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A new Airport Collaborative Decision Making algorithm based on Deferred Acceptance in a two-sided market

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ABSTRACT

The main objective of Airport Collaborative Decision Making (A-CDM) is to allow the stakeholders working together in more efficiently and transparently way to share data and to enhance Air Traffic Management (ATM) processes. The state-of-the-art approaches for A-CDM, currently implemented in many airports in both Europe as well as the United States, are considered mature and well accepted. In many cases it usually focuses on the information sharing and only takes into account the preferences of Air Traffic Control (ATC) units and those of the airlines. This inherently leads to only satisfying the preferences of a limited number of stakeholders within the airport area. In this paper we extend current state-of-the-art approaches to include the preferences of the Airport Management in the A-CDM. The model that we propose is based on the Deferred Acceptance (DA) allocation mechanism from Game Theory and addresses the problem of slot allocation in the Compression step of the classic CDM algorithm currently used. Dealing with this market by using the DA-CDM model enables assigning flights to slots through a one-to-one relationship that respects the preferences of each allocation and is always guaranteed to provide a stable result.

1. Introduction

The global demands of air transportation are increasing significantly over the last decade. The complexity of Air Traffic Management (ATM) has also impacted by various factors due to this increasing (Ball, Hoffman, & Mukherjee, 2010). To efficiently coordinate the movement of passengers, crew, and aircraft, either on the ground or in the air, is covered by many processes where security is a key point for all areas involved. This raises new challenges for several stakeholders, such as Air Traffic Control (ATC) units, regulation agents, airlines, and Airport Management companies, amongst others (Norin, 2008).

The major bottleneck created by this new scenario relates to airspace congestion, a problem usually addressed through the ground delay program (GDP), i.e., implementation of delays for aircraft still on the ground. When implemented and running, GDP involves the reallocation of landing slots in the airport. This results in a new flight arrival schedule for all the related airports. This situation is known as slot allocation problem (Vossen & Ball, 2006).

The management of these delays is based on Collaborative Decision Making (CDM), a paradigm where the major goal is the integration and data exchange between ATM agents. Despite being in use for over a decade, classic CDM implementation of GDP only allows the airlines to join the decision process for competing these available resources. The problem is that, in real world, more stakeholders affect and are affected in Air Traffic Management (ATM) process (Molina, Carrasco, & Martin, 2014).

A more current approach, called Airport CDM (A-CDM), currently implemented in the most airports in both Europe as well as the United States, also only takes into account the preferences of ATC agents and those of the airlines (Brinton, Provan, Lent, Prevost, & Passmore, 2011). This inherently leads to only satisfying the preferences of a limited number of stakeholders may cause lack of motivation and incentives for share true information (Schummer & Rakesh, 2013).

In this paper we extend current state-of-the-art approaches for CDM by designing a new model for ground delay program (GDP). This model, based on Matching Markets Mechanisms of the Game Theory, allows to include the preferences of the Airport Management, next to those of the ATC agents and the airlines.

The choice of Game Theory for our solution is due to the fact that such approaches enable the incorporation of the preferences of different stakeholders (Sönmez & Ünver, 2011) and have been successfully implemented in labor markets (Roth & Sotomayor, 1989), school admission process (Ergin & Sonmez, 2006), P2P networks (Gai et al., 2007), and organ donation markets (Roth,

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Sonmez, & Unver, 2004), and generally in domains that involve the problems of coordination and competition for resources (Balakrishnan, 2007; Pinheiro, Vinicius, Weigang, Melo, & Alba, 2007; Weigang, Alves, & Omar, 1997, 2010). Intelligent systems for the reallocation of flights, gate scheduling, and related problems (Chan, Chow, So, & Chan, 2012; Cheng, Ho, & Kwan, 2012; Genc, Erol, Eksin, Berber, & Guleryuz, 2012; Jo, Jung, & Yang, 1997; Kuwata & Oohama, 1997) have already been extensively applied in this context. Furthermore, the importance to use market models for the allocation of (scarce) resources is that Game Theory approach allows a stable result in the allocation.

Before moving on, a brief introduction outlining the CDM is in place. The Federal Aviation Administration (FAA)/airline interaction in a GDP under CDM is carried out in three steps, as illustrated in Fig. 1. The first step, Ration-by-Schedule (RBS) is intended for the creation of a schedule that (re) assigns flights to available slots. This step always preserves the original order of the arrival of flights (Vossen & Ball, 2006), and has as major drawback the fact that, in case of delays such as those caused by adverse weather conditions, the delay of aircraft increases proportional to their place in the queue. The effect of these delays is cumulative.

The second step of the CDM process, the Substitutions and Cancellations step, enables the airlines to communicate: (i) possible delays due to weather, mechanical failures and other operational problems, (ii) cancellations due to internal adjustments and/or strategic decisions regarding scheduled flights, and (iii) replacement(s) of flights among slots assigned to the airline by prioritizing some flights over others.

After the second step of the CDM process, the resulting schedule may contain unassigned slots. This is optimized in the Compression step of the CDM, as follows: when a slot is empty, the algorithm attempts to assign to it another flight from the same airline that has vacated the slot. If a feasible flight is found, then the exchange is implemented, otherwise a flight from a different airline is used for the exchange. If the latter is also not available, then the slot is left vacant.

Since its adoption, the Compression algorithm has been regarded as having several limitations. For example, it is not guaranteed that airlines report their cancellations due to the lack of incentive to do so (Schummer & Rakesh, 2013). This causes slots to remain unoccupied/unusable since other flights cannot be reallocated to these slots. Also, in some situations, the algorithm is known to generate unstable results (Schummer & Rakesh, 2013).

In more details, the model that we propose in this paper is based on the Deferred Acceptance (DA) allocation mechanism (Gale & Shapley, 1962) and addresses the problem of slot, i.e., resources, allocation in the Compression step of the classic CDM. Dealing with this market by using the DA-CDM model enables assigning flights to slots through a one-to-one relationship that respects the preferences of each allocation and is always guaranteed to provide a stable result (Vossen & Ball, 2006).

The outline of the paper is as follows. In Section 2 we present work related to our endeavour. The DA-CDM model that we propose in introduced in Section 3. A study of our proposed algorithm in relation to the state-of-the-art is presented in Section 4. Last, in Section 5, we conclude this paper and give directions for future work.

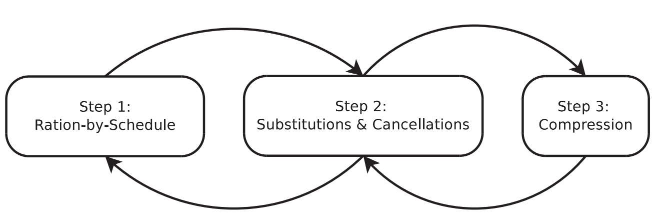

Fig. 1. The classic CDM architecture (Vossen & Ball, 2006).

2. Related work

In this section we give an overview of work related to our endeavour. Section 2.1 gives a brief introduction of CDM and the two versions of CDM currently implemented in airports in Europe and the United States, Airport CDM and Surface CDM, respectively. An overview of matching markets in general is given in Section 2.2. The Deferred Acceptance algorithm that we use to extend the current CDM approaches is presented in Sections 2.3 and then we present recent literature related to matching markets approach and ATM research in Section 2.4.

2.1. Collaborative Decision Making, the A-CDM and the S-CDM

CDM approaches have been considered since the 1990s within Air Traffic Flow Management (ATFM) (Ball & Hoffman, 1998; Hoffman, 1997). The basic premise for this adoption was the idea that the evolution in the processes of communication and information exchange between ATC agents and the airlines would lead to better decisions for the management of air traffic (Ball, Donohue, & Hoffman, 2005). The information exchange, at that time, between the Federal Aviation Administration (FAA) and the airlines allowed the formulation of GDP processes within the CDM framework.

In Europe, CDM is based on the exchange of data between stakeholders to improve shared situational awareness (Brinton et al., 2011). It provides a framework focused on the management of departure operations. This system is in use at many European airports, including Brussels, Munich, and Frankfurt. The A-CDM is divided in the following elements: (i) Information Sharing, (ii) Milestone Approach, (iii) Variable Taxi Time, (iv) Pre-departure Sequencing, (v) Adverse Conditions, and (vi) Collaborative Management of Flight Updates. An Airport CDM partner is a stakeholder airport, who participates in the CDM process. The main Airport CDM partners are: (i) Airport Operator, (ii) Aircraft Operators, (iii) Ground Handlers, (iv) De-icing companies, (v) Air Navigation Service Provider (ATC), (vi) Network Operations, and (vii) Support services (Police, Customs and Immigration, etc.) (European Telecommunications Standards Institute (ETSI), 2010). This is summarized in Fig. 2.

In the United States, the principles of the European A-CDM concept are used under the Surface CDM (S-CDM) denominator. This version of the algorithm recognizes the differences in airport operations that exist between Europe and the United States National Airspace System (NAS). The main differences relate to the facts

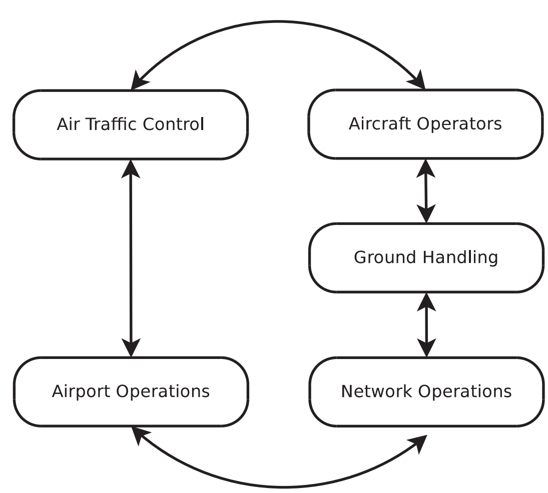

Fig. 2. Overview of A-CDM (Norin, 2008).