Abstract. Based on the analysis of actual consumption data of a large number of consumable spare parts and the application effect of the basic random inventory model, the current statistics of equipment spare parts consumption data in China, four forecasting methods are selected to obtain the forecasted demand and the standard deviation of the corresponding forecast error in each cycle and then find the smallest forecast error standard deviation and the corresponding forecast demand quantity. Finally, the forecast demand and the standard error of the forecast error are used to replace the corresponding values in the basic stochastic inventory model to obtain the demand for spare parts in the next cycle, which provides a basis for the preparation of spare parts procurement plans. A large number of application examples show that this method is more simple and practical, and the spare parts inventory level can be reduced by a large proportion.

Introduction

With the continuous development of China's society and economy and the continuous progress of the equipment manufacturing industry, the equipment is becoming more and more sophisticated, and the types of equipment spare parts are also increasing, which has led to the continuous increase in the level of equipment spare parts inventory. Consumable spare parts refer to a type of spare parts that are directly discarded after equipment maintenance is replaced. With the improvement of spare parts production technology and the progress of equipment maintenance processes, the proportion of consumable spare parts has continued to rise, accounting for about 90% of the entire equipment spare parts. Due to the serious disconnect between inventory management theory and inventory management practice, the inventory management of consumable spare parts often adopts empirical management or a simple random inventory model, which makes the inventory of such spare parts extremely high for a long time, while shortages often occur.

The theoretical research on spare parts inventory has always been valued. Rego JR et al. (2014) used negative binomial distribution, normal distribution, and compound Poisson normal distribution to conduct large-scale simulation research on spare parts demand forecasting and inventory control. The results show that the probability-based forecasting method is more accurate than the traditional forecasting method [1]. Liu Xiaochun, Huang Aijun, et al. (2012) established a model for forecasting the demand for equipment spare parts based on the exponential smoothing method. The forecast results show that this method provides a feasible method for scientifically forecasting the demand for equipment spare parts [2]. Ge Yuanlyuan (2015) divided the computer's spare parts demand forecast into four types, using the Croston method to predict block demand and slow demand, continuous demand using simple exponential smoothing (SES), and irregular demand for spare parts using exponentially weighted moving-average (EWMA). In addition, according to the type of demand, this paper pointed out the safety inventory of slow demand and block demand service spare parts, the method of determining the order point and order quantity [3]. Wu Jingyi et al. (2015) used optical fiber communication transmission equipment as the research object, and used an exponential smoothing model to provide a reasonable forecasting method for communication equipment maintenance support [4]. Wang Lu (2015) considered the impact of trend factors and seasonal factors on the spare parts of class A in the demand analysis, and used the Winter
smoothing index method to predict the spare parts number [5]. However, the above research is only for special spare parts or spare parts with severely restricted use conditions, and has no universal guiding significance.

This paper analyzes the actual consumption data of a large number of consumable spare parts and the analysis of the application effect of the basic random inventory model. Based on the current consumption data of equipment spare parts in China, four forecasting methods are selected, namely moving average method, exponential smoothing method, linear regression method the combined forecasting method, the forecast demand of spare parts in each cycle and the standard deviation of the corresponding forecast error are obtained, and then the forecast error standard deviation with the smallest forecast error standard deviation and the corresponding forecast demand are found. Finally, the forecast demand and the standard error of the forecast error are used to replace the corresponding values in the basic random inventory model to obtain the demand for spare parts in the next cycle, which provides a more accurate basis for the development of spare parts procurement plans. A large number of application examples show that the method is simple and practical, and the inventory level will be greatly reduced.

Mathematical Model of Inventory Optimization under Stochastic Demand

The goal of equipment consumable spare parts inventory management is to ensure that the spare parts inventory rate under the normal maintenance conditions of the equipment reaches the required service level, and the overall inventory level of equipment consumable spare parts is the lowest. Therefore, the difficulty of this type of spare parts inventory management is to determine the demand for spare parts in the next procurement cycle, that is, to know the actual consumption of spare parts in the first n cycles and determine the demand for spare parts in the next cycle. Through the analysis of spare parts demand factor analysis and actual consumption data analysis, the demand for spare parts is a random demand, and due to the variety of spare parts and the complex influencing factors, it is difficult to determine the random characteristics of spare parts demand.

Basic Spare Parts Inventory Management Model (BMM)

In order to facilitate calculation and simplify management, the demand for fake equipment parts often conforms to the normal distribution. Therefore, the basic inventory management model is an inventory model based on statistical mathematical theory, see (1) and (2).

\[ y = \bar{x} + z\sigma \]  \hspace{2cm} (1)

\[ \sigma = \frac{1}{n}\sqrt{\sum_{t=1}^{n}(x_t - \bar{x})^2} \]  \hspace{2cm} (2)

\( y \): The inventory demand value for spare part in phase n+1;
\( \sigma \): Standard deviation of spare parts in the first n periods;
\( \bar{x} \): Mean value of actual demand value for spare parts in the first n periods;
\( x_t \): The actual demand value for spare parts in period t(ADV);
\( z \): The safety factor at a certain service level, see Table 1.

| Service Level | 0.9998 | 0.99 | 0.98 | 0.90 | 0.8 | 0.7 |
|--------------|--------|------|------|------|-----|-----|
| Safety factor| 3.5    | 2.33 | 2.05 | 1.29 | 0.84| 0.53|

Forecast Model of Spare Parts Demand (FMD)

By applying formulas (1) and (2) to calculation examples and actual situation analysis, see Table 3, which has a poor application effect. The main reason is that the actual demand for spare parts does not necessarily follow a normal distribution. Therefore, this paper combines the actual investigation
and analysis of equipment consumption spare parts to improve the inventory management model under random demand, that is, the average value of spare parts demand is replaced by forecast demand, and the standard deviation is replaced by the standard deviation of demand error generated by the corresponding forecasting method, to achieve better results than the basic inventory management model.

According to the current statistical methods of equipment average life, spare parts purchase cycle and spare parts consumption data, this paper carried out a comparative analysis of multiple forecasting methods, and finally identified four forecasting methods, namely: moving average method, exponential smoothing method, linear regression method, and combined forecast law.

**Moving Average Method (MAM).** The simple moving average method is relatively simple in calculation. The moving average of historical data is used to obtain the forecast value for the next period. The formula is as follows:

\[
y_{1,t+1} = \frac{1}{t}(x_1 + x_2 + x_3 + \cdots + x_t)
\]  

(3)

\[
\sigma_1 = \frac{1}{n-1} \sqrt{\sum_{t=1}^{n-1}[x_t - y_{1,t+1}]^2}
\]  

(4)

\(y_{1,t+1}: T + 1\) forecast demand value calculated by moving average method;

\(\sigma_1: \) The forecast standard deviation of the first \(n-1\) periods using the moving average method.

**Exponential Smoothing Method (ESM).** The exponential smoothing method retains all historical data impacts, and the proportion of historical data impacts gradually converges to zero, that is, the impacts continue to weaken. The formula is as follows:

\[
y_{2,t+1} = ax_t + (1-a)y_t
\]  

(5)

\[
\sigma_2 = \frac{1}{n-1} \sqrt{\sum_{t=1}^{n-1}[x_t - y_{2,t+1}]^2}
\]  

(6)

\(y_{2,t+1}: \) The value of forecast demand for \(t + 1\) period calculated by exponential smoothing;

\(a: \) Parameters with exponential smoothing;

\(\sigma_2: \) The forecast standard deviation of the first \(n-1\) periods when using the exponential smoothing method to make forecasts.

**Linear Regression Method (LRM).** Linear regression is a very practical statistical analysis method. The formula is as follows:

\[
y_{3,t+1} = a * t + b
\]  

(7)

\[
\sigma_3 = \frac{1}{n-1} \sqrt{\sum_{t=1}^{n-1}[x_t - y_{3,t+1}]^2}
\]  

(8)

Among them, the parameter \(a\) and \(b\) is solved as follows:

\[
b = \frac{\sum x_t}{n} - a * \frac{t}{n}
\]  

(9)
\[ a = \frac{n \sum x_i t - \sum t \sum x_i}{n \sum t^2 - (\sum t)^2} \]  

\( Y_{t+1} \): The forecast demand value of \( t + 1 \) period calculated by the linear regression method;

\( \sigma_i \): The forecast standard deviation of the first \( n-1 \) periods by linear regression.

**Combination Forecasting Method (CFM)**. The combined forecasting method is a forecasting method that combines multiple single-term forecasting methods. The calculation model is shown in formula (11). The calculation of general weights is based on the error results of the individual forecast values. The combination forecasting method in this paper is a combination of simple moving average method, linear regression method and exponential smoothing method. The weight is obtained by calculating the inverse of the standard deviation of the forecast error. The formulas are as follows:

\[ y_{t+1} = k_1 \times y_{1,t+1} + k_2 \times y_{2,t+1} + k_3 \times y_{3,t+1} \]  

\[ k_i = \frac{\sigma_i^{-1}}{\sum_{i=1}^{3} \sigma_i}, i = 1,2,3 \]  

\[ \sigma_4 = \frac{1}{n-1} \sqrt{\frac{\sum_{i=1}^{4} (y_i - \bar{y}_{t+1})^2}{n-1}} \]  

\( Y_{t+1} \): The forecast value of demand in \( t + 1 \) period calculated by the combination forecast method;

\( \sigma_1 \): The forecast standard deviation of the first \( n-1 \) periods by the combination forecast method.

**Inventory Management Model Based on Forecasting Method (IMMM)**. According to the aforementioned forecast model, the standard deviation of the forecast error of the first \( n-1 \) periods of each forecasting method can be obtained, and the forecasting method with the smallest standard error of forecast error and the corresponding forecast value of \( n + 1 \) period can be found out. Demand for spare parts at \( n + 1 \). The formula is as follows:

\[ \sigma = \min(\sigma_1, \sigma_2, \sigma_3, \sigma_4) \]  

\[ y \leftarrow (y_{1,n+1}, y_{2,n+1}, y_{3,n+1}, y_{4,n+1}) \]  

\[ Y = y + z\sigma \]  

\( Y \): The improved inventory demand value at the service level \( z \) in phase \( n+1 \);

\( \sigma \): The least forecast Standard deviation of spare parts demand of the first \( n-1 \).

**Algorithm Design and Example Analysis**

**Algorithm Flow Design.** 1) Read the actual consumption of the first \( n \) periods of spare parts;

2) Calculate \( y_1, y_2, y_3, y_4 \) and \( \sigma_1, \sigma_2, \sigma_3, \sigma_4 \) respectively;

3) Compare \( \sigma_1, \sigma_2, \sigma_3, \sigma_4 \) to find the least \( \sigma \);

4) Find the value of \( y \) corresponding to the minimum value of \( \sigma \);

5) Calculate the demand for spare parts at a given service level \( z \).

**Examples and Analysis.** Table 2 is the actual consumption of 10 types of spare parts in 10 procurement cycles. The foregoing forecasting methods are used to calculate the demand forecast and the standard deviation of the forecast error for the 10 types of spare parts. The optimal demand...
forecasting method and the minimum standard deviation of the demand error and the optimal forecast demand are shown in Table 3 with detailed data. For example: The spare part number "10010010" with the right guard plate, its best forecasting method is the moving average method, the optimal demand forecast amount is 191, and the actual demand is 185. The forecast error in this article is 3.24%; Stochastic inventory model, the forecast demand is 202, and the forecast error is 9.38%. Figure1 is the line chart of the forecasted demand obtained by the four forecasting methods with number 10010010.

According to the Table3 and a large number of calculation examples in this paper, 50% of the results indicate that the combined forecasting method is better, 10% of the results indicate that the moving average method is better, the exponential smoothing method is 10%, and the linear regression method is 30% better. However, the results obtained by the four forecasting methods are better than or equal to the basic inventory model. This paper also studies the neural network forecasting method and probability forecasting method, both of which have poor results, and will not be repeated here.

Table 2. Actual consumption of 10 types of spare parts.

| Spare part number | Spare part name      | P.1 | P.2 | P.3 | P.4 | P.5 | P.6 | P.7 | P.8 | P.9 | P.10 |
|-------------------|----------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|
| 10010010          | Right guard          | 185 | 187 | 195 | 200 | 191 | 187 | 182 | 188 | 193 | 197  |
| 10010020          | Left guard           | 100 | 110 | 150 | 130 | 140 | 150 | 160 | 140 | 180 | 170  |
| 10030430          | Cleaning rod         | 1380| 1236| 1016| 1372| 1486| 1026| 1404| 1106| 1230| 1416 |
| 10010350          | Complete sets of spare parts | 500 | 550 | 530 | 560 | 521 | 555 | 510 | 514 | 525 | 536  |
| 10030010          | Grip member          | 331 | 341 | 330 | 311 | 320 | 335 | 309 | 336 | 328 | 349  |
| 10030020          | Magazine assembly    | 273 | 224 | 271 | 201 | 239 | 297 | 276 | 239 | 235 | 290  |
| 10030030          | barrel               | 57  | 68  | 59  | 69  | 53  | 54  | 58  | 54  | 61  | 59   |
| 10030390          | Support plate        | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 7   | 9    |
| 10030400          | Support spring       | 25  | 27  | 33  | 30  | 35  | 40  | 37  | 45  | 41  | 39   |
| 10030410          | Spring plate         | 110 | 120 | 130 | 140 | 150 | 160 | 170 | 180 | 190 | 200  |

Figure 1. Line chart of demand calculated by four forecast methods for spare parts 10010010.

**Inventory Management System Design**

**System Function Design**

Based on the research results of this paper and the theory of inventory management, a consumables inventory management system based on forecasting method is designed. This system is divided into two main functional modules: demand forecasting and inventory planning optimization. The system functions are shown in Figure 2.
Demand forecasting is an important part of inventory management decision for consumable parts. This module mainly includes data processing, forecast analysis and forecast query. In the early stage of the forecast, it is necessary to enter and count consumption data on the consumption of spare parts.

There is a lot of historical data in the database. However, the accuracy of demand forecasting needs to be seen from the trend of historical demand forecasting. Therefore, the data query function of historical demand forecasting values for different consumable parts and equipment is provided here. Users can enter the number to query the consumption of this spare part within this period of time and forecast accuracy to understand the condition of the consumable.

The demand forecast value can be provided to the inventory maker so that he can understand the demand trend of spare parts and develop a reasonable inventory strategy. As each method has its own advantages, it is difficult to evaluate the pros and cons. Therefore, the system provides four methods to choose from, including simple moving average method, exponential smoothing method, and linear regression method, three single-item forecasts, and a combined forecasting method of squared and reciprocal error.

At the same time, in order to more intuitively reflect the effect of the forecast result on the demand trend of spare parts, the system also provides a line chart to display the result, showing three single-item forecasts of simple moving average method, exponential smoothing method and linear regression method and the combination. The comparison of the four polylines obtained by the forecasting method with the actual consumption value is also more obvious.

The inventory plan optimization is based on the forecast results calculated based on the demand forecast, and calculates the inventory optimization number that meets a certain satisfaction rate. When the satisfaction rate change, the corresponding inventory optimization numbers will change accordingly. Inventory planning is based on the number of inventory optimizations to enter the number of inventory each time. That is, you can make planned purchases of consumable parts in batches.
System Process Design

Referring to Figure 3, the optimized management of consumable parts demand planning is to provide inventory management personnel with a variety of more scientific inventory management methods through the support of a computer management system. After entering the system, the user first processes the consumption data of the consumables, and then performs a predictive analysis of the consumables based on the consumption data. The analyzed results can be used for some basic queries. Subsequently, the user can use the forecast results to enter the required satisfaction rate to obtain the results of inventory optimization, and then make inventory planning based on the inventory optimization number.

![System flowchart](image)

Conclusion

According to the current consumption data of equipment and spare parts in China, four forecasting methods were selected, namely moving average method, exponential smoothing method, linear regression method and combined forecasting method, to obtain the forecasted demand for spare parts in each cycle and the corresponding forecast error standard deviation, and then find the forecast error standard deviation with the smallest forecast error standard deviation and the corresponding forecast demand. Finally, the forecast demand and the standard error of the forecast error are used to replace the corresponding values in the basic stochastic inventory model to obtain the demand for spare parts in the next cycle, which provides a basis for the preparation of spare parts procurement plans. A large number of application examples show that this method is simple and practical, and the spare parts inventory level can be reduced by a large proportion.

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