Hybrid metaheuristics to aid runway scheduling under uncertainty at London Heathrow airport.

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1 Introduction and Problem Description

London Heathrow Airport is a very popular and busy airport. Indeed it is one of the busiest airports in the world. In order to control noise for residents on flight paths, only one of Heathrow's two parallel runways can be used for departures at any given time. We aim to increase the throughput of the departure system, and in particular the runway, which is a bottleneck for the whole system.

Minimum time separations must be imposed between departing aircraft in order to control congestion and ensure safety, both at take-off and in the air. Reordering the aircraft can often reduce the total required separations and therefore increase the throughput of the runway. The problem of finding the best order for take-off is often called the Departure Problem.

When aircraft are ready to depart they are directed from their stand, around the taxiways, to holding points at the end of the runway. The small physical size of Heathrow airport, combined with the congestion at busy times, means that it is most practical to perform the take-off scheduling within the holding points, rather than earlier. This reordering task is currently performed manually by the runway controller.

There are various constraints to consider when reordering the aircraft.

Some aircraft have a target take-off time which imposes a fifteen minute window upon the aircraft. These must be adhered to and the valid take-off orders are constrained accordingly.

A reordering to reduce total delay in the system would naturally tend to delay aircraft that are associated with larger separations so this needs to be controlled.

The physical structure of the holding points where the reordering must take place imposes complex constraints upon what reordering can take place and how much effort it takes.

The required separations between aircraft depend upon the size, speed and departure routes of the aircraft. Ensuring that separations are maintained between all adjacent aircraft is not sufficient to ensure that required separations are maintained between other aircraft.

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Due to the numerous constraints upon the reordering and the limited time available to the runway controller, the task of reordering the aircraft can be a very complicated one.

Various methods have previously been applied to the Departure Problem. Anagnostakis et al suggested a search tree with branch and bound or A* algorithm in [1]. Anagnostakis and Clarke suggested a two-stage methodology to solve the problem in [2]. Trivizas suggested a dynamic programming solution to the problem in [7] by reducing the search space. Van Leeuwen et al suggested a constraint programming solution in [6]. None of these methods took account of all of the constraints upon reordering at airports such as Heathrow, particularly the physical ones from the holding point structure.

In [4], Craig et al looked at departure scheduling at Heathrow using a dynamic programming approach to handle a simplified holding point structure. This dynamic programming solution is not, however, practical with the more complex, real holding point structures.

2 Model and Solution Approach

We will discuss the various constraints that the controllers have to work under in more detail and present a model that includes these constraints.

We will present and discuss a hybrid meta-heuristic solution which is able to find good solutions to the problem quickly enough to be of use in a real-time system. To do this, the physical holding point constraints are handled separately. We use meta-heuristic searches to determine good take-off orders. Then each order is tested for feasibility, using a model of the physical holding point structure. This decomposition of the problem allows us to use a heuristic assignment of routes through the holding point to prune the search space, eliminating those schedules that impose an unacceptable, or unnecessary, workload upon the controllers or pilots. An early, simpler, version of our model was presented in [3], without take-off time constraints.

The controllers have a very complex task to reorder the aircraft within the available time. It is usual for them to consider only the aircraft already in the holding point. By also considering the aircraft travelling towards the holding point, tests with our model predict a possible decrease of 10 to 25% in the total time the aircraft spend in the holding point. Reducing the delay in the holding point, with the engines running, should have environmental benefits as well as obvious benefits for airlines and passengers.

It is important, in order to be able to produce robust schedules, to understand and manage the uncertainty in the real world system. For example, taxi times and the times at which aircraft complete their pre-take-off checks are not entirely predictable. We will discuss the different areas where only imperfect knowledge is available and show how our model and solution approach have been adapted to handle this situation. Finally, we will present details of some tests, using actual data from Heathrow, with results, to evaluate the effects of the types of uncertainty involved and how well the system handles them.

3 Concluding Comments

The real-world take-off scheduling at London Heathrow is extremely complex due to the short decision times and the range of constraints that need to be imposed upon any reordering. The limited time within which controllers must make the decisions provides an opportunity for an automated decision support system to help the controllers in this difficult task.

The existing academic solutions for the departure problem do not take account of all of the major reordering constraints that occur at an airport like Heathrow. Neither the structure of the holding point where the reordering is to take place, nor the workload of the controller can actually be ignored at Heathrow. We will present a model and solution method that does take account of these crucially important real constraints.

By improving the simulation of the uncertainty involved in the real world we can better understand the effect it has on the scheduling and derive more effective schedules. There are real cost, pollution and passenger satisfaction benefits to be gained from using a decision support system to reduce the delay at the holding point and improve the throughput of the airport. Our methodology addresses this while ensuring that the schedules produced avoid undue workload for the controller and pilots.

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