Decomposition Techniques for the Aircraft Maintenance Routing Problem

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The aircraft maintenance routing problem (AMRP) is one of the main optimization problems emerging in the airline industry. The AMRP deals with a set of flight legs and a set of aircraft available to operate these flights. In this case, the start and the end times of the flight legs are already known. The aircraft are required to carry out these flight legs together with certain maintenance tasks. The scheduling of the maintenance tasks has to be done in accordance with regulations imposed on the aircraft. A comprehensive overview of work in this area can be found in [3], [8], and [9].

A new version of this problem, AMRP-D (AMRP with a maintenance distribution objective), was introduced by Kletzander et al. [6]. The AMRP-D stems from a real-world application, and it focuses on the even distribution of the maintenance tasks. This objective enables the possibility of aircraft schedules with better utilization of maintenance resources, avoiding both over- and underutilization, which in the traditional AMRP are disregarded.

Problem Definition The AMRP-D is specified by a set of flight legs, regulations for maintenance, and a set of aircraft including their history assignments. All times are given as integers.

Flight Legs A set of n flight legs $T = \{t_1, \ldots, t_n\}$ is given, each leg t_i is associated with a start time s_i, an end time e_i, and a flight time f_i. Flight legs are not allowed to overlap for the same aircraft.

Maintenance A maintenance on an aircraft cannot overlap with its other maintenance or flight legs, the following types are required:

– Regular and weekly: An aircraft can fly for at most 47 (156) hours after the end of the previous regular (weekly) maintenance, then it needs regular (weekly) maintenance taking 2.5 (7) hours before taking off again. Weekly maintenance includes regular maintenance.

- Major (4 types): After at most 950 hours of cumulative flight time since the last maintenance of the same type, the aircraft needs major maintenance taking 14 hours before taking off again. Some types require a single hangar.

Aircraft A set of m aircraft $A = \{a_1, \ldots, a_m\}$ is given including history of maintenance.

Objective The objective of the AMRP-D is to minimize $\sum_s m_s^2$, where m_s shows the total number of aircraft in any type of maintenance for each minute s in the planning period. A second requirement is to schedule the major maintenance tasks as late as possible, without violating feasibility.

Solution Methods The first solution methods for the AMRP-D included a Constraint Programming (CP) model and a decomposition approach [4]. The decomposition approach considers slices of the scheduling period by allocating each flight leg based on its time of occurrence to a single slice. Then the CP model is used in every slice for the assignment of the flight legs to the aircraft. We also presented a Simulated Annealing (SA) approach and a Large Neighborhood Search (LNS) to optimize the objective function of the AMRP-D [4].

Since obtaining a feasible solution is hard for this problem, we previously proposed an alternative CP model targeting the provision of feasible solutions [5]. In [4], the assignment of flight legs to aircraft and the start of maintenance tasks for all aircraft were covered with optional variables. In [5], we investigated if the performance of the model can be enhanced when consecutive flight legs are explicitly modeled, expressing the decision variables for the assignment of flight legs to the aircraft with the regular variables *tail*, which represent the aircraft operating the flight legs. For the start of maintenance tasks that are not necessary in the scheduling period we use dummy tasks. In this work, we present a new integration of this model in the decomposition approach [4].

Additionally, we investigate the decomposition of the AMRP-D in the context of a new column generation (CG) approach [1], [2]. In this decomposition, a potential flight schedule for a single aircraft constitutes a column, while the master problem aims to select a subset of columns that cover each flight leg exactly once. This is known as the set partitioning problem, and can be solved fairly efficiently with modern MIP solvers like Gurobi. On the other hand, composing flight schedules for individual aircraft is much easier than finding a feasible schedule for all aircraft at once. Therefore, this approach has large potential to both find feasible solutions to hard instances, and to optimize the distribution objective in future work.

However, there are also several challenges in the application of column generation to the AMRP-D. First, the hangar non-overlap constraint needs to be modeled in the master problem. This is currently done by counting and restricting the hangar use for each time step, which, depending on time granularity, can significantly increase the complexity of the master problem. A similar approach is required to model the optimization of the maintenance distribution. A further challenge comes from the fact that typically column generation is started from a feasible solution, but in the case of the AMRP-D, many instances can not be solved to feasibility with simple heuristics. Instead, an infeasible dummy solution with high cost can be utilized, or the coverage of all legs can be seen as an objective rather than a hard constraint.

Preliminary results show that despite the added constraints for hangar coverage, the master problem can be solved efficiently. New columns are currently obtained by a modified version of our CP models, nevertheless, this approach constitutes the current bottleneck and needs to be replaced by a faster method. A custom label setting approach like in related work on bus driver scheduling [7] shows potential to replace the constraint model. Finally, starting from the dummy solution currently shows to be an issue if dummy columns are selected in the integer version of the master problem, which might require branching in a Branch-and-Price approach, or other mitigation strategies.

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