Combining Aircraft Maintenance Routing with a Distribution Objective

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Scheduling airline operations is a very challenging and demanding task situated in a competitive market with high operational cost and strong regulations [3]. The scheduling process is typically divided into multiple steps due to the overall complexity, which are the flight scheduling problem (FSP), the fleet assignment problem (FAP), the aircraft maintenance routing problem (AMRP), and finally the crew scheduling problem (CSP).

This line of work deals with the AMRP, where the flight legs and the type of aircraft to fly these legs are already fixed, but the specific aircraft (usually identified by its tail number) still needs to be assigned. Since aircraft need a range of different maintenance operations that depend both on the sequence of flights and their location, the assignment of flight legs and maintenance operations is typically combined in the Aircraft Maintenance Routing Problem. There are some recent reviews dealing with this problem [8,9], and a large body of work exists, going back to early work with reduced problem formulations [4]. Capacity constraints were rarely considered, or only with upper limits [3]. Solution methods include heuristic techniques [5], network-based MIP formulations [6,3], and branch-and-price techniques [7]. Heuristic approaches often outperform exact approaches on instances of realistic scale [1,2].

However, as already highlighted by Eltoukhy et al. [3] regarding future research directions, the AMRP rarely includes more considerations on how the maintenance workers are utilised. However, this can have very negative effects on the workforce, leading to both times with very high peak workloads, creating stress and fatigue, while other times are underutilised, leading to excess costs. Therefore, one major contribution of this work is to propose a maintenance distribution objective that aims to evenly distribute maintenance work or can also be easily adapted to other given maintenance target distributions.

Problem Definition We work on a version of the problem where the routing aspect is in the background since there is only one major hub that does the maintenance for all aircraft. Therefore, outgoing and consecutive incoming flight legs are combined, and each resulting (longer) flight leg starts and ends at the same hub. However, we want to extend our problem variant with maintenance distribution to multi-hub problems in the future.

A set of n flight legs $T = \{t_1, \ldots, t_n\}$ is given, each leg i is associated with a start time s_i, an end time e_i, and flight time f_i.

Note that there are different ways to specify aircraft maintenance tasks, often in the notion of checks of type A, B, C, and D. This version of the problem uses a different notion, but the general ideas are independent of the specific requirements. Each aircraft needs the following three types of maintenance:

- Routine: The aircraft can fly for at most 47 hours after the end of the previous routine maintenance, then it needs routine maintenance taking 2.5 hours before taking off again.
- Weekly: The aircraft can fly for at most 156 hours after the end of the previous weekly maintenance, then it needs weekly maintenance taking 7 hours before taking off again. Weekly includes routine maintenance.
- Major: There are four different types of major maintenance. Each of them is independent from the others. Each follows the same rule regarding time: 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. Each type of major maintenance includes routine and weekly maintenance. Further, the types `MH1` and `MH2` require the hangar, meaning that only 1 aircraft can perform any of these two types of maintenance at once.

A set of m aircraft $A = \{a_1, \ldots, a_m\}$ is given, each aircraft j is associated with history regarding the last flight leg and last maintenance tasks.

A feasible solution assigns all flight legs to available aircraft, and the required types of maintenance to specific time intervals, such that:

- The flight history is respected.
- No overlapping legs and tasks are assigned to any aircraft.
- No maintenance intervals are violated.
- At most 1 aircraft is assigned `MH1` or `MH2` at any point in time.

For optimisation, the total number of aircraft in any type of maintenance m_k is calculated for each minute k in the planning period, and $\sum_k m_k^2$ is minimised. This optimises the distribution of maintenance tasks (since peaks are penalised more), and also the total amount of maintenance (leading to maximisation of the available intervals between maintenance tasks). In addition, for each major maintenance the difference to the maximum flight time is added to prevent the maintenance from being done too soon.

Instance Generator One of the issues in the area of aircraft scheduling is that typically instance data is not publicly available, since airlines do not want to reveal details about their operation. However, this creates a difficult situation for scientific comparison, as this makes a thorough comparison of different methods very difficult, if not impossible.

Therefore, while we can also not share real-life data, we developed a flexible instance generator for these kinds of problems with several features to recreate characteristics of real-world instances:

- Instance size: Configurable number of aircraft, time horizon, granularity of flight times, and length of flight legs.

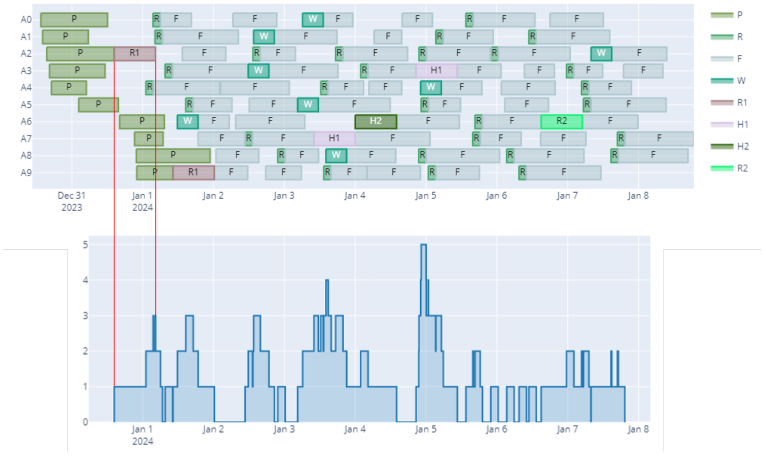

Fig. 1: Solution visualization: Aircraft on top, combined maintenance below

- Density: The density of the instances can be configured in several ways. A density of 1 represents a schedule where there is no idle time of aircraft besides flight legs and maintenance, leading to instances where it is difficult to find a feasible solution. Lower density leads to instances with more idle time where it might be easier to find feasible solutions, therefore, more emphasis can be put on the ideal distribution of maintenance. There are also options for up- or down-sloping density during the planning horizon.
- Peak behaviour: In real life, there are demand peaks during the day, e.g., for long distance flights many of them might start around 10 to 11 am. Peak intensity can therefore be chosen using parameters.

Instances are generated around a feasible, but most likely not optimal solution. We will further extend the generator to allow the generation of instances with different maintenance requirements. The current state of the generator as well as the new set of benchmark instances are available online[3].

Solution Methods We provide a model in the constraint modeling language MiniZinc for this problem. The decision variable $assignment_i$ shows the aircraft to which each leg i is assigned to. As there is at most one of each type of major maintenance per scheduling horizon, the major maintenance tasks are captured with a decision variable that denotes the start time per type for $j \in A$. Given that routine and weekly maintenance tasks can happen multiple times, the start times for these tasks are presented with optional decision variables. Additionally, we use the disjunctive constraint to ensure that no overlapping flights are assigned to any aircraft or tasks to the hangar at any given point in time.

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[3] https://cdlab-artis.dbai.tuwien.ac.at/papers/amr-md/

We have also been working on a solution method using Simulated Annealing, where moves either reassign flight legs to different aircraft, or change the location of a maintenance task within an aircraft.

Preliminary Results We created a new set of benchmark instances ranging from 10 aircraft for one week up to 50 aircraft for a month with various density and peak options. First results indicate MiniZinc together with the solver OR-Tools can solve small instances in short time, and good results can be obtained with Simulated Annealing for larger instances. Compared to pure maintenance assignments (as late as possible), peaks can be reduced significantly while keeping the same quality of aircraft schedules, showing the usefulness of our extension.

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