

Minimizing Corrective Maintenance Cost through Spare Parts Classification and Inventory Control

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Abstract. Maintenance operations have a significant portion in manufacturing cost. It will become larger when related to the value of lost business opportunity while repairs process, and the impact of customer dissatisfaction when his order was short or late. For this reason, this paper studies how to minimize the cost of maintenance. The study focuses on corrective maintenance activities which carried out after a failure has been detected and aims to restore a broken device to full working condition either by repairing it, or by replacing it. This problem leads to either waste of time at significant cost or an unnecessarily large inventory cost. Therefore, this paper develops a classification model for components for replacement as well as designs the inventory model to minimize the inventory cost. A case study in an Open End Yarn company is presented to illustrate the approach.

1. Introduction

Characterizing maintenance costs has always been challenging due to a lack of accurate prior cost data and the uncertainties around equipment usage and reliability. Since preventive maintenance does not completely prevent corrective repairs in demanding environments, any unscheduled maintenance can have a large impact on the overall maintenance costs [1]. Within the overall operating environment, the effectiveness of each constituent system becomes important. System effectiveness is the ability for a system to achieve its required operational capability, from either a cost or availability viewpoint. This is in order to embrace the constituent parts of availability – namely reliability, maintainability and logistics support [2]. Corrective maintenance follows the principle of “run to failure” where the effect is not necessarily serious or disruptive to the mission. The CM action will consist of replacing a failed system, subsystem or component to ensure that full, fault-free, operating condition is restored. Of course, corrective maintenance also covers those unexpected failures which can be serious or disrupt the mission. In addition, they determined the causes for those magnification effects being the main one the decay phenomena (.i.e. the failure rate grows during equipment life due to aging) [3]. Moreover, they added the evaluation of how the spares inventory management strategies affect the result [4].

Research related to inventory management on maintenance is that research consider a periodic review setting with a finite horizon, and seek to minimize the sum of the delay costs and the inventory holding costs. The research assume a replenishment lead time equal to zero. In this case, the difference between planned and unplanned maintenance may seem small. However, the difference is crucial: Observe planned maintenance before make the ordering decision, so that research can order parts to arrive just-in-time, while need to hold safety stock for the unplanned maintenance, since observe those demands only after have ordered and received parts [5].

By the outline, this paper will discuss the classification of spare parts based on the combined matrix FSN-ABC-VED. This classification emphasizes F on the FSN classification because it has a greater risk of stock shortage compared to the S and N. categories while for ABC classification the A and B categories and the VED classification the V and E categories will be selected. The category selection on the combined matrix will be considered a high priority part in the inventory management

system. Then the selected spare parts will be carried out inventory control using the EOQ Probabilistic method: Continuous Review (s, S) and Periodic Review (R, s, S) which will be compared with the company's existing methods so that the smallest total inventory costs can be known.

The paper is organized as follows. Section 2 provides problem identification on company. Section 3 provides a quick literature review focusing on the procedure classification and spare parts management. Then, section 4 are dedicated to the simulation study: they are respectively presenting the simulation and cost models used for the study, and the analysis of the experimental results. Section 5 provides the concluding remarks of this work.

2. Problem Identification

Thread-spinning company to produces open-end thread which is used as material for textile product. Open-end thread production consists of 4 processes, blowing process, carding process, drawing process, and open-end process. The machines operate for 24 hours a day and therefore it require the company to constantly monitor machineries conditions. Problems occurring due to maintenance issues are spare parts shortage and spare parts overstock on corrective maintenance activities that might impact production targets. This problem arise since the company has never considered quantity and reorder point for machine spare parts. On the other hand, spare parts has not been classify according to its priority. This causes error in inventory control of spare parts which then impacts the total inventory cost.

3. Literature Review

a. Procedure Classification

1. FSN Classification

FSN analysis aims at classifying items on the basis of their movement from inventory. The items are classified as fast (F), slow (S) and non moving (N) items by considering average stay and consumption rate. Spare parts can be classified as fast moving if it has less average stay or high consumption rate. FSN analysis takes account of both average stay and consumption rate of spare parts. Table 1 is FSN analysis by considering *average stay* and *consumption rate* [6].

Table 1

Klasifikasi FSN Average Stay dan Consumption Rate

Class	Average Stay	Consumption Rate
F	> 89.99%	≤ 69.99%
S	70% - 89.99%	70% - 89.99%
N	≤ 69.99%	> 89.99%

In this case, rate of flow cannot be defined by consumption pattern or stock stay period alone. For clear picture, it is necessary to combine both consumption rate and average stay and develop a new classification. The single classification index that merges FSN index from consumption rate and FSN index from average stay is obtained from the guidelines given in Table 2.

Table 2

Criteria for Combining Average Stay and Consumption Rate

FSN Classification	Class								
FSN (Consumption Rate)	F	F	F	S	S	S	N	N	N
FSN (Average Stay)	F	S	N	F	S	N	F	S	N
Final FSN Classification	F	F	S	S	S	N	S	N	N

2. ABC Classification

ABC analysis is a descending arrangement of classifications of material groups which is based on usage costs per time period [7]. Spare parts are sorted with decreasing average annual consumption value and corresponding cumulative percentage is calculated. The spare parts are then classified based on the following criteria [6].

Table 3

ABC Classification

Class	Percentage
A	$\leq 69,99\%$
B	70% - 89.99%
C	$> 89.99\%$

3. VED Classification

The VED classification is based on the level of criticality of parts determined from inventory management and the viewpoint of maintenance activities [8]. Spare parts are said to be critical in terms of maintenance activities in which the unavailability has major consequences on the smooth use of facilities and production safety. While in terms of management, the criticality of spare parts is influenced by the time of procurement (lead time). In this classification, spare parts will be classified based on their nature, namely vital, essential, or desirable (VED). The following is an explanation of the factors that affect the criticality of a spare part [9]:

- a. The criticality regarding the production
- b. Criticality regarding availability of purchasing
- c. Criticality regarding safety
- d. Criticality regarding inventory

b. Inventory Management

There are two inventory control systems, which are deterministic inventory system and probabilistic inventory system [10]. Ideal (deterministic) inventory system has its average demand, inventory cost, and lead time known precisely without variance (assumed constant). Product re-ordering was done with the same amount when inventory reaches reorder point.

Demand pattern will always change daily in our reality, or in other words, it is scarce to find cases where the parameters are known precisely. Which is why realistic (probabilistic) inventory system is needed.

Probabilistic inventory models are models used when an inventory system's parameters are not known accurately, that is to say, the parameters are random and uncertain and therefore, probabilistic or stochastic in nature [11]. Probabilistic models are classified into three categories:

1. Constant demand and variable lead time
2. Variable demand and constant lead time
3. Variable demand and lead time

Probabilistic EOQ model can be done using continuous review and periodic review system method [7].

1. *Continuous Review System (s,S)*

When inventory level reaches the reorder point or beyond it, order will be made to fill inventory up to the maximum inventory level (S) where $S = s + Q$. Inventory review with this method is continuously done where $T = 0$, therefore, stock level is always known. Continuous review system has a few characteristics such as:

- a. Order quantity is determined to fill the maximum inventory level (S) where $S = s + Q$.
- b. If inventory level reaches the reorder point or even less than reorder point, then an order must be made.
- c. Interval between orders is not uniform, it is dependent on material usage rate.

The steps in doing continuous review method calculation are as shown below (s,S) [12]:

- a. Determining order quantity

$$qw = \sqrt{\frac{2 \times k \times r}{h}} \quad (1)$$

- b. If there is backorder, then do calculation:

$$F_{L+w}(K) = \frac{\pi r - hq}{\pi r} \quad (2)$$

- But if there is lost sale, then do calculation:

$$F_{L+w}(K) = \frac{\pi r}{\pi r + hq} \quad (3)$$

- c. Determining K constant from safety factors table

- d. Safety stock calculation

$$SS = K \cdot \sigma_L \quad (4)$$

- e. Calculating reorder point

$$s = \mu + SS \quad (5)$$

- f. Calculating maximum inventory level

$$S = q + s \quad (6)$$

2. Periodic Review System (R,s,S)

This review method uses the parameter interval review (R), reorder point (s) and maximum inventory level (S). If it is time for the review, stock level will be known. If inventory level is still above the s value, then no order will be made. But if inventory level is below the s value, then order will be made to fill the maximum inventory level (S). There are a few characteristics inherent to the periodic review method:

- Product quantity differs from order to order.
- Time interval between order is constant.
- Existing stock are used to secure inventory if there are fluctuations in incoming demand.

The steps in doing periodic review method calculation are as shown below (R,s,S) [12]:

- a. Determining order quantity

$$qw = \sqrt{\frac{2 \times k \times \mu}{h}} \quad (7)$$

- b. If there is backorder, then do calculation:

$$F_{L+w}(K) = \frac{\pi r - hq}{\pi r} \quad (8)$$

- If there are lost sale, then do calculation:

$$F_{L+w}(K) = \frac{\pi r}{\pi r + hq} \quad (9)$$

- c. Determining K constant from safety factors table

- d. Determining safety stock value

$$SS = K \cdot \sigma_{L+w} \quad (10)$$

- e. Reorder point calculation

$$s = \mu_{L+w} + SS + \frac{\mu w}{2} \quad (11)$$

- f. Calculating maximum inventory level

$$S = q_w + s - \frac{\mu w}{2} \quad (12)$$

Description:

- μ = Demand during lead time (unit)
- π = Shortage cost (Rp/unit)
- σ_L = Standard deviation during lead time (unit)
- h = Inventory cost (Rp/unit)
- K = Safety factor
- k = Reorder cost (Rp/order)
- L = Lead time (hari)

q	= Order quantity (unit)
qw	= Order quantity (unit)
w	= Periodic review (hari)
r	= Mean order quantity (unit)
S	= Maximum inventory level (unit)
s	= Reorder point (unit)
SS	= Safety stock (unit)

4. Result and Discussion

After a series of data analysis, which is initialized by the classification of 387 rotor spinning machine spare parts. The classification was done based on FSN, ABC and VED classification. FSN classification resulted the most frequented and demanded spare part compared to other spare parts. From 387 rotor spinning machine spare parts, 13 spare parts were classified as category F, 202 spare parts were classified as category S, and 172 spare parts were classified as category N.

ABC classification was done with spare parts usage value considerations, where the result would show the difference between spare parts with a relatively high usage value and that with a relatively low usage value in order quantity and reorder interval. ABC classification resulted in 10 spare parts classified as category A, 18 spare parts classified as category B, and 359 spare parts classified as category C.

VED classification considers the criticality level. This classification was done by reviewing the probability of downtime and ordering lead time of spare parts. Downtime probability was determined through the usage age of spare parts, the shorter the usage age the higher the downtime probability. Other than that, a sufficiently long reorder lead time will impact the determination of reorder time. From VED classification, 75 spare parts were classified as V, 306 spare parts were classified as E, and 6 spare parts were classified as D.

The result of three classifications were 27 matrices, where a class with high criticality level would be chosen. There are 3 spare parts included in said class which are Transfer Tail Plate D54, Seal 9.3-4-1.5 and Washer D40 F.ROT.GEH. With the 3 spare parts determined, the next step was the calculation of total inventory cost using the probabilistic EOQ with continuous review (s,S) and periodic review (R,s,S) method.

Table 4. Comparison of Total Cost and Service Level on Existing Policy, Continuous Review (s,S), and Periodic Review (R,s,S)

Spare Part	Method	Total Inventory Cost	Service Level
Transfer Tail Plate D54	Existing	Rp 11.782.246	100%
	Continuous Review (s,S)	Rp 8.402.963	99%
	Periodic Review (R,s,S)	Rp 10.756.045	98%
Seal 9.3-4-1.5	Existing	Rp 51.659.349	100%
	Continuous Review (s,S)	Rp 19.653.888	100%
	Periodic Review (R,s,S)	Rp 30.342.491	100%
Washer D40 F.ROT.GEH	Existing	Rp 166.747.894	98%
	Continuous Review (s,S)	Rp 77.434.224	95%
	Periodic Review (R,s,S)	Rp 80.381.329	100%

As can be seen in Table 4, comparisons between the total cost and service level of the existing policy, continuous review method (s,S) and periodic review method (R,s,S). Continuous review method (s,S) yields the least total cost relative to the periodic review method (R,s,S), therefore, the chosen method is the continuous review method (s,S).

Every method used has its own advantages and disadvantages, the continuous review method (s,S) has a lower inventory cost compared to the periodic review method (R,s,S), this was caused by the

low amount of stock level in the warehouse. But, this method yields the same total of reorder cost in comparison with the periodic review method (R,s,S), while the reorder amount is high since the review was done continuously. Even though the service level does not reach 100%, the company prioritize a lower inventory cost and the gap can be covered by taking inventory on preventive maintenance. Periodic review (R,s,S) yields a higher inventory cost compared to continuous review (s,S) since the stock in the warehouse is higher, the reorder point (s) and maximum stock level (S) are also higher, therefore, reorder amount will be higher but the service level would also not reach 100%. From both continuous review (s,S) and periodic review (R,s,S), continuous review method (s,S) has a higher decrease in total inventory cost from the existing total inventory cost as shown in Table 5.

Table 5. Difference of Total Inventory Cost

Spare Part	Method	Total Inventory Cost Decrease	%Decrease
Transfer Tail Plate D54	<i>Continuous Review (s,S)</i>	Rp 3.379.283	29%
	<i>Periodic Review (R,s,S)</i>	Rp 1.026.201	9%
Seal 9.3-4-1.5	<i>Continuous Review (s,S)</i>	Rp 32.005.460	62%
	<i>Periodic Review (R,s,S)</i>	Rp 21.316.857	41%
Washer D40 F.ROT.GEH	<i>Continuous Review (s,S)</i>	Rp 89.313.670	54%
	<i>Periodic Review (R,s,S)</i>	Rp 86.366.565	52%

Table 5 shows the total inventory cost decrease of the continuous review (s,S) and periodic review (R,s,S). The continuous review system yielded a decrease of between 29%-54% and the periodic review system (R,s,S) yielded a decrease of between 9%-52%. While the continuous review (s,S) was not able to keep a service level of 100%, it gave a better decrease of total inventory cost.

5. Conclusion

The proposed procedure classification based on FSN-ABC-VED is effective to be used in the estimation of spare parts control in Corrective Maintenance activities. The specific issue in corrective miantenance is the unavailability of materials and spare parts when needed. In addition, the accumulation of spare parts can also affect the balance of the company's inventory costs, although needs are met, inventory costs can swell even more if some parts that have a short service life result in waste. The company needs to have a stock of spare parts to avoid the risk of parts not being available when needed.

Overall it can be concluded that the continuous review method (s, S) results in lower storage costs due to the maximum inventory value and low reorder points resulting in a low total final stock. As for the periodic review method (R, s, S), it can minimize the frequency of orders so that the order costs incurred are lower due to higher reorder points and maximum inventory and also consider the time of review. The application of the chosen method, namely continuous review (s, S) for the needs of the spare parts that was presented, was then carried out with the help of a monte carlo simulation carried out by 5 replications. The fifth replication of selected spare parts results in a total inventory cost in a row, namely Transfer Tail Plate D54 produces between IDR 8,264,235 - IDR 10,840,529, Seal 9.3-4-1.5 gets between IDR 20,498,231 - IDR 22,813,458 and Washer D40 F.ROT.GEH received between Rp 33,246,447 - Rp 35,890,452. This shows that the total cost of inventory using the continuous review (s, S) method is smaller or can minimize the cost of corrective maintenance in terms of inventory management, so that the continuous review (s, S) method can be recommended as the company's inventory control.

6. References

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