Machines Maintenance Interval on Filling Lithos Lubricant Production Line: A Case Study

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Abstract. The growth of industry in Indonesia is fast enough to encourage industrial players to improve their production capability. One of the sectors that has continuous increase in demand is the lubrication sector. This research was conducted in a major lubricants company in Indonesia that has 16 hours of work to meet market needs. The production capability and capacity of the company are affected by its production resources, one of them is the machine. Current machine’s reliability in the company is below 85%, hence it needs efficient maintenance activities to improve and maintain the machine’s reliability. In this research, we develop a simulation model to determine the maintenance interval to achieve world class standard of machine reliability at minimum 85%. From the results of the analysis, we propose three alternatives of maintenance activity. First, preventive maintenance with interval maintenance according to the results of the simulation. Second, preventive maintenance with maintenance interval of half day or twice a day in the break time and after workhours. Third, corrective maintenance. The criteria used in comparing the three alternatives are the machine reliability, maintenance cost, and production loss for doing the maintenance activity. Among the alternatives, the second alternative gave better reliability with the lower cost compared to the other two alternatives.

1. Introduction
This research is conducted in a Lube Oil Blending Plant (LOBP) of a large lubricant company in Indonesia. The company has 60% of share in lubricant oil market for automotive, industry, and marine. It has a modern plant with automatic machines to increase the efficiency of production process to fulfill customer needs. Product layout line production was adopted by the company. If one of the machine in a certain line is breakdown, then the whole machine in the line will stop until the breakdown machine is repaired. Therefore, the company needs a maintenance plan to maintain the machine in order to maintain its performance. The preventive maintenance is very useful to prevent the future failure. It will increase the reliability and time between failures [1]. Without preventive maintenance and only adopts corrective maintenance, the policy will disturb the production process. The failure of one component of machine or a system will make the whole system failed [1].

The production process of the lubricant in the company starts with receiving and storage process, followed by blending process, quality check, and filling process. The concern of this paper is to study the filling process machine. The company has four filling lines which have a very low reliability with average of 42% far below the world reliability standard of 85% [2]. Monte Carlo simulation is used to
solve the problem. According to Raychauduri [4], Monte Carlo simulation can be used to evaluate the probability distribution of downtime data, generating random numbers from the distribution evaluation, and an analysis can be done to determine the improvement or modelling the component replacement plan.

Several research have been conducted in machines reliability analysis. Liberopoulos & Tsarouhas [1] conducted a research about reliability analysis of pizza production line using availability and efficiency value. Tsarouhas & Arvanitoyannis [5] conducted a research about reliability analysis of yogurt production line using simulation to planned the interval of maintenance time to improve the machine’s reliability. Based on those research, the aim of this research is to determine the optimal interval of maintenance (preventive maintenance) for filling lithos process machine using Monte Carlo simulation to improve the reliability the machines.

2. Research Method
The first step in this research is observing the filling process in the company to identify the problem in the lubricant’s production process. The second step is to perform literature study to find out some relevant literature appropriate with this research. Monte Carlo simulation is used to determine the maintenance interval to improve the reliability of the machines. In the third step, we perform data collection and analysis. In this step, we collect downtime data to determine the Time Between Failure (TBF). Afterwards, two tests are performed to the data: chi-square and autocorrelation tests to ensure that the TBF data is Independent and Identically Distributed (IID). In the fourth step, we perform goodness-of-fit test to determine the probability distribution of the TBF data and the parameter distribution. In the fifth step, based on the TBF data, we calculate the existing reliability of the machines. In the final step, simulations are performed to determine the maintenance interval and make comparison between the reliability of the machines before and after preventive maintenance.

2.1. Data Collection and Analysis
In this study, we used downtime data of filling lithos process from August 2015 until July 2016. The assumption used in this study is that every filling line produces the same type and size of lithos, machines work 16 hours per day and 5 days per week. We set the confidence interval at 95% and minimum reliability of the machine is 85% according to the world class standards [2]. Minor maintenance is applied and will not affect the machine life time.

2.2. Probability Distribution Commonly Used in Maintenance
There are several probability distributions commonly used in maintenance model, such as Weibull distribution, exponential distribution, normal distribution, and lognormal distribution.

• Weibull Distribution
  The reliability equation is [6]:
  \[ R(t) = e^{-\left(\frac{t}{\theta}\right)^\beta} \]  
  (1)
  With the mean value is as follows [6]:
  \[ mean = \theta \Gamma \left(1 + \frac{1}{\beta}\right) \]  
  (2)
  Where \( \Gamma \) is gamma function and defined as follows [7]:
  \[ \Gamma(s) = \int_0^\infty x^{s-1} e^{-x} dx, (s > 0) \]  
  (3)

• Exponential Distribution
  The reliability equation is [6]:
\[ R(t) = e^{-\lambda t} \]  

(4)

With the mean value is as follows [6]:
\[ \text{mean} = \frac{1}{\lambda} \]  

(5)

- Normal Distribution

The reliability of normal distribution is calculated by Equation (6) [8]:
\[
R(t) = 1 - \frac{1}{\alpha \sqrt{2\pi}} \int_{-\infty}^{t} \exp \left( -\frac{(x-\mu)^2}{2\alpha^2} \right) dx
\]  

(6)

With the mean value is as follows [8]:
\[ \text{mean} = \mu \]  

(7)

- Lognormal Distribution

The reliability of data with lognormal distribution is calculated by [8]:
\[
R(t) = 1 - \frac{1}{\alpha \sqrt{2\pi}} \int_{0}^{t} \frac{1}{x} \exp \left( -\frac{(\ln x-\mu)^2}{2\alpha^2} \right) dx
\]  

(8)

With the mean value is as follows [8]:
\[ \text{mean} = e^\mu + \frac{\alpha^2}{2} \]  

(9)

2.3. Monte Carlo Simulation

Simulation is a method for conductive research using a model that represents the real system. According to Law & Kelton [9], simulation is a computer technique to evaluate a model numerically, and data are gathered in order to estimate the desired true characteristics of the model. Monte Carlo simulation [4] is a type of simulation that generate random numbers for some variables and statistical analysis is performed to compute the result. This method uses statistics to mathematically model a rela life process and then estimate the likelihood of possible outcomes [10]. According to [9], Monte Carlo simulation has four steps. In the first step, a static model is generated mathematically to transform input variables into output. Second, statistical distribution of the input variables are identified based on historical data. It represents the stochastic nature of the problem under investigation. Third, random variables are generated in which each input variable will result different output due to the stochastic nature of the model. The outputs are then collected and analyse statistically in the last step to draw some conclusions.

3. Results and Analysis

From the downtime data, we determine the Time Between Failure (TBF) of machines in filling lithos process line 1. The descriptive statistics of TBF data of machines in line 1 can be seen in table 1.

| Machine  | Count | Mean  | StDev  | Median | Minimum | Maximum | Skewness | Kurtosis |
|----------|-------|-------|--------|--------|---------|---------|----------|----------|
| Labelling| 60    | 5,418.42 | 6,085.94   | 1,795  | 130     | 23,960  | 1.136    | 0.423    |
| Filling  | 16    | 2,1045 | 29,962.4 | 6,705  | 30      | 105,060 | 1.824    | 3.133    |
| Capering | 23    | 12,424.1 | 13,688.9 | 7,170  | 25      | 47,680  | 1.267    | 1.080    |
| Sensor   | -     | -     | -       | -      | -       | -       | -        | -        |
| Volume   | -     | -     | -       | -      | -       | -       | -        | -        |
| Heater   | -     | -     | -       | -      | -       | -       | -        | -        |
| Induction| -     | -     | -       | -      | -       | -       | -        | -        |
| Seal     | -     | -     | -       | -      | -       | -       | -        | -        |
| Laser    | 19    | 16,133.7 | 31,379.3 | 1,795  | 10      | 134,985 | 3.340    | 12.487   |
Machine | Count | Mean | StDev | Median | Minimum | Maximum | Skewness | Kurtosis
---|---|---|---|---|---|---|---|---
Robotic | 129 | 25,53.57 | 46,98.93 | 550 | 15 | 25,970 | 2.634 | 7.371
Carton erector | 31 | 11,115.3 | 13,529.5 | 4,560 | 60 | 49,875 | 1.343 | 1.109
Carton sealer | 23 | 13,408.5 | 18,666.4 | 6,405 | 135 | 75,500 | 2.313 | 5.530
Palletizing | 25 | 13,490.6 | 19,241.0 | 6,990 | 70 | 85,875 | 2.661 | 8.084

We used chi-square and autocorrelation tests to check the IID of the data. The results of chi-square test are shown in table 2. From the table, we can see that all TBF data are identical.

**Table 2. Chi-Square Test of TBF machines data in filling lithos line 1**

| Machine | df | $\chi^2$ statistic | $\chi^2$ $\alpha$, df | Decision of $H_0$ |
|---|---|---|---|---|
| Labelling | 60 | 403,306.40 | 42.34 | Do Not Reject |
| Filling | 16 | 639,877.03 | 7.26 | Do Not Reject |
| Capering | 23 | 331,810.95 | 12.34 | Do Not Reject |
| Sensor Volume | - | - | - | - |
| Heater | - | - | - | - |
| Induction Seal | - | - | - | - |
| Laser | 19 | 1,098,561.35 | 9.40 | Do Not Reject |
| Robotic | 129 | 1,106,779.87 | 102.87 | Do Not Reject |
| Carton erector | 31 | 1,106,779.87 | 102.87 | Do Not Reject |
| Carton sealer | 23 | 571,692.49 | 12.34 | Do Not Reject |
| Palletizing | 25 | 658,620.55 | 13.85 | Do Not Reject |

After the IID test, we must determine the probability distribution of each TBF data using goodness-of-fit test. In this test, we used Anderson-Darling to determine the probability distribution which has the best fit to the data. The results of Anderson-Darling on TBF data of machines in line 1 can be seen in table 3. The smallest value of Anderson-Darling means that the data fit with the probability distribution. After determine the probability distribution, we determine the parameter of the respective probability distribution. Afterwards, we calculate the existing reliability of all machines which can be seen in table 4.

**Table 3. Anderson-Darling Test of TBF machines data**

| Machine | Normal | Exponential | Weibull | Lognormal |
|---|---|---|---|---|
| Labelling | 4.553 | 4.848 | 1.859 | **1.462** |
| Filling | 1.623 | 3.892 | **0.247** | 0.395 |
| Capering | 1.191 | 2.159 | **0.482** | 0.896 |
| Sensor Volume | - | - | - | - |
| Heater | - | - | - | - |
| Induction Seal | - | - | - | - |
| Laser | 2.905 | 7.899 | **0.299** | 0.322 |
| Robotic | 21.506 | 36.751 | 2.7 | **0.695** |
| Carton erector | 2.235 | 4.468 | **0.555** | 0.685 |
| Carton sealer | 2.389 | 1.397 | **0.17** | 0.182 |
| Palletizing | 2.676 | 1.564 | **0.188** | 0.627 |
Afterwards, Monte Carlo simulation is conducted to determine the maintenance interval of the machines to achieve high reliability start at 85% according to the world standards that have been set [2]. From the simulation, we can find the maintenance interval which gives 85% reliability. The maintenance interval and the respective reliability and maintenance interval of all machines can be seen in Table 5. The table shows that Sensor Volume, Heater, and Induction Seal machines have the highest reliabilities. Since the results of simulation shows that the maintenance interval is less than once a day, so three alternatives are proposed in this research. The first alternative is preventive maintenance as determined by the results of the Monte Carlo simulation. This alternative will generate maintenance and loss cost. The lost cost is measured by the time during the filling lithos line stopped due to preventive maintenance. The second alternative is preventive maintenance which conducted twice a day at rest time and at the end of work. This alternative aims to minimize the loss cost because of machines is temporarily stopped when the resting time and the end of work. The third alternative is corrective maintenance, which is only done when the machine undergoes breakdown. The comparison of reliability for each alternative can be seen in Table 6. From the table, the resulted average reliability of all production lines for Alternative 1, 2, and 3 are 0.92, 0.88, and 0.54 respectively. The comparison of cost for each alternative are shown in Table 7. From the table, the average cost of all production lines for Alternative 1, 2, and 3 are IDR 25,235,015,570, IDR 131,775,700, and IDR 1,410,551,300 respectively.

Table 4. Existing reliability of each machine

| Machine       | Line 1     | Line 2     | Line 3     | Line 4     |
|---------------|------------|------------|------------|------------|
| Labelling     | 0.23425    | 0.307778   | 0.148896   | 0.156603   |
| Filling       | 0.257298   | 0.148556   | 0.274967   | 0.303182   |
| Capering      | 0.299688   | 0.291427   | 1          | 0.601058   |
| Sensor Volume | 1          | 1          | 1          | 1          |
| Heater        | 1          | 1          | 1          | 1          |
| Induction Seal| 1          | 1          | 1          | 1          |
| Laser         | 0.230547   | 1          | 0.317601   | 0.272504   |
| Robotic       | 0.184823   | 0.195844   | 0.151615   | 0.298237   |
| Carton erector| 0.290524   | 0.142759   | 0.275946   | 0.327263   |
| Carton sealer | 0.318573   | 1          | 0.290298   | 0.315464   |
| Palletizing   | 0.309031   | 0.286652   | 0.321126   | 1          |

Table 5. Simulation results

| Machine         | Reliability | Maintenance Interval (minute) | Maintenance Interval (day) |
|-----------------|-------------|-------------------------------|---------------------------|
| Labelling       | 0.862414    | 480                           | 0.5                       |
| Filling         | 0.888921    | 240                           | 0.25                      |
| Capering        | 0.877107    | 480                           | 0.5                       |
| Sensor Volume   | 1           | -                             | -                         |
| Heater          | 1           | -                             | -                         |
| Induction Seal  | 1           | -                             | -                         |
| Laser           | 0.865751    | 120                           | 0.125                     |
| Robotic         | 0.900577    | 60                            | 0.0625                    |
| Carton erector  | 0.900880    | 240                           | 0.25                      |
| Carton sealer   | 0.877512    | 720                           | 0.75                      |
| Palletizing     | 0.862421    | 720                           | 0.75                      |

From the results in tables 6 and 7, if the decision maker of the company concerns only with the machines reliability, then Alternative 1 should be chosen. If cost is the only consideration in decision making, then
the company should choose Alternative 2. While if both criteria are considered the decision maker will prefer Alternative 2 since it gives reliability above world’s standard with very low cost comparing to the other two alternatives.

**Table 6.** The results of alternative comparisons at each line

| Machine          | Line 1 Alternative | Line 2 Alternative | Line 3 Alternative | Line 4 Alternative |
|------------------|--------------------|--------------------|--------------------|--------------------|
|                  | 1 2 3              | 1 2 3              | 1 2 3              | 1 2 3              |
| Labelling        | 0.86 0.86 0.23     | 0.86 0.86 0.31     | 0.91 0.63          | 0.15 0.90 0.72     |
| Filling          | 0.89 0.84 0.26     | 0.89 0.84 0.15     | 0.88 0.82          | 0.27 0.87 0.87     |
| Capering         | 0.88 0.88 0.30     | 0.90 0.88 0.29     | 1 1 1             | 0.85 0.86 0.60     |
| Sensor Volume    | 1 1 1              | 1 1 1              | 1 1 1             | 1 1 1              |
| Heater           | 1 1 1              | 1 1 1              | 1 1 1             | 1 1 1              |
| Induction Seal   | 1 1 1              | 1 1 1              | 1 1 1             | 1 1 1              |
| Laser            | 0.87 0.76 0.23     | 1.00 1 1 0.86      | 0.93 0.32         | 0.85 0.79 0.27     |
| Robotic          | 0.90 0.55 0.18     | 0.88 0.85 0.20     | 0.91 0.64         | 0.15 0.86 0.69     |
| Carton erector   | 0.90 0.85 0.29     | 0.86 0.85 0.14     | 0.90 0.78         | 0.28 0.85 0.92     |
| Carton sealer    | 0.88 0.91 0.32     | 1 1 1              | 0.86 0.89         | 0.29 0.87 0.90     |
| Palletizing      | 0.86 0.89 0.31     | 0.88 0.89 0.29     | 0.87 0.90         | 0.32 1 1           |

**Table 7.** Cost Comparisons of all alternatives

| Line | Alternative | Maintenance Cost | Loss Cost | Total Cost |
|------|-------------|------------------|-----------|------------|
| 1    | 1           | IDR 421,055,900  | IDR 31,331,311,001 | IDR 31,752,366,901 |
| 2    | 3           | IDR 21,003,557,647 | -         | -          |
| 3    | 1           | IDR 21,294,270,647 | -         | -          |
| 1    | 2           | IDR 190,484,000  | IDR 50,479,583,871 | IDR 50,800,603,871 |
| 2    | 2           | IDR 190,484,000  | -         | -          |
| 3    | 3           | IDR 82,484,000   | IDR 1,353,150,000  | IDR 1,359,187,500 |
| 1    | 3           | IDR 290,713,000  | IDR 21,003,557,647 | IDR 21,294,270,647 |
| 2    | 1           | IDR 189,101,000  | -         | -          |
| 3    | 3           | IDR 9,026,500    | IDR 2,053,750,000  | IDR 2,062,776,500 |

**4. Conclusions**

In this research, we determine machines maintenance interval in lubricant oil production using Monte Carlo simulation. Since the results of simulation shows that the maintenance interval is less than once a day, so three alternatives are proposed in this research. The first alternative is preventive maintenance as determined by the results of the Monte Carlo simulation. The second alternative is preventive maintenance which conducted twice a day at the working break time and after work time. The third alternative is corrective maintenance. From the results, we conclude that the second alternative is the best alternative among all. The second alternative is preventive maintenance, which conducted twice a day at the working break time and after work time. By this alternative, the reliability of the machines will increase with the lowest cost both maintenance cost and loss cost. The final result may be different from case to case. Hence, for the further study it is better to apply the Monte Carlo Simulation in several other cases or develop an analytical model to simultaneously maximize the reliability and minimize the cost.
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