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Heuristic search for the coupled runway sequencing and taxiway routing problem

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ABSTRACT

This paper presents the first local search heuristic for the coupled runway sequencing (arrival & departure) and taxiway routing problems, based on the receding horizon (RH) scheme that takes into account the dynamic nature of the problem. As test case, we use Manchester Airport, the third busiest airport in the UK. From the ground movement perspective, the airport layout requires that departing aircraft taxi across the arrivals runway. This makes it impossible to separate arrival from departure sequencing in practice. Operationally, interactions between aircraft on the taxiways could prevent aircraft from taking off from, or landing on, runways during the slots assigned to them by an algorithm optimizing runway use alone. We thus consider the interactions between arrival and departure aircraft on the airport surface. Compared to sequentially optimized solutions, the results obtained with our approach indicate a significant decrease in the taxiway routing delay, with generally no loss in performance in terms of the sequencing delay for a regular day of operations. Another benefit of such a simultaneous optimization approach is the possibility of holding aircraft at the stands for longer, without the engines running. This significantly reduces the fuel burn, as well as bottlenecks and traffic congestion during peak hours that are often the cause of flight delays due to the limited amount of airport surface space available. Given that the maximum computing time per horizon is around 95 s, real-time operation might be practical with increased computing power.

1. Introduction

Due to a huge increase in the air traffic over the past decade, and with further growth forecast (EUROCONTROL, 2013), air traffic congestion on the airport surface is a major constraint on efficient use of airport resources (runways, taxiways and gates/stands). Economically, congestion could cause airborne delays, whereas environmentally, it results in an increase in air pollutants and noise emissions. Even though the expansion of airport capacity and the increase of traffic controllers are the most obvious solutions, these are often not realistic due to cost and space limitations. A more practical solution is the use of highly innovative decision support systems for an effective management of existing resources. This has led research programs, such as the Single European Sky ATM Research (SESAR) project in Europe and NextGEN in the United States, to initiate the development of highly complex decision support systems based on sophisticated optimization methodologies.

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The existing work in the field on transportation research has mainly focused on solving the key airport operations problems in isolation. These include gate allocation, runway sequencing, ground movement and baggage handling, with the relative importance of each varying by airport. Nevertheless, there are obvious benefits from considering different airport operations as a unit from both economical and environmental point of view (Atkin et al., 2010). As discussed in Atkin et al. (2010), the ground movement problem is that of allocating efficient taxi routes to aircraft moving between the runways and stands. Ground movement forms the link between other airport operations problems, including arrival sequencing, departure sequencing and gate allocation. Indeed, an optimal departure sequence is of no use if aircraft cannot reach the runway at allocated take-off times. In real operations, aircraft typically leave the gates to meet on time their departure slot as soon as they are ready for pushback. Since the amount of available airport surface is limited, this results in bottlenecks and traffic congestion during peak hours causing flight delays. Furthermore, arrival aircraft can have a significant effect on ground movement planning, especially at airports where runway crossing is necessary for taxiing aircraft (Mirković et al., 2016). Therefore, prior knowledge of the landing times is required for realistic runway sequencing and ground movement optimization.

Some effort has recently been made on the design of approaches for tackling multiple problems simultaneously. For instance, the authors in Atkin et al. (2007) present a decision-support system based on heuristic search for the departure runway scheduling at Heathrow. A tabu search algorithm is used for finding good take-off orders, which are then tested for feasibility given the holding-point restrictions. In Roling and Visser (2008), the authors propose a mixed-integer linear programming approach that aims to optimize a weighted combination of the total taxi time and the total holding time in such a way to deconflict the taxi plans. The work in Montoya et al. (2011) presents a dynamic programming algorithm for optimal runway sequencing. In addition to miles-in-trail and wake vortex separation constraints, runway crossings are also taken into account. In Clare and Richards (2011), the authors describe an automated tool that incorporates departure runway scheduling with taxiway routing in continuous time at Heathrow, based on a receding horizon technique. The method adopts MILP optimization, while the proposed model imposes the runway separation requirements as a constraint to the taxiway routing process. The work in Jung et al. (2011) describes an airport surface decision support tool that combines departure routing with departure sequencing, and tests the combined solutions using a detailed simulation. In Atkin et al. (2013), the authors propose a two-stage approach that finds a take-off sequence in the first stage, and then uses this in the second stage to calculate push-back times such that an appropriate amount of the delay is absorbed at the stand, prior to starting the engines. The feasibility of the second stage is considered within the first stage. The work in Weiszer et al. (2015) applies multi-objective optimization to the integrated problems of departure sequencing (excluding arrivals), ground movement and airport bus scheduling, with results showing improved fuel and time efficiency over treating the problems in isolation. Other research considering combined airport operations problems can be found in Deau et al. (2008), Lee and Balakrishnan (2012), Neuman and Atkin (2013), Nosedal et al. (2015) and Weiszer et al. (2015).

In recent years, several models have been proposed for the integrated arrival sequencing, departure sequencing and runway routing problems. Among the first such works is a set partitioning model (Yu and Lau, 2014) that largely reduces the number of constraints and makes the problem more manageable. In the proposed model, each possible aircraft route is regarded as a decision variable, while the constraints enforce a minimum separation distance between aircraft at the taxiways and runways. The proposed method has been tested on a small taxiway layout of 36 nodes with one runway, and a single problem instance that includes 6 aircraft. The time required to reach optimality for the given instance is not reported. In Bosson et al. (2015), the authors extended a previously developed mixed-integer-linear programming approach for arrival and departure sequencing to include taxiway operations. The approach is applied to a model of the Los Angeles International Airport, and a preliminary case study is conducted on a set of thirteen aircraft. This test case was solved to optimality in about 240 s. The work in Bertsimas and Frankovich (2015) presents an integer programming model that addresses simultaneously the optimization of arrival sequencing, departure sequencing and surface routing in a tractable manner. The model is divided into two stages considering the problem complexity. The first stage focuses solely on the runway capacities (i.e., runway sequencing), while the second stage can be viewed as the routing phase which determines a routing of flights to achieve a runway processing schedule close to that obtained in the first stage. The approach results in a suboptimal solution, since runway sequencing and taxiway routing are performed in two separate stages. Along with the above mentioned literature, it is also worth mentioning the Spot and Runway Departure Advisor (SARDA),[1] developed and studied by NASA. SARDA is an algorithm for effective management of departures at an airport, which plans gate departure times, spot crossing times, and runway sequences. So far, SARDA has been applied at three airports in USA, chosen for their diversity in geometric and operational characteristics.

While the works in Bertsimas and Frankovich (2015), Bosson et al. (2015) and Yu and Lau (2014) present mathematical models for exact solving of the combined problem, this paper presents probably the first heuristic, based on the Iterated Local Search (ILS) framework, for optimization of the coupled runway sequencing and taxiway routing problems in continuous time. Furthermore our approach incorporates the receding horizon (RH) framework (Bellingham et al., 2003; Hu and Chen, 2005; Hu and Paolo, 2008; Zhan et al., 2010) to take into account the dynamic nature of the problem. As test case, we use Manchester Airport, the third busiest airport in the UK. The airport has two runways, which are operated in segregated mode during busy periods. Manchester Airport has a runway crossing which makes it impossible to separate arrival

[1] http://www.aviationsystemsdivision.arc.nasa.gov/research/surface/sarda.shtml.