Reliability Analysis for Preventive Maintenance of Salt Crusher Machine

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***Abstract*— Crusher is one of the machinery in salt industry with the highest failure frequency. In this study, six components reliability are investigated: Bearing, Electric motor, Pulley, Roll, Adjuster, and V-Belt. From its reliability analysis, four preventive maintenance (PM) plans are created, namely Component reliability-oriented PM, Component lifetime-oriented, PM based in 2016 MTBF, and PM based on 2015 optimum MTBF. Afterward, the four PM plans compared in terms its reliability, cost, and production. The result are the lifetime-oriented PM has the best production, the PM based 2016 MTBF has the best cost, and the PM based on 2015 optimum MTBF has the best reliability. Reliability-oriented PM is the second best in terms of reliability and cost and therefore it is recommended to be applied.**

***Index Terms*—cost, crusher, preventive maintenance, production, reliability**

I. Introduction

In today's industrial world, everyone depends upon the continued functioning of a wide array of complex machinery and equipment for his or her everyday health, safety, mobility and economic welfare [1]. When those machinery and equipment fail, the results can be catastrophic: injury, loss of life, and costly lawsuits. If it occurs more often, repeated failure would lead to annoyance, inconvenience and a lasting dissatisfaction [2].

Maintenance can be defined as an activity to keep a facility or equipment at its required performance [4]. It can be classified to breakdown maintenance, predictive maintenance, and preventive maintenance [5] [6].

Breakdown maintenance is performed when failures occur in an operation. It does not require a maintenance planning and scheduling, which will result in unpredicted interruption production and a further cause of customer dissatisfaction.

Predictive maintenance is performed when there are indications that either a component or the system is likely to fail. It can be done only if the system is checked constantly so that the signs of failure can be identified before the failure happen [7].

Preventive maintenance is performed according to a fixed schedule, determined by the characteristics of the equipment to reduce the chance of failure. It requires historical data to determine the failure pattern of each component. The advantage of the preventive maintenance is that the maintenance is done according to a scheduled time interval, so the required resources can be pre-planned. The disadvantage of preventive maintenance is that it may be scheduled at a time before the system supposed to fail, which will result in wastage of resources [7].

To reduce the wastage and interruption time, reliability needs to become one of the considerations in a maintenance plan. The reliability of a product is a measure of its ability to perform according to its function, if it is required, in a specific time and environment [8] [9]. Reliability can also be defined as the probability of a facility or equipment to work without fail in a specific time interval [10]. It is measured as a probability because failure cannot be prevented entirely [3]. Reliability will be considered in calculating the part replacement time interval and scheduling of the maintenance plan.

The purpose of the present paper is to investigate the different preventive maintenance plan of salt crushing machine from cost, reliability, and the impact to production point of view to determine which preventive maintenance plan is recommended for the salt crusher machine.

II. Methodology

A. Collecting Failure Time Data

Collecting Crusher Machine failure data and its components during the specified period, in this case, the year 2016, is done by using the daily logbook of the maintenance personnel. After that, the failure time data are categorized to its components that resulted in many causes of failure. They are Bearing, Electric Motor, Adjuster, Pulley, Roll, and V-belt.

B. Testing the Data Statistical Distribution

Determination of the most suitable distribution must be done to know which statistical distribution is more likely to match with the failure behavior of each component. The distribution test is done by using Minitab 17 Statistical Software [11].

1) Distribution test: Bearing

The Anderson-Darling coeffient for Weibull distribution resulted 2.069 while Lognormal, Exponential, and Normal distribution resulted 1.383; 3.155; 7.425 respectively.

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The lowest value of Anderson-Darling coefficient determines the most suitable distribution [5]. Compared to the other three, lognormal statistical distribution is the lowest. Therefore, reliability analysis of the bearing component will be done using lognormal statistical distribution

2) Distribution test: Electric motor

The distribution test of electric motor shows 1.557; 1.631; 1.940; 1.909 for Weibull, Lognormal, Exponential, and Normal distribution respectively. The lowest value is weibull distribution. Therefore, the reliability analysis of electric motor will be done using Weibull statistical distribution

3) Distribution test: Pulley

The distribution test of pulley shows 2.703; 2.469; 2.764; 4.827 for Weibull, Lognormal, Exponential, and Normal distribution respectively. Because the lowest value of the Anderson-Darling coefficient is 2.469 of Lognormal distribution, reliability analysis for pulley will be done by using Logormal statistical distribution

4) Distribution test: Roll

Results of the distribution test of roll shows 4.349; 4.207; 4.672; 4.575 for Weibull, Lognormal, Exponential, and Normal respectively. In comparison with the other three, Lognormal distribution shows the lowest results. Hence, the reliability analysis for roll component will be done using the lognormal statistical distribution.

5) Distribution test: Adjuster

The results for distribution test for adjuster are: 2.364 for Weibull distribution; 1.901 for Lognormal distribution; 2.768 for Exponential distribution; and 6.369 for Normal distribution. Since the lowest value of Anderson-Darling coefficient is 1.901, the distribution that suits for reliability analysis of adjuster component is the lognormal statistical distribution

6) Distribution test: V-Belt

The results for distribution test for V-belt are: 3.521 for Weibull distribution; 3.587 for Lognormal distribution; 3.888 for Exponential distribution; and 4.757 for normal distribution. The lowest value is Weibull distribution so the reliability analysis for V-belt component will be done using the Weibull statistical distribution.

C. Reliability Analysis

1) Component reliability analysis: Bearing

Following the lognormal curve pattern, the survival probability of bearing is 80.09% with the TTF (Time to Fail) at 20 hours. This value drastically drops until it reaches 6% with the TTF at 320 hours. Afterwards, it decreases slightly until it reaches below 0.97% reliability when the TTF is more than 970 hours.

2) Component reliability analysis: Electric motor

Electric motor, following the Weibull curve pattern, has high 99% reliability with the TTF at 0.67 hour. Next, this high reliability value decreases significantly to 6.9% if the TTF is 1428 hour. Then it continues to decrease gradually until it reaches lower than 1% reliability when the TTG is longer than 3013.91 hour.

3) Component reliability analysis: Pulley

Pulley, following the lognormal curve, has high 99% reliability with the TTF at 7.53 hour. Next, this value drastically decreases until it reaches 4.3% reliability at TTF 967.65 hour. It decreases further with low reduction until it is lower than 1% reliability if the TTF is longer than 2034.45 hour.

4) Component reliability analysis: Roll

Roll have high reliability around 99% if the TTF is near to 0 hour. It drops significantly to 5.61% reliability at TTF 16500 hour. This decrement continues with little reduction until it reaches lower than 0.94% reliability at TTF longer than 96500 hours. This decremental pattern follows the lognormal curve

5) Component reliability analysis: Adjuster

The adjuster, following its lognormal curve, have 83.1% with TTF 15 hour. Then it drops significantly to 5.35% reliability at TTF 295 hour. It continues to decrease with little reduction to lower than 0.72% reliability if the TTF is longer than 775 hours.

6) Component reliability analysis: V-Belt

The v-belt, following its Weibull curve, will have reliability higher than 85.14% if the TTF is shorter than 15 hours. V-belt reliability is significantly decreases until it reaches 3.89% reliability at TTF 615 hour. Then it decreases slowly to lower than 0.93% reliability if the TTF is longer than 965 hours.

7) Crusher machine reliability with PM based on 2016 MTBF

Reliability of Crusher Machine with its 2016 maintenance plan is calculated by using its MTBF of each component as shown in the table below. In this case, MTBF is the addition of MTTF and MTTR.

TABLE I. MTTF AND MTTR OF 2016 MAINTENANCE PLAN

Component	MTTF (Hour)	TTR (Hour)	MTTR (Hour)
Bearing	97.65	29.75	0.58
E. motor	447.39	6.75	0.75
Pulley	186.32	10.25	0.38
Roll	982.65	6.5	1.3
Adjuster	77.75	18.25	0.31
V-belt	136.148	11.75	0.37

Afterwards, the component reliability and crusher reliability are calculated. The result is shown in the table below.

TABLE II. CRUSHER RELIABILITY WITH PM BASED ON 2016 MTBF

Component	MTBF	Component Reliability	Crusher Reliability
Bearing	98	22%	1.6%
Electric motor	448	60.6%	
Pulley	187	45%	
Roll	984	69.7%	
Adjuster	78	16%	
V-belt	137	36.7%	

The value in the table above means the crusher machine can work without failing in 1.6% of its lifetime.

8) Crusher reliability with PM based on 2015 optimum MTBF

Research on MTBF optimum for salt crusher machine has been done before [12]. It shows that the optimum

MTBF for salt crusher machine is 856.857 minutes or 14.28 hour. The value of 2015 optimum MTBF can be used to calculate reliability value, which is shown in the table below.

TABLE III. CRUSHER RELIABILITY WITH PM BASED ON 2015 OPTIMUM MTBF

Component	TTF	R. Component	R. Crusher
Bearing	14.28	86.9%	64.7%
E. motor	14.28	91.1%	
Pulley	14.28	96.4%	
Roll	14.28	93.8%	
Adjuster	14.28	84.1%	
V-belt	14.28	85.7%	

These values can also be interpreted as the percentage of life time that the crusher machine can work without failing in 64.7% of its life time.

9) Crusher machine reliability with reliability-oriented PM

This method uses parametric distribution test with the component reliability as independent variable and component life time as dependent variable. The component reliability is determined as independent variable because high reliability component will produce high equipment reliability, but to achieve high reliability requires the component to be used in a short life time. The table below illustrates several simulation scenarios of the component life time that are needed to achieve a certain value of reliability.

TABLE IV. SIMULATION SCENARIOS OF RELIABILITY ORIENTED PM

No	Bearing		Electric Motor		Pulley		Roll		Adjuster		V-belt		Crusher
	LT	R	LT	R	LT	R	LT	R	LT	R	LT	R	R
1	2	100	0.25	100	7	100	1	100	2	100	0.25	100	100
2	3	99	1	99	8	99	3	99	3	99	0.5	99	96
3	5	98	2	98	10.5	98	4.5	98	4	98	1	98	92
4	6	97	3	97	13	97	6.5	97	5	97	2	97	88
5	7	96	5	96	15	96	9	96	6	96	3	96	85
6	7.5	95	6.5	95	17	95	11.5	95	7	95	4	95	81
7	8	94	8	94	19	94	14	94	7.5	94	5	94	78
8	9	93	10	93	21	93	16.5	93	8	93	6	93	74
9	10	92	12.5	92	23.5	92	19.5	92	9	92	7	92	71
10	11	91	15	91	24.5	91	22.5	91	9.5	91	8	91	68

10) Crusher Machine Reliability with Lifetime-oriented PM

This method uses parametric distribution test with the component life time as independent variable and component reliability as dependent variable. The component life time is determined as the independent variable because long component life time will affect high production rate. But to achieve long life time requires the component to be used with low reliability. The table below illustrates several simulations of component reliability that are needed to achieve a certain value of component life time.

TABLE V. SIMULATION SCENARIOS OF LIFETIME ORIENTED PM

No	Bearing		E. Motor		Pulley		Roll		Adjuster		V-belt		Crusher
	LT	R	LT	R	LT	R	LT	R	LT	R	LT	R	R
1	1	100.0%	1	98.7%	1	100.0%	1	99.7%	1	100.0%	1	98.2%	96.92%
2	2	99.6%	2	97.8%	2	100.0%	2	99.2%	2	99.6%	2	96.9%	94.39%
3	3	99.1%	3	97.1%	3	99.9%	3	98.7%	3	99.1%	3	95.7%	91.99%
4	4	98.4%	4	96.4%	4	99.8%	4	98.2%	4	98.2%	4	94.6%	89.53%
5	5	97.6%	5	95.8%	5	99.6%	5	97.8%	5	97.2%	5	93.6%	87.11%
6	6	96.6%	6	95.2%	6	99.4%	6	97.3%	6	96.0%	6	92.6%	84.56%
7	7	95.5%	7	94.6%	7	99.1%	7	96.8%	7	94.7%	7	91.7%	81.96%
8	8	94.4%	8	94.1%	8	98.9%	8	96.4%	8	93.3%	8	90.7%	79.49%
9	9	93.3%	9	93.6%	9	98.5%	9	95.9%	9	91.9%	9	89.9%	77.07%
10	10	92.1%	10	93.1%	10	98.2%	10	95.5%	10	90.5%	10	89.1%	74.70%

D. Preventive Maintenace (PM) Cost Calculation

The cost of preventive maintenance is calculated as a consideration to determine which preventive maintenance scenario is feasible.

The cost of preventive maintenance for equipment (CE) is calculated using equation below with under assumption that the component must be replaced each time it fails.

$$\text{CE} = \frac{W_{1y}}{\text{TTR+MTTR}} \times (C_c + C_m). \quad (1)$$

W_{1y} is the number of work hour in a year, TTF (Time to Fail) is the life time of the component until it fails, TTR (Time to Repair) is the time needed to repair a component, C_c is the component cost, and C_m is the cost of maintenance activity. The cost of maintenance activity to pay the worker is 20,000 rupiah or equal to 1.46 USD. The cost of component for each replacement is 230,000 rupiah for bearing, 5,600,000 rupiah for Electric Motor, 1,600,000 rupiah for Pulley, 1,570,000 rupiah for Roll, and 128,650 rupiah for V-Belt. Based from the observation, the cost for adjuster component is negligible because the component is irreplaceable and it would always been repaired by welding.

After each cost of component preventive maintenance has already known, the cost of equipment preventive maintenance can be calculated using Equation

$$\text{CE} = \text{CC}_\text{b} + \text{CC}_\text{e} + \text{CC}_p + \text{CC}_\text{r} + \text{CC}_\text{a} + \text{CC}_\text{v}. \quad (2)$$

CC_b, CC_e, CC_p, CC_r, CC_a, and CC_v is the cost of preventive maintenance for bearing, electric motor, pulley, roll, adjuster, and v-belt respectively. This CE value will be compared to the loss due to downtime (LD) in the year 2016 which are 223,601,616.92 rupiah/year. The maintenance plan that would be chosen should cost less than 223,601,616.92 rupiah/year

1) PM based on 2016 MTBF cost calculation

The Cost of equipment preventive maintenance (CEPM) with 2016 MTBF maintenance plan can be calculated by multiplying the cost of each component by the frequency of failure during the year 2016. The calculation results CEPM of 200,106,675.05 rupiah/year. Because the CEPM is lower than the LD, PM based on 2016 MTBF is one of the suitable maintenance plans.

2) PM based on 2015 optimum MTBF cost calculation

The Cost of equipment preventive maintenance (CEPM) with 2015 Optimum MTBF maintenance plan can be calculated by using the CCPM equation with optimum MTBF, replacing TTF+MTTR as the denumerator. The calculation results 1,239,390,852.44 rupiah/year. Because the CEPM of PM based on 2015 optimum MTBF is lower than the value of LD, PM based on 2015 optimum MTBF is not a suitable maintenance plan.

3) Reliability-oriented PM cost calculation

The cost of preventive maintenance for equipment (CE) with PM based on component reliability can be calculated by using the CC equation with TTF+MTTR, replaced by the TTF that are needed to achieve a certain value of reliability.

4) Lifetime-oriented cost calculation

The cost of equipment preventive maintenance (CEPM) with PM based on component reliability can be calculated by using the CCPM equation with TTF+MTTR is replaced by TTF 1 hour to the TTF that are needed to achieve 100% reliability as denumerator.

The result of CEPM calculation of reliability-oriented PM and time-oriented PM can be compared as in figure below.

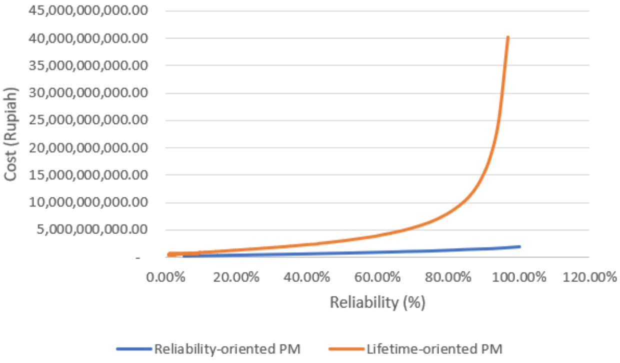

Figure 1. Comparison graph of reliability value of Reliability-oriented PM and Lifetime-oriented PM

From the figure above, it could be seen that to achieve the same reliability value, reliability-oriented PM plan will cost more than the life time reliability-oriented PM plan. The figure also shows that with the same amount of cost, reliability-oriented PM will produce better reliability than the life time oriented PM.

E. Preventive Maintenance Scheduling

1) PM based on 2016 MTBF scheduling

Scheduling for PM based on 2016 MTBF used with MTBF as a time interval for component replacement which the MTBF is consist of MTTF and MTTR.

The result for scheduling for PM based on 2016 MTBF scheduling is the bearing component will be replaced at the 51 hours after its initial use, pulley will be replaced at the 110 hours after its initial use, adjuster will be replaced at the 41 hours after its initial use, and v-belt will be replaced at the 79 hours after its initial use. Note that the scheduling is under the assumption that all components are new and in perfect condition in the initial hour.

2) PM Based on 2015 Optimum MTBF Scheduling

PM based on 2015 optimum MTBF will use 14,28 hours as the time of interval for replacing all components. Therefore, all the component has the same replacement interval of 14,28 (rounded to 15) hour. The scheduling is also under the assumption that all components are new and in perfect condition when maintenance activity being done.

3) Reliability and Lifetime oriented PM Scheduling

To determine which scenarios can be performed from the reliability-oriented PM plan and life time-oriented PM plan, 2016 cost of production loss is used as the limit of cost that are needed for a scenario to achieve a certain reliability.

The graph below shows a cost comparison of scenarios of both reliability-oriented PM and life time-oriented PM

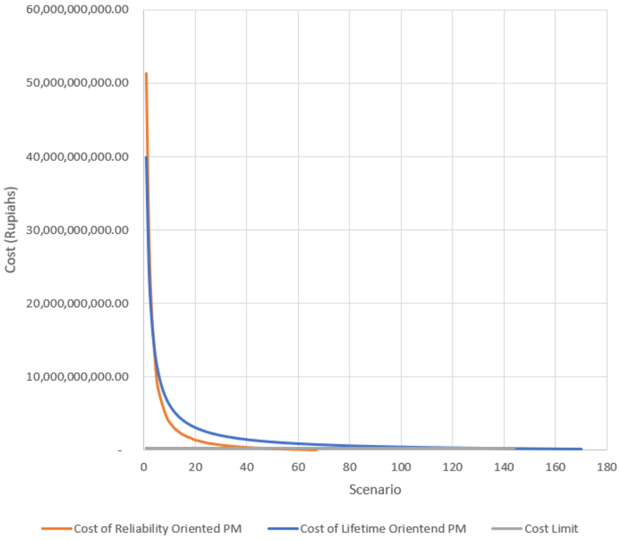

Figure 2. Comparison graph of Reliability-oriented PM and Lifetime-oriented PM scenarios cost and cost limit

When viewed from the intersection of the cost limit line with the cost for reliability-oriented PM and lifetime-oriented PM, it appears that the scenario that could be selected is scenario 47 of reliability-oriented PM with a cost of 417,069,665.65 rupiah/year and scenario number 159 for Lifetime-oriented PM with cost of 433.466,469.81 rupiah/year.

At approximately the same cost, the reliability-oriented PM yields higher reliability of the Crusher Line A Machine compared to the lifetime-oriented PM, 6.7% for the reliability-oriented PM and 1.17% for lifetime-oriented PM. It should be noted, however, that the 47th scenario reliability-oriented PM uses relatively shorter time intervals of component replacement compared to the 159th scenario of lifetime-oriented PM.

It is worth to mention that the lifetime of each component for the 47 scenario of Reliability-oriented PM scenario is aimed on uniform component reliability, while the lifetime of each component of the 159th scenario lifetime-oriented PM scenario is aimed on uniform component life at 159 hours. This lifetime uniformity may affect production rates. If the component lifetime is not uniform, then production activities will often be disrupted by frequent maintenance that is not done on all components at once in one stop of production. If the lifetime is uniform, production activities will be better due to less maintenance frequency, but with reliability as a compromise.

Based on a 47th scenario of reliability-oriented PM, a component maintenance schedule can be made. If all components are replaced at the same time at the start of the maintenance plan implementation, bearing maintenance will be performed in 51 hours after the bearing is installed, maintenance of the electric motor will be performed more than 158 hours after the electric motor is installed, maintenance of the pulley will be done in 110 hours after the installed pulley, roll maintenance will be performed in more than 158 hours after the roll is installed, the adjuster maintenance will be done in 41 hours after the adjuster is installed, and maintenance of the v-belt will be done in 79 hours after the v-belt is installed.

Meanwhile, if it based on a 159th scenario lifetime-oriented PM, a maintenance schedule for replacing bearings, electric motor, pulley, roll, adjuster and v-belt maintenance will be done in 159 hours after all components are installed.

III. Result

A. Comparison for Each Type of PM

After calculating the reliability and maintenance costs of the four maintenance plans, these four maintenance plans can be compared in terms of reliability and cost.

Judging from its reliability value, the highest reliability value is generated by PM maintenance plan based on the 2015 optimum MTBF at 64.72% with component life or uniform component replacement at 14.28 hours. Short component lifetime causes high maintenance frequency. Meanwhile, the lowest reliability value is generated by lifetime-oriented PM at 1.17% with uniform component replacement intervals.

Judging from the cost of maintenance, the highest maintenance cost is generated by PM based on 2015 optimum MTBF which cost 1,239,390,852.44 Rupiahs per year due to the high frequency of maintenance. While the lowest maintenance costs are generated by PM maintenance plans under 2016 maintenance conditions.

Reliability-oriented PM and PM based on 2016 MTBF can be considered as a moderate maintenance plan compared to lifetime-oriented PM and PM based on 2015 optimum MTBF in terms of reliability and cost.

The selection of a maintenance plan is limited to the loss due downtime of 233,601,616.92 rupiah/year. Therefore, the chosen maintenance plan is a maintenance plan that has CE with a value of less than 233,601,616.92 rupiah/year. From that reason, the maintenance plan that feasible to be done is the maintenance plan PM based on 2016 MTBF, Reliability-oriented PM, and Lifetime-oriented PM.

B. Other Consideration

As it has mentioned before, if the life of the components is not as constant as in the reliability-oriented PM and PM based on 2016 MTBF, the production activities would often be disrupted due to inefficient maintenance implementation when not all the component are being replaced in a single stop of production. The implementation of inefficient maintenance also leads to increased frequency of production stoppage and further leads to slower production rate.

In the PM based on the 2015 optimum MTBF, the uniform component lifetime makes the maintenance of PM based on optimum 2015 MTBF more efficient because maintenance for all components is done in one stop of production. However, if the frequency of maintenance is high, the production rate would be disrupted. Therefore, the production capacity would be decreased.

While the lifetime-oriented PM, components have a uniform lifespan, resulting in efficient maintenance implementation where all maintenance of each component is done in one stop of production. In addition, production activities will be better due to less maintenance frequency, but overall on all components at once in one production time.

Estimated cumulative production capacity in tons as a unit of measurement with the application of reliability-oriented PM, lifetime-oriented PM, PM based on MTBF 2016 maintenance conditions, and PM based on optimum 2015 MTBF in 1000 hours can be seen in figure below

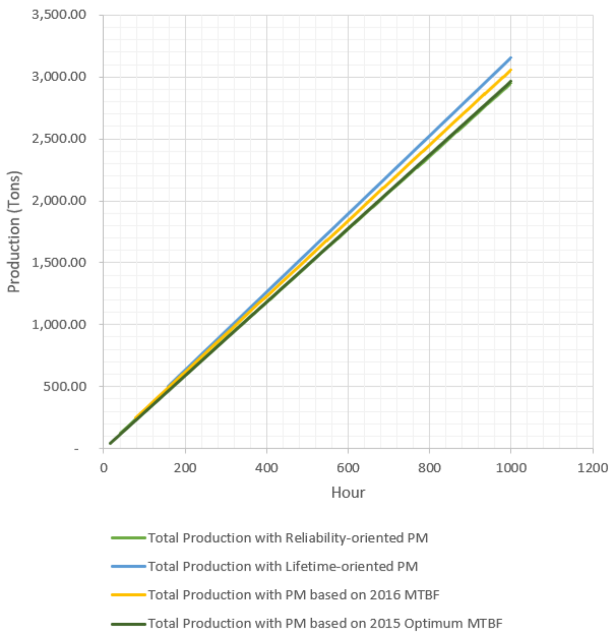

Figure 3. Comparison of Total Production in 1000 hour with Reliability-oriented PM, Lifetime-oriented PM, PM based on 2016 MTBF, PM based on 2015 Optimum MTBF

From the graph above, it shows that reliability-oriented PM will produce a total of 2,949.58 tons per 1000 hours; lifetime-oriented PM will produce a total of 3,155.95 tons per 1000 hours; PM based on MTBF 2015 maintenance condition will produce a total of 3,057.53 tons per 1000 hours, and PM based on MTBF optimum 2015 will produce a total of 2,965.45 tons per 1000 hours.

IV. Conclusion

If each maintenance plan is reviewed from the reliability, the cost to achieve a certain reliability value, and the obtained production capacity, it can be concluded that using the PM based on 2016 MTBF will result in the best maintenance cost, compared to other maintenance plans. PM based on 2015 optimum MTBF yields the greatest reliability value compared to other maintenance plans. This results in the highest maintenance cost compared to other maintenance plans. The impact of increasing maintenance frequency is the decrease in annual production capacity. Thus, this maintenance plan is the second worst in terms of production capacity/year. Reliability-oriented PM yields the second best in term of reliability after PM based on optimum MTBF 2015. Nevertheless, the shortcomings of Reliability-oriented PM lie in low production capacity and it is the worst compared to other maintenance plans. The lifetime-oriented PM is the best maintenance plan in terms of its production factor. This is due to the constancy of the life time of the component so it can be done at the same time of maintenance of all components in one stop production. However, this maintenance plan has a deficiency in its reliability. The reliability of this maintenance plan is the worst compared to other maintenance plans.

It can also be concluded that the maintenance plan of PM based on 2015 optimum MTBF, PM based on 2016 MTBF, Reliability-oriented PM, and lifetime-oriented PM have their advantages and disadvantages respectively to reliability factor, cost, and production. These three factors of consideration have varying degrees of importance for those who apply one of these four maintenance plans. The author's preference in determining the maintenance plan tends to think that reliability and cost factors are more important than production factors.

The preference is based on the reliability factor which is the probability of a component to perform its function properly without failing. The lower the reliability of a component, the higher the failure probability of the component. The impacts caused by damage to these components have the potential to threaten the health and safety of all personnel in the factory area. Therefore, considering the reliability and cost factors as a priority in choosing a maintenance plan, the author's preference lies in the PM maintenance plan oriented to component reliability as the recommended preventive maintenance plan for salt crusher machine.

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