Spare Part Inventory Policy Planning based on FRMIC (Fuzzy-Rule-based approach for Multi-Criteria Inventory Classification) using Base-Stock Policy Method (S-1, S)

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Abstract. Policy in managing inventory becomes an important part of a company, including in Food Factory that involve several production activities. To support production activities, company needs machines to carry out production activities. In order to keep production activities running well, the company always strives to maintain the reliability of these machines. Spare parts are an important component to support these activities. The type and number of spare parts is not only one, but can reach thousands. Therefore, it is necessary to manage a good spare part inventory by the company to ensure the availability of spare parts in warehouses and of course avoid the accumulation of spare parts stock in warehouses that make inventory costs high. This study uses the base-stock policy method (S-1, S) method, which is applied to high priority spare parts. Determination of high inventory (HI) category spare parts is obtained based on FRMIC classification (Fuzzy-Rule-based approach Multi-criteria Inventory Classification) which considers several criteria, including: unit price, consumption value, replenishment lead-time, critically and commonality. The use of the base-stock policy method is proven to be able to reduce total inventory cost.

Introduction

Policy in managing inventory becomes an important part of a company. Companies generally have inventory to support various activities within the company, for example to fulfill all production activities. Not only direct production activities that include raw material inventories, but also supporting activities for the production activities.

Food Factory is one of company that involve several production activities. To support production activities, company needs machines to carry out production activities. To keep production activities running well, the company always strives to maintain the reliability of these machines. Some cases, maintenance activities are not done immediately, to cause outstanding (service delay).

The outstanding condition is certainly detrimental to the company because it inhibits production activities. Hampered production activities will cause loss of sales. Whenever a downtime happens on machine, the availability of spare parts is certainly a very important thing. Spare parts are needed to support and guarantee the reliability of the machine and equipment on the system [1]. Therefore, it is necessary to manage the spare parts supply well to ensure the availability of spare parts in the warehouse. According to [2], the major focus of spare parts inventory management practices is to have the required spares to be ready at right time, in right place with minimum cost.

Inventory is defined as an idle resource which waiting for further process [3, 4]. The problem in spare parts inventory management is the types and the number of spare parts not only one, but can reach thousands. Therefore, spare parts need to be classified to manage the large number of spare parts on warehouse. The Classification of spare parts is useful for categorizing spare parts based on their importance. This is because not all spare parts have the same level of importance. According to [5], spare part classification is used in the management of spare part inventory as a stage to focus on important items and facilitate the decision making process.
One of the most used for classification is ABC Analysis. ABC analysis classifies goods based on the level absorbed in inventory [6]. ABC analysis is a classification method that requires investment value in annual period or consumption value (cost), i.e. product of annual use of the item and its price [2], [7]. However, not only consumption value that needs to be considered in classifying spare parts. Other criteria like lead-time, critically and commonality of spare parts are also need to be considered.

In this paper, we have used FRMIC (Fuzzy-Rule-based approach for Multi-criteria Inventory Classification) model to classifying spare parts. It is a method was discovered by [2]. This method develops ways of classifying spare parts by considering several criteria, including: unit price, consumption value, replenishment lead-time, critically and commonality. The output produced by the FRMIC model is spare parts in the category of high inventory (HI), medium inventory (MI) and less inventory (LI).

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Inventory management of spare parts is not limited to classifying spare parts. After getting the categories, an inventory policy is need to be considered. As suggested by [2], an inventory policy for HI category is (S-1, S), for MI category is (s, Q) and EOQ policy for LI category. In this paper, the research is limited to spare parts with high inventory (HI) category. We have used (S-1, S) inventory policy, also known as base-stock policy. According to [8], this (S-1, S) inventory policy also called base-stock, is very useful in the inventory control of A items and particularly for expensive spare parts with lifetime longer than replenishment lead-time.

**Review of literature**

**Classification of Spare Parts**

Spare parts are part of a system that has certain functions and characteristics that affect the performance of the system occupied [9]. Spare part classification is used in the management of spare part supplies as a stage to focus on important items and facilitate the decision-making process [5]. Item classification or critically analysis can be used to identify different classes of spare parts that will be managed differently depending on the critical level produced. The critical level of spare parts can be a first step for practitioners to take their steps in a care perspective [10].

**FRMIC**

FRMIC model is a new method found by Sarmah and Moharana. This method develops ways of classifying spare parts with fuzzy-rule-base and considers several criteria, including: consumption value, unit price, replenishment lead-time, commonality and critically. The output of FRMIC model is the spare part category (HI, MI and LI). The steps of FRMIC model include: fuzzification of input criteria, rule-base development and defuzzification of output criteria. The basic concept in the FRMIC model is an If-then rule by considering the input parameters and output parameters [2].

**Base-Stock Policy (S-1, S)**

(S-1, S) policy also called base-stock policy is very useful in inventory control of class A items and especially for expensive spare parts with a longer lifetime than replenishment leads-time [8]. S-1, S) policy as described above, is equivalent to the M / G / S / S queue whose steady-state probability is known as the truncated Poisson distribution [8]. The penalty cost L is charged when the stock S is exhausted before replenishments are received and a holding cost h is charged for each item in stock.

The average holding cost is given by Eq.1 and the average penalty cost is given by Eq. 2.

\[
\text{Holding Cost} = h \times [S - (1 - p(S))\lambda\tau] \tag{1}
\]

\[
\text{Penalty Cost} = \lambda L p(S) \tag{2}
\]

where

\[
p(S) = Q_s(0) = (\lambda\tau)^S / S! \tag{3}
\]
S* is obtained by solving

\[
\frac{dTC(S)}{dS} = 0 \text{ for } S = S^*
\]

(4)

\[
S^* = \lambda \tau + \alpha \sqrt{\lambda \tau}
\]

(5)

where

\[
\alpha = \left[2 \ln \left(1 + \frac{L}{h \tau}\right)\right]^{1/2}
\]

(6)

Information:

\(\lambda\): Demand

\(\tau\): Lead-time

\(S\): Desired stock

\(h\): Holding cost/unit

\(L\): Penalty cost/unit

**Total Inventory Cost**

Inventory costs are all expenses and losses arising from inventories during a certain time [1]. Total inventory cost includes the inventory carrying cost and the personnel cost, office space, and systems employed in managing inventory [11].

a. Ordering Cost

The cost includes administrative cost to place an order, trucking cost to transport the order, and labor cost to receive the order [12]

b. Holding Cost

Holding cost is the cost of carrying a unit in inventory for a specified period of time, usually one year [12]

c. Shortage Cost (Penalty Cost)

Shortage costs is due to the unavailability of spare parts in the warehouse, causing losses to the company.

**Methodology**

Fig.1 represents systematic of research. The explanation of step is as follows:

a. Literature review: gathering information that is relevant to the topic of research.

b. Observation: obtaining information or data by plunging directly into company.

c. Identification of problems: this process identifies problems, setting research objectives and setting boundaries of the problem.

d. Data collection and processing: this process collects all information for research and processing data using FRMIC model to classify spare parts and using inventory policy (S-1, S) or base-stock policy for spare parts with high inventory (HI) category.

e. Data analysis: this process analyzes data against the results of previous data processing.

f. Draw Conclusions: this process concludes the results of the study.
Case Study

The company handles 8470 types of spare part and among those spare parts, 327 spare parts are selected based on annual consumption in 2018. Five criteria are considered, namely: unit price, consumption value, lead-time, commonality and critically. Each criteria has three category: high, medium and less. The company has set a scale to each criteria. Unit price, consumption value and lead-time are quantitative criteria, while commonality and critically are qualitative criteria, which is converted to quantitative factor. All the 243 ($3^5$) rules was reviewed by experts. Spare parts with category high inventory was selected and base-stock policy (S-1, S) was selected to be inventory policy as suggested [2].

Results and Analysis

Framework Modeling System

The following is a knowledge basic that addresses the system represented by the function of associating linguistic variables. If implemented and included input parameters using MATLAB program, the system design will be as shown in the following figure.

![Fig. 2 FRMIC Diagram using MATLAB](image)

Fuzzification of Input Criteria

In the FRMIC model, there are five variables which are input parameters. Membership function chosen and domain value for input parameters are represented in table 1.

| Parameter    | Category | Membership | Domain Value   |
|--------------|----------|------------|----------------|
| Unit Price   | Less     | Trapezoidal| 0 – IDR 1,250,000 |
|              | Medium   | Trapezoidal| IDR 1,000,000 – IDR 5,000,000 |
|              | High     | Trapezoidal| IDR 4,000,000   |
| Consumption  | Less     | Trapezoidal| 0 – IDR 1,250,000 |
| Value        | Medium   | Trapezoidal| IDR 1,000,000 – IDR 5,000,000 |
|              | High     | Trapezoidal| IDR 4,000,000   |
| Lead-time    | Less     | Trapezoidal| 0 – 21 days     |
|              | Medium   | Trapezoidal| 14 – 90 days    |
|              | High     | Trapezoidal| > 75 days       |
| Commonality  | Less     | Trapezoidal| 0 – 0.1         |
|              | Medium   | Trapezoidal| 0.05 – 0.2      |
|              | High     | Trapezoidal| > 0.15          |
| Critically   | Less     | Trapezoidal| 0 – 0.4         |
|              | Medium   | Trapezoidal| 0.2 – 0.8       |
|              | High     | Trapezoidal| > 0.6           |

Figure 4 (a) – (e) shows pictorial representation of input parameters.
Note: (a) Unit Price; (b) Consumption Value; (c) Lead-time; (d) Commonality and (e) Critically

**Rule-base development**

There are 243 rules was reviewed by experts. The following are the rules and the output value for each rule.

| Rule Number | Unit Price | Consumption Value | Lead-time | Commonality | Critically | FRMIC |
|-------------|------------|-------------------|-----------|-------------|------------|-------|
| 1           | HP         | HV                | HL        | HC          | HCOM       | HI    |
| 2           | HP         | HV                | HL        | HC          | MCOM       | HI    |
| 3           | HP         | HV                | HL        | HC          | LCOM       | HI    |
| ...         | ...        | ...               | ...       | ...         | ...        | ...   |
| 243         | HP         | LV                | LL        | LC          | LCOM       | LI    |

**Defuzzification of Output**

The output of the model is FRMIC classified (HI, MI and LI) with the input parameter was mentioned before. The defuzzified output is determined by COG (Center of gravity) method. The output is value ranging between 0 to 1. Membership function chosen and domain value for input parameters are represented in table 3 and was represented by pictorial representation of output parameter in fig. 4.

| Parameter | Category  | Membership | Domain Value |
|-----------|-----------|------------|--------------|
| FRMIC     | Less      | Trapezoidal| 0 – 0.4      |
|           | Medium    | Trapezoidal| 0.2 – 0.8    |
|           | High      | Trapezoidal| > 0.6        |
Classification Results using FRMIC Model

There are 327 spare parts used as the object of this research based on the use of engine spare parts in 2018. The process of classifying FRMIC is done automatically by the system using the MATLAB program. The classification results of spare parts are presented in table 4.

| Number | Spare Part Code | Unit Price  | Consumption Value | Lead-time (hur) | Commonality | Critically | Defuzzification | FRMIC |
|--------|-----------------|-------------|-------------------|----------------|-------------|------------|-----------------|-------|
| 1      | 366-366123      | Rp 1.176.154| Rp 2.352.307      | 295            | 0,56        | 0,5        | 0,7             | HI    |
| 2      | 350-350105      | Rp 1.716.434| Rp 29.179.370     | 55             | 1,00        | 1          | 0,847           | HI    |
| 3      | 366-366121      | Rp 5.630.235| Rp 5.630.235      | 90             | 0,56        | 0,5        | 0,847           | HI    |
| …     | …               | …           | …                 | …              | …           | …          | …               | …    |
| 327    | 534-534117      | Rp 790.000  | Rp 790.000        | 13             | 0,56        | 0,5        | 0,153           | LI    |

Based on FRMIC model, from 327 spare parts, 45 spare parts are in the HI (High inventory) category, 125 spare parts are in the MI (Medium Inventory) and 157 spare parts are in the LI (Less Inventory) category.

Calculation of Base-stock Policy (S-1, S) Parameter

The following is the example of calculation parameter using base-stock policy (S-1, S) for spare part with 366-366123 code.

Known:
\[ L = \text{Rp 11.936.416} \]
\[ h = \text{Rp 58.808} \]
\[ \lambda = 2 \text{ units} \]
\[ \tau = \frac{295 \text{ days}}{365 \text{ days}} = 0,81 \text{ year} \]
\[ \alpha = \left[ 2\ln \left( 1 + \frac{L}{h\tau} \right) \right]^{1/2} = \left[ 2\ln \left( 1 + \frac{\text{Rp 11.936.416}}{\text{Rp 58.836 \times 0,81}} \right) \right]^{1/2} = 3,33 \]
\[ S^* = \lambda \tau + \alpha \sqrt{\lambda \tau} = (2 \times 0,81) + (3,33 \sqrt{2 \times 0,81}) \approx 6 \text{ units} \]
The S * results are used to test the probability of the absence of stock p (S). The company sets a service level value of 95%. The value of S is set when p (S) ≤ 5%.

*Iteration 1 (S = 6)
\[ p(S) = Qs(0) = \frac{(\lambda \tau)^S}{S!} = \frac{(2 \times 0.81)^6}{6!} = \frac{18,076}{720} = 0.0248 = 2.48\% \]

Because \( p(S) \) value for \( S = 6 \) = 2.48% < 5%, then \( S = 6 \) units

\( S = 6 \) units
\( S - 1 = 6 - 1 = 5 \) units

The \( S \) value is the maximum inventory level and \( S-1 \) is reorder point. The maximum inventory level for spare part with 366-366123 code is 6 units and the reorder point is 5 units.

**The Calculation of Total Inventory Cost**

Inventory costs consist of several costs, namely: ordering cost, holding cost and penalty cost. The following is an example of calculating the inventory cost component for spare parts coded 366-366123.

Known:
- \( \lambda = 2 \) units
- \( \tau = 0.8 \) year
- \( p(S) = 2.48\% \)
- \( S = 6 \) units

Ordering cost = \( f \times A \)
\[ = 5 \times Rp 88.212 \]
\[ = Rp 441.058 \]

Holding cost = \( h \cdot [S - (1 - p(S)) \lambda \tau] \)
\[ = Rp 58.808 \cdot \left[ 6 - ((1 - 2.48\%) \times 2 \times 0.8) \right] \]
\[ = Rp 260.142 \]

Penalty cost = \( \lambda Lp(S) \)
\[ = 2 \times Rp 11,936.416 \times 2.48\% \]
\[ = Rp 591.461 \]

Inventory cost = Ordering cost + Holding cost + Penalty cost
\[ = Rp 441.060 + Rp 260.142 + Rp 591.461 \]
\[ = Rp 1,292.661 \]

Table 5 shows the calculation of total inventory cost.

| No | Spare Part Code | Ordering Cost | Holding Cost | Penalty Cost | Inventory Cost |
|----|----------------|---------------|--------------|-------------|---------------|
| 1  | 366-366123     | Rp 441.058    | Rp 260.142   | Rp 591.461  | Rp 1,292.661  |
| 2  | 350-350105     | Rp 901.128    | Rp 476.839   | Rp 1,739.775| Rp 3,117.741  |
| 3  | 366-366121     | Rp 422.268    | Rp 495.720   | Rp 110.704  | Rp 1,028.692  |
| ...| ...            | ...           | ...          | ...         | ...           |
| 45 | 366-366612     | Rp 340.337    | Rp 399.537   | Rp 110.704  | Rp 850.578    |
| TOTAL |            | Rp 26,190.679 | Rp 35,202.304| Rp 34,005.311| Rp 16,214.895 |

**The Comparison of Initial Condition and Proposed Condition**

Table 6 presents the comparison of the total inventory cost and its components in initial condition and proposed condition.
Table 6 The Comparison of Initial Condition and Proposed Condition

| Component Cost        | Initial Condition | Proposed Condition | Decreased/ Increased | %Decreased / Increased |
|-----------------------|-------------------|--------------------|-----------------------|------------------------|
| Total Ordering Cost   | Rp 26.190.679     | Rp 35.202.304      | + Rp 9.011.625        | +34.41%                |
| Total Holding cost    | Rp 39.598.583     | Rp 34.005.311      | - Rp 5.593.701        | -14.12%                |
| Total Penalty Cost    | Rp 48.716.763     | Rp 16.214.895      | -Rp 32.501.868        | -66.72%                |
| Total Inventory Cost  | Rp 113.472.911    | Rp 85.422.510      | -Rp 28.050.402        | -24.72%                |

Conclusions

Based on the results of the study using the FRMIC model, there are 45 spare parts with HI (High Inventory) category, 125 spare parts with MI (Medium Inventory) category and 157 spare parts with LI (Less Inventory) category. Based on the calculation using base-stock policy method (S-1, S), the total ordering cost has increased Rp 9.011.625 or has increased 34.41%, the total holding cost has decreased Rp 5.593.701 or has decreased 14.12% and the total penalty cost has decreased 66.72% or Rp 32.501.868. It can be included that the total inventory cost decreased Rp 28.050.402 or decreased of 24.72% from the initial condition.

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