Maintenance Scheduling of a Fighter Aircraft Fleet with Multi-Objective Simulation-Optimization

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Abstract

We consider the multi-objective scheduling problem for the periodic maintenance of a fleet of fighter aircraft. We describe a simulation-optimization approach based on discrete-event simulation [2] and simulated annealing [1] for the generation of the non-dominated solutions of the problem. In addition, we suggest the use of a multi-attribute decision analysis model [9] to support the maintenance decision maker in selecting the preferred non-dominated solution. Uncertainty about the values of the objective functions and incomplete preference statements are incorporated into the selection by using intervals and preference programming [6,7].

The fighter aircraft in the fleet periodically undergo extensive maintenance in order to guarantee their flight safety and performance. The maintenance is time-consuming and therefore needs to be scheduled adequately. The objective of scheduling is to maximize the availability of the aircraft which ensures the operational capability of the fleet. In practice, the timing of the maintenance is affected by uncertainties such as unplanned failure repairs and thus the planned and actual starting dates of the maintenance may be different. This presents an additional objective, since workforce, equipment, and spare parts are supplied for the activities according to the planned starting dates. The deviations between the planned and the actual starting dates should be minimized.

We present a multi-objective simulation-optimization approach for solving the scheduling problem. The performance of maintenance schedules cannot be described analytically due to the complexities and uncertainties of aircraft maintenance and usage. Therefore, the values of the objective functions that measure the performance are evaluated through discrete-event simulation [2] based on the validated model of an actual fighter aircraft fleet [5].

In the simulation-optimization approach, a simulated annealing [1] (SA) algorithm is used to generate non-dominated solutions. Methods for finding the non-dominated solutions in the context of multi-objective simulation-optimization are rather sparse as of yet [3]. We chose SAs after conducting numerical experiments with single-objective versions of the scheduling problem in which they outperformed genetic algorithms (GA) [4]. Our implementation of the SA is largely based on the one presented by Smith et al. [8] who found their version to perform well in a number of multi-objective test problems compared to other SAs and GAs. The main idea is to determine the fitness of a candidate solution based on the number of currently found non-dominated solutions that dominate it. The SA in [8] is intended for

deterministic problems. In our implementation, the uncertain values of the objective functions are estimated through multiple replications of the simulation of the maintenance of the aircraft fleet.

A maintenance decision-maker (DM) must ultimately select one of the non-dominated solutions for implementation. We describe a multi-attribute decision analysis model for the selection. In particular, we utilize interval techniques [6,7] to consider the uncertainty about the values of the objective functions as well as the possible imprecision in the DM's preference statements. Single-attribute value functions map the estimated ranges of the values of the objective functions to interval scores. Moreover, the DM is not required to state exact weights for the single attribute value functions. Instead, the DM may define incomplete statements which only give the lower and upper bounds for the weights. The interval scores and the weights are combined into overall value intervals of the non-dominated solutions. The final decision about the preferred solution is made according to dominance relations [7] under the decision analysis model. If a dominating solution is not found, a number of different decision rules [7] can be applied.

The presented approach provides an effective way to construct and update maintenance schedules. It offers maintenance DMs considerable savings in time as well as improved schedules. We illustrate the approach by analyzing a real life scheduling case.

Keywords: Maintenance scheduling; Multi-objective simulation-optimization; Multi-criteria decision analysis; Preference programming

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