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# *Research on Initial Aviation Spares Based on Rough Set and GM(1,1) Model*

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***Abstract:*** The supply of initial spares is not practical. As for the actual supply of airlines, its supply reliability is still relatively low, which leads to the contradiction between supply and demand of spares and restricts the capacity formation rate to some extent. The relationship between the variety and quantity of initial spares will directly affect the economic benefits of airlines. Based on the analysis of the characteristics of initial aviation spares, the mathematical method, rough set, is adopted to analyze and determine the types of initial aviation spares, and the $GM(1,1)$ model in grey theory is used to quantitatively predict and analyze the initial aviation spares, which provides a new analysis idea for determining the demand of aviation equipment and a new decision-making method for determining the initial aviation spares, whose prediction accuracy is higher than that of traditional methods.

## 1. Introduction

Initial aviation spares, referred to as initial spares [1], are defined in China's Encyclopedia as: spares needed to ensure the formation of initial capability of new aircraft. The relevant project and quantity are determined jointly by the leading organs and contracting units based on the design and test data of corresponding products and after reliability analysis. Special funds are reserved for ordering the spares which are delivered together with the aircraft. Usually, their supply period is 1 year-2 years. Seen from this definition, initial spares are determined according to the technical data of the initial spares, and the method of combining practical support experience with scientific prediction method to determine the demand for spares is still in the initial research stage.

At the initial stage of equipment, the quantity of initial spares almost determines the capability of the new aircraft. The relationship between the variety and quantity of initial spares will directly affect the economic benefits of airlines [2]. Once the quantity is insufficient, the aircraft can not be repaired in time or the maintenance work of the aircraft can not be completed as planned, which will eventually lead to the grounding of the faulty aircraft. On the contrary, excessive types and quantities of initial spares will causes a serious waste of funds. Moreover, some initial spares may cause outdated technology. Therefore, in the supply guarantee of initial aviation materials, it is one of the research topics worthy of attention to scientifically determine the structural relationship of the initial aviation spares.

In this paper, rough set and GM (1,1) model are used to predict the types and quantities of initial aviation spares, which improves the efficiency and accuracy of scientific decision-making, reduces the support cost, and provides an intentional reference for improving the support efficiency of new aircraft.

## 2. Method of Determination the Nature of Initial Aviation Spares

### 2.1. Main Factors Affecting Aviation Initial Spares

There are various factors that affect the demand for aviation spares, including external factors and internal factors, such as the use environment of aviation materials, maintenance factors, reliability of spares and cost of spares. According to the analysis of the factors that affect the demand for spares, there are mainly the following factors: reliability, criticality, maintainability and cost of spares.

### 2.2. Method for Determining Similarity of Initial Spares [3]

When determining the initial spares, the aircraft that is most similar can be selected as the reference for determining the spares. For different types of aircraft, the specific model of a type of equipment may be different, but the demand for equipment types of the same type of aircraft is similar. Therefore, the selected initial spares of similar equipment can be used as a reference to determine the initial spares of new aircraft. Similarity method can be combined with quantitative research method. The types of initial spares are initially determined in the aircraft development stage.

### 2.3. Rough Set Analysis of Similarity Method

Rough set theory [4] is a new mathematical tool to deal with fuzzy and uncertain knowledge. Its main idea is to derive the decision-making or classification rules of the problem through knowledge reduction under the premise of keeping the classification ability unchanged. In this paper, rough set theory and similarity principle are used to analyze the items and types of initial spares of a certain aircraft.

(1) Determination of spares attributes

When determining the initial spares configuration by similarity method, the criticality, reliability level, maintainability level and economy of spares are mainly considered. Since the severity of the components is determined according to the failure mode, influence and hazard analysis during the reliability design of the aircraft, the criticality can be determined accordingly based on the severity of the components; the reliability level and maintainability level can be measured by Mean Time between Failures (MTBF) and Mean Time to Repair (MTTR) of components respectively. Economic factors are measured by the ordered unit price of components.

(2) Collection of spares data

When the initial spares are determined by similarity method, the aircraft similar to the new aircraft is selected as a reference, and the types of initial spares of similar aircraft are investigated as the basis for configuring initial spares of the new aircraft. Although the specific model of a type of equipment may be different for different types of aircraft, and the requirements of the same type of aircraft for the types of equipment are similar, the properties of spares of the same aircraft are also very different, and some differences will seriously affect the initial spares configuration. For example, with the advancement of technology, the reliability of spares has been greatly improved and the price has risen. Without taking into account of these differences, the allocation of spares will be seriously affected and the best economic benefits will not be achieved.

8 kinds of important similar equipment of similar aircraft are selected. According to the statistics of initial spares determined by similarity method, the statistics of criticality, reliability, maintainability and economy of equipment are summarized in Table 1.

Table 1: Equipment indicators

| | Criticality | MTBF ($10^3$ hours) | MTTR (hour) | Expense (RMB 10,000) | *d* |
|---|---|---|---|---|---|
| 1 | I | 1.30 | 5.23 | 3.52 | 1 |
| 2 | I | 1.12 | 6.75 | 2.50 | 1 |
| 3 | II | 1.35 | 7.42 | 4.89 | 2 |
| 4 | II | 1.08 | 6.90 | 5.41 | 2 |
| 5 | III | 0.98 | 9.25 | 1.26 | 2 |
| 6 | I | 1.47 | 4.32 | 3.78 | 1 |
| 7 | II | 1.15 | 7.12 | 2.85 | 1 |
| 8 | II | 0.88 | 6.65 | 4.56 | 2 |

Among it, the attribute $d = \{1, 2\}$. 1 indicates that the corresponding equipment is finally selected as the initial spare part, and 2 indicates that the corresponding equipment is not finally determined as the initial spare part.

(3) Pretreatment of information table

The reliability, maintainability, economy and cost of different models of similar equipment are different. Because the ability of rough set method to deal with continuous data is not strong, the rough set method is used to set different thresholds for the properties of different equipment. Taking the reliability of equipment as an example, the thresholds are set as 1 and 1.2, with those less than 1 being as short, those greater than 1.2 as long, and those between 1 and 1.2 as medium. In the same way, thresholds 6 and 8 are set for the reliability of equipment and thresholds 3 and 4 are set for the cost, with those less than 3 as low, those greater than 4 as high, and those between 3 and 4 as medium. After processing, Table 2 is obtained.

Table 2: Table of pretreated indicators

| | Criticality | MTBF ($10^3$ hours) | MTTR (hour) | Expense (RMB 10,000) | *d* |
|---|---|---|---|---|---|
| 1 | I | Long | Short | Medium | 1 |
| 2 | I | Medium | Medium | Low | 1 |
| 3 | II | Long | Medium | High | 2 |
| 4 | II | Medium | Medium | High | 2 |
| 5 | III | Short | Long | Low | 2 |
| 6 | I | Long | Short | Medium | 1 |
| 7 | II | Medium | Medium | Low | 1 |
| 8 | II | Short | Medium | High | 2 |

(4) Extraction of certain rules

According to the information in Table 2, the discernibility matrix is constructed by rough set method. a, b, c and d in the table represent the criticality, reliability, maintainability and economy of the conditional attributes respectively, as shown in Table 3.

Table 3: Discrepancy matrix

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | |
| 2 | $b,c,d$ | | | | | | | |
| 3 | $a,c,d$ | $a,b,d$ | | | | | | |
| 4 | $a,b,c,d$ | $a,d$ | $b$ | | | | | |
| 5 | $a,b,c,d$ | $a,b,c$ | $a,b,c,d$ | $a,b,c,d$ | | | | |
| 6 | | $b,c,d$ | $a,c,d$ | $a,b,c,d$ | $a,b,c,d$ | | | |
| 7 | $a,b,c,d$ | $a$ | $b,d$ | $d$ | $a,b,c$ | $a,b,c,d$ | | |
| 8 | $a,b,c,d$ | $a,b,d$ | $b$ | $b$ | $a,c,d$ | $a,b,c,d$ | $b,d$ | |

According to the decision matrix, the difference function of the decision system is obtained as follows:

$$\Delta=(b\vee c\vee d)(a\vee c\vee d)(a\vee b\vee c\vee d)(a\vee b\vee d)(a\vee d)(a\vee b\vee c)(a)(b)(d)(b\vee d)=a\cdot b\cdot d$$

It indicates that the system has reduction (abd)

According to the decision table, $U/C=\{\{1,6\},\{2,3,4,5,7,8\}\}$, $U/d=\{\{1,2,6,7\},\{3,4,5,8\}\}$

Deterministic decision rules are obtained:

When (Criticality, I) (MTBF, long) and (cost, medium) →(d,1)

When (Criticality, II) (MTBF, *) and (cost, high) →(d,2)

When (Criticality, II) (MTBF, medium) and (cost, low) →(d,1)

When (Criticality, III) (MTBF, short) and (cost, low) →(d,2)

When (Criticality, I) (MTBF, medium) and (cost, low) →(d,1)

Where, * represents any attribute value of the attribute.

Thus, if the decision rule obtained from rough set is considered as a decision box, when making a decision on the spares of a new machine, it is only necessary to take the attributes of similar spares as input. The rule box will automatically give an output, so that the rule box has the self-learning function and the initial spares of the new machine can be determined. With the accumulation of data and the increase of alternative equipment, the decision rules obtained by this method will be more abundant, which can provide more accurate reference for the selection of spares.

## 3. Determination of Initial Spares Quantification Based on *GM (1, 1)*

### 3.1. Characteristics of Grey Theory

The grey system theory [5] founded by Professor Deng Julong, a scholar in China, is a new method to study the uncertainty of less data and information. Grey system theory takes the uncertain system with "small sample size" and "poor information" as the research object, and mainly extracts valuable information through the generation and development of "partial information" to realize the correct description and effective monitoring of the system operation behavior and evolution law. "Black" is used to indicate that the information is unknown; "white" is used to indicate that the information is completely clear, and "gray" is used to indicate that some information is clear and some information is not clear. Accordingly, a system with completely clear information is called a white system; a system with unknown information is called a black system, and a system with partly clear information and partly unclear information is called a gray system.

### 3.2. Modeling Process of Grey Prediction Model GM(1,1)

(1) The original data processing of common consumable parts and the modeling process of grey prediction model are essentially the accumulation of irregular original data to generate ($r-AGO$). After obtaining generated sequence with strong regularity, the model is built; the data obtained by generating the model are subject to cumulative reduction to generate ($r-IAGO$), which is reduced to the original series. Grey prediction is based on grey model GM (1,1). GM (1,1) model is the most commonly used gray model, which is a model composed of a first-order differential equation with only one variable. The model is a differential (approximate differential, gray differential), differential (time-varying difference) and exponential compatible model. It has some properties of differential equation, difference equation and exponential equation, and can better predict the demand of consumable parts. The modeling conditions of the consumption grey prediction model of consumable parts are as follows.

1) The original series of common consumable consumption is an equal time series, that is $\Delta t = t_j - t_{j-1}$, which is a constant. Where, $\Delta t$ represents the time interval;

2) There are at least four data $x_j$ in the original series X of common consumable consumption.

(2) Establishment of differential equation. The idea of grey system modeling is to directly transform time series into differential equations. If the given original time data series is:

$$X^{(0)} = (X^{(0)}(1), X^{(0)}(2), \cdots, X^{(0)}(n)) \tag{1}$$

Most of these data are irregular and random, with obvious swing. If the original data column is subject to accumulated generation once.

$$X^{(1)}(j) = \sum_{k=1}^{j} X^{(0)}(k) \quad j = 1,2,\cdots,n; \tag{2}$$

That is, $r-AGO$ gets a new data column:

$$X^{(1)} = (X^{(1)}(1), X^{(1)}(2), \cdots, X^{(1)}(n)) \tag{3}$$

The dynamic model of the development and change of the abstract system is established with the new sequence, that is, the gray dynamic model. $GM(1,1)$ model is:

$$\frac{dX^{(1)}(t)}{dt} + aX^{(1)}(t) = u \tag{4}$$

The value of parameter $a,u$ is estimated by least square method;

Let $B = \begin{bmatrix} -\frac{1}{2}(X^{(1)}(1) + X^{(1)}(2)) & 1 \\ -\frac{1}{2}(X^{(1)}(2) + X^{(1)}(3) & 1 \\ \cdots & \cdots \\ -\frac{1}{2}(X^{(1)}(n-1) + X^{(1)}(n) & 1 \end{bmatrix}$ $X_n = \begin{bmatrix} X^{(0)}(2) \\ X^{(0)}(3) \\ \vdots \\ X^{(0)}(n) \end{bmatrix}$

Then: $\begin{bmatrix} a \\ u \end{bmatrix} = (B^T B)^{-1} B^T X_n$

Based on this:

$$\hat{X}^{(1)}(k+1)=(X^{(1)}(1)-\frac{u}{a})e^{-ak}+\frac{u}{a} \tag{5}$$

## 3.3. Error Detection

The modeling accuracy of grey prediction model is usually tested by residual test.

1) Absolute error of original series and predicted series:

$$\Delta X^{(0)}(i)=|X^{(0)}(i)-\hat{X}^{(0)}(i)| \quad i=1,2,\cdots,n; \tag{6}$$

2) Relative error between original series and predicted series:

$$\Phi(i)=\frac{\Delta X^{(0)}(i)}{X^{(0)}(i)}\times 100\% \quad i=1,2,\cdots n; \tag{7}$$

## 4. Prediction Example of *GM (1,1)* Model of Initial Spares

The number of 660×800-2N tyres consumed by 16 aircraft similar to the new aircraft in an airport every year from 2015 to 2020 (as shown in Table 4).

Table 4: Historical data of tire consumption

| Year | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|
| Consumption | 147 | 143 | 142 | 151 | 152 | 155 |

The $GM(1,1)$ model is established according to instance data:

Then: $\begin{bmatrix} a \\ u \end{bmatrix}=(B^T B)^{-1} B^T X_n$

Based on this: $\hat{X}^{(1)}(k+1)=(X^{(1)}(1)-\frac{u}{a})e^{-ak}+\frac{u}{a}$

Then: $\hat{X}^{(1)}(k)=(147+5984.544)e^{-0.033875}-5984.544;$

Namely: $\hat{X}^{(1)}=\{147,288.87,434.03,582.55,734.50,889.97\};$

Therefore: $\hat{X}^{(0)}=\{147, 141.87,145.16,148.5,151.95,155.47\};$

Test is carried out with residual:

1) It can be obtained from $\Delta X^{(0)}(i)=|X^{(0)}(i)-\hat{X}^{(0)}(i)|$ that

$\Delta X^{(0)}=\{0, 2.13, 3.16, 2.5, 0.05, 0.47\};$

2)It can be obtained from $\Phi(i)=\frac{\Delta X^{(0)}(i)}{X^{(0)}(i)}\times 100\%$ that:

$\Phi=\{0\%, -0.78\%, 2.22\%, -1.65\%, 0.03\%, 0.30\%\};$

Seen from the residual, the precision of fitting the initial spares consumption by the exponential function of grey model $GM(1,1)$ is relatively high, and the relative errors are all less than 2.5%. This model is used for predicting the next 2 years, namely 159 and 163 respectively.

According to the general regulations on the guarantee of initial spares for aviation materials, the general guarantee of initial spares is 2 years. Based on this, it can be determined that the number of initial spares for 16 new aircraft with similar aviation tires for two years is 322. In 2021 and 2022, the actual consumption of aviation tires is 316, indicatingg an accuracy of 98.14%.

## 5. Conclusion

In this paper, the rough set analysis of similarity method is used to determine the types of initial spares that are often consumed, and the model $GM(1,1)$ in grey theory is used to quantitatively predict and analyze the initial aviation spares. The combination of qualitative and quantitative analysis is a new attempt to determine the initial aviation spares, which provides a new decision-making method for determining the initial aviation spares. The advantages of this model are: the model is applicable to all initial spares; this method can be programmed and calculated by computer. It is also easy to popularize and operate.

During the operation of the actual calculation method, attention should be paid to the following: first, its original data must be the same type of aircraft as the new aircraft and similar models; second, the calculation results should be tested by mathematics and manual intervention; third, the changes in demand caused by special factors of consumption should be taken into account properly; fourthly, the rolling correction method should be used to continuously correct the calculation model and improve the prediction accuracy[6].

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