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Coordination of scheduling decisions in the management of airport airspace and taxiway operations

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Abstract

This paper addresses the real-time problem of coordinating aircraft ground and air operations in an airport area. At a congested airport, airborne decisions are related to take-off and landing operations, while ground (taxiway) decisions consist of scheduling aircraft movements between the gates and the runways. Since the runways are the initial/terminal points of both decisions, coordinated actions have a great potential to improve the overall performance. However, in the traffic control practice the different decisions are taken by different controllers, at least in large airports. Weak coordination may result in long queues at the runways, with increasing aircraft delays and energy consumption. This paper investigates models, methods and policies for improving the coordination between taxiway scheduling and airborne scheduling. The performance of a solution is measured in terms of delay and travel time, the latter being related to the energy consumption of an aircraft. A microscopic mathematical formulation is adopted to achieve reliable solutions. Exact and heuristic methods have been analysed in combination with the different policies, based on practical-size instances from Amsterdam Schiphol airport, in the Netherlands. Computational experience shows that good quality solutions can be found within limited time, compatible with real-time operations.

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1. Introduction

To a large extent, the real-time management of airport operations is still based on the decisions of human traffic controllers, who develop feasible aircraft schedules in each airport based on their past experience, intuition and some scheduling rules. Recently though, initiatives like the Airport Collaborative Decision Making (A-CDM) of SESAR program are pushing airports towards the adoption of at least automated advisory systems for some of the airport operations, see e.g. Eurocontrol (2011), Grushka-Cockayne et al. (2008), Pellegrini and Rodriguez (2013) or SESAR (2015). The annual report 2016 of the U.S. Federal Aviation Administration cites, among the potential benefits of sophisticated scheduling software, (1) the mitigation of the safety risks associated with controller fatigue; (2)

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the improvement of the ability of diverse facilities to generate efficient schedules; (3) the possibility of development of staffing standards at FAA headquarters and the creation of work schedules at the facility level. Some commercial arrival manager systems are in operation at some airports, see Hasevoets and Conroy (2010) and Zelinski and Jung (2015). However, with these systems, controllers usually have to manually adjust the aircraft sequencing produced automatically, since the existing systems do not fully take into account the microscopic detail of the aircraft movement required to ensure feasible landing and take-off schedules. These systems usually take decisions based on local and partial information on airport management, while optimization is often limited to very simple scheduling rules. Furthermore, the management of a Terminal Control Area (TCA) requires to coordinate a number of operations (e.g., ground and/or air traffic) that are under the control of different authorities (e.g., Furini et al. (2015) cite the Terminal Radar Approach Control, or TRACON, the Ground Control and the Tower Control). Hence, the overall plan of operations must take into account the different needs and points of view of the various stakeholders, see SESAR (2015). As a result, even when some decisions are supported by advisory systems, a significant part of the controller workload consists of manually coordinating arrivals, departures and other operations to ensure the global feasibility of the overall schedule, see Djokic et al. (2010). Diffenderfer et al. (2013) report on the current need of adding the computation of arrival and departure schedules to the functionalities of the systems dedicated to the support of traffic controllers, pointing out that main limitations of the current practice are related to a lack of precision in modeling safety separations between consecutive aircraft and a lack of coordination between arrival and departure operations. These limitations may cause the generation of inefficient schedules in practice. The authors identify the manual communication between controllers as a cause of the slow and inefficient process of coordinating the schedules produced by the Tower Control and by the TRACON, and clearly show that a better coordination of traffic flows might significantly improve the airport performance. However, they do not report nor propose existing methods to this aim.

From the above discussion, it follows that a prerequisite for the introduction of advanced scheduling systems is the development of optimization models and methods that should be able to:

- Incorporate an increasing level of realism, to ensure the schedule feasibility in practice;
- Include the different operations having an impact on performance indicators, or at least address the coordination of different traffic control authorities;
- Support different performance indicators and/or scheduling policies. A scheduling policy prescribes the distribution of slack time for the aircraft besides their minimum traversing time, e.g., at the gate or along the taxiway for take-off aircraft, or before/after entering the TCA for landing aircraft.

So far, the aircraft scheduling literature mainly addressed the first challenge. An extensive overview of early contributions can be found in Ball et al. (2007), while more recent surveys can be found in Barnhart et al. (2012), Bianco et al. (2006) and Pellegrini and Rodriguez (2013). We observe that, while the coordination issue is often referred to multi-airport coordination, as in Aktürk et al. (2014) or Andreatta et al. (2011), this paper focuses on coordination of operations in a single airport. In the latter context, Balakrishnan and Chandran (2010), and Sölveling et al. (2010) focus on the runway scheduling, Artiouchine et al. (2008), Hu and Chen (2005), and Hu and Di Paolo (2008,2009) focus on the landing scheduling from airspace resources to runways, while other authors deal with the coordination of the TCA airspace and the runways (landing and take-off scheduling), e.g., D'Ariano et al. (2012, 2015), Lieder and Stolletz (2016), Murça and Müller (2015), Samà et al. (2013, 2014, 2015, 2017). Other papers focus on ground control (including taxiway resources and runways), e.g., Atkin et al. (2008, 2013), Clare and Richards (2011), Marin (2006), Ravizza et al. (2013). Overall, most of the optimization models proposed in the literature for a single control area suffer from a lack of coordination between air and ground operations, so that the solutions produced are not always feasible when implemented in practice. This lack of research motivates the present paper.

This paper focuses on the overall Aircraft Scheduling Problem (ASP) faced by three different authorities: the Approach Radar Control, the Ground Control and the Tower Control. The ASP consists of scheduling aircraft from the border of the TCA until the gate and *vice versa*, by integrating taxiway, landing and take-off scheduling into a single optimization model. We consider the gate assignment problem as solved beforehand, and formulate the overall scheduling problem as a job shop scheduling problem with additional constraints, following a successful stream of research described in Bennell et al. (2011). Along this stream of research, optimization models tend to incorporate an increasing number of details of the practical problem that affect the feasibility of the solutions. Models in this stream, that we call *microscopic optimization models*, have been proposed in Bianco et al (2006), D'Ariano et al. (2012, 2015), Samà et al. (2013, 2014, 2015, 2017) for the ASP limited to air resources and runways. Bianco et al. (2006) propose a no-wait version of the job shop scheduling problem to model airborne aircraft movements. The latter six papers are based on the alternative graph model introduced by Mascis and Pacciarelli (2002), that is able to model aircraft movements with an increased level of detail. The higher modelling precision includes further relevant TCA aspects such as holding circles, waiting in flight before landing, traveling in feasible time windows, hosting multiple aircraft simultaneously in air segments and the single blocking capacity of the

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