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A double-level combination approach for demand forecasting of repairable airplane spare parts based on turnover data

Feng Guo [a], Jun Diao [a], Qiuhong Zhao [b,*], Dexin Wang [a], Qiang Sun [a]

[a] Naval Aeronautical Engineering Institute Qingdao Branch, Qingdao 266041, China
[b] School of Economics and Management, Beihang University, Beijing 100191, China

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ABSTRACT

To address the problem that the demand forecasting methods for repairable airplane spare parts are not advanced, and that the basic forecasting data are not consistent with actual consumption, this paper proposes a double-level combination forecasting approach for repairable spare parts based on relevant data. First, we conduct an analysis for the factors that influence the demand of repairable spare parts. Second, five types of individual direct forecasting models are combined to establish a double-level combination forecast model, which is superior to both individual combination forecasting models and individual direct forecasting models. Finally, we evaluate the forecasting performance by utilizing consumption data for an aircraft fleet and turnover data for an aircraft. The forecasting results provide strong evidence that that the double-level combination forecast model is more accurate and consistent with actual demand.

1. Introduction

Quantifying the consumption of airplane spare parts is highly complicated, especially due to the nonlinear, grey and trending characteristics of demand. Spare parts suppliers commonly determine the demand for spare parts by experience; however, this is a random, blind procedure that could result in a large backlog of spare parts because of less consumption than anticipated and a shortage of critical spare parts. The key to solving this problem is to forecast the demand for spare parts accurately.

Assessing future demand plays an important role in order management for spare parts, which requires accurate forecasting. Demand forecasting is the foundation of ordering decisions for spare parts. Demand forecasting is conducive to accurately determining the consumption of various spare parts and further enhancing ordering accuracy and supply effectiveness for spare parts (Bacchetti & Saccani, 2012; Basten, Van der Heijden, & Schutten, 2012).

Consequently, suppliers should gauge the consumption of spare parts and use scientific methods to forecast demand. Although many factors that influence the consumption of repairable spare parts are considered, a commonly neglected one is that the actual consumption of repairable spare parts is constantly affected by aircraft number and repair cycle. Furthermore, the accuracy of different forecasting theories and methods is often directly affected by the manner in which they are applied. Therefore, current studies and applications on demand prediction often encounter two major challenges: inconsistent data with actual demand and less accurate forecasting approaches.

In recent decades, annual consumption data for an aircraft fleet are commonly adopted to forecast demand for aircraft spare parts, often causing the purchase quantities for reparable parts to far exceed the actual required turnover number. The authors have been analyzing the overstocked and scrapped reparable spare parts for nearly 10 years and have found that the annual average cost of the overstocked and scrapped reparable spare parts accounts for about 11% of annual procurement funds for Chinese naval aviation. Obviously, the waste of funds is serious; meanwhile, the inventory of critical spare parts is often insufficient. The aircraft readiness rates of various aircraft rarely reach more than 90% each year, some even just 70%. In order to overcome the problem of inconsistent data with actual demand, in this paper, annual turnover data for an aircraft, rather than annual consumption data for an aircraft fleet, are used to forecast the demand for repairable spare parts.

To address the second problem of inaccurate methods, there are currently two forecasting strategies for spare parts. One is to forecast directly by individual forecasting methods, which is known as an item-level forecast or direct forecast (DF). The other is to forecast indirectly by combining individual forecasting methods, which

* Corresponding author.
E-mail address: qhzhao@buaa.edu.cn (Q. Zhao).

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is known as a group-level forecast or combination forecast (CF), in which individual forecasting methods are members (Hyndman, Ahmed, & Athanasopoulos, 2007; Miller, Berry, & Lai, 2007; Zotteri, Kalchschmidt, & Caniato, 2005). But the prediction accuracy of these methods cannot meet the actual demand. In this paper, we propose a double-level combination forecast (DCF) method to forecast the demand for repairable spare parts. A double-level combination forecast model is composed of two combination forecast models, including a low-level combination forecast (LCF) model and a top-level combination forecast (TCF) model. A low-level combination forecast model consists of several direct forecast models, and a top-level combination forecast model is used to optimize the demand forecasts further based on the results of a low-level combination forecast model. A double-level combination forecast model can obtain a superior final result by automatic optimization combination of multiple models, which does not require decision makers to make subjective judgements. It is very important for demand forecasting models to forecast a large number of spare parts precisely, and it is not possible for each spare part to make subjective judgements again to find a superior result after forecasted by different methods. Because aviation corps in many countries often have more than tens of kinds of aircrafts, and have about tens of thousands of fault reparable spare parts, it is necessary for us to adopt a double-level combination forecast method capable of automatic optimization to forecast.

In summary, this paper adopts relevant data pre-processed in accordance with actual demand. In addition, a double-level combination forecast model is established using advanced and reliable methods to forecast the demand for repairable spare parts. This methodology is unique and innovative in the field of demand forecasting.

The remainder of this paper is organized as follows. In Section 2, we provide a review of relevant literature. We conduct an analysis on the demand forecasting methods for repairable spare parts from the rationality of basic data and the accuracy of forecasting methods. Section 3 analyzes and determines the factors influencing the consumption of repairable spare parts, which provides a suitable foundation for modeling. In Section 4, we found five direct forecast models and a double-level combination forecast model. In Section 5, we conduct a comparative analysis for the forecasting effectiveness of the proposed models and data. The theoretical and computational analyzes suggest that the models and approaches provided in this paper have higher accuracy and applicability for repairable spare parts; the forecasting results are consistent with the actual demand for repairable spare parts. Finally, we put forward some conclusions for the study in Section 6.

2. Related research

A forecasting method based on a Poisson distribution has been studied in the field of demand forecasting of repairable spare parts. This method commonly assumes that the random demand mean is constant, and the time between failures follows an exponential distribution, such that the demand for spare parts follows a Poisson distribution during a specified time period (Branch, 2014; Lau & Song, 2008). In practice, with the growth of the observation cycle, the variance-to-mean ratio of certain spare parts gradually increases, and the demand for spare parts will follow a non-steady incremental Poisson process that will change over time (Tiemessen & Van Houtum, 2013). In addition, for spare parts with wear and tear faults, such as tires and batteries, their variances are less than their means. Therefore, it is notably complex to determine a suitable demand distribution for different spare parts, which means that it is difficult to accurately forecast their demand using traditional analytical methods (Cattani, Jacobs, & Schoenfelder, 2011).

For some spare parts, annual actual consumption is characterized by trends, and some time-series methods are used to forecast the demand for these parts over a long time. Classical methods include the exponential smoothing method and grey theory. Exponential smoothing is a trend-analysis forecasting method developed from the moving average method (Li & Kuoa, 2008). The exponential smoothing method mainly includes three kinds: linear exponential smoothing (LES), secondary exponential smoothing (SES) and cubic exponential smoothing (CES), which have different prediction accuracies for different regular time series. Researchers have suggested that the linear exponential smoothing method is suitable for time series with great fluctuation, and the secondary exponential smoothing method is suitable for time series with upward trend, whereas the cubic exponential smoothing method is suitable for time series with downward trend (Guo, Liu, & Li, 2012).

These three types of exponential smoothing methods are suitable for forecasting the demand for spare parts with different consumption trends. Grey theory performs well in the demand forecasting for spare parts with a small sample size (Ghobbar & Friend, 2002). In this theory, the service period for a new type of aircraft is often only a few years, and the sample size of consumption data is small. The simplest grey model is the GM(1,1) model Chen & Huang, 2013, which can weaken the randomness and volatility of an original sequence and provide more useful information. This is very effective for the demand forecasting for spare parts of military aircraft.

Generally, the consumption of spare parts is caused by multiple factors, whose demand can be forecasted by regression analysis methods such as linear regression, non-linear regression and neural network. Of these methods, neural network has a suitable adaptive and self-learning ability and strong anti-interference properties, which is suitable to solve linear and non-linear problems (Kayacan, Ulutas, & Kaynak, 2010; Kourentzes, 2013; Tuğba & Önüt, 2012). Among neural network, back-propagation neural network is often used in many fields. For example, a moving back-propagation neural network and a moving fuzzy neuron network have been applied to forecast the demand for critical spare parts (Chen, 2013), and a back-propagation neural network has been used to forecast stock indices (Chen, Chen, & Kuo, 2010). However, a general neural network has faults such as a slow convergence rate and a high tendency to fall into local minima (Wang, Wang, Zhang, & Guo, 2011). To overcome these faults, a genetic algorithm is often used to optimize neural network (González-Romera, Jaramillo-Morán, & Carmona-Fernández, 2007). This method is called genetic neural network (GNN). A genetic algorithm has characteristics of global search and population optimization, which are used not only to optimize a neural network but also to solve an optimization model. A novel approach based on a genetic algorithm has been proposed in which the most probable excess stock and shortage levels required for inventory optimization in a supply chain are distinctively determined to achieve the minimum total supply chain cost (Hajiaghaei-Keshteli, Molla-Alizadeh-Zavardehi, & Tavakkoli-Moghaddam, 2010).

In the above mentioned studies, the adopted forecasting approaches are all direct forecast methods that directly forecast demand alone; however, they do not fully analyze or determine the factors that affect the consumption of repairable spare parts. Thus, the accuracy and scope of these approaches are limited. To solve this problem, different direct forecast methods are often combined to perform forecasts, which can provide distinct useful information (Radhakrishnan, 2014). The combination forecast approach can provide a comprehensive utilization of the useful information provided by the direct forecast methods, which can greatly improve forecasting accuracy. It has been demonstrated