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Integration of aircraft ground movements and runway operations

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ABSTRACT

The Ground Routing Problem focuses on finding the optimal routing of aircraft from parking stands to runways. The Runway Sequencing Problem consists in ordering the sequence of takes-offs and landings on runways. We study the integration of these two problems with the aim of simultaneously increasing runway efficiency and reducing taxi times. We propose a heuristic sequential approach based on a novel mathematical formulation. We test our methods using real data of a major European airport. Our approach significantly reduces the total completion and taxi times within reasonable computation times, making it viable to be used in daily operations.

1. Introduction

This paper focuses on the management of the departure process, from push back to take-off, through an integration of the Ground Routing Problem (GRP) and the Runway Sequencing Problem (RSP). In this first section, we present briefly the two problems and their interactions. Then we present the research questions addressed in this work and the outline of the rest of the paper.

1.1. Runway sequencing problem

The RSP consists in sequencing runway operations while ensuring safety, i.e. deciding in which order (and when) each aircraft takes off, lands on or crosses a runway, while respecting minimum separation requirements. Depending on the airport layout, runway assignment can be also part of the problem. This problem is issued by Air Traffic Controllers (ATC) on an operational window of typically 10–40 min. Longer time windows can hardly be considered because of perturbations occurring the day of operations. Hence a sliding time window scheme is used in the literature and in practice. Consequently, the problem has to be solved very often and computation times are critical.

Minimum separation requirement is the main limiting factor of runway capacity. Because of wake vortex, an air mass is perturbed when it is crossed by an aircraft and a minimum separation time must be respected between two aircraft to ensure the safety of the second one. The heavier the leading aircraft, the bigger its wake vortex is and, thus, the separation time is longer. The lighter the trailing aircraft, the more it is subject to turbulence and the longer is the separation time. Aircraft are classified in wake vortex categories by the International Civil Aviation Organization (ICAO) and the minimum

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separation between two aircraft depends on their respective classes (see e.g. Table 1). Additional separations may be necessary to prevent conflicts in airspace segment of routes, also known as Standard Instrument Departure routes (SID). SID separation constraints depend upon the departure routes and speeds of the aircraft.

When an air sector of an aircraft flight plan is congested or when the destination airport is facing adverse conditions, the Network Manager Operations Center (NMOC) assigns a Calculated Take-Off Time (CTOT). It generally results in delaying the take-off to prevent the situation to become worse in the perturbed sector. The take-off is allowed within the interval $[\mathrm{CTOT} - 5\ \mathrm{min}\,;\mathrm{CTOT} + 10\ \mathrm{min}]$, called a NMOC slot. Otherwise, the aircraft has to wait for another slot from the NMOC. For a more detailed description of constraints that have to be taken into account in take-off scheduling, we refer the reader to Atkin et al., 2009b.

The quality of a runway sequence can be evaluated with different criteria. The main criterion is the efficiency and the good use of the runway capacity. In the literature, it is often modeled by the runway throughput (makespan), the total (weighted) completion time or the total (weighted) deviation to targeted take-off or landing times. Equity is another important criterion, it is often measured by the deviation to the First Come First Serve order (FCFS, the fairest order) or the maximum delay.

1.2. Ground routing problem

The GRP consists in scheduling the movements of aircraft between airport facilities without conflicts and in the most effective way. An arriving aircraft has to be routed from its landing runway to its stand or hangar. A departing aircraft has to be routed from its current parking position to its departure runway. The ground movements occur on a network of roads called taxiways which link airport facilities. In practice this problem is issued by Air Traffic Controllers (ATCs) on an operational window of typically 10–40 min.

The main constraints of the problem are related to the safety of aircraft: as in airspace, aircraft have to be separated from each other to avoid collisions. Several other routing constraints must also be taken into account such as taxi speeds and acceleration for passengers comfort, turning angle and aircraft/taxiway segment compatibility due to weight or width. There are also many different conflicts in the stand area. Among them, the push back conflicts and the head-on conflicts between departures and arrivals are the most common ones (see Fig. 1).

The quality of a routing schedule can be evaluated with different performance indicators. Among them the average taxi time and the average completion time are frequently used. The taxi time measures the time an aircraft spends on the ground with engines on, between push back (i.e. leaving the parking position) and take-off for a departure and between landing and park-in for an arrival. It includes any waiting time (e.g. runway queuing time) and not just the time spent moving, as engines cannot be turned off once started up. The completion time is the take-off time for departing flights and the park-in time for arriving flights.

For departures, the completion time and the taxi-time depend on the take-off sequence. Hence, the GRP and the RSP are intimately linked.

1.3. Towards a better integration

Two different managements of the departure process can be observed nowadays. In the first one, aircraft are pushed back as soon as possible and taxi to the runway where they can potentially be reordered to increase the runway capacity. The second practice proceeds sequentially in three steps. First, an earliest time at the runway is estimated for every aircraft through an estimation of taxi times. Then, the take-off sequence is optimized. Finally, ground movements (or only push back) are scheduled to match the predicted take-off sequence. This approach is recent and promoted by the Airport Collaborative Decision Making (A-CDM) project (Eurocontrol, 2009). It targets a better synchronization of ground movements and runway operations. It particularly allows to reduce runway queuing times through a better scheduling of push backs: aircraft can be held at their stand with engines off instead of waiting at the runway with engines on.

The aim of a better integration of the GRP and the RSP is to further improve this synchronization. The motivations are twofold: increasing runway efficiency and reducing taxi times. A-CDM approach relies on estimations of taxi times, which are particularly difficult to forecast. Nevertheless, the accuracy of these estimations is crucial. If taxi times are underestimated, aircraft are held too long, consequently creating idle time between take-offs and wasting runway capacity. On the contrary, if taxi times are overestimated, aircraft are not held long enough. Thus, an excessive queue will appear at the departure runway and fuel will be wasted. Furthermore, inaccurate taxi times can make the aircraft reach the runway in a different order from the desired one. Aircraft can be reordered at the runway but Atkin et al. (2009a) show that this reordering is constrained by the holding point layout and that not all sequences are feasible. A better synchronization leads to less reordering and potentially enables more efficient sequences.

1.4. Research questions

We mainly address two research questions in this paper. Is a better integration of runway sequencing and ground routing valuable? How can the integrated problem be solved efficiently? Indeed, computation times are critical since the GRP and