Examining Inventory Management for Spare-Part Warehouse

Dedy Ermawanto and Nani Kurniati
Department of Industrial and System Engineering
Institut Teknologi Sepuluh Nopember
Surabaya, Indonesia
dedyermawanto988@gmail.com, nanikur@ie.its.ac.id

Abstract

Spare parts availability becomes crucial to support maintenance tasks, especially for the continuous process industry. The main purpose of this research is to examine several methods of inventory management that may suitable for spare parts. Examining the demand pattern of the spare parts utilize ABC and ADI-CV classification useful for understanding the type of demand. Spare parts mostly displayed a lumpy pattern, which guides to the possible inventory methods. In general, the three inventory methods: continuous review, periodic review, and reliability-based methods, provide better performance compared to the existing min-max method currently applied. The higher service level and the lower inventory cost demonstrated by the three proposed methods with no always dominant methods in all cases. Moreover, the reliability-based method provides better performance. The possible reasons due to careful attention to the demand i.e. the optimal replacement policy. This will keep the spare parts requirement consider the reliability characteristics of equipment where it is equipped. This method taking into account the reliability factor, lead time, standard deviation of demand, continuously checking items with a fixed number of orders, and the desired target service level at the beginning of the calculation, which it does not yet have in the existing method.

Keywords
Spent Bleaching Earth, Hazardous Waste, Feasibility Study

1. Introduction
Inventory is one of the critical aspects of a company. In the case of inventories for supplies, materials, or parts of production machines, the availability of replacement parts to support maintenance activities becomes a core issue that affects the equipment efficiency of typical process industries. The requirement to manage the spare part inventory, also called maintenance inventory (Eloff and Carstens 2013), even challenging due to some situations e.g. the demand comes in stochastics manner as the nature of breakdown machines, items have superbly long lead time of procurement. Over the decades, many scholars put great attention to optimize spare parts inventory, include Kurniati et al (Kurniati et al. 2013), who tried to combined maintenance policy and the consequences of spare part inventory policy. For a typical process industry, spare parts are divided into two categories i.e. routine (consumables) and non-routine spare parts. Routine spare parts refer to parts or material consumed for machine operations e.g. oil lubricants, cleaning fluid, bag cloth. Any user or department in a company could request it. While non-routine spare parts mean parts needed to support equipment maintenance, the purchase requests could be filed by either mechanical, electrical, or instrumentation unit.

As a potential problem reveals in stock, the spare part inventory may also experience either over-stock and under-stock. These two situations happen considering both demand and the number of stocks. A typical Min-Max method is usually applied for practical reasons. The average of historical demand becomes Min stock (also referred to as the reorder point), while the Max stock is calculated as 70% above the average. However, the spare part availability doesn't fulfill the requirement of maintenance, longer downtime due to waiting for the spare part cause considered production losses. Raw Mill, the main equipment of cement production has experienced failure. Since bearing was stock out, persuade the company to follow procedures at Director level approval to command access form another plant. The losses were equivalent to US$ 1.65 million.

Considering more on the causes of downtime, for two years of operations, there are around 12% of downtime, about 37% of it due to stock out. Therefore, it is quite a big challenge for the maintenance unit to maintain the equipment ready to meet the production. Moreover, from the warehouse side, the inventory value was increased significantly for non-routine parts as depicted in Figure 1. If these conditions weren't controlled properly, the inventory value will continue to increase.

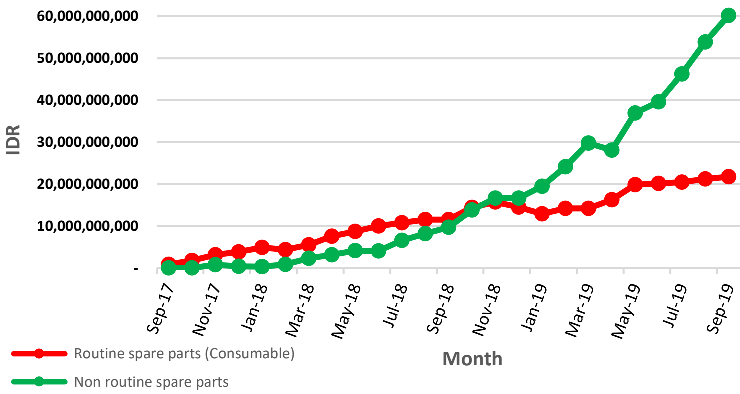

Figure 1. The value of spare parts

This research examines several inventories management methods that may suitable for managing the spare-part. Comparisons conducted based on criteria of inventory performance i.e. service level and total cost. From those criteria, we expect the most appropriate inventory management will originate. This examination needs to be occupied with a prior analysis of the spare-part demand pattern. The data pattern tells about the characteristics of demand, could guide to the appropriate inventory management methods, considering the requirements of each method.

2. Literature Review

Some literature related to this research is presented. A review of the literature on inventory includes the periodic review method and continuous review method, the inventory performance, as well as the reliability approach.

2.1. Periodic Review Method

This inventory method also refers to the (R, s, S) method. Checking to the inventory conducted at every R unit time, the order issued whenever the stock touch the reorder-point s, until the stock reaches the S value. According to Waters 0, the calculations used as follows:

$$\text{Safety stock} = Z \times \text{standard devidation over } (T + TL) = Z_\alpha \times \sigma \times \sqrt{T + LT} \quad (1)$$

$$\text{Target stock level} = \text{D} \times (\text{T+LT}) + (Z_\alpha \times \sigma \times \sqrt{T + LT}) \quad (2)$$

$$\text{Order quantity} = \text{target stock level - stock on hand - stock on order} \quad (3)$$

where Z is the inverse number of the normal distribution according to the service level 〈, T is stock checking period, LT is lead time, D is average demand, and target stock level is maximum stock.

2.2. Continuous Review Method

This inventory method also refers to (s, Q) system. The calculations as follows 0:

a. Calculate the lot size: $$q_0 = \sqrt{2 \times A \times D / h} \quad (4)$$

b. Calculate α and r': $$\alpha = h \times q_0 / C_u \times D \quad (5)$$

$$r' = D \times L + Z_\alpha \times D \times \sqrt{L} \quad (6)$$

c. Calculate the value of q_{01} with the equation:

$$q_{01} = \sqrt{2 \times D \times (A + C_u \times N) / h} \quad (7)$$

While $$N = \sigma \times D \times L \times \left[f(Z_\alpha) - Z_\alpha \times \psi(Z_\alpha) \right] \tag{8}$$

d. Recalculate the values α and r_1' :

$$\alpha = h \times q_{01} / C_u \times D \tag{9}$$

$$r' = D \times L + Z_\alpha \times \sigma \times D \times \sqrt{L} \tag{10}$$

e. Evaluate, if $r' = r_1'$ then stop iteration, whilst continues to the next iteration until the same

f. Calculating safety stock (SS): $$SS = Z_\alpha \times \sigma \times D \times \sqrt{L} \tag{11}$$

g. Calculate the maximum inventory (S) : $$S = q + r \tag{12}$$

Where D is average demand per year, σ is the standard deviation of demand, L is lead time (year), σ DL is the standard deviation of demand during lead time, A is order cost, C_u is stockout cost, h is holding cost/unit/year. The value of Z_α obtained from the normal distribution table for α

2.3. Age of Replacement Model

The calculations total expected replacement cost per unit time 0 as follow:

$$C(t_p) = \frac{\text{total expected replacement cost per cycle}}{\text{expected cycle length}} = \frac{C_p R(t_p) + C_f [1 - R(t_p)]}{(t_p + T_p) R(t_p) + [M(t_p) + T_f][1 - R(t_p)]} \tag{13}$$

Where $C(t_p)$ is the total expected replacement cost per unit time 0, C_p is the total cost of a preventive replacement, C_f is the total cost of a failure replacement, T_p is the mean time required to make a preventive replacement, T_f is the mean time required to make a failure replacement, and $M(t_p)$ in the meantime to failure when preventive replacement occurs at age t_p.

The required number of spare parts determined by considering the risk of stock out α. The number of spare parts n determined from the probability of available stock as follow:

$$P_n(t) = \sum_{n=0}^{N_{\max}} \frac{H^n(t)}{n!} \times e^{-H^n(t)} \geq 1 - \alpha \tag{14}$$

2.4. Inventory Performance

The percentage of units demand that met from stock is the most obvious measure of service level 0.

$$\text{Service level} = \frac{\text{number of deman period} - \text{number of shortage period}}{\text{number of demand period}} \tag{15}$$

$$\text{Total cost} = \text{holding cost} + \text{order cost} + \text{purchase cost} + \text{stockout cost} \tag{16}$$

3. Research Methodology

This methodology will ensure well-structured research and achieve predetermined goals. Several stages include collecting and processing data, analysis and discussion, followed by conclusion and recommendation. The flow chart of research methodology is provided in Figure 2.

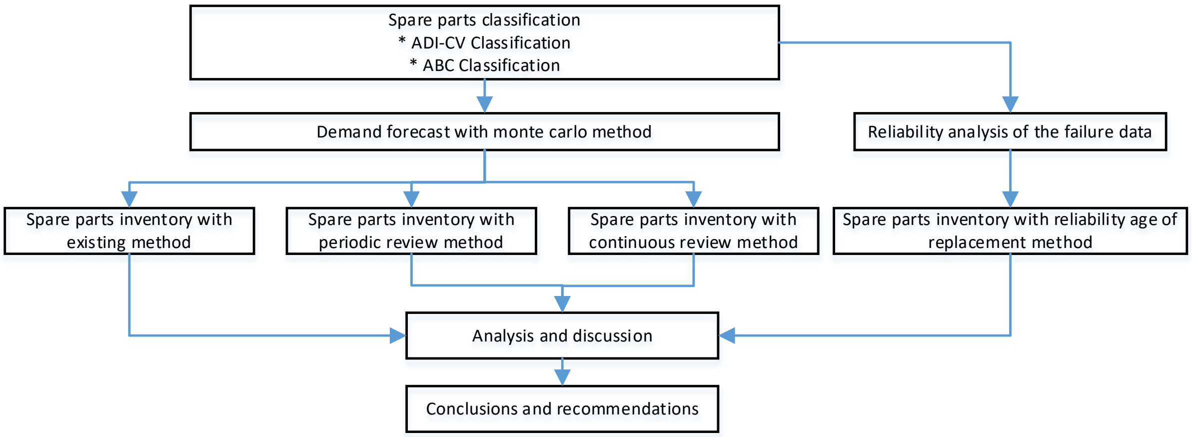

Figure 2. Research methodology

The characteristics of data collected from the company database include the type of spare parts, usage, price, lead time, order size, production history, and equipment maintenance data. The first process of data was conducted by classifying the spare parts, using ADI (Average Demand Interval) - CV (Coefficient of Variations), and the ABC method. This stage will classify spare parts into several classes to represent its data pattern. Under the assumption of the pattern data will be continuing to the future, the Monte Carlo method will ensure it. Therefore, the similarity test of the two data (original historical demand and simulation random generation data) important to test the data validity. If the test results the two data are not significantly different, the generated random numbers consider as the same as the demand data. The validity conducted using Nonparametrics analysis under Mann Whitney method.

All the forecasted data will be examined using four different methods to compare i.e. existing company used method (min-max method), continuous review, periodic review, and reliability approach. All these methods are compared in terms of the total cost and service level in the Analysis and Discussion stage. The conclusion mostly provides the most appropriate proposed method for managing the spare part.

4. Result and Analysis

4.1. Spare Parts Classification with ADI-CV Analysis

The ADI-CV considers the intervals between requests and variations in the level of demand. These two parameters are suitable for the characteristics of spare parts e.g. demand not to sustain and large variations. The spare part demand cannot be seen, however, the probability (stochastic) includes expectations, variance, and distribution pattern that can be predicted ($S \neq 0$). There are two methods for determining the supply control system model with stochastic demand: continuous review method (transaction reporting system) and periodic review method. Figure 3 displayed the ADI-CV classification of spare parts. Almost 451 parts or 97.0 % follow *lumpy* pattern (ADI>1.32; CV>0.49).

4.2. Spare Parts Classification with ABC Analysis

ABC classification also refers to the Pareto analysis or '80-20 rule', which means 20 percent of inventory items require 80 percent special attention and have a significant impact on costs 0. The classification of each category is provided in Table 1.

Figure 3. ADI-CV classification of non-routine spare part

Table 1. ABC classification results for non-routine spare parts

Category	Qty Item	Percentage of Items	Percentage of Use By Value	Value (IDR)
A	19	4.09%	69.81%	43,497,942,568
B	62	13.33%	20.05%	12,492,678,182
C	384	82.58%	10.14%	6,317,499,714
Sum	**465**	**100%**	**100%**	**62,308,120,464**

Combining the two classification methods, Focusing on the first ten spare parts with the highest demand and price to be the numerical example of the calculation and analysis, which lumpy profile. These spare parts will be further analyzed using the existing method, periodic review method, continuous review method, then conducted a discussion with the reliability method.

4.3. Inventory Using Existing Company Method

The current inventory control method has been done using the min-max method. the min stock calculated from the average of the historical demand, the max stock is 70% above the average, while reorder points use a minimum reference stock. Under the current practice in the company, the availability of spare parts still does not meet the requirement of the equipment maintenance. The downtime is high and production losses due to waiting for upcoming order spare parts or waiting for spare parts reconditioning. For non-routine spare parts, most of the service levels below those required by the company (minimum 95.00%), where the amount of stock out can affect the service level. For instance, a typical spare parts WEAR SEGMENT 45DEG; OEM DWG NO 13016485 has a service level of 88.46% and the total cost Rp8,810,230. From the simulation results, there was possible stockout in three periods with a total amount of 31 unit or worth Rp310,000,000.

4.4. Inventory Using Periodic Review Method

Inventory calculation and service level of non-routine spare parts conducted based on equation (1), (2), (3), (15), and (16). The related information and the periodic review method applying to one of the non-routine spare part 307-200044 - WEAR SEGMENT 45DEG; OEM DWG NO 13016485 is:

- price of spare parts is Rp71,800,000,
- holding cost/units is Rp1,495,833,
- ordering cost is Rp4,340,000,
- stockout cost is Rp10,000,000,
- LT (lead time) is 5 month,
- T (goods checking period) is 1 month, get result total cost is Rp12,679,545,000 and service level 92.31%
- the savings made by the company to the total inventory cost for all spare parts was Rp1,127,050,554 (1.81 %) compared to the existing method and service level increase from 90.38 % to 96.15% (5.77%)

The periodic review method has considered the lead time factor, the standard deviation of demand, the period for checking goods, and the desired target service level at the beginning of the calculation, which is not yet available in the existing method.

4.5. Inventory Calculation with Continuous Review Method

The calculation was conducted using equation (4) to (11), (15), and (16). The information and calculations results for typical non-routine spare parts 307-200044 - WEAR SEGMENT 45DEG; OEM DWG NO 13016485, is :

- average demand per year (D) is 73,
- standard deviation of demand (σ) is 10.26,
- lead time (L) is 0.5 year,
- standard deviation of demand during a lead time (σ DL) is 7.25,
- order cost (A) is Rp4,340,000,
- stockout cost (C_u) is Rp10,000,000,
- holding cost/unit/year (h) is Rp1,495,833
- price of spare parts/unit (v) is Rp71,800,000,
- resulting the total cost is Rp12,656,812,500 and service level 92.31%
- the savings made by the company to the total inventory costs for all spare parts were Rp5,614,008,190 (9.03%) compared to the existing method and service level increase from 90.38 % to 96.54% (6.15%)

The continuous review method takes into account the lead time factor, the standard deviation of demand, continuously for checking goods with a fixed order number, and the desired target service level at the beginning of the calculation, which it does not yet have in the existing method.

4.6. Inventory Using Reliability Approach

The historical data of replacement attached to certain equipment related to the non-routine spare parts. The replacement data distribution and parameters important to determining the time between the replacement of critical spare parts. After that MTTF can be obtained as a basis for further steps. Table 2 provides the time between replacement and the time required for replacement of typical non-routine spare parts.

Table 2. Replacement data of spare parts 307-200044 - WEAR SEGMENT 45DEG; OEM DWG NO 13016485 COOLER

No	Date	Time between replacement (hours)	Time for replacement (hours)
1	20-Apr-18		240
2	11-Dec-18	5640	240
3	9-Mar-19	2112	240
4	15-Jul-19	3072	240

The replacement data distribution and parameters it found to follow Weibull distribution with shape parameter refer to an increasing failure rate spare parts. The Means Time To Failure (replacement) value is easily determined then. The Optimum spare parts replacement interval the chosen spare parts is based on the following data :

- Tp is the mean time required to make a preventive replacement is 240 hours,
- Tf is the mean time required to make a failure replacement is 288 hours,
- M(t_p) is the meantime to failure when preventive replacement occurs at age t_p (1840 hours) is 7136,66 hours, under equation (13) and (14).
- By changing the value of t_p that is still in the range above and below the existing t_p , and examine the $C(t_p)$.
- The minimum expected total cost found at the time interval t_p of 1840 hours at cost of Rp21,282,754
- However, some adjustments permitted by the company due to the continuing production process. Existing the time interval is 4,380 hours (6 months), and permitted by management is 2,920 hours (4 months) then the total cost resulted is equal to Rp21,447,996

The next step is to calculate the requirement spare parts demand for 1 year (365 days x 24 hours). Considering the risk of loss as much as 5% according to the company requirements. The required n must fulfill the cumulative of $P_n(t)$ for n = 0 to Nmax couldn't exceed then ($1-\alpha$) = 95%. Resulted in Nmax = 5 and gets total cost Rp7,069,682,778 and service level 84.62%. The savings made by the company to the total inventory costs for all spare parts were Rp14,847,900,072 (23.88%) compared to the existing method and service level increase from 90.38 % to 96.92% (6.54%)

Reliability method taking account the reliability factor, lead time, standard deviation of demand, continuously checking items with a fixed number of orders, and the desired target service level at the beginning of the calculation, which is not available in the existing method.

4.7. The Comparisons Amongst Inventory Methods

The overall analysis using four methods into the first ten critical non-routine spare parts with a lumpy pattern is provided in Table 3. In general, it can be seen the three inventory methods that are examined to the spare parts provide better performance compared to the existing min-max method employed in the typical continuous process industry. The higher service level and the lower inventory cost demonstrated by the three proposed methods, even there are no always dominant methods in all cases. The reliability approach used to infer the inventory spare part management seems to perform better even compare to the common inventory model for any goods, continuous and periodic review methods. This reasonable due to more careful attention to the demand related to the characteristics of spare parts. The spare part demand was triggered by the failure equipment required replacement action. The failure randomly happened related to the aging and deterioration characteristics of production equipment which are considered as a stochastic event.

5. Conclusion

The study of several inventory methods examination for spare parts inventory has been conducted for a typical process industry i.e. cement company. For that industry, the production process runs continuously under expectation without or minimum downtime may cause some extremely high cost or opportunity lost. Therefore, the availability of spare parts in the warehouse is important to handle, as well as to keep the warehouse performance indicator achieved. The classification of spare parts helps management to focus on very critical items. Amongst 465 non-routine spare parts in the company, category A, B, and C are 4.09%, 13.33%, 82.58% respectively. Based on ADI-CV analysis, around 97% displays the lumpy pattern. Based on the examination of three inventory methods to the non-routine spare parts, it is found that the reliability-based methods provide better performance compared to the continuous and periodic review methods, more significant even compare to the existing min-max method. The possible reasons for this situation due to careful attention to the demand spare part, which is considered as the optimal replacement policy that was calculated first. This will keep the spare parts requirement consider the reliability characteristics of equipment where the spare parts equipped. The reliability-based method taking into account the reliability factor, lead time, standard deviation of demand, continuously checking items with a fixed number of orders, and the desired target service level at the beginning of the calculation, which it does not yet have in the existing method.

There is a possibility of some management adjustments may be required to determine the inventory policy following the reliability-based inventory methods. The continuous examination of the spare parts stock ensures updated information towards uncertain demand for replacement.

Table 3. Recapitulation of existing methods, periodic review methods, continuous review methods, and reliability methods for critical non-routine spare parts

No.	Spare parts	Performance	Method			
			Existing	Periodic Review (R,s,S)	Continuous Review (S,Q)	Reliability
1	307-200044 - WEAR SEGMENT 45DEG; OEM DWG NO 13016485	Service Level	88.46%	94.23%	89.42%	84.62%
		Total Cost	8,810,230,833	14,154,071,250	12,881,942,708	7,069,682,778
2	635-200068 - CYLINDER,HYD ACTUATOR; ECS.S60.002.00.17	Service Level	92.31%	100.00%	96.15%	100.00%
		Total Cost	6,808,050,885	6,200,266,165	6,419,414,792	4,544,600,781
3	316-200923 - DRIVE PLATE, 4200M; F/CLINKER COOLER	Service Level	92.31%	98.08%	98.08%	96.15%
		Total Cost	5,357,235,000	5,980,558,333	5,313,021,667	7,890,360,000
4	316-200921 - CROSS BAR, KJ-210M; F/CLINKER COOLER	Service Level	92.31%	94.23%	94.23%	96.15%
		Total Cost	10,482,512,500	10,491,426,250	11,584,764,375	10,143,207,500
5	316-201129 - CROSS, BAR KJ-210	Service Level	88.46%	96.15%	97.12%	100.00%
		Total Cost	4,080,891,250	4,162,970,833	4,564,156,563	5,162,487,083
6	SI00006207 - WEL ROD; 2.8MM; WELDING ALLOY; HC-0 250	Service Level	88.46%	95.19%	99.04%	100.00%
		Total Cost	15,499,846,042	7,428,681,875	3,116,321,432	1,916,943,333
7	635-200033 - CYLINDER, HYDRAULIC ACTUATOR	Service Level	88.46%	94.23%	96.15%	100.00%
		Total Cost	2,500,430,000	3,549,910,625	3,730,651,875	4,195,922,500
8	324-200207 - BELT, CONV.; 800MMXEP500X4PLYX8X3MM	Service Level	88.46%	93.27%	97.12%	92.31%
		Total Cost	2,261,350,000	1,762,464,688	1,838,217,188	1,902,825,000
9	633-200003 -PULL ROD KIT; 7418324; FOR COAL MILL	Service Level	92.31%	100.00%	99.04%	100.00%
		Total Cost	4,919,895,000	6,352,395,000	6,027,047,500	3,934,930,000
10	613-200743 - VALVE, SOLENOID; 5/2 WAY; L12BA452B00061	Service Level	92.31%	96.15%	99.04%	100.00%
		Total Cost	1,465,290,213	975,936,150	1,096,185,434	576,872,675
		SL Average	**90.38%**	**96.15%**	**96.54%**	**96.92%**
		TC Cum.	**62,185,731,723**	**61,058,681,169**	**56,571,723,533**	**47,337,831,651**

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