The Analysis of Maintenance System Using Risk Based Inspection Approach

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ABSTRACT

Maintaining machines is considered to be the main factor that support the company in decreasing machines breakdown/failure. Machines breakdown is often caused by their decreasing reliability that, in turn, influence production process. Based on the above explaination, an analysis using Risk Based Inspection (RBI) is carried out and aimed to empower preventive maintenance besides its function in process control. In initial step of RBI, it is critical to identify any priority section and equipments and to determine critical components that tend to break frequently. It is, therefore, found out that the critical components include: bearing, packing,sleeve, impeller, and sealing. In order to find out the failure mode experienced by each component, Root Cause Failure Analysis(RCFA) is used. RCFA describes various failures, their causes, and their impact on the production process that will be show the value of RPN. The determination of preventive maintenance is based on the calculation of TTR and TBF using distributions. Applying Weibull distribution, Bearing component's MTBF value is 521,235 and MTTR has the value of 7,42857 with exponensial distribution. Packing component with exponential ditribution produces MTBF and MTTR value of 787,8 and 4,03022 . Sleeve component has MTBF and MTTR value of 1013,25 and 3,33 while Impeller has the value of 557,6071 and 8,61901 for both indicators. Based on the interval calculation inpection and replacement, the Bearing component requires 91 hours inspection interval and scheduled replacement interval of 521,235 hours. Packing component inspection interval is 128 hours and schedule replacement should be done within the interval of 787,8 hours. Each o Sleeve component, Impeller and Sealing has inspection interval of 140, 87 and 89 hours while their replacement were scheduled within 2,73; 2,73 hours and 2,09 hours. We conclude the Maintenance system using RBI could increase performance of each component due to increasing availaibility and minimized machine downtime.

Keywords : RBI, FMEA, Maintenance Scheduling

1. INTRODUCTION

1.1 Background

In every industry – particularly manufacturing industry - , the smoothness and uninterrupted process are required to produce good quality products effectively and efficiently. In addition, the performance of machines becomes critical factor that support the entire production activity. In order to keep the machines in good performance, the maintenance activity should contribute to continuous operation of machines. Machine breakdown will affect to the production process while threats the

ISSN: 1978-774X

health and safety of workers. Besides, financially the enterprise will suffer from machine breakdown due to production loss while idle.

Current machine maintenance at PT. X - recorded on machine maintenance sheet - is Preventive Maintenance which is executed within three months period and carried out by Maintenance Department. However, breakdown maintenance still occurs although regular inspection has been done.

Due to the above problem, Risk Based Inspection is suggested in order to make preventive maintenance more effective without interrupting production process and planning.

1.2 Problem Identification

The problems identified is the current maintenance practice which is carried out on habitual based practice without an effort to reduce downtime.

1.3. Research Objective

The aims of this research are :

1. Suggest the improved machine maintenance system using Risk Based Inspection.
2. Compare suggested maintenance system with current maintenance based on maintenance cost.

2. THEORETICAL BACKGROUND

The objectives of maintenance can be defined as follows:

1. To ensure that theoretical useful life of asset / machine is achieved
2. To guarantee optimum availability of equipment used in order to generate profit on products manufactured.
3. To guarantee operating readiness of all equipment anytime they are need including in emergency condition
4. To protect health and safety condition of workers
5. To keep the acceptable quality level .
6. To reduce maintenance cost by executing maintenance activity efficiently and effectively.
7. To avoid maintenance activities that could potentially harm workers.

2.1. Risk Based Inspection

Risk Based Inspection (RBI) is a method based on risk identification in deterimining the priority of maintenance inspection program. RBI is first introduced in Petrochemical and Oil Refinery Industry to reduce mecha failures - where failure within piping system contributes the biggest portion of total failures. As a maintenance method, RBI can be applied to identify risk and give priority on high risk system and provide best solution to reduce the risk involved.

The objective of RBI include :

- Controlling operation unit in factory to identify high risk area.
- Estimate risk value involved in every single equipmet installed.
- Priority decision of equipment based on risk measurement.
- Develop inspection program
- Managing failure risk sistematically
- Estimate risk value related to installed equipment.
- Give priority level on equipments based on risk measurement.
- Develop inspection program
- Manage risk of equipment failure and breakdown systematically.

Consequence.

Consequence is the result of an event and in terms of RBI it explained abnormal condition .

Probability of Failure.

Failure refers to incapabillity of machine/parts to operate its normal function. Ex; internal corrosion, external corrosion and crack /leakage.

Risk

Risk is defined as chance of something bad happening. The ”chance” itself refers to probability and “something” means consequencce. The Risk can be measured by multiplying Probability of failure and consequence of failure .

Mean Time To Failure (MTTF)

Mean Time To Failure (MTTF/MTBF) is defined as average of expected value in a failure distribution .

MTTF itself can be approached using the following distribution .

- Exponential distribution : MTTF = 1 / λ ……(1)
- Weibull Distribution:MTTF = $\phi\Gamma(1+1/\beta)$ …….(2)
- Normal Distribution : MTTF = µ …..(3)
- Lognormal distribution: MTTF = $t_{med}\ e^{s^2/2}$ ….(4)

Mean Time To Repair (MTTR)
MTTR is the central value of time interval between repairs which is calculated start from the failure occurs and ended when repair is done completely. The estimation of MTTR based on various distribution as follows :

- Exponential Distribution : MTTR = 1 / λ …fefer to (1)
- Lognormal Distribution :MTTR = $t_{med}\ e^{s^2/2}$ …refer to (4)

2.2 Optimum Maintenance Interval
Optimum maintenance interval is defined as time needed to accomplish maintenance. It is divided to preventive replacement and routine inspection. The condition that require Preventive Replacement is : Total replacement cost exceeds preventive replacement i.e, replacement is executed before breakdown occurs.

a. Optimum Preventive Replacement Interval Model aims to determine t_p i.e.. optimum duration between replacement to minimize downtime per time unit

Cost of replacement per time unit [TC(t_p)] at time **t_p** is formulized as follow :
TC(t_p)=

$$\frac{C_P R(t_P)+C_f F(t_P)}{(t_P+T_P)R(t_P)+[M(t_P)+T_f]F(t_P)}$$

…..(5)
Note:
t_p = interval of preventive replacement interval waktu penggantian pencegahan.
C_p = *preventive maintenance* cost per cycle
C_r = Biaya kerusakan (korektif) dalam satu siklus.

b. Optimum Preventive Replacement Useful life Determination Model. Under this model, preventive replacement calculation is determined by useful life of components.

2.3 Reliabillity Model
The next reliability models are based on assumption that the system performance will be reconditioned as initial condition after preventive maintenance is carried out. Given R(t) is the system reliability without preventice action, T is time interval between preventive maintenance, and Rm(t) refers to system reliability under preventive maintenance, hence :

Rm(t) = R(t) for 0≤t< T , and
Rm(t) = R(T)R(t-T) untuk T≤t< 2T .....(6)

When preventive replacement is applied to system that has constant failure , this will not improve the reliability of system. In order to achieve the suitable reliability value, we can use the following distributions :

Weibull Distrubution
Reliability value without maintenance : R(t) $= \exp\left[-\left(\frac{t}{\theta}\right)^{\beta}\right]$ ….(7)
Reliability value with preventive maintenance:

$$Rm(t) = \exp\left[-\left(\frac{T}{\theta}\right)^{\beta}\right]\exp\left[-\left(\frac{t-nT}{\theta}\right)^{\beta}\right]$$

, for nT≤t< (n+1)T …..(8)

Distribusi Lognormal
Reliability value without maintenance :
R(t) = 1-$\phi\left(\frac{1}{s}\ln\frac{t}{t_{med}}\right)$….(9)
Reliability value with preventive maintenance :

Rm(t)

$$=\left[1-\phi\left(\frac{1}{s}\ln\frac{t}{t_{med}}\right)\right]^{n}\left[1-\phi\left(\frac{1}{s}\ln\frac{t-nT}{t_{med}}\right)\right],$$

nT≤t< (n+1)T ....(10)

ISSN: 1978-774X

Normal Distribution

Reliability value without maintenance: R(t) = 1-$\phi\left(\frac{t-\mu}{\sigma}\right)$ ….(11)

Reliability value with preventive maintenance :

Rm(t)

$$=\left[1-\phi\left(\frac{t-\mu}{\sigma}\right)\right]^{n}\left[1-\phi\left(\frac{t-\mu-nT}{\sigma}\right)\right],$$

nT≤t< (n+1)T …..(12)

III. RESEARCH METHOD

Research method of this paper is described in figure 1 below :

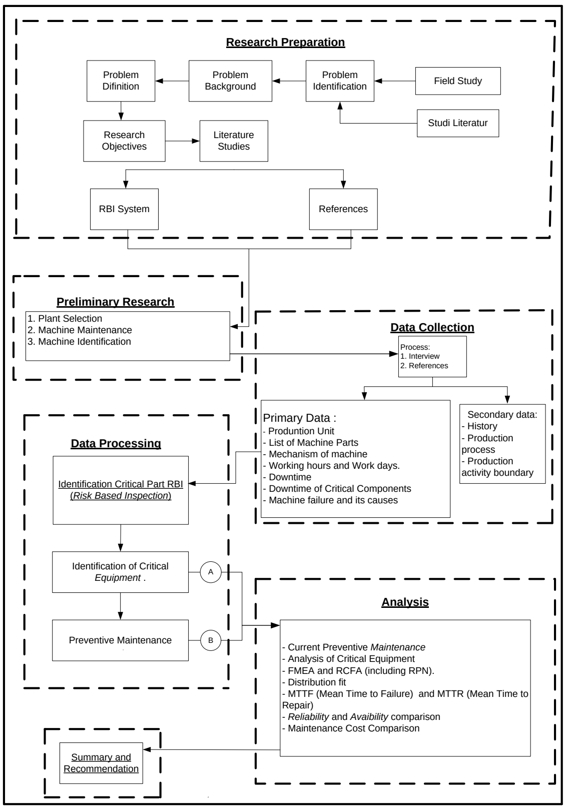

Figure 1. Research Methodology.

4. RESULT AND DISCUSSION

PT X produces three kinds of diesl machine product i.e. Generator Set, Pump set and Stationer Diesel Set (TS and TF model). TS type has 30 HP Power with seven variants while TF type has two variants.

4.1.Data Processing

RBI *Screening*

Initial step within RBI system is RBI screening. After completing this step in overall painting Process section, we conclude primer booth as critical part. The whole parts are described as below :

1. *Vassel Cleaning.*
2. *Degreating Tank.*
3. *Water Rinse Tank.*
4. *Air Blow.*
5. *1st. Small Oven.*
6. *2nd. Small Oven.*
7. *Primer Booth.*
8. *Finish Booth.*
9. *Baking Oven.*
10. *Conveyor.*
11. *Hoist.*

The highest probability training found was on blower motor i.e. Consequence Rating 17 that means very high. From the combining influence of probability and consequence rating, we calculated Overall Rating Risk of Very High for Primary Booth section.

4.2 Critical compenent Determination

Tabel 1. describes the data of breakdown time which are collected at Maintenance Section.

Table 1. Data of Breakdown of Blower Primer booth

No.	Tanggal	Jam	No. Kejadian	Uraian	Lama Perbaikan (Jam)
Bearing					
1	30-01-08	10**-- 12**	3b	- Oli masuk ke bearing ----> bersihkan bearing beri grease	2
2	04 -02-08	07**-- 09**	4	- Periksa bearing motor blower dan kencangkan bearing	2
3	14-03-08	23**--05**	7	- Kasih grease pada bearing	6
4	19-03-08	01**--07**	8b	- Beri grase pada bearing	6
5	15-04-08	13**-- 22**	9b	- Ganti bearing ----> korosi	9
6	22-07-08	07**--10**	14	- Bersihkan Bearing motor	3
7	28 -10-08	11**--**	17	- Ganti bearing	24
Packing					
1	30-01-08	10**-- 12**	3a	- Packing bocor ----> ganti	2
2	15 -02-08	08**-- 11**	5a	- Ganti Packing --> bocor	3
3	15-04-08	13**-- 22**	9a	- Packing bocor ----> ganti	9
4	18-06-08	18**--22**	12a	- Ganti Packing	4
5	22-08-08	08**--12**	15a	- Ganti Packing --> bocor	4
6	22 -12-08	11**--**	19b	- Ganti Packing	24
Sleeve					
1	15 -02-08	08**-- 11**	5b	- Sleeve aus --> ganti	3
2	15-05-08	08**-- 11**	10	- Ganti Sleeve --> Aus	3
3	22-08-08	08**--12**	15b	- Sleeve aus --> ganti	4
Impeller					
1	04 -01-08	11**--**	1	- Ganti Impeller	24
2	18-01-08	08**--11**	2	- input clamp untuk impeller	3
3	20 -02-08	11**--18**	6b	- Ganti Impelleer -->Impelleer ngempos	7
4	19-03-08	01**--07**	8a	- Ganti Impeller	6
5	05 -09-08	11**--17**	16	- Ganti Impelleer	6
6	22-11-08	23**--05**	18b	- Ganti sealing	5
Sealing					
1	20 -02-08	11**--18**	6a	- Ganti sealing --> Sealing bocor	7
2	19-05-08	10**--15**	11	- Kegagalan pada Sealing --> Motornya terbakar	5
3	18-06-08	18**--22**	12 b	- Bersihkan Sealing	4
4	18-07-08	17**--22**	13	- Ganti sealing --> Sealing *buckling*	5
5	22-11-08	23**--05**	18a	- Ganti sealing	5
6	22 -12-08	11**--**	19a	- Ganti sealing	24

Root Cause Failure Analysis **(RCFA)**

Root Cause Failure Analysis (RCFA) is the next step of RBI Screening. RFCA can identifiy technical matters involved with failure causes of the fuction of pumps, detail of breakdown causes, the explaination why it happened and the effect of the failure. Under FMEA (Failure Mode And Effect Analysis), priority determination of failure is based on RPN calculation for each failure mode.

Tabel 2 RPN Value of Components of Blower Motor

Information				***FMEA Scoring***			
				Severity	***Occurance***	***Detection***	**RPN**
No	*Bearing*						
1	1	A	1	9	10	9	810
2	1	B	1	9	8	7	504
	Packing (gland)						
3	1	A	1	9	10	8	720
4	1	B	1	9	10	8	720
5	1	C	1	9	10	7	630
	Sleeve						
6	1	A	1	9	10	9	810
	Impeller						
7	1	B	1	8	10	9	720
8	1	A	1	9	6	8	432
	Slealing						
9	1	A	1	9	10	2	180

Tabel 3 Index of fit comparison of Four Distribution of TBF

INDEX OF FIT VARIOUS DISTRIBUTION TBF		
DISTRIBUSI	***INDEX OF FIT***	
Weibull	0,9720858	Max
Normal	0,9353	
Eksponensial	0,97073	
Lognormal	0,958865142	

Tabel 4 . Index of Fit

INDEX OF FIT KEEMPAT DISTRIBUSI TTR		
DISTRIBUSI	***INDEX OF FIT***	
Weibull	0,7563982	
Normal	0,7394	
Eksponensial	0,76780	
Lognormal	0,772264572	Terbesar

4.3 Goodness of fit distribution test on TBF and TTR

Good fitness of distribution was executed to determine whether the Time to Failure on the compenents reflects the fitted distribution proved with the greatest index of Fit.

Below are the distribution test used within this research:

- Mann's test with α = 0,05 for Weibull distribution
- Barlett test with α = 0,05 for Exponential Distribution.
- *Kolmogorov-Smirnov test with* α = 0,05 for Normal and Lognormal distribution.

The results are shown in below tables:

Table 5. TBF and TTR Result : Bearing

Bearing				
TBF		TTR		
Uji Mann's		Uji Barlett		
F tabel	M	$\chi^2_{1-\frac{\alpha}{2}, r-1}$	B hitung	$\chi^2_{\frac{\alpha}{2}, r-1}$
9,28	0,436505	1,237	4,3575	14,49
Kesimpulan: Terima Ho		Kesimpulan: Terima Ho		

Table 6. TBF and TTR Result : Packing Component

Packing				
TBF			TTR	
Uji Barlett			Uji Mann's	
$\chi^2_{1-\frac{\alpha}{2}, r-1}$	B hitung	$\chi^2_{\frac{\alpha}{2}, r-1}$	F tabel	M
0,831	1,654682	12,832	9,28	5,63321
Kesimpulan: Terima Ho			Kesimpulan: Terima Ho	

Table 7. TBF and TTR Result : Sleeve Component

Slevee					
TBF			TTR		
Uji Barlett			Uji Barlett		
$\chi^2_{1-\frac{\alpha}{2}, r-1}$	B hitung	$\chi^2_{\frac{\alpha}{2}, r-1}$	$\chi^2_{1-\frac{\alpha}{2}, r-1}$	B hitung	$\chi^2_{\frac{\alpha}{2}, r-1}$
0,0^{3}982	0,099458	5,024	0,0506	2,314954	12,832
Kesimpulan: Terima Ho			Kesimpulan: Terima Ho		

Table 8. TBF and TTR Result : Impeller Component

Impeller				
TBF			TTR	
Uji Barlett			Uji Mann's	
$\chi^2_{1-\frac{\alpha}{2}, r-1}$	B hitung	$\chi^2_{\frac{\alpha}{2}, r-1}$	F tabel	M
0,484	3,515022	11,143	9,28	3,83043
Kesimpulan: Terima Ho			Kesimpulan: Terima Ho	

Table 9. TBF and TTR Result : Sealing Component

Sealing					
TBF			TTR		
Uji Barlett			Uji Barlett		
$\chi^2_{1-\frac{\alpha}{2}, r-1}$	B hitung	$\chi^2_{\frac{\alpha}{2}, r-1}$	$\chi^2_{1-\frac{\alpha}{2}, r-1}$	B hitung	$\chi^2_{\frac{\alpha}{2}, r-1}$
0,484	1,54091	11,143	0,831	2,315736	12,832
Kesimpulan: Terima Ho			Kesimpulan: Terima Ho		

4.4 Maintenance Inspection Interval Estimation to minimize Maintenance Cost

Maintenance inspection interval is calculated based on inspection frequency as the result of distribution fitting of Time To repair. The result is assumed to reach optimum solution considering maintenance cost (see table 10),

In addition, replacement interval (in month) is the product of replacement interval (in month) which distribution is based on Time To Repair's one. (see table 11)

Table 10. List of Inspection Interval of Components

Component	TTR Distribution	Monthly Inspection Freq	Inspection Interval (hour)
Bearing	Eksponensial	4	91
Packing	Weibull	3	128
Slevee	Eksponensial	3	140
Impeller	Weibull	4	87
Slevee	Eksponensial	4	89

Table 11. List of Interval of Replacement Scdl

Component	TBF Distribution	Replacement Interval (hour)	Replacement Interval (month)
Bearing	Eksponensial	521,235	1,40
Packing	Weibull	787,8	2,12
Slevee	Eksponensial	1013,25	2,73
Impeller	Weibull	780,65	2,10
Sealing	Eksponensial	775,95	2,09

Downtime and availability time calculation based on inspection frequency is shown in table 12.

Table 12, Result of Downtime and Availability calculaction on Motor Blower Primer Booth

Component	Downtime [D(n)]	Availability [A(n)]
Bearing	0,00859	0,99141
Packing	0,00599	0,99401
Slevee	0,00568	0,99433
Impeller	0,00848	0,99151
Slevee	0,008389	0,99161

The comparison between preventive maintenance and corrective cost (see table 13) show that Preventive Maintenance Practise as suggested has potential advantage compared to Corrective action.

Table 13. Maintenance Cost estimation on Motor Blower Primer Booth (in IDR)

Component	C-Failure	C-Preventive	Cost Reduction
Bearing	27.743.400.000.000	9.247.720.000.000	18.495.680.000.000
Packing	27.743.300.000.000	9.247.720.000.000	18.495.580.000.000
Slevee	27.743.400.000.000	9.247.720.000.000	18.495.680.000.000
Impeller	27.743.500.000.000	9.247.720.000.000	18.495.780.000.000
Slevee	27.743.500.000.000	9.247.720.000.000	18.495.780.000.000

Calculation and comparison of Reliability after Implementation

⇒ Of time t_p is defined to maintenance inspection interval which is calculated with trial and error method, we can conclude the following formula: ;

$$R(t) = \exp\left[-\left(\frac{t}{\theta}\right)^{\beta}\right] \quad \text{.... (13)}$$

Reliability result if prevention inspection is carried out: Rm(t) =

$$\exp\left[-\left(\frac{T}{\theta}\right)^{\beta}\right]\exp\left[-\left(\frac{t-nT}{\theta}\right)^{\beta}\right] \quad \text{.... (14)}$$

The increased reliability is calculated with below formula :

Reliability Increment = [R(t-Nt)-R(t)] x 100 % = 1- 0,388452450 =0,61154755 = 61,15 %

Availability

Availability means the comparison (in percentage) of available / productive time used by machines to produce goods compared to total machine time. From table. 14 , the record of availability improvement is shown as the result of monthly calculation using formula ;

Availability= Planned Avaibility x Uptime

Table 14. Monthly Availability Improvement

Month	*Avaibility Improvement*
January	4,203733364
February	2,876710122
March	3,357067598
April	2,270814055
May	1,98300126
June	0,919438871
July	2,018501382
August	1,03723316
September	1,575341257
October	3,219175613
November	1,09588957
December	3,219175613

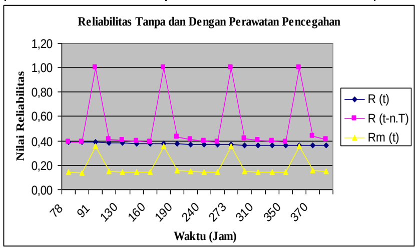

figure 6. Reliability Comparison between W/O vs WITH preventive maintenance

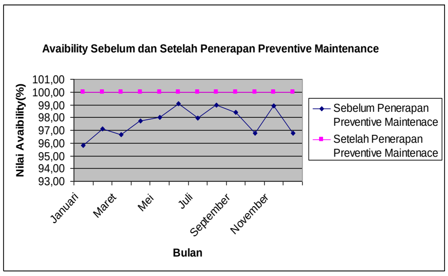

figure 7. Availability Motor Blower at Primer Booth – Comparison between no vs with preventive maintenance

4.5 Recommendation

❖ **Bearing *Component***

Based on data processing process, it is highly recommended to execute preventive maintenance i.e. replacement on Bearing
within 521. 235 hours and regular inspection of 4 times monthly. The particular parts involved are oil chamber and bearing reel with maintenance activity as below:

- Checking on oil chamber is suggested in order to monitor whether any leakeage occurs. In addition Bearing position should be checked by monitoring the distance between vertical shaft position and normal distance between bracket bearing and bearing housing (0.5 mm)
- Inspection on bearing reel in which no lubricant allowed since it can melt Grease and Imprecision due to friction.

❖ ***Packing Components***

It is suggested to replace Packing every 787.8 hours with regular inspection of three times per month on bolts, sealing (rongga sealing) and packing position

❖ ***Sleeve Components***

It is suggested to replace Sleeve compenent in every 1013.25 hours with regular inspection of three times per month and inspection of sleeve position,

❖ ***Impeller Components***

It is suggested to replace impeller compenent in every 780.65 hours with regular inspection of four times per month on clamp position at impeller to ensure the clamp locked.

❖ ***Sealing Components***

It is suggested to replace sealing compenent in every 775.95 hours with regular inspection of four times per month on clamp position at impeller to ensure the clamp locked. Cleaning of Sealing Hole is suggested when machine in overhaul condition to ensure good result.

5. CONCLUSION

1. Based on RBI Screening, we can determine the critical part i.e. Primer Booth.
2. Under RCFA, we can conclude the causes of failure at Motor Blower Primer booth as follow :
    - ***Bearing***: component failure due to leakage of Bearing and since the latter lose its grease, the balls of bearing can not be in position precisely ***packing****: component breakdown is resulted from untightened fastener bold, dirty sealing hole.*
    - *sleeve*: breakdown due to shifting sleeve.
    - *Impeller* component : component breakdown is resulted from unmatched of impeller due to air leakage through the clamp
    - Sealing Componen : sealing is clogged up due to dirty sealing hole
3. RPN is the result of multiplying factors that contribute to component falure i.e. SOD (*Severity*, *Occurance* dan *Detection*). The value of RPN is used as index to classify serious event. Bearing 1A1 has the highest value of 810 and is assumed to have the most serious cause.
4. Based on cost estimation , *inpection preventive maintenance cost produce lower cost compared to Failure corrective maintenance*. This is due to fewer breakdown under planned inspection.
5. We can estimate reliability improvement for Bearing *Bearing* under recommended preventive maintenance.

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