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Cost adjustment for single item pooling models using a dynamic failure rate: A calculation for the aircraft industry

R. Fritzsche *

Department of Business Management and Economics, Technical University of Dresden, Dresden, Germany

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ABSTRACT

This paper presents an analytical model for cost estimation in a single-item, multi-hub (S-1,S) inventory policy-pooling model for high-value spare parts in the aviation industry. The model extends existing, static pooling models by implementing a dynamic failure rate, using a maintenance free operating period (MFOP) as a measurement technique to increase availability of aircraft components. The gained results through a dynamic failure rate show significant effects for a reduction of total costs of ownership and achieving a better operational stock planning, which is demonstrated in a numerical application.

1. Introduction

Over the past years, many flights of various airlines were canceled because of different defects in aircraft components. These aircraft-on-ground (AOG) situations produce enormous costs and damage the affected airlines' images. This and the airline company's repairable spare parts inventory problem is the motivation for this research. The expected range of the global airline industry spare-parts inventory is estimated at several billion US-dollars (Ilgin and Gupta, 2009), and pooling is a possibility for a high potential in rationalization by inventory management (Kennedy et al., 2002). Investigations in existing pooling models showed that the failure performance of installed components is considered to be static. In the case of a constant failure rate, the used components are thus always replaced preventively at equal intervals. Consequently, component life time is lost by exchanging them too early. However, the aircraft industry aspires to utilize the service life of components in the aircraft as long as possible.

The airline companies are confronted with two problems. At first, guaranteeing a high availability of spare parts through optimal logistical designing and, secondly, simultaneously reducing the related costs. This is with the understanding that life-cycle and complexity increases with technological advances. In combination with rising customer requirements and expanded variant diversity, there are increasing demands on the productive efficiency of the spare-parts supply. It turns out that a cumulative spare-parts supply develops into an advantage in competition to reduce the average number of backorders and the total annual costs (Tiemessen and van Houtum, 2010) and is named as a factor of success for companies in industry. However, not only does the structure of the products become more complex but an increasing complexity in business processes is observable in a growing interconnectivity of global concerns. Often, this yields a higher error rate regarding information about these products (Lee et al., 2005). A major difference in the planning of spare-parts pooling in the aircraft industry and other areas is the variability of the machine's position. While most of the pooling models deal with fixed

* Tel.: +49 351 463 37414; fax: +49 351 463 37779.
E-mail address: roy.fritzsche@tu-dresden.de

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locations, an aircraft will move from one station (hub) to the next. The high value of the aircrafts and their components causes an additional challenge to the spare-parts supply. The logistical administration of repairable spare parts is more complicated than the logistics of conventional replacement parts, because the repairable spare parts are designed to be quickly repairable, and this set of components can easily and swiftly be replaced (Kilpi et al., 2009). However, the expensive aircraft components are not fully responsible for the high value of the airline industry's spare-parts supply. This also results from the large amount of spare parts that has to be available to satisfy the rising customer demands. In the airline industry, most of the installed spare parts are very expensive but critical to avoid AOG situations.

This paper focuses on the aircraft industry and primarily discusses the disadvantages in the main pooling models for high-value spare parts. Furthermore, established assumptions of existing pooling models are considered more in detail, and it is demonstrated that two of them hardly find practical applications in the airline industry. These two critical assumptions are as follows: (i) *a network has infinite repair capacity,* and (ii) *there is a failure rate, which occurs with constant rates, according to an independent Poisson process*. The absence of a dynamic failure rate was already criticized by Rustenburg et al. (2001), Diaz and Fu (1997), Albright (1989) and Gross et al. (1977). An important research to limit the repair capacities and thus refute assumption (i) was performed in the models of Albright (1989) and Diaz and Fu (1997) in detail and therefore can be assumed uncritical. This leads to the conclusion that only assumption (ii), the constant failure rate, must be regarded as critical.

The pooling models presented in current literature deal exclusively with a static view of the spare-parts problem. For each spare part, a predefined failure rate of their failure performance is assumed, which is not modified over the entire observation period, and thus no improvement in the operational planning can be achieved. Here, this will be improved by integrating the learning concept of Duffey and Saull (2003) and hence the dynamic approach of the failure rate into the spare-parts problem. As demonstrated in Duffey and Ha (2009), the human error probability and thus the learning effect for the failure rates is dynamic and can be used as an objective measure for risk in any technology. Duffey (2005) supposes that humans learn from their mistakes as experience is gained. In relation to the spare-parts inventory problem, that means that information about components is observed, and events are recorded in the frame of calendar time. They translate the observation frame from "time passing" to "experience space" so that a learning environment can be utilized. The dynamic character of the system occurs due to the used learning techniques for the data acquisition needed for the MFOP methodology. van Jaarsveld and Dekker (2011) claim that the most effective learning methods for collecting the best spare-parts failure data are redundant systems. In this case, installed components can fail at their real breakdown because of a second (or third) parallel, identical installed component, and this real time of failure is recorded and used for the lifetime adjustment of the component for following periods. Engineers, regulators, and designers use quality systems to track and improve components, provide procedures, and adopt design and safety standards. Suggestions for enhancement and their implementation are stored in impressive lists by the airline. All these collected data are useful, but they are reactive. In this paper, the term *predictive* is used, which utilizes acquired experience and learning deployments. Kaiser and Gebraeel (2009) established the linkage between maintenance scheduling and the degradation states of components by a sensor-updating procedure. By means of their model description and a well-placed flow chart for observed and updated degradation, the possibility for periodical adjustment of the failure rate is observable. With the help of these learning methods, it is possible to adjust the failure rate over a time period downwards in order to achieve the desired service life extension. Additionally, the scheduling operator improves his planning ability of the replacement time by increasing his experience in the failure behavior of components. The resulting benefits for the aircraft industry are fewer lateral transshipments, as spare parts and manpower can be transported with their own aircrafts to the estimated replacement location. This leads to shorter service and repair time on the ground and fewer flight cancelations, resulting in an improved image of the airline company (Wong et al., 2005). Due to the extension of a component's lifetime, the airline provides fewer spare parts in their own hubs, so there are significantly fewer spare parts in the circuit, whereby the inventory can be reduced, leading to reduced capital commitment costs (Samaranayake et al., 2002). Decisions are easier to make about based-stock and reserved-stock levels concerning the cost allocation problem, according to Wong et al. (2007).

Increasing the operational reliability of the system and decreasing downtime and maintenance costs is a target for every airline in the world. Traditional reliability models are based on the concepts of mean time between failure (MTBF), mean time to failure (MTTF), mean time to repair, (MTTR) or mean time between unscheduled removals (MBTUR) (Kumar, 1999). Kumar et al. (1999) agree that failures cannot be precisely forecasted or prevented, resulting in unscheduled maintenance. The MFOP concept combined with a well-planned preventive maintenance system, well established in the aircraft industry (Crocker and Kumar, 2000; Kumar, 1999), leads to a downward adjustment of the failure rate. This paper extends existing pooling models by implementing a dynamic failure rate using the operational learning effect of Duffey and Saull (2003) integrated in the MFOP concept of Kumar (1999) with the objective to enhance availability of aircrafts, to gain a better operational planning potential, and to reduce costs and situations like aircraft on ground (Chew et al., 2008). Recapitulating, the ambition of this paper is to establish the spare-parts stocking levels at all hubs to minimize the total inventory holding costs and altogether the total system costs. The main objective of the MFOP concept is to reduce maintenance costs by replacing unscheduled corrective maintenance with more scheduled activities. The focus is on relatively expensive and critical components to reduce costs (inventory costs, warehouse costs, and transportation costs) and to get an optimal inventory stock by integrating a dynamic failure rate in well-known pooling models.

The paper is organized as follows. In the next section, a literature review of existing pooling models and well-established assumptions is presented and the critical ones are discussed. In Section 3, a model formulation based on these assumptions is