to the exponential distribution).
If $\beta > 1$, failure increases over time (degradation).

Probability distributions applied to cranes can help identify specific failure patterns for each component or system, allowing the maintenance department to plan maintenance before failure.

2.2 Maintenance strategies

Maintenance strategies are designed to ensure that equipment operates at maximum reliability. In the oil and gas industry, three main approaches to maintenance are [24, 25]:

a. Preventive maintenance (PM)

Preventive maintenance is performed periodically action before failure occurs, based on a predetermined time or usage [26, 27]. In pedestal cranes, this maintenance includes inspection and replacement of components prone to failure, such as cables and bearings. Preventive maintenance aims to reduce unexpected downtime and prevent failures that could impact operational efficiency [28].

b. Corrective maintenance (CM)

Corrective maintenance is maintenance that is performed after a component has failed. In the context of cranes, corrective maintenance can include the immediate repair or replacement of components that have failed due to sudden failure. Although effective in restoring function, corrective maintenance can cause long downtimes, so it is only applied to non-critical components or in urgent situations [29].

2.3 Reliability performance measurement

Reliability performance measurements are essential to assess maintenance effectiveness and operational reliability. Three key metrics are [30]:

a. Mean time between failures (MTBF)

MTBF is the average time between successive failures in a component or system. This metric indicates the reliability of the equipment. The higher the MTBF value, the more reliable the component or system is. In pedestal cranes, MTBF is useful for planning component replacement schedules to minimize downtime [31, 32].

b. Mean time to repair (MTTR)

MTTR is the average time required to repair a component after a failure. A low MTTR indicates efficient repairability. In crane operations, a low MTTR is critical to minimize the impact of downtime on production and logistics processes [33].

c. Availability

Availability measures the percentage of time that equipment is available compared to total operational time. The formula for calculating Availability is [34, 35]:

$$A = \frac{MTBF}{MTBF+MTTR} \quad (1)$$

In the context of cranes, high Availability indicates the readiness of the equipment to be used at any time, which is essential in the oil and gas industry, where operational delays can cause significant losses.

2.4 Pareto principle

The Pareto Principle, also known as the 80/20 rule, states that 80% of the impacts result from 20% of the causes. In the context of pedestal crane maintenance, this principle helps operators focus on the most critical components or problems contributing to the most failures or losses. By applying Pareto analysis, operators can prioritize maintenance on frequently failing components, improving overall reliability [36].

2.5 Failure mode and effects analysis (FMEA)

FMEA is a risk analysis method used to identify and evaluate potential failures in a system and their impact on operations. The steps of FMEA include [37]:

a. Identify Failure Modes

Determine all possible failure modes for each crane component, such as cable failure, drive system wear, or electronic control problems.

b. Failure Impact Evaluation

Assess the impact of each failure on the crane system. This impact can be downtime, safety risks, or decreased operational efficiency.

c. Risk Assessment and Prioritization

Use metrics such as severity, occurrence, and detectability to assess the risk of each failure mode. It helps determine maintenance priorities by focusing on the most vulnerable components that impact crane reliability.

d. Mitigation Action Development

Based on the risk analysis, mitigation actions or maintenance strategies are developed to reduce the likelihood of failure or its impact, such as scheduled component replacement or additional inspections of vulnerable components.

3. METHODOLOGY

This riset begins with the focus of the riset, namely improving reliability and reducing downtime through preventive, corrective, and imperfect maintenance strategies, with the Object to be analyzed, namely the pedestal crane. Then, collect data such as operation and maintenance patterns, the current maintenance strategy's effectiveness, and the pedestal crane's reliability. Furthermore, the reliability analysis uses a probability distribution to find the reliability value, MTBF, MTTR, and availability. The next stage is to carry out simulations and iterations by implementing the right maintenance strategy by referring to the maintenance time interval with a comparison of the crane's condition before and after the implementation of the new maintenance strategy to see if there is an increase in reliability, MTBF, MTTR, or availability. Furthermore, FMEA and the Pareto Principle should be applied to identify and group the risks of failure in each component, determine mitigation actions, and prioritize components with the highest risk level to improve overall maintenance effectiveness. In addition, a discussion of the main findings of each analysis of how the strategy contributes to reducing downtime and improving operational reliability is better. Finally, a conclusion that links the analysis results with the research objectives is presented, and a summary of how improvements are achieved in reliability and maintenance performance is provided.

4. RESULTS AND DISCUSSION

4.1 Operation and maintenance data on pedestal cranes

The following is the operation and maintenance data on pedestal cranes obtained from the maintenance division and the results of interviews with operators and mechanics who are on duty at the work location along with those collected from maintenance and operation records from January 1, 2023, to October 31, 2024, at oil and gas companies in Indonesia:

Fig. 1. Pedestal Crane.

Table 1. Pedestal crane maintenance data (January 1, 2023 - October 31, 2024).

No	Type	Maintenance Action	TBF (Hours)	TTR (Hours)
1	PM	PM boom system (lubrication)	205	16
2	CM	Main hydraulic pump repair (leakage)	355	80
3	PM	PM engine (tune-up)	390	16
4	CM	Replacement of anti-two-block wire rope (broken cable)	273	32
5	PM	PM mechanical system (lubrication of swing gear, pulley, etc.)	140	16
6	CM	Replacement of hydraulic hose (line control valve to winch due to fatigue)	200	24
7	PM	PM running gear equipment (visual inspection of hook, wire rope, pulley, etc.)	210	16
...	...	...	...	...
17	PM	PM work equipment (visual inspection of hook, wire rope, pulley, etc.)	152	8
18	CM	Main hoist wire rope replacement (cable broken)	254	24
Total			4912	440

Table 1 shows the data on the number of incidents, as many as 18 incidents during the data collection period, the type of maintenance carried out consisting of PM and CM, the cause of failure and corrective actions, the duration of operation before failure (TBF) and the duration of downtime for corrective actions (TTR). Based on the operation and maintenance data, the initial or current conditions were obtained using the exponential equation, commonly used for initial reliability analysis [38], 39] at t = MTBF.

$$\mathrm{MTBF}=\frac{\sum \mathrm{TBF}}{\mathrm{N_{failure}}} \tag{2}$$

$$\mathrm{MTTR}=\frac{\sum \mathrm{TTR}}{\mathrm{N_{failure}}} \tag{3}$$

$$\lambda=\frac{1}{\mathrm{MTBF}} \text{ or } \lambda=\frac{1}{MTTR} \tag{4}$$

$$R(t)=e^{-\lambda t} \tag{5}$$

Table 2. Results of initial condition calculations for pedestal crane.

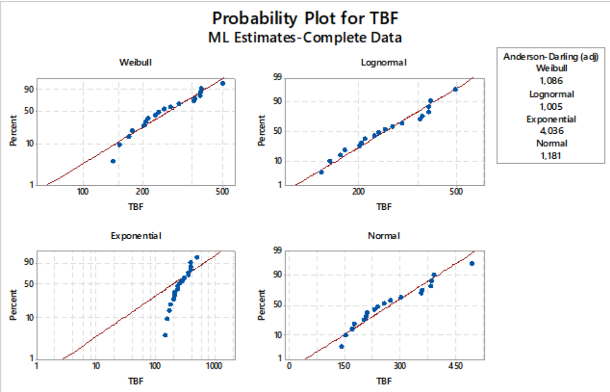
R	λ	MTBF	MTTR	A
36,79%	0,0037	272,89	24,44	91,78%

In Table 2, the initial condition of the pedestal crane is R = 36.79% with λ = 0.0037 and an MTBF value of 272.89 hours, an MTTR of 24.44 hours, and an A value of 91.78%. Next, a reliability analysis will be carried out using a probability distribution.

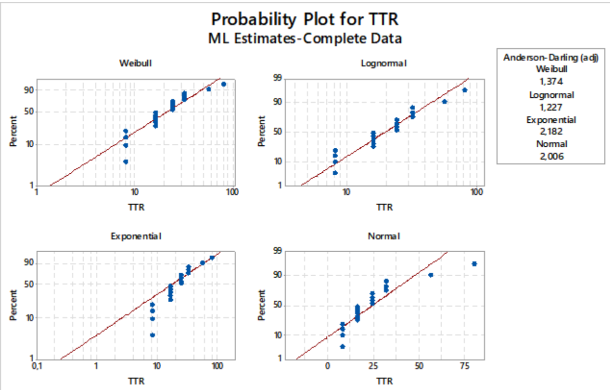
4.2 Reliability analysis with the probability distribution

Searching for the appropriate distribution and its parameters for previous operation and maintenance data using the help of Minitab 18 software [40]. Selection of distribution (Weibull, exponential, lognormal, and normal) using maximum likelihood concerning the smallest Anderson Darling (AD) value [41]. The search results are shown in Figure 2.

Figure 2 shows that the smallest AD value in the lognormal distribution in TBF and TTR data with values 1.005 and 1.227 is known. Therefore, a reliability analysis will be carried out using lognormal distribution. Before conducting the analysis, a search for the scale parameter (s = α) and location parameter (tmed) was carried out.
The search results are as shown in Figure 3.

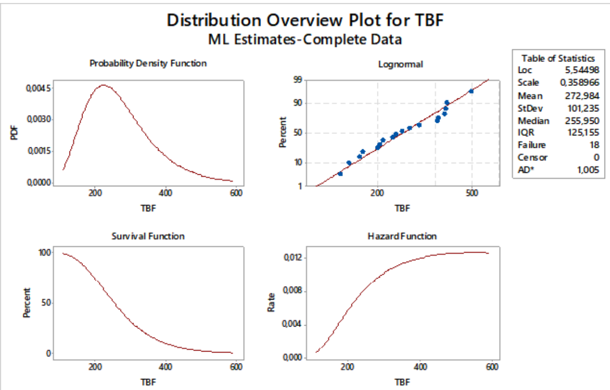


(a) Probability Plot for TBF

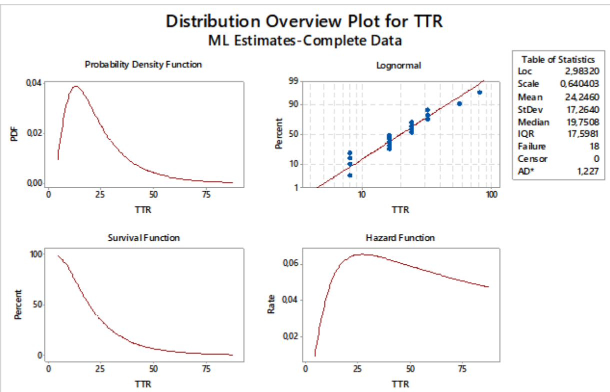


(b) Probability Plot for TTR

Fig. 2. Probability Plot for TBF and TTR.



(a) TBF data parameters



(b) TTR data parameters

Fig 3. TBF and TTR data parameters are lognormal distribution.

Figure 3 shows that TBF data has parameter values s = 0.358966 and tmed = 255.95. TTR data has parameter values s = 0.640403 and tmed = 19.7508. After obtaining the parameter values, the next step is calculating reliability, MTBF, MTTR, and Availability. The calculation results use the formula in equation 1 for Availability, while for reliability, MTBF and MTTR are as follows [42-44]:

$$R(t) = 1 - \Phi\left(\frac{1}{s} \times ln\frac{t}{t_{med}}\right) \tag{6}$$

$$MTBF = MTTR = t_{med} \times e^{\left(\frac{s^2}{2}\right)} \tag{7}$$

The calculation results are shown in Table 3 as follows:

Table 3. Results of pedestal crane calculations using the lognormal equation at t = MTBF.

MTBF	MTTR	A	R
272,98	24,25	91,84%	42,88%

It can be seen in Table 3 that there is an increase in MTBF time, A and R values , and a decrease in MTTR time. Analysis positively impacts reducing downtime, increasing availability, and increasing reliability. However, the R-value is still at 42.88%. Furthermore, further simulations were carried out to confirm the optimum value of the R and A conditions of the pedestal crane.

4.3 Simulation and iteration for maintenance schedule optimization.

In the lognormal equation, a simulation is carried out to obtain an ideal schedule for implementing maintenance on the pedestal crane. The following are the results of the simulation and iteration that carry out the implementation starting at t = 152 hours and multiples of 8 hours for TBF and 24 hours for TTR. Implementing t = 152 hours refers to the lowest TBF value of 152 hours.

Table 4. Simulation and iteration of pedestal crane maintenance time.

t = TBF	t = TTR	A	R
152	24,00	86,36%	92,67%
160	24,00	86,96%	90,47%
168	24,00	87,50%	87,96%
176	24,00	88,00%	85,16%
...	...	...	...
272	24,00	91,89%	43,27%
MTBF = 272,98	MTTR = 24,25	91,84%	42,88%
280	24,00	92,11%	40,12%
288	24,00	92,31%	37,12%
...	...	...	...
344	24,00	93,48%	20,51%
352	24,00	93,62%	18,74%
360	24,00	93,75%	17,10%

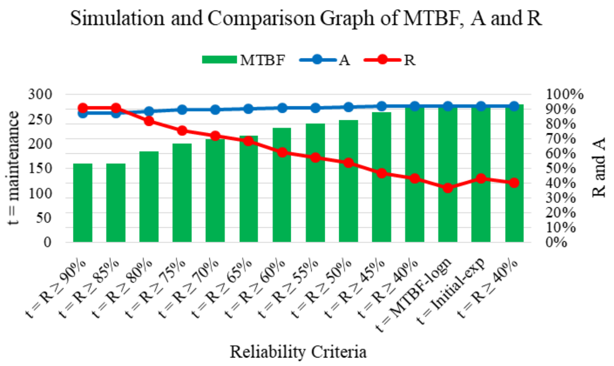


Fig. 4. Simulation and Comparison Graph of MTBF, A and R.

Based on the iteration and simulation results shown in Table 4 and Figure 4, it is known that t at MTBF (272.98 hours) and MTTR at 24 hours can increase the A value by 0.06% and R by 6.09%.

4.4 Application of FMEA and Pareto Principle

The scoring of the Severity (S), Occurrence (O), and Detection (D) criteria is as follows:

1. Severity (S): Describes the severity of the failure's effect on safety and operational performance.

Value 9-10: Failure that impacts safety or causes operations to stop completely, for example, wire rope failure that can cause accidents.
Value 7-8: Failure that has a major impact on the system's main function, such as a hydraulic pump leak that causes failure in the boom or hoist function.
Value 5-6: Failure that has a moderate impact, such as engine problems that affect efficiency but do not cause operations to stop.
Value 3-4: Minor failure that does not affect the overall operation too much, for example, lack of lubrication that only reduces the efficiency of a small part of the system.
Value 1-2: The impact of failure is very small or has almost no effect.

2. Occurrence (O): Describes the frequency or likelihood of failure.

Value 5: Failure often occurs, for example, components that wear out quickly due to intensive use.
Value 4: Failures occur frequently, but not every cycle of use, such as a hydraulic pump that may leak due to age.
Value 3: Failures, such as cables, experience material fatigue over time and occur occasionally.
Value 2: Failures, such as a load moment indicator error, occur infrequently due to incorrect settings.
Value 1: Failures occur very rarely.

3. Detection (D): Describes the ease of detecting failures before they impact operations.

Value 5: Failures are difficult to detect before they impact operations, such as internal leaks in a hydraulic system that are only visible when severe.
Value 4: Failures are difficult to detect, such as wear on internal components that are difficult to observe without disassembly.
Value 3: Failures can be detected by routine inspection or monitoring, such as visual inspection of cables.
Value 2: Failures are relatively easily detected by simple testing or direct inspection.
Value 1: Failures are very easily detected by monitoring or automatic indicators.

Here are the results of FMEA and Pareto with S, O, and D values and integrated downtime data.

Table 5. FMEA and Pareto with S, O, and D values and integrated downtime data.

No	Component/ System	Failure Mode	S	O	D
1	Hydraulic System	Hydraulic pump leaks, hose leaks	8	2	4
2	Running Gear	Running gear and mechanical system deformation (bent, broken wire, worn, kink)	9	3	3
3	Engine	The engine is not optimal	6	2	3
4	Safety device	Anti-two block wire rope broken, LMI accuracy reduced	8	2	3
5	Boom System	Lack of lubrication	7	1	3

No	RPN	Downtime (hours)	Downtime Contribution	Cumulative Percentage
1	96	160	36,36%	36,36%
2	81	144	32,73%	69,09%
3	54	72	16,36%	85,45%
4	48	40	9,09%	94,55%
5	21	24	5,45%	100,00%

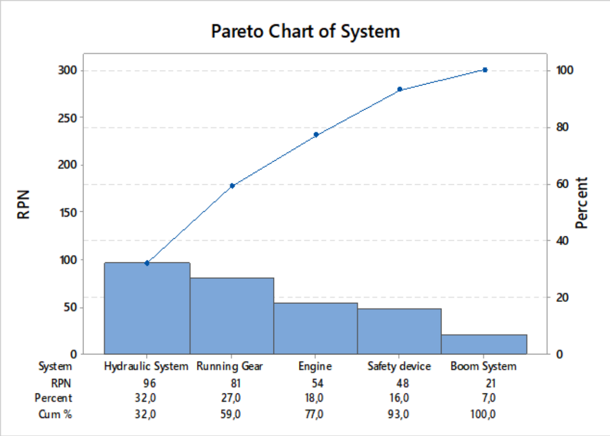


Fig. 5. Pareto principle based on RPN value.

In Figure 5 and Table 5, the hydraulic system has the highest RPN value (96) and the largest downtime (160 hours). Failures in this system (internal leaks and damage to the inside of the pump) are difficult to detect (D = 4). Mitigation of the hydraulic system is to conduct periodic inspections of the hydraulic system with a focus on areas prone to leaks. Running gear has a high RPN (81) and a major operational safety impact. Visual inspection of wire rope and periodic replacement are the main mitigation steps. The engine has a high RPN value (72), requiring standard maintenance to maintain operational performance. With the combination of these three systems, more than 85% of downtime comes from three main categories: hydraulic system, running gear, and engine. Analysis shows that improving these three categories can significantly reduce crane downtime. Although safety devices and boom systems have lower RPN and downtime, they still need to be maintained to avoid a domino effect on crane operations.

4.5 Discussion

The results of this riset show significant differences compared to previous studies related to the maintenance and reliability of pedestal cranes in the oil and gas industry. This research uses a reliability analysis based on lognormal distribution, which differs from previous studies that use exponential or normal distribution approaches and Weibull. The analysis results show an increase in reliability from 36.79% to 42.88%, which is higher than several previous studies that only achieved an increase in reliability below 40% in similar environmental conditions.

Previous studies often focus on time-based maintenance methods that rely on routine schedules without considering the actual condition of the components. In this riset, the reliability-centered maintenance approach proved to be more effective. For example, applying a preventive maintenance strategy based on a lognormal distribution reduced MTTR from 24.44 hours to 24.25 hours, while previous studies showed a less consistent decrease in MTTR when using the exponential approach.

Another prominent finding is identifying critical components such as the hydraulic system, running gear, and engine, which account for more than 85% of the total downtime. The analysis differs from previous research results that generally focus on structural component failures without paying more attention to dynamic aspects such as hydraulics, mechanical systems, and prime movers. With a maintenance strategy focused on these components, this riset managed to increase availability from 91.78% to 91.84%, slightly higher than the average results of previous research in the offshore environment, which tends to be stable at 90-91%.

In addition, this riset adopts the Failure Mode and Effects Analysis (FMEA) method and the Pareto principle, which have not been widely reviewed in previous research. As a result, this riset provides more focused guidance to reduce downtime by prioritizing repairs on components with the highest RPN (Risk Priority Number) values, which is an important innovation in the context of maintenance in the offshore oil and gas environment.

Overall, this riset confirms the effectiveness of a reliability-based maintenance strategy and shows a greater increase in operational efficiency compared to traditional approaches, making a real contribution to maintenance optimization in the oil and gas industry sector.

5. CONCLUSION

The main findings of this study highlight the importance of focusing on critical components such as hydraulic systems, running gear, and engines, which are responsible for more than 85% of downtime. With a more planned preventive maintenance strategy, companies can reduce the risk of major failures that can disrupt operations while improving safety and performance. This research provides evidence that reliability-based maintenance can be an efficient solution in facing the challenges of the harsh offshore environment. With the results obtained, this study offers valuable guidance for oil and gas companies to optimize maintenance strategies, improve operational performance, and reduce future risks. In addition, this study successfully identified critical components on pedestal cranes operating in the oil and gas industry environment. Using a lognormal distribution-based reliability analysis and FMEA approach, this study provides insight into the importance of a planned preventive maintenance strategy. The implementation of the strategy successfully increased reliability and availability values, although there is still room for further improvement, especially in the aspect of operational reliability, which is still low. For further research, it is recommended to focus on implementing predictive maintenance and the economic impact of downtime and repairs. In addition, it is also possible to conduct comparative research on maintenance strategies that compare the effectiveness of reliability-based maintenance strategies with predictive maintenance methods to see which strategy is more efficient in the context of the oil and gas industry.

REFERENCES

[1] J. Krukowski, A. Maczyński, and M. Szczotka, “The influence of a shock absorber on dynamics of an offshore pedestal crane,” *J. Theor. Appl. Mech.*, vol. 50, no. 4, pp. 953–966, 2012.

[2] J. Krukowski and A. Maczyński, “Application of the rigid finite element method for modelling an offshore pedestal crane,” *Arch. Mech. Eng.*, vol. 60, no. 3, pp. 451–471, 2013, doi: 10.2478/meceng-2013-0028.

[3] M. Fonte, M. Freitas, B. Li, P. Duarte, and L. Reis, “Welding assessment of a damaged crane pedestal of a container ship,” *Cienc. e Tecnol. dos Mater.*, vol. 27, no. 1, pp. 10–14, 2015, doi: 10.1016/j.ctmat.2015.04.001.

[4] Z. Yang, J. Li, C. Chen, J. He, H. Tian, and L. Yu, “A study on overall line efficiency (OLE) centered production line maintenance prioritization considering equipment operational reliability,” *Int. J. Adv. Manuf. Technol.*, vol. 124, no. 11–12, pp. 3783–3794, 2023, doi: 10.1007/s00170-021-07547-9.

[5] N. Zhang, J. Zhang, and J. Shen, “Reliability and maintenance analysis of a system with dependent main and auxiliary components,” *Comput. Ind. Eng.*, vol. 179, no. 109188, 2023, doi: https://doi.org/10.1016/j.cie.2023.109188.

[6] M. Song, X. Zhang, and M. Lind, “Automatic identification of maintenance significant items in reliability centered maintenance analysis by using functional modeling and reasoning,” *Comput. Ind. Eng.*, vol. 182, no. March, p. 109409, 2023, doi: 10.1016/j.cie.2023.109409.

[7] M. A. Igder, M. Rafiei, J. Boudjadar, and M. H. Khooban, “Reliability and Safety Improvement of Emission-Free Ships: Systemic Reliability-Centered Maintenance,” *IEEE Trans. Transp. Electrif.*, vol. 7, no. 1, pp. 256–266, 2021, doi: 10.1109/TTE.2020.3030082.

[8] R. Jafarpisheh, M. Karbasian, and M. Asadpour, “A hybrid reliability-centered maintenance approach for mining transportation machines: a real case in Esfahan,” *Int. J. Qual. Reliab. Manag.*, vol. 3, no. 7, pp. 1550–1575, 2021, doi: https://doi.org/10.1108/IJQRM-09-2020-0309.

[9] X. Yang, Y. He, D. Zhou, and X. Zheng, “Mission reliability–centered maintenance approach based on quality stochastic flow network for multistate manufacturing systems,” *Eksploat. i Niezawodn.*, vol. 24, no. 3, pp. 455–467, 2022, doi: 10.17531/ein.2022.3.7.

[10] L. Koutsoyiannis, “Using Asset Performance Management APM to Deliver a Reliability Centered Maintenance RCM Approach in an Offshore Production Environment,” in *Offshore Technology Conference*, 2022, p. OTC-32137-MS. doi: https://doi.org/10.4043/32137-MS.

[11] D. Cevasco, S. Koukoura, and A. J. Kolios, “Reliability, availability, maintainability data review for the identification of trends in offshore wind energy applications,” *Renew. Sustain. Energy Rev.*, vol. 136, no. October 2020, p. 110414, 2021, doi: 10.1016/j.rser.2020.110414.

[12] D. Kumar, S. Gupta, and P. K. Yadav, “Reliability, availability and maintainability (RAM) analysis of a dragline,” *J. Mines, Met. Fuels*, vol. 68, no. 2, pp. 68–77, 2020.

[13] C. A. Ropero-Gaona and A. Lucas-Marmol, “Analysis of reliability based on preventive maintenance of failures in the VSH-2 mechanical pumping unit for oil extraction,” *Int. J. Syst. Assur. Eng. Manag.*, vol. 14, pp. 2695–2719, 2023, doi: https://doi.org/10.1007/s13198-023-02125-6.

[14] M. L. Rebaiaia and D. Ait-Kadi, “A new integrated strategy for optimizing the maintenance cost of Production systems using reliability importance measures,” *IFAC-PapersOnLine*, vol. 55, no. 10,

pp. 1569–1575, 2022, doi: 10.1016/j.ifacol.2022.09.614.

[15] A. F. Shahraki, O. P. Yadav, and C. Vogiatzis, "Selective maintenance optimization for multi-state systems considering stochastically dependent components and stochastic imperfect maintenance actions," *Reliab. Eng. Syst. Saf.*, vol. 196, p. 106738, 2020, doi: 10.1016/j.ress.2019.106738.

[16] V. Vita, G. Fotis, V. Chobanov, C. Pavlatos, and V. Mladenov, "Predictive Maintenance for Distribution System Operators in Increasing Transformers' Reliability," *Electron.*, vol. 12, no. 6, 2023, doi: 10.3390/electronics12061356.

[17] H. P. Jagtap, A. K. Bewoor, R. Kumar, M. H. Ahmadi, M. El Haj Assad, and M. Sharifpur, "RAM analysis and availability optimization of thermal power plant water circulation system using PSO," *Energy Reports*, vol. 7, pp. 1133–1153, 2021, doi: 10.1016/j.egyr.2020.12.025.

[18] J. Wang, Q. Qiu, H. Wang, and C. Lin, "Optimal condition-based preventive maintenance policy for balanced systems," *Reliab. Eng. Syst. Saf.*, vol. 211, 2021.

[19] V. Lukinskiy, V. Lukinskiy, and B. Sokolov, "Control of inventory dynamics: A survey of special cases for products with low demand," *Annu. Rev. Control*, vol. 49, no. xxxx, pp. 306–320, 2020, doi: 10.1016/j.arcontrol.2020.04.005.

[20] M. J. Rahimdel, M. Ataei, R. Khalokakaei, and S. H. Hoseinie, "Reliability-based maintenance scheduling of hydraulic system of rotary drilling machines," *Int. J. Min. Sci. Technol.*, vol. 23, no. 5, pp. 771–775, 2013, doi: 10.1016/j.ijmst.2013.08.023.

[21] P. Tsarouhas, "Reliability, availability and maintainability (RAM) analysis for wine packaging production line," *Int. J. Qual. Reliab. Manag.*, vol. 35, no. 3, pp. 821–842, 2018, doi: 10.1108/IJQRM-02-2017-0026.

[22] M. Bulut and E. Özcan, "A new approach to determine maintenance periods of the most critical hydroelectric power plant equipment," *Reliab. Eng. Syst. Saf.*, vol. 205, no. September 2020, p. 107238, 2021, doi: 10.1016/j.ress.2020.107238.

[23] J. M. Wakiru, L. Pintelon, P. Muchiri, and P. Chemweno, "Integrated maintenance policies for performance improvement of a multi-unit repairable, one product manufacturing system," *Prod. Plan. Control*, vol. 0, no. 0, pp. 1–21, 2020, doi: 10.1080/09537287.2020.1736684.

[24] F. Zhang, J. Shen, H. Liao, and Y. Ma, "Optimal preventive maintenance policy for a system subject to two-phase imperfect inspections," *Reliab. Eng. Syst. Saf.*, vol. 205, no. December 2019, p. 107254, 2021, doi: 10.1016/j.ress.2020.107254.

[25] S. Al-Toubi, P. B. Alkali, P. D. Harrison, and P. S. C.V., "Identifying Centrifugal Pump Effectiveness Through Utilizing OEE Measures as a Basis Towards Optimum Process Stability," *Int. J. Recent Technol. Eng.*, vol. 11, no. 2, pp. 18–20, 2022, doi: 10.35940/ijrte.b7044.0711222.

[26] P. Nganga, J. Wakiru, and P. Muchiri, "Maintenance Performance Optimization for Critical Subsystems in Cement Pre-Grinding Section: A Case Study Approach," *Int. J. Ind. Eng. Manag.*, vol. 14, no. 3, pp. 200–213, 2023, doi: 10.24867/IJIEM-2023-3-333.

[27] G. A. Kechagias, A. C. Diamantidis, T. D. Dimitrakos, and M. Tsakalerou, "Optimal maintenance of deteriorating equipment using semi-Markov decision processes and linear programming," *Int. J. Ind. Eng. Manag.*, vol. 15, no. 1, pp. 81–95, 2024, doi: 10.24867/IJIEM-2024-1-349.

[28] G. D. Putnik, L. Varela, P. Pinheiro, S. Maia, and C. Alves, "Identification Of The Major Trends In Current Maintenance Policies Using Lda Methodology For Semantic Analysis Of The Published Research Results," *Int. J. Qual. Res.*, vol. 18, no. 2, pp. 587–602, 2024, doi: 10.24874/IJQR18.02-17.

[29] J. Geisbush and S. T. Ariaratnam, "Reliability centered maintenance (RCM): literature review of current industry state of practice," *J. Qual. Maint. Eng.*, vol. 29, no. 2, pp. 313–337, 2023, doi: https://doi.org/10.1108/JQME-02-2021-0018.

[30] S. S. Patil, A. K. Bewoor, and R. B. Patil, "Availability Analysis of a Steam Boiler in Textile Process Industries Using Failure and Repair Data: A Case Study," *ASCE-ASME J Risk Uncert Engrg Sys Part B Mech Engrg*, vol. 7, no. 2, 2021, doi: 10.1115/1.4049007.

[31] P. Tsarouhas, "Improving operation of the croissant production line through overall equipment effectiveness (OEE): A case study," *Int. J. Product. Perform. Manag.*, vol. 68, no. 1, pp. 88–108, 2019, doi: 10.1108/IJPPM-02-2018-0060.

[32] A. Tayal, N. S. Kalsi, M. K. Gupta, D. Y. Pimenov, M. Sarikaya, and C. I. Pruncu, "Effectiveness improvement in manufacturing industry; trilogy study and open innovation dynamics," *J. Open Innov. Technol. Mark. Complex.*, vol. 7, no. 1, pp. 1–21, 2021, doi: 10.3390/joitmc7010007.

[33] T. A. Souza, G. L. Roehe Vaccaro, and R. M. Lima, "Operating room effectiveness: a lean health-care performance indicator," *Int. J. Lean Six Sigma*, vol. 11, no. 5, pp. 987–1002, 2020, doi: 10.1108/IJLSS-12-2017-0141.

[34] C. Ruiz, E. Pohl, and H. Liao, "Bayesian degradation modelling for spare parts inventory management," *IMA J. Manag. Math.*, vol. 32, no. 1, pp. 31–49, 2021, doi: 10.1093/imaman/dpaa008.

[35] B. Samatemba, L. Zhang, and B. Besa, "Evaluating and optimizing the effectiveness of mining equipment; the case of Chibuluma South underground mine," *J. Clean. Prod.*, vol. 252, 2020, doi: 10.1016/j.jclepro.2019.119697.

[36] P. Gao, Y. Wang, H. Wang, C. Song, S. Ye, and X. Wang, "A Pareto front-based approach for constructing composite index of sustainability without weights: A comparative study of implementations," *Ecol. Indic.*, vol. 155, no. 110919, 2023, doi: 10.1016/j.ecolind.2023.110919.

[37] B. Salah, M. Alnahhal, and M. Ali, "Risk prioritization using a modified FMEA analysis in industry 4.0," *J. Eng. Res.*, vol. 11, no. 4, pp. 460–468, 2023, doi: 10.1016/j.jer.2023.07.001.

[38] F. Rahman, S. Sugiono, A. A. Sonief, and O. Novareza, "Availability Optimization of the Mobile Crane Using Approach Reliability Engineering at Oil and Gas Company," *Math. Model. Eng. Probl.*, vol. 9, no. 1, pp. 178–185, 2022, doi: 10.18280/mmep.090122.

[39] F. Rahman, S. Sugiono, S. As'ad, and O. Novareza, "Optimization maintenance performance level through collaboration of overall equipment effectiveness and machine reliability," *J. Appl. Eng. Sci.*, vol. 20, no. 3, pp. 917–936, 2022, doi: 10.5937/jaes0-35189.

[40] I. Minitab, "MINITAB [Internet]," 2020. http://www.minitab.com/en-US/products/minitab/ (accessed Jan. 26, 2022).

[41] "Anderson–Darling Test BT - The Concise Encyclopedia of Statistics," New York, NY: Springer New York, 2008, pp. 12–14. doi: 10.1007/978-0-387-32833-1_11.

[42] C. E. Ebeling, *An Introduction to Reliability and Maintainability Engineering*. McGraw-Hill Science, 1997.

[43] B. S. Dhillon, *Engineering maintenance: A modern approach*. 2002.

[44] M. Ben-Daya, S. O. Duffuaa, A. Raouf, J. Knezevic, and D. Ait-Kadi, *Handbook of Maintenance Management and Engineering*. 2009.