Spare part requirement and inventory policy for Rovema’s 1 machine using Reliability Centered Spare (RCS) and Min-Max stock methods

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Abstract. XYZ company is a manufacturing company engaged in the field of medicines, food, and natural products. One of the problems found in the machine delay, called "outstanding". An outstanding occurs is mostly caused by the unavailability of the spare parts. Based on the downtime losses data, the highest downtime, as well as unavailability spare parts, was owned by Rovema’s machine, one of the packaging machines in food plant division. Therefore in this research, the Reliability Centered Spare (RCS) method was applied to calculate the optimal critical spare part policy using the Poisson process and Min-Max stock analysis. The analysis result shows that the critical component of Rovema’s machine is steel band and brass insert are must be stored in a technical warehouse for one year ahead with optimal inventory quantity is 18 and 15 pieces with minimum stock is 10 pieces each.

1. Introduction
Policies in managing inventory are very important in a company. Without a good inventory control system, the company cannot run their production smoothly, and it's difficult to fulfill customer demand. Inventory is one part of company spending that absorbs the largest cost. Over excess inventory causes high storage costs, but if there is a shortage of inventory there can be a risk of not being able to meet consumer demand. Spare part inventory is one of the critical aspects to support the whole inventory system in the manufacturing process.

The purpose of spare parts inventory management is to maintain the level of inventory of spare parts at an optimal level with a minimum inventory cost, determine when spare parts are ordered and determine the number of spare parts ordered. D. Louit et al. 2011 [1] present the spare parts inventory model used to determine the optimal stock size of the non-repairable and repairable component. Non-repairable parts are components that do not allow to be repaired physically, so the components must be replaced, meanwhile, repairable parts are damaged components that can be returned to their original function or operational state by repairing the components. The need for the number of critical spare parts that must be provided within a certain period using the Reliability Centered Spares (RCS) is analyzed in [2]-[3]. Meanwhile, [4] presented an integrated spare part inventory management approach for multi-
component systems subjected to random failures. Others researchers [5]–[7] used the deterministic deteriorating inventory (DDI) model, the stochastic deteriorating inventory (SDI), stocking policy, and dynamic predictive maintenance model for spare part analysis which follows the principle of inventory control level system.

In the manufacturing process, a spare parts inventory control must be concerned by the Engineering Maintenance Department to ensure the availability of each machine's spare part, especially for its critical and fast-moving item. A problem related to spare part inventory also faced by XYZ company, one of the manufacturing company engaged in medicine, food, and natural products. In the food plant division, there are several machines which used for the production process, however, in fact, the reliability of a machine can decrease over time, which can cause the machine downtime. Figure 2 shows a graph of the total downtime per machine in the food plant division.

![Food plant division downtime data](image)

**Figure 1.** Downtime data of several machines in food plant division

Based on Figure 2, it can be seen that the highest downtime occurred on Rovema’s 1 machine. Rovema’s machine is one of the packaging machines which used for the final package of the food product.

Based on data from the company, there are several main factors causing machine downtime or in this term is called an “outstanding”. An outstanding is the delay in machine repair which caused by several factors. Figure 2 shows the Pareto diagram for the outstanding of Rovema’s machine in 2018.
From Figure 2, it can be seen that the outstanding cause consists of several factors such as spare part unavailability, operator unavailability, production schedule, material supply, and other causes. From the Pareto diagram above, it can be seen that the main cause of outstanding is the spare part unavailability. To minimize the problem of availability of spare parts above, the purpose of this study is to analyze, determine, and propose an optimum spare parts inventory stock policy, especially for critical components in the Rovema’s I machine. The analysis is using Reliability Centered Spares (RCS) method with the Poisson process and Min-Max stock analysis. Therefore, the RCS method is used to determine the optimum number of spare parts requirements based on equipment needs and maintenance operations for a certain period, whereas, the Min-max stock is used to determine the minimum and maximum spare parts inventory.

2. Research Methodology

As stated in the introduction, this research was conducted in Food plant division, in the Rovema’s machine, one of the packaging machine which mainly produces snack products. Figure 3. shows and explains the main steps of this research.
Based on Fig. 3, this research was conducted at Rovema’s 1 machine. To identify the structure of a machine, a System Breakdown Structure (SBS) of the Rovema’s 1 machine is performed to determine the subsystems and components. Then, perform a Risk Matrix based on the severity and likelihood levels to determine the critical subsystems and critical components. Critical components are classified into two, namely non-repairable or repairable. If the component is non-repairable, then the component must...
be replaced with a new component. In the meantime, if the component is repairable, then the component can be repaired or serviced to return it as a new one. From machine history data, we can find out TTF data and TBF data. TTF and TBF data were tested for distribution to determine the distribution of TTF and TBF data using software Minitab. Then, determine the parameters of TTF and TBF using software AvSim+ 9.0. The parameters obtained for each data distribution are used to calculate MTTF and MTBF values. Furthermore, spare parts requirements are calculated using the Poisson Process. After obtaining spare parts requirements, each critical spare part is determining inventory policy using the Min-Max Stock and Reorder Point method. Min-Max Stock is used to determining the minimum and maximum inventory of critical parts, meanwhile the Reorder Point is used to decide the limit of -reorder the spare part.

The first step in this research is to determine the component or spare parts of the Rovema’s 1 machine which will be the focus and further analysis. System Breakdown Structure (SBS) must be carried out to facilitate the process of identifying parts of the machine. System Breakdown Structure (SBS) is a tool for analyzing, documenting and communicating machine structures at the system, subsystem, and component-level in detail. SBS classifies systems in equipment based on function. The existing functional system can be identified more easily and clearly. SBS is the first step that must be done to identify the components of a system to be further analyzed in [8]. SBS can also be used to identify the level at which failures occur and analyze their effects on systems, subsystems or related components. SBS provides a representation of parts of the equipment in the form of interrelated diagrams based on their functions. How to analyze SBS is to divide the machine into several main parts of the machine, such as electrical systems, mechanical systems, pneumatic systems, hydraulic systems, and machine support systems. From the main parts of the machine will be divided again into more detailed parts or sub-systems and components.

After analyzing the SBS, the next step is to determine the critical components or parts of the machine. The determination and selection of critical spare parts use the Risk Matrix. The Risk Matrix is a risk matrix that is used to determine the various levels of risk from several categories of hazard probabilities and the effects of these risks [9]. Risk assessment in the risk matrix can be seen from the level of severity or consequences and probability or likelihood [10]–[12] [13]. For the 5x5 risk matrix model, the severity level consists of insignificant, minor, moderate, major, and catastrophic categories. Meanwhile, the likelihood level consists of rare, impossible, possible, likely, and almost certain categories.

After the critical components (spare parts) have been selected, then the failure history data of each component is used to determine the Mean Time To Failure (MTTF), Mean Time Between Failure (MTBF). MTTF is the average interval of damage from distribution of damage, MTB is the time between failures of a component operating under normal conditions.

For the calculation of MTTF and MTBF use the following basic reliability formulas [14].

\[
MTTF = \int_{0}^{\infty} t \cdot f(t) \, dt \tag{1}
\]

\[
MTBF = \int_{0}^{\infty} R(t) \, dt \tag{2}
\]

Which \( t \) is time, \( f(t) \) is time function and \( R(t) \) is reliability function.

There are several types of failure distribution functions based on reliability that are often used to analyze maintenance problems, for example, Exponential distribution, Normal distribution, and Weibull distribution. Failure data from critical components are analyzed using Minitab 17 and AvSim 9.0 software to determine the type of failure distribution. This software is one of the software to calculate
and determine the type of distribution that represents the failure in critical components of the engine. The next step is processing and analyzing data using the Reliability Centered Spares (RCS) method. Reliability Centered Spares (RCS) is one method of managing spare parts analysis by considering several aspects such as maintenance needs of what is needed by the machine and the consequences that occur if parts are not available. This method allows maintenance activities without having to wait for the procurement of replaced components. RCS can be used to determine spare parts inventory levels based on equipment needs and maintenance operations [15]–[17]. In carrying out this RCS calculation the parts or components will be divided into components that can be repaired (repairable) and components that cannot be repaired (non-repairable). The calculation of these parts is based on the failure rate of each critical component using Poisson Process [5], [18], [19]. Poisson Process is a technique to calculate the need for parts based on reliability. The demand for spare parts due to a component replacement or failure that occurs as a result of maintenance is an event that is described as a Poisson distribution that occurs based on events that occur within a certain interval. For components that cannot be repaired (non-repairable) use the following formula [20]–[23]:

\[ \lambda t = \frac{(A \times N \times M \times T)}{MTTF} \]  

(3)

As for components that can be repaired (repairable) using the formula:

\[ \lambda t = \frac{(A \times N \times M \times T)}{MTBF} \]  

(4)

Where \( \lambda t \) is failure rate, \( A \) is a Number of Components, \( N \) is a number of units/machines used, \( T \) is an initial period, \( M \) is utility / operating machine, \( MTTF \) is Mean Time To Failure and \( MTBF \) is Mean Time Between Failure. In general, using the RCS analysis, it will help to ensure the availability of spare parts in conducting maintenance, determine the strategy of spare parts, and the number of spare parts needed in a certain period, for example in one year.

To support the RCS method, the Min-Max Stock and Reorder Points analysis also will be conducted. The Min-Max Stock method is a method in controlling spare parts inventory, which is determined by minimum stock and maximum stock of spare parts [24]. If it has reached the minimum, it is necessary to order spare parts to reach the maximum limit of spare parts. The application of the Min-Max Stock method will help the warehouse to determine how much minimum stock must be available to meet the production quantity capacity and the maximum stock of spare part in the warehouse. Inventory control using the Min-Max Stock method consists of several stages, namely determining safety stock, min stock, and max stock [25]. The following are the equations in the calculation using the Min-Max Stock method [26], [27]:

Safety Stock = (Maximum Usage – T) \times C  
Min Stock = (T \times C) + S  
Max Stock = 2 \times (T \times C)  

(5)  
(6)  
(7)

Where \( Q \) is an average usage per certain period (unit), \( C \) is lead time (month), and \( S \) is safety stock (unit).

Reorder Points (ROP) is a method of inventory points or limits, where reorder will be made [28]. In calculating this reorder point is determined by the length of the lead time, average usage and safety stock [29][30]. Here’s the equation in reordering point calculations:

\[ ROP = (AU \times LT) + SS \]  

(8)
3. Result and Discussion
The result and of this research will be explained in several subchapters as follow.

3.1. System Breakdown Structure (SBS)
The results of the analysis System Breakdown Structure (SBS) for the Rovema’s machine are described in Figure 4

![Figure 4. System Breakdown Structure](image)

Figure 4 shown that Rovema's machine is divided into three main systems which are an electrical system, mechanical system, and pneumatic system. Each of the systems consists of several components. Following completed the System Breakdown Structure (SBS) of the Rovema machine system, the next step is selecting critical components that will be the main focus of this research.

Where the AU is an average usage per certain period (unit), LT is lead time (month), and SS is Safety stock (unit).
3.2. Determination of Critical Subsystem and Component

Selection of critical subsystems and critical components using the Risk Matrix. The selection of subsystems and critical components is carried out to determine the subsystems and components that have a very high impact or risk for the whole machine system. In the risk matrix, it consists of two categories, which is severity and likelihood. In the severity category, there are three aspects used, specifically production, operational, and safety. The likelihood is the probability of damage or failure of subsystems and components.

*Table 1. The Risk Matrix of the critical component*

| Likelihood       | Severity          | Sub sistem Insignificant (1) | Minor (2) | Moderate (3) | Major (4) | Catastrophic (5) |
|------------------|-------------------|-----------------------------|-----------|--------------|-----------|------------------|
| Almost Certain   | Steel Band,       | Yellow                      |           | Green        | Red       | Brass Insert     |
|                  | Carbon Brush      | Yellow                      |           | Green        | Red       |                  |
| Likely           | Transport Belt    | Yellow                      |           | Green        | Red       | Conveyor         |
| Possible         |                   | Yellow                      |           | Green        | Red       |                  |
| Unlikely         |                   | Yellow                      |           | Green        | Red       |                  |
| Rare             |                   | Yellow                      |           | Green        | Red       |                  |

Based on the results of the Risk Matrix in Table 1, it can be seen that the components of steel band and brass insert are included in the category of very high (red-colored) which means further action needs to be taken, carbon brushes and conveyors are included in the medium category (yellow colored) which means the risk can be tolerated, and the transport belt is categorized as low (green) which means the risk is acceptable or still safe. Consequently, the critical components that will be further investigated or as critical components in the mechanical sub-system are steel band and brass insert.
3.3. Determination of TTF and TBF data distribution tests

Time To Failure (TTF) is the time of damage or failure after a system has been repaired until it is damaged again. Time Between Failure (TBF) is the time of failure or failure of a system where the system has been damaged again after experiencing previous damage. A distribution test is done to determine the distribution that represents TTF, and TBF data using the Anderson-Darling test. The distribution used in this distribution test is a Normal, Exponential, and Weibull distribution. Determining the distribution of TTF and TBF data using Minitab software. This data uses the significance level (α) which is 0.01. If P-Value < α then reject the initial hypothesis (H0). The chosen distribution is the distribution with the smallest Anderson-Darling (AD) value and the P-Value > α. Following Anderson-Darling's hypothesis:

H0: Component TTF / TBF data with Normal / Exponential / Weibull distribution

H1: Component TTF / TBF data are not Normal / Exponential / Weibull distribution

Table 2. Time To Failure (TTF) analysis result

| Components   | Distribution | AD  | P-Value | Selected Distribution |
|--------------|--------------|-----|---------|------------------------|
| Steel Band   | Normal       | 1.208 | < 0.005 | Weibull distribution   |
|              | Exponential  | 3.287 | < 0.003 |                         |
|              | Weibull      | 0.426 | > 0.250 |                         |
| Brass Insert | Normal       | 0.889 | 0.015   | Weibull distribution   |
|              | Exponential  | 0.268 | 0.851   |                         |
|              | Weibull      | 0.238 | > 0.250 |                         |

Based on table 2, the TTF data of Steel Band component has a Weibull distribution because it has the smallest AD value of 0.426 and the largest P-value of more than a significant level (α) which is 0.250. The TTF data of the Brass Insert component has a Weibull distribution because it has the smallest AD value of 0.238 and the largest P-value of more than a significant level (α) which is 0.250.
Table 3. Time Between Failure (TTF) analysis result

| Components   | Distribution | AD  | P-Value | Selected Distribution |
|--------------|--------------|-----|---------|-----------------------|
| Steel Band   | Normal       | 1.134 | < 0.005 |                       |
|              | Exponential  | 2.118 | 0.005   | Weibull distribution  |
|              | Weibull      | 0.323 | > 0.250 |                       |
| Brass Insert | Normal       | 0.851 | 0.019   | Exponential distribution |
|              | Exponential  | 0.253 | 0.873   |                       |
|              | Weibull      | 0.261 | > 0.250 |                       |

Based on table 3, the TBF data of Steel Band component has a Weibull distribution because it has the smallest AD value of 0.323 and the largest P-value, where the P-value is more than the significant level (α) that is 0.250. Meanwhile, the TBF data of the Brass Insert component has an Exponential distribution because it has the smallest AD value of 0.253 and the largest P-value, where the P-value is more than the significant level (α) that is 0.250.

3.4. Determining the Value of Mean Time To Failure (MTTF) and Mean Time Between Failure (MTBF)

Mean Time To Failure (MTTF) is the average time interval of failure that occurs when the machine or component is repaired until the machine or component is a failure again. Whereas, Mean Time Between Failure (MTBF) is the average distance between failure.

Table 4. MTTF and MTBF analysis result

| Components   | Parameters | MTTF (hours) | Parameters | MTBF (hours) |
|--------------|------------|--------------|------------|--------------|
| Steel Band   | η 1234.34  | 3546.87      | η 1480.12  | 3583.12      |
|              | β 0.422761 |              | β 0.45466  |              |
| Brass Insert | η 2326.85  | 3193.12      | η 2539.51  | 2539.51      |
|              | β 0.647443 |              | β          |              |
Based on Table 4, the MTTF value for Steel Band and Brass Insert components are 3546.87 hours and 3193.12 hours respectively, in the meantime the MTBF value for Steel Band and Brass Insert components are 3583.12 hours and 2539.12 hours.

3.5. Component Classification

After the MTTF and MTBF calculation, the classification of component is needed to specify of repairable or non-repairable. Non-repairable is a component that cannot be repaired, therefore that a component is must be replaced. Meanwhile a repairable is a component that can be repaired which means that it can be used and operated again.

| Components   | Classification |
|--------------|----------------|
| Steel Band   | Non-repairable |
| Brass Insert | Non-repairable |

Based on Table 5, both of Steel Band and Brass Inserts including into non-repairable components, which means when it gets damaged, this component need to be replaced and can't be repaired again.

3.6. Determination of component and inventory policy

Determination of component requirements using the Reliability Centered Spares (RCS) method with Poisson analysis shows the final policy and quantity of critical component for 1 year ahead. The following is the calculation based on equation (3) and (4) of critical component requirements for the next year.

| Components   | Policy | Requirement (unit) |
|--------------|--------|---------------------|
| Steel Band   | Store  | 18                  |
| Brass Insert | Store  | 11                  |

Based on Table 6, the final policy both of the Steel band and Brass Insert needs to be stored in a technical warehouse for the next one years with the number of components needed is 18 units and 11 units.
respectively. This policy is to minimize the downtime machine caused by the deficiency of a critical component.

3.7. Determination of Minimal and Maximal stock

To optimize inventory policy for the critical components of Rovema’s1 machine, it’s important to analyze the minimal and maximal (Min-Max) stock for this critical component using equation 5, 6 and 7. This analysis is important to minimize problem-related to the possibility of out of stock for the critical component, especially when the machine suddenly getting a breakdown. The Min-Max Stock method is a method used to determine the minimum and maximum inventory of spare parts with the aim of no shortage of spare parts and excess parts or accumulation in the warehouse. If there already reached the minimum level of stock, it will need to order spare parts or in general called reorder point. Reorder point is the point or boundary of the company having to order spare parts again. Moreover, safety stock is needed because there is a possibility that the use of component will change and suddenly increase and the ordered items arrive late. The following results determine the min-max inventory policy for each critical component.

| Component      | Min Stock | Max Stock |
|----------------|-----------|-----------|
| Steel Band     | 10        | 18        |
| Brass Insert   | 10        | 15        |

Table 7 shows the min-max stock policy for steel band and brass insert which min-max stock for Steel Band is 10 and the maximum is 18 and for Brass Insert minimum is 10 and maximum is 15 pieces respectively. Based on the equation, the reorder point for this critical component is 10 pieces. This mean, after the remaining inventory reaching 10 pcs, the component must be ordered again to meet the optimal stock level.

4. Conclusion

This paper proposed of spare part and inventory analysis for steel band and brass insert as a critical component in Rovema’s packaging machine. The Reliability Centered Spare (RCS) method was applied to calculate the optimal critical spare requirement using the Poisson process and Min-Max stock analysis. The RCS method using Poisson process with considering the failure rate of critical component is used to determine the optimal policy of inventory, meanwhile, the min-max stock analysis used to decide the quantity minimum and maximum critical spare part. The result shows that both of steel band and brass insert must be stored in certain quantity at the technical warehouse for one year ahead to minimizing the downtime which caused by unavailability spare part. Using this result analysis, the company can consider their current spare part inventory system to keep the Rovema’s packaging machine run smoothly during the production process. For the next research, further analysis is needed for the others component, i.e. electrical or pneumatic system to increase the Rovema’s machine reliability, availability and maintainability.
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