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Stable two-sided matching of slot allocation in airport collaborative decision making by top trading cycles mechanism

Márcio Augusto DA SILVA SOUZA [a], **Weigang LI** [a,*], **Reinaldo Crispiniano GARCIA** [b]

[a] *TransLab, Department of Computer Science, University of Brasilia, 70910-900 Brasilia, DF, Brazil*
[b] *Department of Production Engineering, University of Brasilia, 70910-900 Brasilia, DF, Brazil*

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Abstract The problem of capacity shortage in some airports needs to be dealt with sustainable solutions including a more efficient use of the existing runway slots at the airports. The Collaborative Decision Making (CDM) is an important approach applied to Air Traffic Management (ATM) to achieve this efficient use of the slots allocation. Using the Matching approach for two-sided markets of Game theory, the Top Trading Cycle CDM (TTC-CDM) algorithm developed in this research is an extension of the CDM approach aggregating the Ground Delay Program (GDP) of the air sector. The paper compared the developed TTC-CDM model to the existing models such as the conventional Compression algorithm in CDM, the Trade Cycle algorithm and the Deferred Acceptance CDM (DA-CDM) model to evaluate the performance of the proposed model. Through a case study, the results show the effective application of TTC-CDM model to slot allocation in ATM and also presents the advantage of considering the preferences of airport managers beside ATC controllers and airlines in the decision processing.
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1. Introduction

The airport congestion problem is one of the main challenges facing the air transport system. According to the EUROCONTROL (European Organization for the Safety of Air Navigation) forecasts, even after taking into account currently-planned infrastructure enhancements in Europe, 10% of the demand for air transport will not be accommodated in 2030, due to a shortage of airport capacity. Building more runways and new airport infrastructure is the obvious solution,

* Corresponding author.
E-mail address: weigang@unb.br (W. LI).
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however, the impact on environment and on land planning is a growing concern besides the current economic crisis, for which the government needs to put the budget balance into a long-term sustainable path. Therefore, more cost-effective solutions have to be found to tackle congestion than relying on expanding hard infrastructure. Any option ensuring a more efficient use of existing capacities allowing a more sustainable aviation system has to be contemplated.

In Air Traffic Management (ATM), slot allocation is one of these options even though it can neither generate additional capacity nor providing the same benefits as additional runway or terminal capacity. What's more, slot allocation cannot solve the many difficult issues created by a lack of capacity such as providing congested hubs with enhanced connections to all world regions. Nevertheless, slot allocation can be an effective tool for managing scarce capacity. An efficient assignment of slots is then definitely a cost-effective solution to be implemented at the airports. The Game theory and related algorithms can be applied to achieve this efficient assignment of slots.

In recent decades, Game theory has been used as a mathematical approach for modeling and analyzing strategies among multiple players. One of the reasons for its success is the diversity of actual and theoretical scenarios where it can be applied.[1–5] Furthermore, Game theory has been used to study the relationships between supply and demand of resources in societies.[6,7]

An application of Game theory includes the Matching approach, which aims to define, analyze and propose solutions to resource allocation problems in specific markets. Matching can be defined as a match among the players not violating the rules of the market. The Matching approach can then be applied to the problem of slot allocation in order to achieve an efficient allocation among the flights and the slots.

Previous studies have obtained an efficient slot allocation based on the preferences either of the airlines.[7–9] Therefore, this research aims to apply the Top Trading Cycle (TTC) algorithm of Matching theory to the slot allocation problem taking into account the preferences of the two already mentioned entities, the airlines and the airport managers in the Collaborative Decision Making (CDM) process. Once comparing the proposed Top Trading Cycle CDM (TTC-CDM) model to the existing models such as the conventional Compression algorithm in the CDM and, the Trade Cycle.[7–9]Another research developed a Deferred Acceptance CDM (DA-CDM) model algorithms[10] in the same process. But this paper applies the implemented model in the air traffic data from the Tancredo International Airport (SBCF) in the city of Belo Horizonte (Brazil). The results show the capabilities of the TTC-CDM and DA-CDM to the slot allocation issue including the preferences of the different agents involved such as the airlines and the airport managers.

This paper is structured in the following manner. Section 2 gives the background of this research including a brief introduction of the game and the matching theories. Section 3 provides the theory of the matching for two-sided market applied to the market of slot allocation. Section 4 describes the TTC-CDM model developed in this research and the Trade Cycle Schummer algorithm. A theoretical and a practical case study by TTC-CDM are presented in Section 5. The paper ends in Section 6, presenting relevant conclusions and future work.

2. Background

The Matching approach for a two-sided marketis a theory for the market with two distinct user groups providing network benefits. In the management of airports, using the airport runway can be considered asusing a limited resource, where at one time, only one aircraft can use this interval. The use of this intervalis made through the concept of slot, a right granted by the airport owner allowing the slot holder, airlines, to schedule a landing or departure during a specific time period. Therefore, the process of allocating the aircraft to the slots for landing or take off operations can be modeled as a "market".[1,7–9,11,12]

The increase in air traffic may result in congestion either at the airports or at the air sector. The management of the available air resources has been made by the CDM policy.[1] The CDM includes concepts of property, prioritization, justice and efficiency in resource allocation and aims to improve the exchange of information among the various airport agents such as Air Traffic Control (ATC), airlines and airport managers. Currently, the ATC classical model for slots allocation is based on the CDM, where airlines must provide reliable information in a timely manner to the ATC to achieve a better outcome.

The CDM process initially includes three steps: Ration-By-Schedule (RBS), substitutions/cancellations and compression. In the last step, the compression includes the re-allocation of the free slots after the step of substitutions/cancellations. The Compression algorithm integrates the airlines to fill the vacant slots according to pre-agreed rules of the involved agents.[2,13–15]

The CDM model seeks to include various interested parties so that the exchange of information results better decisions in the air traffic management.[1] Nevertheless, the CDM does not consider all stakeholders in the decision-making process related, but only the interests of the ATC agents and the airlines.[16] In order to solve the slot allocation issue, one can take insights of other applications where this allocation problem is also presented.

Notable market design applications have included the allocation of heterogeneous indivisible objects without monetary transfers, such as assigning pupils to public schools in a school choice program, or re-matching kidney patients with donors when patients have donors with incompatible kidneys. A common feature of such problems is the ranking of individuals needs in apriority order. The TTC approach and its variants emerge as a desirable solution to incorporate such priorities in the allocation process.[17,18]

The TTC algorithm in a two-sided matching environment has been an important method for achieving efficient outcomes as in school choice problems.[18] The TTC mechanism takes another perspective on how priorities must be treated. When applying the TTC to the school choice problem, each student points to his/her most favorite school and each school points to her top ranked student. When the cycles form, the students are matched with their favorite schools which then will be removed from the problem, and the algorithm continues with the remaining students and schools. This TTC mechanism allows students to trade their priorities through a very well-structured process.

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