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An innovative method to optimize the maintenance policies in an aircraft: General framework and case study

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A B S T R A C T

Maintenance policies applied to aircrafts are governed by a mix of airworthiness authorities' regulations and choices of suppliers and users. This allows airlines to use different strategies to minimize the total costs of maintenance. In this paper, a new approach that integrates the failure and reparation processes, such as modelling, optimization algorithms, and simulation methods, is proposed to define the best maintenance strategies for complex systems.

A case study of an airline carrier is presented. In particular, several critical components for the A320 aircraft family are considered. The impact of the spare parts inventory management is discussed. Different preventive maintenance policies are tested and simulated. With the new policies, the average availability of the aircraft is satisfactory and the total annual cost is reduced to a value of approximately 20% in comparison with the previous policies adopted by the company.

1. Introduction

Maintenance costs represent on average of 14% of the variable costs incurred by airlines (Sriram and Haghani, 2003; Ferrari et al., 2002). Global competition forces airlines to improve flying hours as well as the availability of their aircrafts with adequate maintenance costs.

An aircraft maintenance program must ensure the realization of the inherent safety and reliability levels of the equipment at a minimum total cost, including maintenance costs and the costs of resulting failures.

The target must be the optimization of the technical total cost of service of an aircraft due to two elements: the maintenance costs (e.g., in terms of labour, spare parts purchase, logistics, etc.) and aircraft downtimes (e.g., in terms of repair and inspection time, waiting time for missing spare parts, etc.). For an aircraft's components, the two cited costs usually have a countertrend, and the goal must be to find the best mix of maintenance policies in agreement with the minimization of the total cost of service. The three-step method proposed pursues this optimization.

Aircraft maintenance is highly regulated. There are various airworthiness authorities around the world (i.e., the European Aviation Safety Agency (EASA), Europe; the Federal Aviation Administration (FAA), the United States; and others). Manufacturers and users (e.g., airlines) of aircrafts are important actors in defining effective maintenance policies after licensing by authorities.

The initial maintenance policies schedule follows the well-known Maintenance Steering Group-3 (MSG-3) process. The MSG-3 process was defined by the participation and combined efforts of the Federal Aviation Administration (FAA), Civil Aviation Authority (CAA/UK), Aircraft Electronics Association (AEA), U.S. and European aircraft and engine manufacturers, U.S. and foreign airlines, and the U.S. Navy.

This process outlines the general organization and decision processes for determining scheduled maintenance requirements initially projected for the life of the aircraft (Life Data Analysis Reference Book, 1993). The initial scheduled maintenance program has been specified in Maintenance Review Board (MRB) Reports. The MRB development process is also discussed in different Advisory Circulars of the FAA (i.e., AC No: 121-22A (1997), 121-22B (2010), 121-22C (2012)).

All of these documents become the basis for the first issue of each airline's maintenance requirements to govern its initial maintenance policy. Adjustments may be necessary to address

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Nomenclature

C_{tot} Total cost of maintenance policies (for each analysed component)
C_{CM} Cost of Corrective Maintenance (CM) policy
C_{PM} Cost of Preventive Maintenance (PM) policy
C_{IM} Cost of Inspection (IM) policy
C_{STOCK} Cost of spare parts stock management
$C_{CREW_{CM}}$ Cost of crew (CM)
$C_{PARTS_{CM}}$ Cost of spare parts (CM) due to part acquisition from the company warehouse or from the supplier (cost of item plus cost of logistics in normal/emergency provisions)
$C_{LOSS_{CM}}$ Cost of loss of service (CM)
$C_{I_{CM}}$ Cost of CM interventions (linked to maintainability function in RPM analysis)
$C_{TE_{CM}}$ Cost of travel expenses of maintenance crew for CM interventions. The airplane can be stopped in a random airport of the network, considering the regional focus of the network. In the proposed case study, the analysed fleet of A-320 works only in southern Europe, and then $C_{TE_{CM}}$ is assumed as the average value coming from the study of 2009–2012 CM past interventions.
$C_{FH_{CM}}$ Cost due to the loss of flight hours. This term considers the mean time to failure (MTTF) originating from the FPM analysis and the average values of flight delays and cancelled flights. In the case study, data comes from the study of 2009–2012 CM past interventions.
$C_{RP_{CM}}$ Cost of passengers rerouting. In the case study, the average value coming from the study of 2009–2012 CM past interventions is considered.
$C_{CREW_{PM}}$ Cost of crew (PM)
$C_{PARTS_{PM}}$ Cost of spare parts (PM) due to part acquisition from the Company warehouse or from the supplier (cost of item plus cost of logistics in normal provisions)
$C_{LOSS_{PM}}$ Cost of loss of service (PM)
$C_{I_{PM}}$ Cost of PM interventions
$C_{TE_{PM}}$ Cost of travel expenses of maintenance crew for PM interventions. In general, the PM interventions can be realized in different airports of the network. In the case study, considering the regional focus of the network (the analysed fleet of A-320 works only in southern Europe), the $C_{TE_{PM}}$ is assumed as the average value coming from the study of 2009–2012 PM past interventions. A significant fraction of PM actions are realized in the repair station without travel expenses.
$C_{FH_{PM}}$ Cost due to the loss of flight hours. PM interventions are realized over-night or during weekend stops (i.e., no flight hours losses), but a delay in the interventions can cause a loss of service. In the case study, the data originated from the study of 2009–2012 PM past interventions.
$C_{CREW_{IM}}$ Cost of crew (IM)
$C_{LOSS_{IM}}$ Cost of loss of service (IM)
$C_{I_{IM}}$ Cost of IM interventions
$C_{TE_{IM}}$ Cost of travel expenses of maintenance crew for IM interventions. In general, the IM interventions can be realized in different airports of the network. In the case study, considering the regional focus of the network (the analysed fleet of A-320 works only in southern Europe), the $C_{TE_{IM}}$ is assumed as the average value coming from the study of 2009–2012 IM past interventions. A significant fraction of IM actions are realized in the repair station without travel expenses.
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C_{STOCK} Cost of the stock and the management of spare parts in the warehousing centre

operational and/or environmental conditions unique to the operator. As operating experience is accumulated, additional adjustments may be made by the operator to maintain an efficient maintenance program. For example, AC 121-22C provides the Statistical Analysis Tasking Optimization (SATO) procedure that describes an original equipment-customized program for the optimization of scheduled maintenance.

The MSG-3 logic was task-oriented, and generally, there are two groups of tasks: scheduled tasks to be accomplished at specified intervals (i.e., Lubrication/Servicing (LU/SV), Operational/Visual Check (OP/VC), Inspection/Functional Check (IN/FC), Restoration (RS), Discard (DS)), and non-scheduled tasks (i.e., corrective measures deriving from malfunctions, usually generated by the operating crew reports).

For an aircraft, the inspection/replacement interventions are the most relevant in terms of effort and costs. For this reason, this paper is focused on the optimization of the preventive maintenance policy, in particular considering the on-aircraft repair operations, which are usually out of A/C planned checks.

This study discusses the optimization of maintenance policies. Often, policies are based on a manufacturer's or maintainer's experience. The initial MRB for any new aircraft is developed in the absence of actual in-service experience. As a result, the tendency is to be conservative in the decision-making process. However, as service experience is accumulated, task intervals should be adjusted to reflect the results of a professional analysis of actual in-service data. However, intervals of intervention/replacement are often not seriously based on the actual system reliability. This causes maintenance costs to be higher than the optimum. The authors show how it is possible to achieve significant improvements in terms of availability and reduction of maintenance costs using a systematic procedure of data analysis based on RAM (Reliability, Availability, Maintainability) principles. The proposed method is applied in a real case involving an important airline carrier. Different maintenance strategies, including corrective (CM) and preventive (PM) maintenance policies, are compared. The choice of the best maintenance policy has also been linked to a study of inventory management strategies to identify the most effective one from an operational point of view. Both studies are related to the economic impact assessment.

This paper is organized as follows. The next section presents the literature review with regard to the problem. Section 3 explains the new proposed method. An exhaustive case study of an airline carrier is discussed in Section 4. Finally, conclusions are given in Section 5.

2. Literature review

The growing importance of maintenance has generated increasing interest in the development and implementation of