10th International Conference of the Practice and Theory of Automated Timetabling
PATAT 2014, 26-29 August 2014, York, United Kingdom

Lessons from Building an Automated Pre-Departure Sequencer for Airports

Daniel Karapetyan · Andrew J. Parkes · Jason A.D. Atkin · Juan Castro-Gutierrez

Abstract Commercial airports are under increasing pressure to comply with the Eurocontrol Collaborative Decision Making (CDM) initiative, to enable overall airspace improvements. An important element of a CDM system is the provision of automated decision support to aid the controllers to schedule the take-off times and the associated times at which aircraft should push back from the stands. The CDM system then aids effective operations by communicating these scheduling decisions to other relevant parties within the airport and the airspace. One of the major CDM components is aimed at predicting the target take-off times; for medium-sized airports, a common choice for this is a "Pre-Departure Sequencer" (PDS). Here we describe the design and requirements challenges which arose during our development of a PDS system. Firstly, the scheduling problem is highly dynamic and event driven. For example aircraft can be delayed or runway capacity can change, and this requires a careful separation of data ownership responsibility between the system components and special attention to integrity constraints. Secondly, it is important to end-users that the system be predictable and, as far as possible, and transparent in its operation, with decisions that can be explained. These human factors, which influenced the choice of methods for solving the problem, are also explained in this abstract, along with the consequent decisions which were made.

Keywords Airport Operations · On-line Scheduling · Algorithm Design

1 Introduction

Each departing flight in an commercial airport typically follows the following steps:

This work was supported in part by an EPSRC 'Research Development Fund' and also by EPSRC grant EP/F033613/1

School of Computer Science, University of Nottingham
E-mail: {dxk, ajp, jaa, jpc}@cs.nott.ac.uk

1. The aircraft crew and other airport services report the time at which the flight will be ready to depart, called the TOBT.
2. The airport controllers schedule the 'off-block' / 'push back' times based upon these TOBTs and other information. The procedure is usually for a tug to push the aircraft back from the stand, since most of the aircraft are not capable of moving in the reverse direction without risking damage to the stands.
3. The aircraft is pushed back and its engines are turned on.
4. The aircraft taxies towards the end of the runway where it may join a queue of departing aircraft.
5. The aircraft taxies onto the runway, lines up and takes off.

Operations need to be coordinated, so these stages should be scheduled in advance and the relevant timings for the key stages distributed to those people and systems that need to know. To aid this, organisations such as Eurocontrol[1], who are responsible for the management of the airspace over Europe, have introduced and promoted "Collaborative Decision Making" (CDM) systems [2]. In particular, from a Eurocontrol brochure about "Airport CDM" (A-CDM) [3], some key aims are:

> *"Information sharing is the first and most essential element of A-CDM as it creates the foundation by creating a common situational awareness. In addition, it potentially brings predictability and resource efficiency benefits. . . . With the pre-departure sequencing function the target start-up approval time (TSAT) can be calculated, providing an off-block sequence."*

Commercial airports are under increasing pressure to ensure that they have a minimum of a "Pre-Departure Sequencer" (PDS) system deployed within the Air Traffic Control (ATC) systems of the airport. The primary responsibility of the PDS is to predict the basic information as to the time at which aircraft plan take off. This time is called the "Target Take-Off Time" (TTOT), and is usually linked to the time when the aircraft plan to start engines to move towards the runway ("Target Start-up Approval Time", TSAT). A key input to the PDS is the "Target Off-Block Time" (TOBT) which is the time specified by the airline operator at which they plan to be ready to leave. This is initially taken from published flight schedules, but can be modified due to operational reasons. The PDS system, optionally with the manual intervention of the ATC, is then responsible for taking the TOBTs together with information about current airport conditions and capacities and producing the TSATs and TTOTs.

Another responsibility of PDS is to comply with the Eurocontrol instructions. To manage bottlenecks in the airspace, Eurocontrol may declare a flight *regulated* and issue a so-called "Calculated Take-Off Time" (CTOT), which defines a time window for the flight departure. A CTOT window is a hard constraint; if the flight is not ready to depart before the end of the CTOT window,

[1] `https://www.eurocontrol.int/`

a new CTOT usually has to be requested, which may cause additional delays and associated costs. In other words, any plan which would violate a CTOT is strongly undesirable for the airport.

For the largest airports, a more complex "Departure Management" (DMAN) system becomes a standard choice. The fuller DMAN system being needed when the schedules need to be optimised with consideration of additional requirements such as wake-vortex separation rules, when runways cannot be used in mixed mode but capacity must be maximised, see [1]. However, for medium-sized airports a PDS system is a simpler, and so better, choice, especially when it is to be the first CDM system at the airport.

In this abstract, we discuss some lessons learned from building a pre-departure sequencer intended for a moderate size airport, that can automate most of the airport controller operations related to pre-departure sequencing, and can take and respect user modifications from the ATC. We believe that some of the lessons are also relevant to other scheduling and timetabling problems. In Section 2, we briefly describe the problem, and outline our approach. Finally, in Section 3, we report our conclusions.

2 Designing an Automated Pre-Departure Sequencer

A pre-departure sequence needs to provide TSAT values that obey constraints such as:

- $\mathrm{TSAT} \geq \mathrm{TOBT}$ (the aircraft cannot be pushed back before it is ready);
- TSAT cannot be in the past for any flight at the stand;
- $\mathrm{TTOT} = \mathrm{TSAT} + \mathrm{EXOT}$ (where EXOT is the time needed for the aircraft to reach the runway);
- $\mathrm{CTOT} - 5 \leq \mathrm{TTOT} \leq \mathrm{CTOT} + 10$.

Below we describe the main challenges we faced while designing PDS.

Minimal Perturbation. Besides the above constraints, one of the most important aspects of the PDS is the interaction with humans, for example, with decision makers in the ATC and ground operations. This has the immediate consequence that the system decisions should not 'churn': TSAT values should not be changed more than is needed, as constant updates lead to difficult and inefficient operations. This is an important criterion in the algorithm design.

'Predictability' and 'Explainability' of Decisions. It was also important that the human aspects required the PDS decisions to be predictable, repeatable, and potentially explainable to people that are experts in ATC, but not experts in algorithms or search. If the PDS is stochastic, then the exact outcome is unpredictable, which can be very disconcerting for operators and also makes the software testing phase both onerous and complex, or impossible to guarantee. Also, there should be the potential for decisions to be given explanations that make sense to the human experts. These issues limited the choice of algorithms that would be appropriate, for example, a standard stochastic local search would be a last resort — as it tends to be non-repeatable, and also very difficult to explain or justify the final decisions.

Data Ownership Issues. Another important lesson was the need to decide as early as possible upon the division of responsibility over data between the PDS and the main CDM database: what information was sent, which system 'owned' it and which had authority to make changes.

Overall, this led us to an event-driven rule-based approach; though with multiple passes through carefully designed sets of rules, and various triggers corresponding to circumstances such as the runway capacity changing. We do not present the algorithm here, but it is based on splitting the runway resource into time slots of the same lengths, which are computed from maximum number of take-offs per hour as provided by the ATC. The sequence is updated in reaction to events such as 'a new flight is declared', 'EXOT is changed' or 'controller reallocated a flight'. Such a system avoids unnecessary alteration of flights and has an easy to understand behaviour. With a flexible system of flight locks, we guarantee a certain level of predictability and transparency.

3 Conclusions

We have introduced the main issues that influenced the design of a decision support system for automated on-line pre-departure sequencing. Such a system can significantly improve many aspects of airport operations. Apart from obeying the basic constraints, the system keeps the number of changes in the pre-departure sequence to the minimum and has easily predictable and explainable behaviour. The traditional focus of OR optimisation projects is on the problem alone; however, one of our main lessons was that the "meta-problem" of the human context, with the need for development of high trust levels in the autonomous operations, had an important influence on the user acceptability of different algorithms.

Acknowledgements We would like to thank Ultra Electronics Limited for their collaboration with us in building a prototype of the automated pre-departure sequencer.

References

1. Jason A D Atkin, Geert De Maere, Edmund K Burke, and John S Greenwood. Addressing the pushback time allocation problem at heathrow airport. *Transportation Science*, 47(4):584–602, 2013.
2. EUROCONTROL. European Airport CDM: Airport Collaborative Decision Making. Website: `http://www.euro-cdm.org/` (last accessed Feb 2014).
3. EUROCONTROL and ACIEurope. A-CDM Airport Collaborative Decision Making, 2010. Brochure available at: `http://www.euro-cdm.org/library/cdm_brochure.pdf`.