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Implementation of Preventive Maintenance Using Reliability Availability Maintainability (RAM) Method

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Abstract: PT. Aneka Adhilogam Karya is a company engaged in metal casting, in the production process. The company uses 90% of the engine, but still applies a corrective maintenance system. This study aims to analyze the value of Reliability Availability and Mantainability on the Hoist machine, then provide suggestions for values that are not in accordance with existing standards in the company using the Reliability Availability and Maintainability (RAM) methods. This study also uses the Poisson Process method to determine component inventory for one year, and uses the Economic Order Quantity method to determine the number of orders for each order. The results of this study suggest a preventive maintenance interval to increase the reliability value of each Hoist engine component, and the proposed duration of repair of a Hoist engine component in case of damage.
Keywords: implementation; reliability; availability; maintainability

Introduction

PT. Aneka Adhilogam Karya is a company engaged in the metal casting industry. This company produces superior products, namely water pipe connections. In the implementation of the production process this company uses several machines to produce the desired product. Machines used such as, lathe, drill, welding, sand sifting, mixer, cooling pump, compressor, hoist, and also machines for melting metal (induction furnace). This company applies a corrective maintenance system that results in a high level of damage to a machine, and data obtained from the beginning of 2017 to the end of 2018 occurred 263 times and 59 other damages occurred on the induction Hoist machine.

In resolving these problems, preventive maintenance needs to be done. The purpose of preventive maintenance is to maintain the reliability of a machine so that it reduces damage in order to production system continues to run without getting hampered due to machine damage that occurs during the production process. In accordance with the company's wishes that the reliability for the machine is at least 70%, and also the results of research conducted (by Kurniawan, 2017) which states that machines with reliability values above 70% can be said to still function properly.

These objectives can be achieved using the Reliability Availability Maintainability (RAM) method. Azmi (2017) in the Nugrahaningrum Journal (2018) states that Reliability Availability and Maintainability (RAM) Analysis is a method that can be used to predict the performance of reliability, availability and maintainability of a component or system. RAM analysis is also a tool that can be used to provide guidelines for optimizing components.

In the event of damage to engine components, a backup component is required. Determination of inventory reserve components can use the Poisson Process method. Poisson Process is a method that can be used to determine the supply needs of spare parts according to the time required. This method can be used for components that are repairable and non-repairable. After the reserve component inventory requirements are known, an optimal order quantity will be determined in each order transaction using the Economic Order Quantity (EOQ) method. EOQ is a method used to optimize the number of orders in order to minimize the cost of the message and also the cost of saving (Rachmawati, 2014).

Methode

1. Hoist Machine Component Damage Data

Table 1. Time of Hoist Machine Component Damage

Name of Component									
Push Button Control		Electric Trolley		Inverse Phase Squance Protecting Device		Upper and lower limit Switch		Safe Brake System	
No	The date	No	The date	No	The date of	No	The date of	No	The date

	of damage		of damage		damage		damage		of damage
1	03-Jan-17	1	09-Mar-17	1	02-Feb-17	1	22-Feb-17	1	07-Jan-17
2	20-Feb-17	2	16-Apr-17	2	04-Apr-17	2	04-Apr-17	2	27-Apr-17
3	17-Mar-17	3	04-May-17	3	19-May-17	3	25-Aug-17	3	19-Jul-17
...	...	...	...	...	...	...	...	4	27-Dec-17
16	15-Nov-18	15	18-Sep-18	11	29-Oct-18	8	04-Oct-18	5	17-Jul-18
17	19-Dec-18	16	13-Nov-18	12	15-Dec-18	9	01-Dec-18		

Table 1 is data of hoist engine component damage from the beginning of 2017 until the end of 2018. From this table, it can be seen that the Push Button Control component is the component that is most frequently damaged, in which there are 17 times the failure that occurred from early 2017 to the end 2018.

1. Suitability Test for Damage Distribution

This test is done to prove that the index of fit (r) that has been obtained using Minitab 16 software is acceptable. H_0 is the distribution that has the largest value of r produced by Minitab software, and H_1 is a statement that the data to be tested is not distributed according to the results from Minitab 16.

a. Mann's Test forWeibull distribution

$$M = \frac{k1 \sum_{i=ki+1}^{r-1} \left[\frac{\ln ti+1-\ln ti}{Mi}\right]}{k2 \sum_{i=1}^{k1} \left[\frac{\ln ti+1-\ln ti}{Mi}\right]} \quad \text{.......... (1)}$$

$$\text{Mi} = Z_{i+1} - Z_i \quad \text{.......... (2)}$$

$$\text{Zi} = \ln\left[-\ln\left(1 - \frac{i-0,5}{n+0,25}\right]\right. \quad \text{.......... (3)}$$

Description:

- ti = time damage data of i
- xi = ln (ti)
- R,n = the number of data
- Mi = approach value*Mann* for data of-i
- M_a,K_i , K_2 = value of $M_{table}$for*weibull distribution* (table F)
- If M_{count}< $M_{table\ (\alpha,\ k1,\ k2)}$ H_0 is accepted

b. Barlett's Test forExponential distribution

$$B = \frac{2r\left[\ln\left(\frac{1}{R}\right)\sum_{i=1}^{r} ti - \left(\frac{1}{R}\right)\sum_{i=1}^{r} \ln ti\right]}{1+\frac{(r+1)}{6r}} \quad \text{.......... (4)}$$

Description:

- ti = time damage data of i
- r = the number of data
- B = statistical test values for the Barlett's Test
- If$X^2\,\frac{1-\alpha}{2}, r-1 <$ B $< X^2\,\frac{1-\alpha}{2}, r-1$;$H_0$ is accepted

c. Kolmogorov-Smirnov for Normal distribution and Log-normal

$$D_1 = \max\left\{\emptyset\left(\frac{ti-t}{s}\right) - \frac{i-1}{n}\right\};\ D_2 = \max\left\{\frac{i}{n} - \emptyset\left(\frac{ti-t}{s}\right)\right\} \quad \text{.......... (5)}$$

$$t = \sum_{i=1}^{n} \frac{t_i}{n} \quad and\ S^2 = \frac{\sum_{i=1}^{n}(t_i-t)^2}{n-1} \quad \text{.......... (6)}$$

Description:

- ti = time damage data of-i
- t-bar = average damage time
- s = standard deviation
- n = the number of damage
- If Dn < $D_{critical}$, H_0 is accepted.

1. Reliability

Reliability is the probability of a system that will function normally when used for the desired period of time in specific operating conditions (Dhillon, 1997). Meanwhile, according to Ebeling (1997) reliability can be defined as the probability that the system will have performance according to the functions needed within a certain time period.

Reliablity Weibull distribution

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

Reliablity Exponential distribution

$$R(t) = e^{-\lambda t} \quad \text{...(8)}$$

Reliablity Normal distribution

$$R(t) = \frac{1}{\sigma\sqrt{2\pi}} \int_1^{\infty} e^{\left\{\frac{-(t-\mu)^2}{2\sigma^2}\right\}} dt \quad \text{...(9)}$$

Reliablity Log-Normal distribution

$$R(t) = 1 - \phi\left(\frac{1}{s}\ ln \frac{t}{t_{med}}\right) \quad \text{...(10)}$$

Description:

R : *Reliability*
μ : average of distribution
δ : standard deviation of distribution
e : 2,718
λ : failure rate
t : operating time

2. Availability

Availability is the probability of a system operating according to its function within a certain time in a predetermined operating condition. Therefore, availability is a function of the failure rate (Ebeling, 1997). Availability of a system can be calculated using the following equation:

$$A = \frac{MTTF}{MTTF + MTTR} \quad \text{...(11)}$$

Availability that changes with time can be calculated using the following equation:

$$A(t) = \left[\left(\frac{\mu}{\lambda+\mu}\right) + \left(\left(\frac{\mu}{\lambda+\mu}\right)\right) e^{-(\lambda+\mu)\,t}\right] \quad \text{...(12)}$$

Description:

t = time (variable)
μ = data average
λ = failure rate

3. Maintainability

Maintainability is defined as the probability of a system/component that will return to a satisfactory state and under operating conditions capable of achieving minimum downtime (Dhillon, 1997). Another definition of maintainability is the probability that a damaged component or system will be repaired under a certain condition within a certain time period according to a predetermined procedure (Ebeling, 1997). If f (t) is a probability density function of the time needed to influence the action (repair, overhaul, or replacement). Then the maintainability of an equipment can be defined as follows:

$$\int_0^T f(t)_{dt} \quad \text{...(13)}$$

$$Speed\ of\ improvement = \frac{1}{MTTR} \quad \text{...(14)}$$

$$M(t) = 1 - e^{-\mu t} = 1 - e^{-\left(\frac{t}{MTTR}\right)} \quad \text{...(15)}$$

Description:

t : the average time given for maintenance actions
M : *Maintainability*

The equation is quoted from (Stephens, 2004)

4. Mean Time To Failure

The reliability of a system is often given in the form of a number stating the expected lifetime of the system which is denoted E (t) and is often called the average damage time or Mean Time To Failure (MTTF) while Mean Time To Repair is the average time of component replacement . In accordance with the MTTF definition, then by integrating reliability between zero to infinity we get the following formula:

Weibull distribution

$$MTTF = \theta\Gamma\left(1+\frac{1}{\beta}\right) \qquad \text{.......... (16)}$$

Exponential distribution

$$MTTF = \frac{1}{\lambda} \qquad \text{.......... (17)}$$

Normal distribution

$$MTTF = \mu \qquad \text{.......... (18)}$$

Log-normal distribution

$$MTTF = t_{med}\ e^{\frac{s^2}{2}} \qquad \text{.......... (19)}$$

Description:

Γ : Function of gamma, Γ(n) = (n-1)

λ : failure rate

5. Poisson Process

Poisson Process according to Louit, D., and Pascual, R., (2006) is one method for calculating the need for spare parts in a period. In calculating component requirements using the Poisson process, components are classified into repairable and non-repairable components. Where a repairable component is failured, it can be returned to its operational state by repairing it, while a non-repairable component is a situation when repairing a component is difficult and impossible or when the cost of repairs is greater than the cost of purchasing the component. The calculations are as follows:

$$\lambda t = \frac{A.N.M.T}{MTTF} \qquad \text{.......... (20)}$$

Rachmawati, (2014) states that a repairable component is a component that if failure occurs, the component can still be repaired, in contrast to the calculation of non-repairable components, repairable components using MTTR values and the scrap rate calculation values are as follows:

$$\lambda 1 = \frac{A.N.M.R.T}{MTTF} \qquad \text{.......... (21)}$$

$$\lambda 2 = \frac{A.N.M.MTTR}{MTTF} \qquad \text{.......... (22)}$$

$$P \leq \sum_{x=0}^{n} \frac{(\lambda t)^x e^{-\lambda t}}{X!} = e^{-\lambda t}\left[1+\lambda t+\cdots+\frac{\lambda t^{n-1}}{(n-1)!}\right] \qquad \text{.......... (23)}$$

Description:

A : number of component

N : Number of Machines used

M : Machine operating hours

R : *scrape rate*

P : *confidence level*

T : Period

6. Economic Order Quantity

Economic Order Quantity (EOQ) according to Heizer and Render (2015) is one of the most widely known inventory control techniques. The EOQ method is used to determine the size of an order that will minimize the amount of inventory costs and message costs:

EOQ calculations can be seen in the following equation:

$$EOQ = Q = \sqrt{\frac{2\ x\ D\ x\ S}{H}} \qquad \text{.......... (24)}$$

$$H = C\ x\ i \qquad \text{.......... (25)}$$

$$F = \frac{D}{Q} \qquad \text{.......... (26)}$$

$$T = \frac{number\ \ of\ workdays\ \ per\ year}{F} \qquad \text{.......... (27)}$$

Description:

C: Component Prices

i: Component Management Costs

F: Number of Order Frequencies

T: The time period between each order

Q : Order Amount
D : *Demand in one period*
S : Cost every time you order
H : Save Cost

Kasmir (2010) states that the management costs are costs associated with the ownership of the stock which includes, among others, the capital costs invested in the stock. This means the costs that should exist to manage inventory, such as the following:
a. Storage costs or warehousing fees
b. Insurance
c. Property tax
d. Physical depreciation costs
e. Obsolescence (out of model)

The large amount of management costs is usually around or even more than 25% of the investment in inventory value.

Result and Discusion

1. Determination of Damage Distribution

Determination of the distribution of engine damage is done using the Minitab 16 software. The initial stage is to enter the value of the number of days between the damage of each component in columns C1, C2, C3, C4, and Cn. Then click on the Stat menu - Reliability / Survival - Distribution Analysis Right Censoring - Distribusion ID Plot. The results can be seen in the following figure 1:

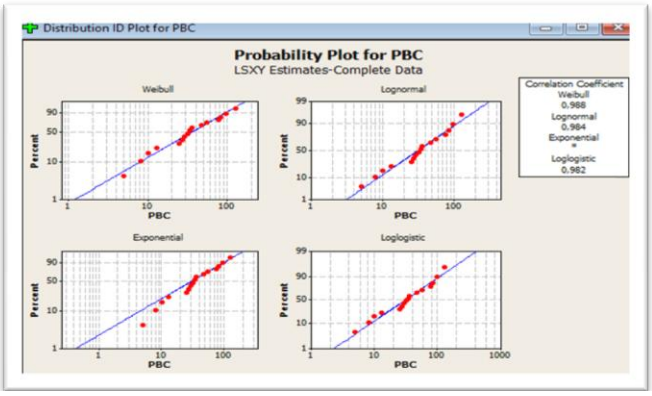

Fig 1. Result of Index Of Fit (r)

Figure 1 is the output of Minitab 16 software is the value of r (index of fit). For the distribution of damage the selected components are those that have the highest index of fit (r) value from the results of the Minitabe 16 software. The largest r value for the Push Button Control component is Weibull of 0.988. This value indicates that the Push Button Control component has a weibull distribution.

The damage distribution for each component resulting from the Minitab 16 Software results are:
a. Push Button Control Weibull distribution
b. Electric trolley Weibull distribution
c. Upper and lower limit switch log-normal distribution
d. Inverse phase squance protecting device Weibull distribution
e. Safe brake system log-normal distribution.

Goodness Of Fit Test Data Distribution

Based on the results of the Minitab 16 index of fit (r) software, the biggest Push Button Control damage is the Weibull distribution, so the test is done using man's test.

H_0 : Push Button Control failure time interval data is distributed by Weibull.
H_1 : Push Button Control failure timeout data is not distributed by Weibull.

The first calculation is done by finding the value of Zi using the 3rd equation. Where ti is the time lapse data between damage sorted from the smallest data to the largest data. The level of confidence is 95%, then the α value of 5% or 0.05.

$Z_1 = \ln\left[-\ln(1 - \frac{1-0,5}{16+0,25}\right]$
$Z_1 = \ln[-\ln(1 - 0,031]$
$Z_1 = -3,466$

Then, using the same equation will determine the value of Z_2 to Z_{17}.

After finding the value of Zi, the next calculation is to find the value of M_i using the 2nd equation. The calculation is as follows:

$M_1 = Z_{1+1} - Z_1$
$M_1 = -2,335 - (-3,466)$
$M_1 = 1,131$

After getting the value of M_1, the next step is to look for values of M_2 to M_{16} using the same equation. After searching for the Mi value, the next calculation is to find the M_{count}using the 1st equation. The calculation is as follows:

$$K1 = \frac{16}{2}$$
$K_1 = 8$

$$K2 = \frac{15}{2}$$

$K_2 = 7,5 \approx 7$

$$M_{count} = \frac{8\sum_{i=ki+1}^{r-1}\left[\frac{\ln ti=1-\ln ti}{Mi}\right]}{7\sum_{i=ki+1}^{i=1}\left[\frac{\ln ti=1-\ln ti}{Mi}\right]}$$

$$M_{count} = \frac{8\,x\,(6,7)}{7\,x\,(5,287)}$$

$$M_{count} = 1,45$$

M_{table} 0,05 ; 8; 7 = 3,73 (Table of distribution F)

From the results of data processing that have been carried out, it can be concluded that from the results of the fit test of the Push Button Control damage distribution using the Mann's test the value of $M_{count} < M_{table}$, nilai M_{count}value is 1.45 and the M_{table} value is 3.73 then the null hypothesis (H_0) received, the Push Button Control damage distribution is Weibull.

The results of data processing in determining the fit distribution test of Push Button Control damage using mann's test can be seen in table 2. below:

Table 2. Push Button Control Damage Distribution Suitability Test

No	Ti	Ln(ti)	Zi	Mi	ln(ti+1)-ln(ti)	(ln(ti+1)-ln(ti))/Mi
1	5	1,609438	-3,466	1,131	0,470	0,416
2	8	2,079442	-2,335	0,545	0,223	0,409
3	10	2,302585	-1,789	0,373	0,262	0,704
4	13	2,564949	-1,416	0,290	0,654	2,253
...	...	...	...	...	...	...
14	83	4,418841	0,575	0,227	0,146	0,642
15	96	4,564348	0,801	0,322	0,288	0,893
16	128	4,85203	1,124			
∑	706	55,06856	-9,470	4,589	3,243	11,987

2. **The Calculation of*Mean Time To Failure* (MTTF)**

   The Calculation ofValue of MTTF *Push Button Control*

   $$MTTF = 47,9\Gamma\left(1 + \frac{1}{1,26}\right)$$

   $MTTF$ = 44,547 ≈ 44 Hari

3. **The Calculation of RAM**

   a. **Reliability Push Button Control**

   $$R(44) = e^{-\left(\frac{44}{47,9}\right)^{1,26}}$$

   $R(44)$ = 0,4069 = 40,69%

   b. **Availability Push Button Control**

$$A = \frac{44\ x\ 8\ x\ 60}{(44\ x\ 8\ x\ 60) + 87}$$
$A = 0{,}9958 = 99{,}58\%$

c. Maintainability Push Button Control

$M(90) = 1 - e^{-\left(\frac{90}{87}\right)}$
$M(90) = 0{,}64 = 64\%$

4. Calculation of Proposed Maintenance Intervals and Duration of Machine Repair Time

a. Calculation of Proposed Maintenance Intervals for Push Button Control Components

$R(pm) = e^{-\left(\frac{pm}{47,9}\right)^{1,26}} = 70\%$
$R(pm) = e^{-x} = 70\%$
$e_{Log\,0,7} = -x$
$x = \frac{Log0,7}{Loge}$
$-x = 0{,}357$
$\left(\frac{pm}{47,79}\right)^{1,26} = 0{,}357$
$\left(\frac{pm}{47,79}\right) = \sqrt[1,26]{0{,}357}$
$\left(\frac{pm}{47,79}\right) = 0{,}442$
$pm = 21{,}12 \approx 21$ Hari
$R(21) = e^{-\left(\frac{21}{47,9}\right)^{1,26}}$
$R(21) = 0{,}7020 = 70{,}2\%$

b. Calculation of Proposed Duration of Time to Repair Push Button Control Components

$M(tm) = 1 - e^{-\left(\frac{tm}{87}\right)} = 70\%$
$M(tm) = 1 - e^{-(x)} = 70\%$
$= e^{-x} = 0{,}3$
$= e_{Log\,0,3} = -x$
$= x = \frac{Log\,0,3}{Loge} = -1{,}204$
$= \frac{tm}{87} = 1{,}204$
$= tm = 87$ x 1,204 = 104,75 ≈105 Menit
$M(105) = 1 - e^{-\left(\frac{105}{87}\right)}$
$M(105) = 1 - 0{,}2991 = 0{,}7009 = 70{,}09\%$

2. Calculation of*Poisson Process*

Calculation of *Poisson Process* Komponen *Push Button Control*

$$\lambda 1 = \frac{1\ x\ 1\ x\ (8x26) x\ 12\ x 0,3}{44\ x\ 8}$$
$\lambda 1 = 2{,}13$
$$\lambda 2 = \frac{1\ x\ 1\ x\ (8x26) x\ 1,45}{44\ x\ 8}$$
$\lambda 2 = 0{,}8568$

P1 probability calculations for push button control components are as follows:

- For 0 *spare*, $\text{P1} = e^{-(2,13)} = 0{,}12$
  P(0) = 0,12
- For 1 *sapre*, $\text{P1} = 0{,}12$ x $(1 + 2{,}13) = 0{,}376$
  P(1)= 0,376 – 0,12 = 0,256
- For 2 *spare*, $\text{P1} = 0{,}12$ x $(3{,}13 + 2{,}27) = 0{,}648$
  P(2) = 0,648-0,376 =0,272
- For 3 *sapre*, $\text{P1} = 0{,}12$ x $(5{,}4 + 1{,}61) = 0{,}84$
  P(3) = 0,84 – 0,648 = 0,192

Calculation of P2 probability for push button control components is as follows:

- For 0 *spare*, $\text{P1} = e^{-(0,8568)} = 0{,}4245$

P(0) = 0,4245

- For 1 *sapre*, $P1 = 0{,}4245 \text{ x } (1 + 0{,}8568) = 0{,}7882$
  P(1)= 0,7882 – 0,4245 = 0,3637
- For 2 *spare*, $P1 = 0{,}4245 \text{ x } (1{,}8568 + 0{,}3671) = 0{,}9441$
  P(2) = 0,9441-0,7882 =0,1559
- For 3 *sapre*, $P1 = 0{,}4245 \text{ x } (2{,}2239 + 0{,}1048) = 0{,}9885$
  P(3) = 0,9885 – 0,9441 = 0,044

Table3. Push Button Control Components that can be fixed

I	P(i,λ1 = 2,13)	P(i,λ2 = 0,989)
0	0,12	0,4245
1	0,256	0,3637
2	0,272	0,1559
3	0,192	0,044

Table 3 is a collection of the results of the calculation of probability P1 and P2 for the number of components needed. For the iteration calculation the push button control component requirements are as follows:

- For 0 *spare* P(0) = 0,12 x 0,4245 = 0,051 = 5,1%
- For 1 *sapre* P(1) = 0,051 + 0,3637 + (0,256 x 0,4245) = 0,5234 = 52,34%
- For 2 *sapre* P(2)=0,051 + 0,3637 + 0,1559 +(0,256x 0,4245) + 0,3637 + (0,272 x 0,4245) = 1,16 = 116%

The company must provide at least 3 components in 1 year, where n-1 = 2, n = 2 + 1 = 3 to meet the needs of push button control components,

3. The Calculation of Economic Order Quantity

Push Button Control

$$EOQ = Q = \sqrt{\frac{2 \ x \ 3 \ x \ 100.000}{0{,}25 \ x \ 200.000}} = 3{,}46 \approx 3$$

4. Result of Data Processing

Table4. Result of Data Processing

No	Name of component	The number of damage				MTTF (day)	R %	A%	M%	Suggestions	
		2017	MTBF (day)	2018	MTBF (day)					Interval Preventive Maintenance (day)	Duration Time Repair Component (minute)
1	*Push Button Control*	7	52,14	10	36,6	44	40,69	99,58	64	21	105
2	*Electric Trolley*	9	40,56	7	52,29	38	46,67	99,41	55,51	26	180
3	*Inverse phase squance protecting device*	6	60,83	6	61	62	40,13	99,6	63,21	40	150
4	*Upper and lower limit switch*	4	91,25	5	73,2	83	43,04	99,74	58,26	46	124
5	*Safe brake system*	4	91,25	1	366	144	40,9	99,81	60,55	101	156

Table 4 is the overall results obtained from the data processing that has been done. Proposed preventive maintenance intervals are carried out before the average time damage for each component of the Hoist machine occurs. Proposed duration of repair of Hoist engine components is carried out to restore the reliability of engine components by 70%. The availability value was not given an improvement proposal because the initial condition availability condition of the Hoist engine component was in accordance with the provisions which reached 99%.

Conclusions

1. Push Button Control Components have an average damage time every 44 days, the reliability value is 40.69%; Availability 99.58% and Maintainability of 64%. In order to maintain the reliability value of 70%, preventive maintenance must be carried out every 21 days. If damage occurs to the Push Button Control component, then the maintenance time duration of 105 minutes is required.
2. Electric Trolley Components on average the time of damage occurs every 38 days, its reliability value of 46.67%; Availability 99.41% and Maintainability of 55.51%. In order to maintain the reliability value of 70%, preventive maintenance must be carried out every 26 days. If damage occurs to the Push Button Control component, 180 minutes of treatment time are required.
3. Inverse phase squance protecting device components the average time of damage occurs every 62 days, the reliability value of 40.13%; Availability 99.6% and Maintainability of 63.21%. In order to maintain the reliability value of 70%, preventive maintenance must be carried out every 40 days. If damage occurs to the Inverse phase squance protecting device component, a maintenance time duration of 150 minutes is required.
4. Upper and lower limit switch components have an average damage time every 83 days, the reliability value is 43.04%; Availability 99.74% and Maintainability of 58.26%. In order to keep the reliability value at 70%, preventive maintenance must be carried out every 46 days. If there is damage to the components of the Upper and lower limit switches then the maintenance time duration is 124 minutes.
5. Safe Brake System components the average damage time every 144 days, the reliability value of 40.9%; Availability 99.81% and Maintainability of 60.55%. In order to maintain the reliability value of 70%, preventive maintenance must be carried out every 101 days. If damage occurs to the Safe Brake System component, a 156-minute duration of treatment is required.

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