Comparison of Economic Cost and Effectiveness Between Existing Salt Industry Maintenance Program, Reliability Maintenance Program and Age-Replacement Maintenance Program on Salt Crusher Machine

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This study compared an existing salt crusher machine maintenance program to two other maintenance programs. Due to the limited technology of detection against damage, high content of salinity and conventional engine conditions so that it requires different maintenance program than the existing maintenance program. This study provides the statistical calculation and analysis of the lifetime data of each salt crusher machine component in order to find the best maintenance scheduling program. The lifetime data is calculated to predict the distribution of the failure so that the best replacement time can be determined by using age-replacement formula. The cost and the effectiveness of maintenance are then compared in order to find the best maintenance program among three maintenance programs.

Keywords: economic cost, effective, salt industry, maintenance program

1. Introduction
In general, every industry that produces products in the form of goods uses various machines in its production. The better the production process is carried out, the more efficient and effective the resulting impact will be. For the sake of running a good and smooth production, maintenance is needed for the machines used. The good and bad of production certainly have an impact on the company's financial condition. When a machine fails, the company will incur losses. [2].

A conventional salt production industry often has some problem such as the absence of adequate sensor technology and high salt levels in the air. The high level of salt in makes sat industry difficult to predict the failure that will occur because high salt levels will cause corrosion. Therefore, a replacement policy plan is needed in order to minimize losses experienced. Almost all units that operate will experience a failure which means that the unit's components must be replaced. If the replacement process or procedure is not carried out correctly, it will increase international costs. [2]. Replacements made before failure occurs are called preventive replacements, replacements made after failure occurs are called corrective replacements. The important thing that needs to be understood in the replacement is that the more often the replacement is made, the higher the
costs incurred. Age-based replacement policy or known as age replacement and block replacement are two methods in determining the most appropriate replacement policy [4]. Reliability, which theoretically is the integral of failure distribution, is measured as a probability since failure cannot be prevented entirely, it is important to minimize both its probability of occurrence and the impact of failures when they occur. Reliability will be considered in age replacement time calculation in this study. The purpose of this study is to investigate different maintenance program of salt crusher machine in scope of cost and effectiveness of the production

2. Lifetime Data Distribution Conformance Calculation

Collection of salt crusher lifetime data is conducted in a specified period. In this study, we collect lifetime data year 2016, is done by using the daily logbook of the maintenance personnel. The lifetime data then broken down into its components that have possibility of causing machine failure the most, which are bearing, electric motor, adjuster, pulley, roll, v-belt.

In this section, a probability density function (PDF) distribution analysis of each component will be carried out. Each component certainly has a different age distribution. This difference will result in different PDF for each component. This calculation is done by using Minitab 17 Statistical Software. We use Anderling-Darson as coefficient of conformance, the smaller the value, the more conform the data to a specific distribution.

1) Bearing

![Figure 1. Distribution Conformance](image)

The Anderson-Darling coefficient for Weibull distribution resulted 2.069 while Lognormal, Exponential, and Normal distribution resulted 1.383; 3.155; 7.425 respectively. The lowest value of Anderson-Darling coefficient determines the most conformance distribution [7]. The character of bearing lifetime distribution follows the lognormal distribution so that it can be assumed that the bearing lifetime distribution is the same as the Lognormal distribution.

2) 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 character of electric motor lifetime distribution follows the lognormal distribution so that it can be assumed that the electric motor lifetime distribution is the same as the Weibull distribution.

3) Pulley
The distribution test of pulley shows 2.703; 2.469; 2.764; 4.827 for Weibull, Lognormal, Exponential, and Normal distribution respectively. The character of pulley lifetime distribution follows the lognormal distribution so that it can be assumed that the pulley lifetime distribution is the same as the lognormal distribution.

4) 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. The character of roll lifetime distribution follows the Lognormal distribution so that it can be assumed that the pulley lifetime distribution is the same as the Lognormal distribution.

5) 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, therefore the character of roll lifetime distribution follows the Lognormal distribution so that it can be assumed that the adjuster lifetime distribution is the same as the Lognormal distribution.

6) 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 that it can be assumed that the v-belt lifetime distribution is the same as the Weibull distribution.

3. Reliability
Each component has each lifetime distribution that follows a statistical distribution. By using this distribution, we can get reliability of each component. Reliability can also be defined as the probability of a facility or equipment to work without fail in a specified time interval [10]. Reliability follows this equation:

\[
R(x) = 1 - F(x) = 1 - \int_{-\infty}^{x} f(x)dx
\]

(1)

The symbol \(f(x)\) means the component’s distribution. The reliability graph looks like this picture below:
The X axis is the lifetime or what is called the lifetime or failure time (FT) and the Y axis shows the reliability of the component. R-squared (R-Sq) shows how conformance the given function to the graph, in this study we refer to reliability graph. The higher the value, the more conformance the function to the graph. The shape of the survival chart varies in each component, but tends to decrease with increasing lifetime. To calculate the cost per unit time of maintenance-replacement and block replacement maintenance, the function of the reliability graph must be determined using the regression method. In figure 2, the function of that graph is $0.7651 - 0.001144 \text{ FT} + 0.000001 \text{ FT}^2$.

**Table 1. Reliability Graph Function**

| No. | Component Name   | Function                                      |
|-----|------------------|-----------------------------------------------|
| 1   | Bearing          | $R(FT) = 0.7651 - 0.001144 \text{ FT} + 0.000001 \text{ FT}^2$ |
| 2   | Electric Motor   | $\log_{10}[R(FT)] = -0.07394 - 0.001010 \text{ FT}$ |
| 3   | Pulley           | $\log_{10}[R(FT)] = -0.07394 - 0.001010 \text{ FT}$ |
| 4   | Roll             | $\log_{10}[R(FT)] = -0.1560 - 0.0003 \text{ FT}$ |
| 5   | Adjuster         | $\log_{10}[R(FT)] = -0.02304 - 0.006407 \text{ FT} + 0.000009 \text{ FT}^2$ |
| 6   | V-belt           | $\log_{10}[R(FT)] = 0.04330 - 0.002852 \text{ FT} + 0.000001 \text{ FT}^2$ |

Function of each graph is then be used for determining the age replacement time which will be covered in the next section of this paper.

**4. Age Replacement Calculation**

This policy is applied to reduce costs and determine the optimal interval for replacing an asset or component. There are two types of policies, namely age replacement and block replacement (Smith, 2011). In this paper we study only about finding the optimum time to replace based on the concept of age replacement.

$$
\left( C_u \times (1 - R(FT)) + C_p \times R(FT) \right) \int_0^{FT} R(FT) \, dt
$$

(2)
With $Cu$ is unplanned replacement costs which consist of the price of component and cost losses due to downtime, $Cp$ is the cost of planned replacement which consist of only the component’s price. The price for each component is 230,000 rupiah for bearing, 5,600,000 rupiah for electric motor, 1,600,000 rupiah for pulley, 1,570,000 for roll, 128,650 rupiah for v-belt. $Cu$ in the table 2 obtained using this equation

$$Cu = Price\ of\ Component + (Avg\ Salt\ Prod \times MTTR \times Price\ of\ Salt)$$

(3)

The needed data to do $Cu$ calculation is provided in table 2. Each component has each $Cu$ stated in Indonesia’s currency (Rupiah).

**Table 2. Cost of Unplanned Replacement**

| Component     | Price of Component | Average Salt Production/Hour | MTTR | Price of Salt/Ton | $Cu$ (Rupiah) |
|---------------|--------------------|------------------------------|------|-------------------|---------------|
| Bearing       | 230000             | 3.175                        | 0.58 | 200000           | 3913000       |
| Electric Motor| 5600000            | 3.175                        | 0.75 | 200000           | 10362500      |
| Pulley        | 1600000            | 3.175                        | 0.38 | 200000           | 4013000       |
| Roll          | 1570000            | 3.175                        | 1.0  | 200000           | 9825000       |
| Adjuster      | 70000              | 3.175                        | 0.31 | 200000           | 2038500       |
| V-belt        | 128650             | 3.175                        | 0.37 | 200000           | 2478150       |

The integration of reliability, $\int_0^{FT} R(FT) \, dt$, is needed in order to find the optimum time to replace.

**Table 3. Result of Age Replacement Time Calculation on Bearing**

| FT (In Hour) | Reliability | Simpson Calculation | Cost per Unit Time |
|--------------|-------------|---------------------|--------------------|
| 594          | 0.211894654 | 272.6192346         | 11490.72256        |
| 594.5        | 0.211648405 | 272.689009          | 11491.10826        |
| 595          | **0.211402442** | **272.8284362**  | **11488.55614**   |
| 595.5        | 0.211156765 | 272.8632626         | 11490.40587        |
| 596          | 0.210911374 | 272.8632626         | 11493.71807        |

In the previous section of this paper we can see the function of reliability graph for each component, it is then be used in order to find the reliability at a specific time $R(FT)$ and to find the result of integration of reliability $\int_0^{FT} R(FT) \, dt$ using Simpson’s 1/3 rule. In Table 2 we can see that the most economic cost of bearing replacement is at the lifetime of 595 hours. We calculated the optimum time to replace and the result is in the table 4.

**Table 4. Result on Age Replacement Time Calculation on Every Component**

| No. | Component | FT  | Reliability | Age Replacement Cost per Unit Time |
|-----|-----------|-----|-------------|-----------------------------------|
| 1   | Bearing   | **595** | 0.211402442 | 11488.55614                     |
| 2   | Electric Motor | 356  | 0.130793813  | 56140.36072                      |
| 3   | Pulley    | **595.5** | 0.09896161  | 19519.79278                      |
| 4   | Roll      | **595.5** | 0.462753807 | 17504.83404                      |
5 Adjuster 59 0.407134682 31156.05175
6 V-belt 68 0.544433449 23198.23875

By looking at the lowest cost we can determine the optimum replacement time for each component. Replacement of bearing, electric motor, pulley, roll, adjuster and v-belt are respectively 595 hours, 356 hours, 595.5 hours, 59.5 hours, 59 hours and 68 hours. This FT is then be used to make schedule of replacement. The schedule should be look like in the figure 3 below.

![Figure 3. Age-Replacement Schedule](image)

5. Comparison of Economic Costs
In this section three maintenance programs will be compared, namely existing salt industry maintenance program, reliability-centered maintenance program taken from Hidayanto’s thesis and age-replacement maintenance programs. The type of cost that determines how efficient the maintenance program is the cost of replacing the component and the cost loss due to downtime. In the following sub-chapters, simulations of the implementation of maintenance programs for a year is conducted. Costs due to component replacement or the so-called cost of replacement (COR) can be found by the following formula

\[
COR = \text{Replacement frequency} \times \text{component's price}
\]  

(4)

By calculating COR we obtained the cost that is resulted from the replacement. The table below provide the simulation of COR in one-year-duration of each maintenance.

| Component   | Price of Component | Existing Salt Industry Maintenance | Reliability Maintenance | Age-Replacement Maintenance |
|-------------|--------------------|-------------------------------------|-------------------------|----------------------------|
|             |                    | Replacement Frequency | COR | Replacement Frequency | COR | Replacement Frequency | COR |
| Bearing     | 230000             | 51                     | 11730000 | 99             | 22770000  | 9              | 20700000 |
| Electric Motor | 560000           | 9                      | 50400000 | 27             | 151200000  | 11             | 61600000  |
| Pulley      | 1600000           | 27                     | 43200000 | 41             | 65600000   | 9              | 14400000  |
| Roll        | 1570000           | 5                      | 7850000  | 14             | 21980000   | 9              | 14130000  |
| Adjuster    | 70000             | 68                     | 4760000  | 112            | 7840000    | 84             | 5880000   |
| V-belt      | 128650            | 31                     | 3988150  | 55             | 7075750    | 70             | 9005500   |
| Total       | 191               | 121928150              | 348       | 276465750      | 192         | 107085500     |     |

6
Respectively the lowest COR is achieved by age-replacement maintenance, existing salt industry maintenance and reliability maintenance. While the cost of losses due to downtime or cost of breakdown (CBD) can be found with the following formula:

\[
\text{CBD} = (\text{Replacement Frequency} \times \text{MTTR} \times \text{Rata} - \text{Average Salt Production per Hour} \times \text{Price of Salt per Ton})
\]  

(5)

The table below shows the difference amount of cost of breakdown among the three maintenance programs.

|               | Breakdown Time (In Hour) | Avg Salt Production (In Ton) | Price of Salt/Ton | Cost of Breakdown    |
|---------------|--------------------------|------------------------------|-------------------|----------------------|
| Existing Salt Industry Reliability | 85.64 | 3.175 | 2000000 | 543814000 |
| Age-Replacement | 166.52 | 3.175 | 2000000 | 1057402000 |

Judging from the table above the biggest breakdown loss cost is maintenance reliability of IDR 1,057,402,000. This is because the replacement lifetime interval of the components is very short so the replacement of components becomes often. Part replacement resulted in production stopping. The lowest CBD is the age-replacement maintenance program fee of IDR 511,365,500. This is because the life of the components is quite long so that the replacement of the components done is not as much as the other maintenance program.

| Component | Existing Salt Industry Maintenance | Reliability Maintenance | Age-Replacement Maintenance |
|-----------|----------------------------------|-------------------------|-----------------------------|
| Total COR | IDR 121,928,150.00                | IDR 276,465,750.00      | IDR 98,080,000.00           |
| Total CBD | IDR 543,814,000                   | IDR 1,057,402,000       | IDR 511,365,500             |
| Overall Cost | IDR 665,742,150               | IDR 1,333,867,750       | IDR 609,445,500             |

The table above shows the total costs incurred by each maintenance program. The highest cost is generated by the reliability maintenance program of IDR 1,333,867,750 followed by existing salt industry maintenance program cost of IDR 665,743,150, while the lowest cost is generated by the age-replacement maintenance program of IDR 609,445,500. Age-replacement maintenance program is the most economic maintenance program among the 2 others.

6. Comparison of Effectivity

A good maintenance program is certainly not only a program that requires low cost, but also a program that can achieve a company's production target. Effectiveness is assessed as to how effective a maintenance program is in achieving production targets. Production targets per year are a measure of effectiveness for each maintenance program.
Table 8. Comparison of Effectiveness

|                                | Existing Salt Industry Maintenance | Reliability Maintenance | Age-Replacement Maintenance |
|--------------------------------|------------------------------------|-------------------------|-----------------------------|
| Production Rate per Hour (In Ton) | 3.175                              | 3.175                   | 3.175                       |
| Total of Production in A Year (In Ton) | 27541.093                         | 27284.299               | 27557.31725                 |
| Effectiveness                           | 0.92867753                         | 0.920018512             | 0.929224607                 |

Production target in a year is 29656.25 ton. Effectiveness is obtained by dividing the total production in a year to the production target in a year. In this paper, effectiveness is directly proportional to the number of changes that occur. The less the amount of replacement, the more effective the maintenance program will be and vice versa. The highest effectiveness is achieved by age-replacement maintenance program which effectiveness is 92.9%, then followed by the existing salt industry maintenance 92.8% and the last is reliability maintenance 92.0%.

7. Conclusion
Reviewing the economics of costs and effectiveness for all three maintenance programs, the most economic maintenance program is achieved by age-replacement maintenance program of IDR 609,445,500. Then the second economic is the existing salt industry maintenance program of IDR 665,742,150 and the worst economic cost is achieved reliability maintenance program that generates a cost of IDR 1,333,867,750.

The highest effectiveness is owned by the age-replacement maintenance program, which is 92.92%. The second highest effectiveness is achieved by the existing salt industry maintenance program 92.87% and the lowest effectiveness is achieved by the maintenance program of reliability of 92.00%. Comparison of Economic Costs

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References
[1] Andrew, J., & Moss, T. (2002). Reliability and Risk Assessment Second Edition. New York
[2] Barabady, J. (2005). Improvement of System Availability Using Reliability and Maintainability Analysis. Sweden: Division of Operational and Maintenance Engineering, Lulea University of Technology
[3] Croakin, C. (2006). Engineering Statistics Handbook. Gaithersburg: National Institute of Standards and Technology.
[4] Smith, D.J., (2011). Reliability, Maintainability and Risk. Oxford: Butterworth-Heinemann.
[5] Kapur, K.C., & Pecht, M. (2014). Reliability Engineering Handbook. New Jersey: Prentice Hall, Inc..
[6] O'Connor, P. D., & Kleyner, A. (2012). Practical Reliability Engineering. West Sussex: Wiley.
[7] Pochampally, K. K., & Gupta, S. M. (2016). Reliability Analysis With Minitab. Boca Raton: CRC Press.
[8] Hidayanto, T. E. (2017). Analisis Keandalan Untuk Preventive Maintenance Mesin Crusher Line A PT.XYZ. Depok: Universitas Indonesia