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Rolling horizon approach for aircraft scheduling in the terminal control area of busy airports ☆

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ABSTRACT

This paper addresses the real-time problem of scheduling aircraft in a terminal control area. We formulate this problem via the alternative graph formulation. A rolling horizon framework is introduced to manage busy traffic situations with a large number of delayed aircraft. As scheduling algorithms, we compare a branch and bound (BB) algorithm with a first come first served (FCFS) rule. The algorithms are evaluated on practical size instances from Roma Fiumicino and Milano Malpensa. Experimental results demonstrate that BB better minimizes aircraft delays and travel times compared to FCFS. BB also requires less frequent changes of aircraft scheduling decisions.

1. Introduction

Due to the increasing traffic demand and the limited availability of airport resources, aviation authorities are seeking methods to better use the existing infrastructure during operations and to better manage aircraft movements in the proximity of airports, trying to improve punctuality while maintaining the required safety level.

From a logical point of view, it is possible to divide Air Traffic Control (ATC) decisions in a Terminal Control Area (TCA) into: (i) routing decisions, where an origin–destination route for each aircraft has to be chosen regarding air segments and runways; (ii) scheduling decisions, where feasible aircraft sequencing and timing have to be determined in each air segment, runway and (eventually) holding circle, satisfying scheduling regulation and giving optimized solutions. In this work, a traffic control system is developed in order to support traffic controllers in taking optimal scheduling decisions for given aircraft routes. Aircraft re-routing decisions are considered in other studies, we refer the interested reader e.g. to Pistelli et al. (2011) and D'Ariano et al. (2012a,b).

We study the aircraft scheduling problem (ASP) that is one of the challenging problems in air traffic control during disturbed traffic situations. Given a set of landing/take-off aircraft, and given for each aircraft its approach/leaving path in the TCA, its current position, its scheduled runway occupancy time, and a time window to accomplish the landing (departing) procedures, our problem definition is to assign the passing time to each aircraft at all resources of its path (holding circles, air segments, common glide paths, runways) in such a way that all aircraft potential conflicts are solved, all the constraints on safety separation distances are satisfied, the available airport capacity is efficiently used and aircraft delays due to conflicting paths are significantly reduced.

Recent literature reviews of Ball et al. (2007), Barnhart et al. (2012), Bennell et al. (2011), D'Ariano et al. (2012a,b), Eun et al. (2010) and Kuchar and Yang (2000) presented at least two types of ASP classification.

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First, ASP models can be grouped as *basic* or *detailed*. Basic models include only the runways in the TCA, while detailed models also schedule aircraft on other relevant TCA resources. Most of the early papers on ASP fall in the former category. This choice is motivated by the fact that the runways are often the bottleneck of the TCA. With a basic model the ASP is typically formulated as a single/parallel machine scheduling problem, while detailed models of the ASP are formulated as a job shop scheduling problem. In later level of modelling, a significant number of real-world constraints and characteristics of the ASP can be included. In this paper a detailed ASP model is presented based on the alternative graph formulation of Mascis and Pacciarelli (2002) that is able to enrich the model of Bianco et al. (2006) by including additional real-world constraints, such as holding circles, time windows for aircraft travel times, multiple capacities of air segments and blocking constraints at runways. This optimization model has been already successfully adopted to manage rail and air transportation problems (Corman et al., 2012; D'Ariano et al., 2007, 2010, 2012a,b).

Second, ASP approaches can be classified as *static* or *dynamic*. In the static ASP, landing/departing aircraft must be sequenced when all information is known, whereas in the dynamic ASP aircraft enter the TCA during a current time period of traffic prediction, and a new sequence of take-off/landing aircraft has to be recomputed for every time period in which new incoming aircraft positions are known. In this paper static ASP algorithms are utilized, provided that they are able to compute a feasible schedule, in a dynamic environment in which the information on the landing/departing aircraft is updated during the traffic prediction (Abdelghany et al., 2008; Clarke and Solak, 2009; Steria et al. 2011).

The main objective of this work is the investigation of potential benefits of an advanced rolling horizon approach for the management of aircraft traffic flows at busy airports. Rolling horizon approaches have already been applied to transportation problems in which data variability is inherently associated with incomplete information on the real-time operations (Hu and Chen, 2005; Lai et al. 2008; Meng and Zhou, 2011; Zhan et al. 2010). The proposed rolling horizon approach enables the dynamic management of aircraft ingoing and outgoing the TCA. Compared to the centralized approach in which all aircraft are managed in one step for the entire time horizon of traffic prediction, the rolling horizon approach divides the problem in multiple steps, enabling the dynamic management of aircraft for large time horizons.

The originality of this approach is the design and implementation of a dynamic setting for air traffic control based on a detailed problem modelling and on the adoption of heuristic and exact ASP algorithms. With a special focus on mathematical modelling and design of advanced algorithmic strategies, this research contribution evaluates the quality of ASP solutions in case of various sources of disturbance. A rolling horizon framework is developed based on alternative graphs, taking care of uncertainty of the predicted operational conditions over time, and solved by heuristic and exact ASP algorithms. Specifically, we address the relevant questions "how does the traffic control system react when disturbances arise", "when and how is it more convenient to reschedule aircraft in the TCA", "which algorithm performs best in terms of delay and travel time minimization", "which algorithm is the less sensitive to disturbances".

The architecture of our optimization-based traffic control system with rolling horizon mechanism works as follows. The aircraft scheduling procedure considers a roll period and a look-ahead period (i.e., a time horizon of traffic prediction). Given currently available and predicted information on the operational conditions, the optimization algorithm adopted for the current ASP problem delivers the scheduling plan periodically for every roll period. At the beginning of each roll period, the operational conditions are predicted for a time period in the future. The look-ahead period is defined as the time period from the end of the roll period to the end of the current traffic prediction. This dynamic mechanism complicates the scheduling aspect compared to single optimization run, due to overlapping time periods and to additional constrains from current operations.

At each stage of the rolling horizon approach, we run a scheduler plus eventually a pre-processing phase, in which holding decisions are taken for incoming aircraft in order to avoid potential conflicts between the aircraft from the previous time period still occupying resources in the TCA and next incoming aircraft. We then apply the following scheduling algorithms for solving the ASP of the current time period of traffic prediction. As rule-based method, first come first served (FCFS) is evaluated, taking ASP decisions one at a time by assigning each conflicting resource to the first aircraft requiring it. This local rule requires no look-ahead control action but ignores useful information on the actual traffic conditions since aircraft run in the airport area on the basis of their actual order of arrival at each air segment or runway. According to Bennell et al. (2011) FCFS is a common dispatching rule, even if human controllers may adjust the FCFS sequence in order to recover possible infeasibilities. As optimization method, the truncated branch and bound (BB) algorithm of D'Ariano et al. (2010, 2012a,b) is used to solve the ASP to near-optimality.

The ASP instances are generated by varying the following factors: (i) the two main Italian airports (Roma Fiumicino and Milano Malpensa, the airport models are shown in Pistelli et al., 2011) are investigated, having different infrastructures and traffic flows; (ii) delay configurations with multiple ingoing and outgoing delayed aircraft; (iii) various level of uncertainty regarding the aircraft entry times in the TCA.

For all the proposed ASP instances, the ASP algorithms are evaluated on the following key performance indicators: (1) system configurations: roll and look-ahead periods are critical components to be assessed in the rolling horizon approach (Hozak and Hill, 2009). From the one hand, high rescheduling frequency may be connected with updated information on the traffic flow status. From on the other hand, low rescheduling frequency may cause less nervous changes of the scheduling plans over time due to minor disturbances. The length of the look-ahead period has clearly impact on the BB performance. (2) The computation time of the algorithms needs to be evaluated for each system setting. A dynamic approach may not be usable on-line only if the CPU requirement is too high. This may be a limitation on the number of viable system settings. (3) Delay propagation and disturbance robustness of the two ASP algorithms: entrance and exit aircraft delays are to be