Research on Inventory Strategy of Spare Parts Based on Demand Rate

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Abstract. The demand intensity of spare parts is the key factor to the inventory strategy. Firstly, one scientific calculation method for the demand rate of spare parts is put forward in this paper. Secondly, spare parts is classed by the value and universality of spare parts, the difficulty in purchasing, the demand stability and so on. Lastly, the storage categories and classification management method of spare parts is set up according to the characteristics of spare parts preparation, which sets the foundation for the research of scientific inventory management.

1. Introduction
Scientific and reasonable management of spare parts is helpful to reduce the life cycle cost of the equipment and maintain the integrity rate of equipment. According to the relevant literatures, the current research on spare parts optimization mainly focuses on three ideas, such as the optimization of decision-making methods, the planning optimization at the plan stage, and the material configuration optimization at the usage stage [1]. The research in the plan stage is more thorough, for example, the planning of multiple resources [2-3]. The calculation model of spare parts demand considering preventive maintenance is studied in Literature [4]. The prediction model of spare parts security probability and demand quantity considering combat missions is studied in Literature [5]. The analytical algorithm of spare parts demand for unit voting system with different life distribution is studied in Literature [6]. The influence of timing replenishment to the demand for spare parts is studied in Literature [7]. The spare parts optimization model in the above literatures is too complex, and less consideration is given to inventory decision. So, a convenient method of spare parts optimization considering demand rate and support time is set up.

2. Determination of Spare Parts Demand Rate
The demand intensity of spare parts is usually evaluated by demand rate. The spare parts demand rate refers to the quantity of spare parts required per unit time, which is affected a lot of factors, such as the failure rate, usage mode, maintenance strategy, management level and so on.

The demand rate of spare parts, which is only judged by reliability is not consistent with the actual situation. Therefore, the spare parts with same type installed in different equipments have some differences in preventive maintenance, breakdown repair and usage environment. Predicting demand rate based only on the reliability level of the spare parts may produce large errors. Therefore, it is feasible to use the actual consumption of spare parts as an approximate value of the demand rate.

The definite method is as follows:
Step 1, select the statistical time interval, denoted as $n$ unit time.
Step 2, determine the number of statistical samples, denoted as \( m \).

Step 3, count the total amount of spare parts \( j \) consumed in the given time interval, denoted as \( X_j \).

Step 4, calculate demand rate \( x_j \).

If \( x_j > 0 \), \( x_j = \frac{X_j}{n \times m} \).

If \( x_j = 0 \), further judgment need to be made. It is not believed that the equipment has no demand for spare parts, which may be caused by inaccuracy of statistical data, or may be the equipment has not failed within the period. According to the statistical theory of fixed time truncated reliability test, when \( x_j = 0 \), the Mean Time Between Failures (MTBF) can be calculated at the given degree of confidence. The demand rate can be calculated according to the MTBF.

The calculation mode of the MTBF is shown in equation (1).

\[
\text{MTBF}_L = \frac{2S(t_0)}{\chi^2_\alpha(2)}
\]  

where \( S(t_0) \) is the total reliability test time, \( S(t_0) = n \times m \) when the unit is year. \( \alpha \) is the given confidence degree and MTBF\(_L\) is MTBF according to the given \( \alpha \). The value of \( \chi^2(2) \) can be obtained by the \( \chi^2 \) distribution table according to \( \alpha \).

The key to solve MTBF is to determine the confidence degree. Since there are errors in the actual consumption statistics process, different confidence degrees should be set for different situations. In general, the lower the failure rate, the higher the probability that there is no failure during the statistical period, so its confidence is also higher. The main factors that affect the failure probability of spare parts are the spare part's quality, failure mechanism, work intensity, etc. The failure probability of spare parts can be divided into five grades: the highest, the higher, the medium, the lower and the lowest. Accordingly, the confidence degree is 0.3, 0.5, 0.7, 0.8 and 0.9 respectively.

(a) When the failure probability is the highest grade, take \( \alpha = 0.3 \), which shows the probability that the total amount of spare parts consumed equals 0 is 30\%. According to the \( \chi^2 \) distribution table, the corresponding \( \chi^2 \) value under the confidence degree is 2.408. Thus, the demand rate of is calculated in equation (2).

\[
x_j = \frac{2.408}{2 \times n \times m}
\]  

(b) When the failure probability is the higher grade, take \( \alpha = 0.5 \), which shows the probability that the total amount of spare parts consumed equals 0 is 50\%. According to the \( \chi^2 \) distribution table, the corresponding \( \chi^2 \) value under the confidence degree is 1.386. Thus, the demand rate of is calculated in equation (3).

\[
x_j = \frac{1.386}{2 \times n \times m}
\]  

(c) When the failure probability is the higher grade, take \( \alpha = 0.7 \), which shows the probability that the total amount of spare parts consumed equals 0 is 70\%. According to the \( \chi^2 \) distribution table, the corresponding \( \chi^2 \) value under the confidence degree is 0.713. Thus, the demand rate of is calculated in equation (4).

\[
x_j = \frac{0.713}{2 \times n \times m}
\]  

(d) When the failure probability is the higher grade, take \( \alpha = 0.8 \), which shows the probability that the total amount of spare parts consumed equals 0 is 80\%. According to the \( \chi^2 \) distribution table, the
corresponding $\chi^2$ value under the confidence degree is 0.446. Thus, the demand rate of is calculated in equation (5).

$$x_j = \frac{0.446}{2 \times n \times m}$$  \hspace{1cm} (5)

(f) When the failure probability is the higher grade, take $\alpha = 0.9$, which shows the probability that the total amount of spare parts consumed equals 0 is 90%. According to the $\chi^2$ distribution table, the corresponding $\chi^2$ value under the confidence degree is 0.211. Thus, the demand rate of is calculated in equation (6).

$$x_j = \frac{0.211}{2 \times n \times m}$$  \hspace{1cm} (6)

3. Classification of Spare Parts Based on Demand Rate

Different spare parts has different consumption characteristics and demand rate. Higher consumption rate means more demand rate and lower consumption rate means less demand rate. It is necessary to classify the spare parts according to its consumption characteristics and demand rate and the spare parts can be according to the classification.

According to the consumption rate and turnover time, the required reserve quantity can be calculated. The general calculation model of the spare parts reserve quantity is shown in equation (7).

$$P_{S \leq S} = \sum_{k=0}^{S} \frac{(\lambda T)^k e^{-\lambda T}}{k!}$$  \hspace{1cm} (7)

where $P$ is the support probability under the given number of spare parts denoted $S$, $T$ is the turnover time of the spare parts, $\lambda$ is the demand rate of spare parts, $S$ is the quantity of spare parts to be reserved, $X$ is random variable, indicating the number of spare parts failures.

According to the support probability requirement of 0.95 for one single equipment, the relationship among demand rate, support time and spare parts reserve quantity is shown in table 1.

| Demand rate (1/year) | Support time | Reserve quantity |
|----------------------|--------------|-----------------|
| 0.65                 | One month    | 1               |
| 0.64                 | One month    | 0               |
| 0.21                 | One quarter  | 1               |
| 0.2                  | One quarter  | 0               |
| 0.11                 | Half a year  | 1               |
| 0.1                  | Half a year  | 0               |
| 0.06                 | One year     | 1               |
| 0.05                 | One year     | 0               |
| 0.026                | Two years    | 1               |
| 0.025                | Two years    | 0               |

The demand rate inflection points under different support times is shown in table 1. Considering the demand rate of spare parts and the operability of classification, spare parts can be divided into four types, that is Frequent, High, and Low consumption type.
(a) Frequent consumption spare parts: the average annual consumption of per equipment is more than 0.64.
(b) High consumption spare parts: the average annual consumption of per equipment ranges from 0.2 to 0.64.
(c) Low consumption spare parts: the average annual consumption per equipment is less than 0.2.

4. Inventory Strategy for Different Types of Spare Parts
In order to reduce the storage cost, different inventory strategies need to be adopted for spare parts with different consumption rates. The inventory strategy needs to consider the consumption and preparation characteristics of spare parts. At present, spare parts preparation time can be divided into four categories: market procurement, short preparatory period, medium preparatory period and long preparatory period. Combining three consumption types of spare parts, that is Frequent consumption, High consumption, and Low consumption, with four types of preparation methods, there are 12 kinds of spare parts inventory strategies, as shown in table 2. For the point of inventory control, inventory strategies can be simplified to 7 kinds inventory strategies, as shown in table 3.

Table 2. Spare parts consumption and preparation characteristics summary and inventory strategy.

| Category (spare parts)                  | Preparation characteristics | Equipment inventory strategy                                                                 |
|----------------------------------------|----------------------------|-----------------------------------------------------------------------------------------------|
| Market procurement and Frequent consumption | Order and arrive anytime | Set up the inventory to support one month supply, order every three months                      |
| Short preparatory period and Frequent consumption | Preparatory period ≤ six months | Set up the inventory to support six months supply, order every six months                       |
| Medium preparatory period and Frequent consumption | Six months < preparatory period ≤ one year | Set up the inventory to support one year supply, order once one year                            |
| Long preparatory period and Frequent consumption | Preparatory period > one year | Set up the inventory to support two years supply, and arrange the annual order according to the actual consumption |
| Market procurement and High consumption | Order anytime and arrive anytime | Set up the inventory to support three month supply, order every three months                    |
| Short preparatory period and High consumption | Preparatory period ≤ six months | Set up the inventory to support six months supply, order every six months                       |
| Medium preparatory period and High consumption | Six months < preparatory period ≤ one year | Set up the inventory to support one year supply, order once one year                            |
| Long preparatory period and High consumption | Preparatory period > one year | Set up the inventory to support two years supply, and arrange the annual order according to the actual consumption |
| Market procurement and Low consumption | Order anytime and arrive anytime | Set up the inventory to support one year supply, and arrange the annual order according to the actual consumption |
| Short preparatory period and Low consumption | Preparatory period ≤ six months | Set up the inventory to support one year supply, and arrange the annual order according to the actual consumption |
Medium preparatory period and Low consumption

Preparation characteristics: Six months prep period ≤ one year

Equipment inventory strategy: Set up the inventory to support one year supply, and arrange the annual order according to the actual consumption.

Long preparatory period and Low consumption

Preparation characteristics: Preparatory period > one year

Equipment inventory strategy: Set up the inventory to support two years supply, and arrange the annual order according to the actual consumption.

Table 3. Simplified inventory strategies of spare parts category.

| Category (spare parts) | Classification principle | Inventory strategy |
|------------------------|---------------------------|--------------------|
| Market procurement and Frequent consumption | Average annual consumption rate of per equipment is more than 0.64 and can be directly purchased from the market | Set up the inventory to support one month supply |
| Market procurement and High consumption | Average annual consumption rate of per equipment is between 0.2 and 0.64 and can be directly purchased from the market | Set up the inventory to support three months supply |
| Short preparatory period and Frequent and High consumption | Average annual consumption rate of per equipment is more than 0.2 and the preparatory period is less than half a year | Set up the inventory to support six months supply |
| Medium preparatory period and Frequent and High consumption | Average annual consumption rate of per equipment is more than 0.2 and the preparatory period is between half a year and one year | Set up the inventory to support one year supply |
| Long preparatory period and Frequent and High consumption | Average annual consumption rate of per equipment is more than 0.2 and the preparatory period is more than a year | Set up the inventory to support two years supply |
| Preparatory period within one year and Low consumption | Average annual consumption rate of per equipment is less than 0.2 and no preparatory period or the preparatory period is less than a year | Set up the inventory to support one year supply |
| Long preparatory period and Low consumption | Average annual consumption rate of per equipment is less than 0.2 and the preparatory period is more than a year | Set up the inventory to support two years supply |

5. Conclusion

According to spare parts demand rate, the spare parts are divided into three categories: Frequent consumption, High consumption and Low consumption. Seven spare parts inventory strategies are synthetically set up according to the consumption type and preparation methods. The inventory strategies are simple and convenient to manage to spare parts, which deserves to be referred to set up scientific spare parts inventory.

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