

Availability Optimization of the Crawler Crane Using Approach Reliability Engineering at Logistic Shore Base Company in Indonesia

Tiara Shinta Raharkandi, Dendi P. Ishak
Industrial Engineering Department, Faculty of Engineering
Universitas Indonesia
Salemba 10430, Indonesia
tiara.shinta@ui.ac.id

Abstract

Reliability engineering is needed for scheduling maintenance to improve system or equipment performance. The purpose of this paper is to provide recommendations for maintenance schedules based on reliability, availability, and maintainability (RAM) analysis that optimizes the availability of Crawler Cranes operating in Logistic Shore Base companies in Indonesia. This paper begins with searching for a critical system using the Pareto principle. The critical system is then made a reliability block diagram to facilitate the analysis. However, before conducting the analysis, it is necessary to know the characteristics of the probability distribution of the data so that the analysis results are accurate and stable. Analysis of reliability, availability, and maintainability (RAM) is then carried out in the probability distribution equation for each system. RAM analysis results show that by implementing reliability maintenance at t=OD and maintainability for 120 minutes, there is an increase LS system availability by 0.42% (98.78% to 99.20%), ESE availability by 0.57% (97.30% to 97.87%) and US system by 0.95% (97.35% to 98.31%), and overall system availability by 0.32% (98.11% to 98.42%). In this study, the overall equipment performance of the Crawler Crane was not considered, and the performance evaluation was only based on the calculation of availability and usage. Future research should include the measurement of key performance indicators (KPIs) with Maintenance Performance Level (MPL).

Keywords

Crawler Crane, Logistic Shore Base Company, Preventive Maintenance, Availability and Reliability.

1. Introduction

Equipment maintenance aims to repair or maintain equipment in good and acceptable working conditions. There are two types of maintenance based on time, namely corrective maintenance (CM) and preventive maintenance (PM). CM is carried out when equipment is damaged and then repaired. In contrast, PM is carried out before the equipment is damaged to reduce damage and a greater risk of failure.

In the previous research literature, it is seen that probability distributions (PD) are included to analyze RAM, such as normal distribution, lognormal distribution, exponential distribution, and Weibull distribution. In addition, several published pieces of literature reveal that previous researchers have continued to investigate RAM-based maintenance scheduling, which is used in various industries and equipment.

However, there are very few cases of its application to lifting equipment, especially Crawler Cranes. Therefore, it is interesting to do RAM research on lifting equipment, especially Crawler Cranes. The selection of Crawler Cranes to be studied compared to other lifting equipment is based on the consideration that Crawler Cranes are lifting equipment that has complex systems and components compared to other lifting equipment such as overhead cranes, gantry cranes, and pedestal cranes. The complexity of the Crawler Crane can be seen from the working area, which can move from one location to another, and several configurations influence its operation. The configuration effect intended for Crawler Cranes is divided into three parts which can also be referred to as the main system, namely the lower structure (powertrain, chassis, outrigger, etc.), electrical & safety equipment (lamp, indicators, safety equipment, etc.), and

upper structure (counterweight, number of installed part lines, running gear, boom length, boom angle, working radius, lifting position start and end lifting, etc.).

1.1 Objectives

It is also important to note that some previous research was limited to developing and analyzing theoretical models. However, few try to solve it in a realistic environment. Therefore, an academic, practical, and systematic approach is needed to analyze the performance of Crawler Cranes. In addition, the lack of attention from some previous studies to use optimization techniques. In this study, researchers will perform availability optimization techniques for Crawler Cranes. The main reason behind this research is that the optimized availability parameter can be used to modify the maintenance schedule of the existing equipment. As a result of improved maintenance schedules, availability can be optimized. Based on this, through this research, efforts will be made to fill the gaps in research conducted by several previous researchers. The purpose of this study is to provide recommendations for a RAM-based Crawler Crane maintenance schedule that optimizes availability. As the main contribution, this study proposes a RAM analysis framework by optimizing availability parameters for Crawler Cranes. The Crawler Crane that is the object of this research is critical lifting equipment for loading and unloading activities at the Jetty, operated by an Indonesian Logistic Shore Base company. The failure of this Crawler Crane can result in the failure of lifting operations to supply material to cargo ships to be forwarded offshore.

2. Literature Review

In recent decades, maintenance scheduling through reliability engineering analysis has played an important role in maintaining the system in an operating state. Several recent studies have analyzed reliability, availability, and maintainability (RAM) in various types of industries and equipment, such as the ice cream industry, the bag industry, in mining with load, haul and dump machines (LHD machine), in the textile process industry on steam boiler equipment, on conveyor system equipment, on deck objects on fishing vessels, plug-in electric vehicles, dragline equipment, truck unloading.

3. Methods

3.1 Principle Pareto

A Pareto principle is a useful tool for identifying problems by showing how many times they occur. The frequency with which problems occur is shown in a combination of bar graphs and line graphs. Bar graphs and line graphs are ordered from largest to smallest. Thus, it can be known which problems must be studied and then narrowed down the causes of which problems must be addressed first.

3.2 Probability distribution function selection

In this study, the probability distribution function (PDF) selection by looking at the probability plot is a linear relationship between the variables x and y . The linear relationship between the variables x and y was assessed by Anderson Darling (AD) and correlation coefficient (CC). The smaller the AD value and the larger the CC value, the better the linear relationship between the two random variables x and y . CC has a value between 0 and +1 which indicates the strength of the linear relationship between the variables x and y . If the CC value is close to a value of 1, it can be said that the time between failure (TBF) or time to failure (TTR) data distribution is very well distributed with this distribution. As an example of a linear relationship between TBF and PD, as shown in Figure 1, the TBF data distribution is normally distributed because it has the smallest AD value of 2.116 and the largest CC value of 0.975. The PD used in this study are the normal distribution, the lognormal distribution, and the Weibull distribution.

The normal distribution has parameters Mean (μ) and Standard Deviation (σ). The lognormal distribution has a median repair time parameter (t_{med}) and a scale parameter ($s=\alpha$), and the Weibull distribution has shape parameters (β), scale parameter (α), and time factor (t) [15]. The distribution is used to predict equipment failure patterns, which will help determine time intervals for PM.

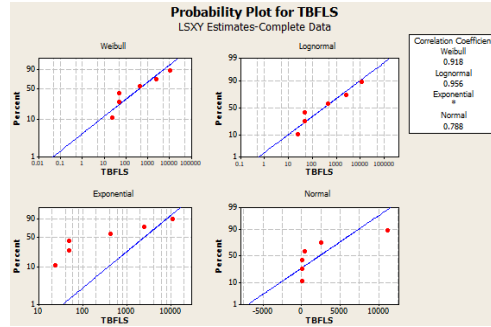


Figure 1. Probability plot

3.3 Mean time between failure (MTBF) and mean time to repair (MTTR)

MTBF is the average time between failures for a repairable component/system, while MTTF is the expected failure time for a non-repairable system/component. MTTR is the average time for repairing the system/component of the machine. The calculation of MTBF and MTTR for the normal distribution uses Eq. (1), and the lognormal distribution uses Eq. (2), the exponential distribution uses Eq. (3), and Weibull uses Eq. (4).

The Weibull distribution is a lifetime distribution widely used in reliability engineering and maintenance. The Weibull distribution helps represent many different phenomena or physical forms. It depends on the shape parameter's value; function failure rate can be decreased, constant, or increased. Therefore, the Weibull distribution can model the failure behavior of some real-life systems. The Weibull distribution has scale parameters (α) and shape parameters (β) as well as a gamma function (Γ). This study used the help of Minitab 16 software to get the value of the scale parameters (α) and shape parameters (β) in the Weibull distribution. Then, the gamma function ($\Gamma(x)$) value was from the gamma function table ($\Gamma(x)$).

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

$$\frac{MTBF}{MTTR} = t_{med} e^{\frac{s^2}{2}} \quad (2)$$

$$\frac{MTTR}{MTBF} = \frac{1}{\lambda} \quad (3)$$

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

3.4 Reliability, maintainability and availability

3.4.1 Reliability

Reliability is an assessment of the probability for a certain time and conditions for the equipment to perform its required function without failure. If the reliability of the equipment or system cannot be maintained properly, it will experience operational failure and result in considerable losses. Of course, this failure needs to be avoided, especially for critical equipment. Each piece of equipment has reliability characteristics. These characteristics will determine the operating conditions. This study estimated the reliability characteristics using the distribution selected through the PDF test. The following distribution equations will be used in this study: the normal distribution using Eq. (5), the lognormal distribution using Eq.(6), and the Weibull distribution using Eq. (7).

$$R(t) = 1 - \phi\left(\frac{t-\mu}{\sigma}\right) \quad (5)$$

$$R(t) = 1 - \phi\left(\frac{1}{s} \ln \frac{t}{t_{med}}\right) \quad (6)$$

$$R(t) = e^{-\left(\frac{t}{\alpha}\right)^\beta} \quad (7)$$

Reliability analysis of complex systems a logical approach in reliability analysis is to apply a systems approach with a reliability block diagram (RBD). RBD can be connected in series, parallel and combined series-parallel. Analysis of RBD connected in series (R_s) using Eq. (8) and connected in parallel (R_p) using Eq. (9).

$$R_s(t) = R_1 \times R_2 \times R_3 \times R_n \leq \min\{R_1, R_2, R_3, R_n\} \quad (8)$$

$$R_{ps}(t) = 1 - (1 - R_1) \times (1 - R_2) \times (1 - R_3) \times (1 - R_n) \leq \min\{R_1, R_2, R_3, R_n\} \quad (9)$$

3.4.2 Maintainability

Maintainability is the maintenance of equipment expressed in terms of its probability of maintaining the equipment to a working condition after being repaired within a certain time interval. In this study, the calculation of the maintainability of the Crawler Crane system follows the PD. Data analysis is normally distributed using Eq. (10), lognormal distribution using Eq. (11), and Weibull distribution using Eq. (12).

$$M(t) = \phi\left(\frac{t-\mu}{\sigma}\right) \quad (10)$$

$$M(t) = \phi\left(\frac{1}{\alpha} \ln \frac{t}{t_{med}}\right) \quad (11)$$

$$M(t) = 1 - e^{(-\frac{t}{\alpha})^\beta} \quad (12)$$

3.4.3 Availability

Availability is the possibility of the equipment being ready to operate when needed at a certain time by taking into account uptime and downtime. Uptime is the total time the equipment is in reliable condition. Uptime consists of operating time, standby time, and other waiting times. Uptime is closely related to the MTBF and reliability. On the other hand, downtime is the total time the equipment is in failure/unreliable condition. Downtime is related to MTTR and maintainability. To optimization equipment availability, it is necessary to consider the PD of failure and the PD of repair. It calculates the availability of the system using Eq. (13).

$$A = \frac{MTBF}{MTBF+MTTR} = \frac{uptime}{uptime+downtime} \quad (13)$$

3.4.4 Methodology

The methodology section begins by collecting data on the main system configurations that affect the effectiveness of Crawler Crane performance. Then, perform the analysis to rank critical systems and assess the current availability performance of the Crawler Crane. Next, analyze the characteristics of RAM based on damage data using several PDs such as the Weibull distribution, exponential, lognormal, and normal with the help of Minitab 16 software. The selected RAM characteristics of the PD have been determined by referring to the least square method with the lowest AD value and the highest CC. Thus, RAM analysis is a helpful tool or method and helps in deciding the right maintenance strategy. The results & discussion section presents MTBF & MTTR calculations, reliability analysis, maintainability analysis, availability analysis, and performance evaluation of Crawler Cranes. Finally, the conclusion presents conclusions about optimizing the availability of Crawler Cranes using the reliability engineering method.

4. Data Collection

General data and Crawler Crane technique as the object of this research is a Crawler Crane with the Sany brand with unit number A9. The maximum lifting capacity of the Crawler Crane is eighty tons operating for oil and gas companies in Indonesia. The main system configurations of Crawler Cranes are grouped into three, consisting of the lower structure (LS), electrical & safety equipment (ESE), and the upper structure (US). The object of research is a Crawler Crane, as shown in Figure 2.



Figure 2. Crawler Crane 120 T

The Crawler Crane's main system configuration's operational performance is expressed using the TBF and TTR data. Historical TTR and TBF data were collected from January 2020 to December 2022 in minutes. TBF is the duration of the Crawler Crane in an uptime state before entering a failed state. In contrast, TTR is the duration of the Crawler Crane in a downtime state before returning to an uptime state. TBF and TTR data for the Crawler Crane system are shown in Table 1 and illustrated in Figure 3.

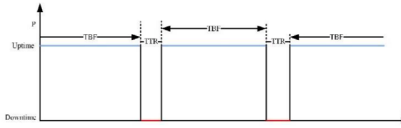


Figure 3. Illustration of TBF and TTR Crawler Crane

Table 1. Crawler Crane system TBF and TTR data

LS				ESE				US			
TBF (hour)	TBF	TTR (hour)	TTR	TBF (hour)	TBF	TTR (hour)	TTR	TBF (hour)	TBF	TTR (hour)	TTR
0	0	3	180	0	0	6.00	360	0	0	3	180
24	1440	3	180	24	1440	6.00	360	1896	113760	0.33	20
48	2880	3	180	24	1440	3.00	180	840	50400	3	180
2520	151200	3.5	210	2136	128160	0.25	15	24	1440	4	240
48	2880	2	120	1368	82080	1.00	60	24	1440	4	240
432	25920	5	300	2184	131040	0.25	15	768	46080	6	360
11136	668160	2	120	1560	93600	1.00	60	144	8640	6	360
				1704	102240	0.50	30	3480	208800	1	60
				744	44640	0.25	15	3144	188640	1	60
				912	54720	0.25	15	216	12960	1	60
				1032	61920	0.25	15	3264	195840	4	240
				816	48960	0.33	20	1968	118080	4	240
				2496	149760	0.50	30	24	1440	5	300
				1560	93600	0.33	20	72	4320	3	180
				456	27360	0.33	20	3096	185760	2	120
				864	51840	1.00	60				
				192	11520	2.00	120				
				1248	74880	4.00	240				
				6312	378720	3.00	180				
				24	1440	2.00	120				

Based on TBF and TTR data, an assessment of the current availability of Crawler Cranes is carried out using the general RAM equation, namely the exponential distribution. The results of the current availability performance assessment are as shown in Table 2. The LS availability value is 98.78%, the ESE availability value is 98.18%, the US availability value is 97.35%, and the system availability value is 98.11%.

Table 2. Performance assessment of the current availability of Crawler Cranes

Ai			A system
LS	ESE	US	
98.61%	97.30%	97.35%	97.76%

4. 1 Data Analysis

Data analysis starts from finding critical systems using Pareto principles based on failure frequency data. The high frequency of critical system failures will affect the overall performance of the equipment. In this study, a system that failed three or more times would be designated a critical system. The results of the Pareto principle analysis in Figure 4 show that the most frequent failures occurred in LS 9 times with a percentage of 45%, followed by ESE 6 times with a percentage of 30% and US 5 times with a percentage of 25%. Because all systems failed more than three times during the study period, it can be stated that all Crawler Crane systems are critical systems. Furthermore, the critical system is made RBD facilitate the analysis of RAM. The critical system RBD is shown in Figure 5.

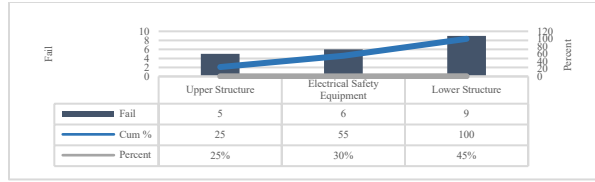


Figure 4. Crawler crane critical system analysis

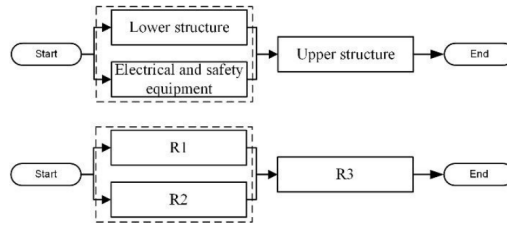


Figure 5. Crawler Crane critical system RBD

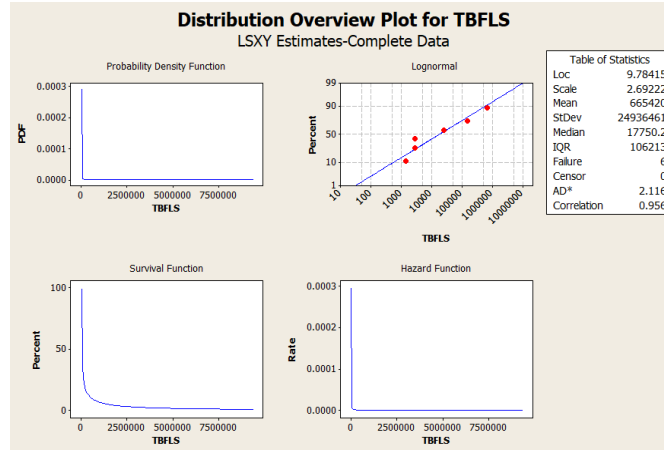
The next data analysis tests the PD and searches for its parameters using the Minitab 16 software based on the critical system TBF and TTR data. The results of the PD test analysis on TBF and TTR data are shown in Table 3, and the parameters are in Figure 6 and Table 4. The analysis results show that TBFLS is Lognormal distributed, TTRLS is lognormally and normally distributed, and TBFESE, TTRESE, TBFUS, and TTRUS are normally distributed.

Table 3. Testing the PD of TBF and TTR data

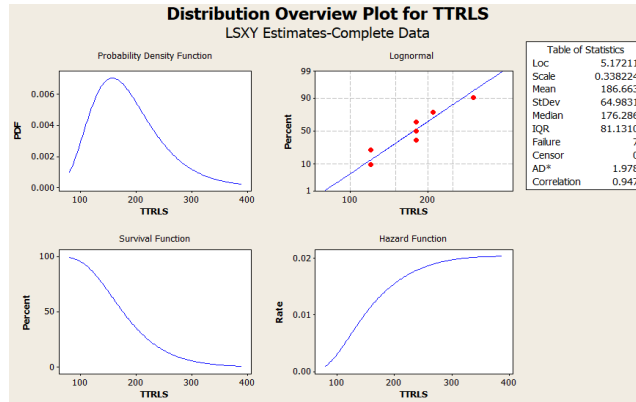
TBF	LS	ESE	US
PD	Lognormal	Weibull	Weibull
Shape (β)		0.76	0.609
Scale (α)	2.692	80091.3	62553.9
Tmed	17750.20		

TTR	LS	ESE	US
PD	Lognormal	Lognormal	Normal
Scale (α)	0.338	1.157	
Tmed	176.286	51.487	
Mean (μ)			189.33
StDev ($\sigma=s$)			113.023

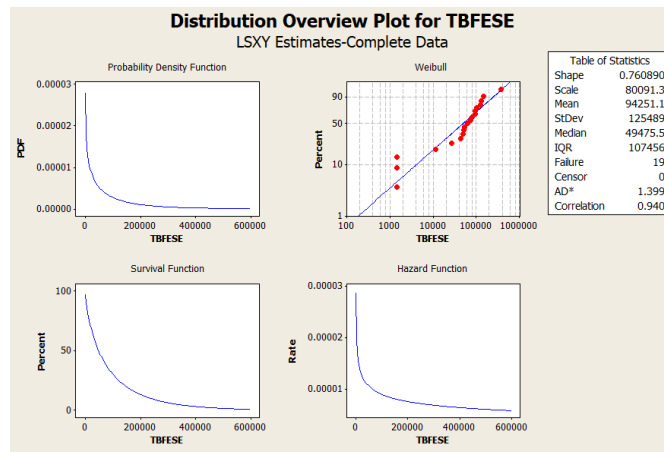
Data	PD	AD	CC
TBFLS	Lognormal	2.116	0.956
TTRLS	Lognormal	1.978	0.947
TBFESE	Weibull	1.399	0.94
TTRESE	Lognormal	1.437	0.947
TBFUS	Weibull	2.029	0.93
TTRUS	Normal	1.149	0.975



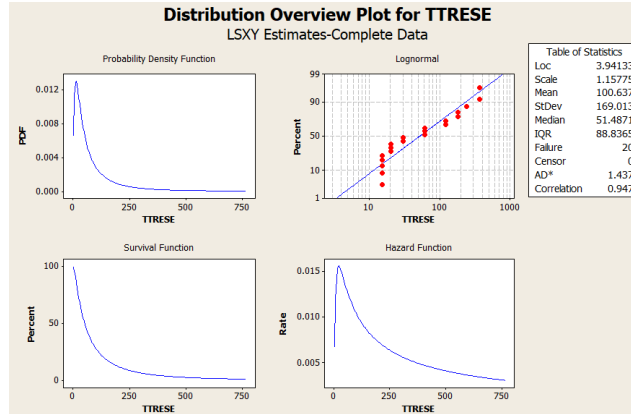
(a) Distribution overview plot for TBFLS



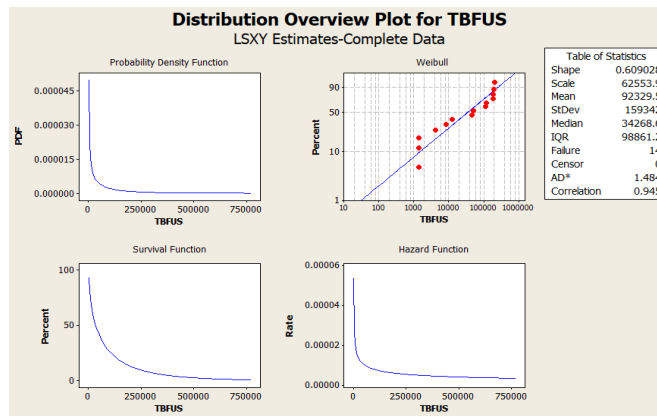
(b) Distribution overview plot for TTRLS



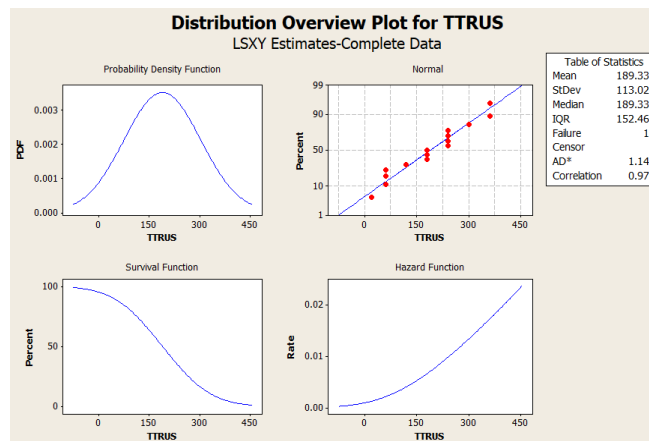
(c) Distribution overview plot for TBFESE



(d) Distribution overview plot for TTRESE



(e) Distribution overview plot for TBFUS



(f) Distribution overview plot for TTRUS

Figure 6. Distribution overview plots

5. Results and Discussion

5.1 Numerical Results

5.1.1 Calculation of MTBF, MTTR and Availability

Calculation of the critical system MTBF and MTTR using each PD's equation and parameter values. The results of the MTBF and MTTR calculations are shown in Table 4. The highest MTBF value in the LS system was 13,065 minutes, followed by US 6,968 minutes and ESE 5,501 minutes. While the highest MTTR value in the US system was 189 minutes, followed by LS at 184 minutes and US at 92 minutes

Table 4. Recapitulation of MTBF & MTTR calculations

System	MTBF	MTTR	Availability	A System
LS	13,065	184	98.61%	
ESE	5,501	92	97.05%	97.67%
US	6,968	189	97.35%	

After getting the MTBF and MTTR values, the next step is to analyze reliability (R), availability (A), and maintainability (M) according to the selected PD.

5.1.2 Reliability Analysis

In this study, the overall system reliability was evaluated at different reliability levels, namely 94%, 92%, 90%, 88%, at t (time) = MTBF and at t (time) = optimal downtime (OD) with the help of Microsoft Excel software. The results of the reliability analysis are listed in Table 5.

Table 5. Calculation of the reliability of the Crawler Crane system

State	94%	92%	90%	88%	MTBF	OD
time	250	380	500	700	14931.43	18000
R of LS (%)	94.18	92.07	90.49	88.49	53.98	50
time	2,000	3,000	4,000	5,226	5,226	5,500
R of ESE (%)	94.12	92.09	90.25	88.19	88.19	87.75
time	600	1,000	1,500	2,000	6,968	7,500
R of US (%)	94.26	92.26	90.2	88.43	76.89	75.97
R of System (%)	94.19	92.14	90.31	88.37	73.02	71.24

Based on the system reliability analysis results using RBD, shown in Table 6. Crawler cranes achieve a system reliability level of 94.19%, from the LS system maintenance task (R=94.18), ESE (R=94.12%), US (R=94.26%). It must be performed at or before the operation to reach 250 minutes, 2000 minutes, and 600 minutes, respectively. Likewise, to achieve a system reliability level of 88.37%, maintenance tasks must be carried out on or before system operation reaches 700 minutes for LS (R=88.49%), 5226 minutes for ESE (R=88.19%), and 6968 minutes for US (R=76.89%). Likewise, to achieve the current average level of system reliability with t =MTBF and system R of 73.02%, maintenance tasks must be carried out on or before operation reaches 14931.43 minutes for LS (R=53.98%), 5226 minutes for ESE (R=88.19%) and 6968 for US (R=76.89%). The results obtained from Table 6 show that the LS and US systems are the most critical Crawler Crane systems because they have a shorter uptime duration than US from the reliability analysis of 94%, 92%, 90%, 88%, t =MTBF and t =OD. As a result, companies must take significant steps to improve the reliability of LS and ESE systems, which in turn will increase system availability.

5.1.3 Maintainability

In calculating the maintainability of a critical system, the time required to repair the system based on TTR data ranges from 60 minutes to 1000 minutes. These results can be used as verification to show that each critical system has the opportunity to be repaired (maintainability) between 60 minutes to 1000 minutes. In addition, the magnitude of the parameter value also affects the time that can maintain system opportunities and is faster for the maintenance process. The results of the maintainability calculation are shown in Table 6. Based on the results of the maintainability calculation, suggestions can be given to the company to carry out preventive maintenance when the machine has a system reliability value close to 50%, namely when $R(t) = OD$ of each system. The ideal time needed to carry out preventive maintenance is from 120 minutes to 1000 minutes while taking into account the safety factor of the structure in carrying out maintenance. This is done to increase availability while still paying attention to maintenance activities on critical systems. Reliability calculated based on this time interval is not only for planning service/repair work but also for implementing the replacement of the components under consideration. This analysis adds value to the implications for equipment safety and operational readiness. This valid recommendation is recommended for

scheduling preventive maintenance of Crawler Cranes.

Table 6. Calculation of critical system maintainability values

time	Maintanability		
	LS	ESE	US
60	27.79%	46.21%	27.16%
120	47.86%	71.07%	46.94%
180	62.35%	84.44%	61.35%
240	72.81%	91.63%	71.85%
300	80.37%	95.50%	79.50%
360	85.82%	97.58%	85.06%
420	89.76%	98.70%	89.12%
480	92.61%	99.30%	92.08%
540	94.66%	99.62%	94.23%
600	96.15%	99.80%	95.80%
660	97.22%	99.89%	96.94%
720	97.99%	99.94%	97.77%
750	98.29%	99.96%	98.10%
800	98.70%	99.97%	98.54%
850	99.01%	99.98%	98.88%
900	99.24%	99.99%	99.14%
1000	99.56%	100.00%	99.49%
184	63.21%	85.11%	62.22%
97	40.84%	63.21%	40.01%
189	64.21%	85.87%	63.21%

5.1.4 Availability analysis and performance evaluation

The reliability calculation shows that the system has a relatively long preventive maintenance time because it is carried out at $t=OD$. Hence, the system may have a fairly large availability value. In addition to involving reliability, availability analysis which is a performance parameter, also involves calculating system maintainability. In this study, availability optimization applies maintenance when reliability reaches the OD and several maintainability scenarios. The maintainability scenario in question is when $t=MTTR$, $t=120$ minutes and $t=180$ minutes. The results of the calculation of system availability are as shown in Table 7.

Table 7. System availability calculation

System	LS	ESE	US	A system
Current Availability	98.78%	98.18%	97.35%	98.11%
Availability with MTTR	98.96%	97.09%	97.80%	97.95%
Availability with M (120)	99.20%	97.76%	98.31%	98.42%
Availability with M (180)	98.81%	96.67%	97.48%	97.65%

The analysis results show that the highest value of system availability is at maintainability for 120 minutes, and the lowest is at maintainability for 180 minutes. Therefore, it is suggested that the company set a system maintainability time of 120 minutes. RAM analysis shows that by applying reliability at $t=OD$ and maintainability for 120 minutes, there is an increase in LS system availability by 0.42% (98.78% to 99.20%), ESE availability by 0.57% (97.30% to 97.87%) and US system by 0.95% (97.35% to 98.31%), and overall system availability by 0.32% (98.11% to 98.42%). Comparison of current availability values with optimized availability by RAM analysis as shown in Figure 7.

5.2 Graphical Results

Comparison of current availability values with optimized availability by RAM analysis as shown in Figure 7.

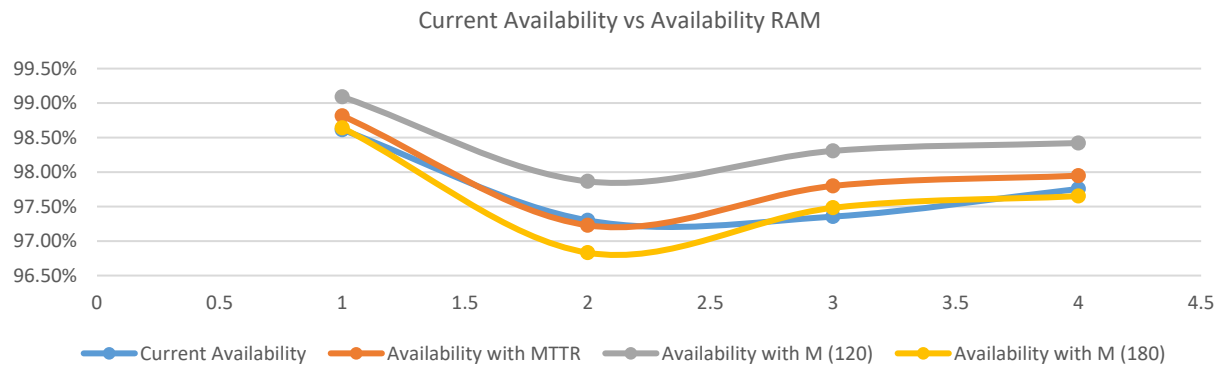


Figure 7. Comparison of current availability with availability optimization with RAM analysis

5.3 Proposed Improvements

The analysis results show that the highest value of system availability is at maintainability for 120 minutes, and the lowest is at maintainability for 180 minutes. Therefore, it is suggested that the company set a system maintainability time of 120 minutes. RAM analysis shows that by applying reliability at $t=OD$ and maintainability for 120 minutes, there is an increase in LS system availability by 0.42% (98.78% to 99.20%), ESE availability by 0.57% (97.30% to 97.87%) and US system by 0.95% (97.35% to 98.31%), and overall system availability by 0.32% (98.11% to 98.42%).

5.4 Validation

The RAM framework proposed in this study will help decision-makers plan maintenance activities according to the criticality level of each system and allocate appropriate resources. This research can be expanded by analyzing the performance of subsystems or components of each system using the proposed RAM framework for lifting equipment or other equipment from different industries. In addition, in the study, there are several assumptions used such as the failure rate and repair of each system is constant and statistically independent, only one system fails at a time, the repaired system is as good as the new one, and the standby unit follows its last condition, namely failed state or operating state.

6. Conclusion

RAM analysis is quantitative reliability engineering required for scheduling maintenance to improve system or equipment performance. This study highlights the importance of RAM analysis for lifting equipment such as Crawler Cranes. Crawler Cranes have three main systems, namely LS, ESE and US. Based on the Pareto principle, all three are critical systems. The results of the PD test showed that TBFLS, TTRLs and TTRESE had a lognormal distribution, TBFESE and TBFUS had a Weibull distribution and TTRUS had a Normal Distribution. The PD equation for each system is then used in the RAM analysis to suggest a preventive maintenance schedule. RAM analysis results show that by implementing reliability maintenance at $t=OD$ and maintainability for 120 minutes, there is an increase LS system availability by 0.42% (98.78% to 99.20%), ESE availability by 0.57% (97.30% to 97.87%) and US system by 0.95% (97.35% to 98.31%), and overall system availability by 0.32% (98.11% to 98.42%). In this study, the overall equipment performance of the Crawler Crane was not considered, and the performance evaluation was only based on the calculation of availability and usage. Future research should include the measurement of key performance indicators (KPIs) with Maintenance Performance Level (MPL)

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Biographies

Tiara Shinta Raharkandi graduated from Universitas Brawijaya in Malang, East Java, Indonesia in 2018 and received her Bachelor's Degree in Mechanical Engineering. Her research on bachelor study discussed about Material

Composite of Natural Fiber with Vacuum Infusion Method. She currently has her postgraduate study of Industrial Engineering in Universitas Indonesia starting from 2021 with interest in logistics-and-production system. She works in Shore Base Company in Penajam Paser Utara, East Kalimantan as an Innovation, Digitalization and Bonded Logistic Center Department Head. She has taught courses in logistic, management and corporate entrepreneurship, innovation and digitalization project for all engineers.

Dendi P. Ishak is currently active as lecture in Industrial Engineering Department in Universitas Indonesia. He received his Bachelor's Degree from Wayne State University in 1989, Master's Degree from Wayne State University in 1991, and his Doctoral's Degree from Universiti Teknologi MARA in 2021. His research manly focus in Virtual Manufacturing / Simulation, Lean, Safety and Quality Management Consultant.