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Rescheduling of flights during ground delay programs with consideration of passenger and crew connections

Jens O. Brunner *

Universitäres Zentrum für Gesundheitswissenschaften am Klinikum Augsburg - UNIKA-T, Neusässer Straße 47, 86156 Augsburg, Germany

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A B S T R A C T

We address the rescheduling problem by an airline when a ground delay program (GDP) is issued with mathematical programming techniques. The objective is to minimize delay measures, cost for crew and passenger misconnections, and cost of flight cancelations subject to several restrictions. We present a new linear integer model that incorporates all objectives. Using real-world and random data we present extensive computations to evaluate the model that is solved with standard software. High quality solutions are found quickly, i.e. within seconds. We show the significant effect of setting cost values for misconnections and cancelations on the new slot assignments.

1. Introduction

Organizing airport operations in an efficient manner is a critical task for airport operations management. Airlines are one of the big players in this business. During the last decade, for airlines it is more and more important to increase utilization since they face an immense cost pressure. A major challenge for airlines is capacity management. However, on the day of operation carefully planned crew and passenger connections can become infeasible due to external disruptions (like bad weather conditions) and/or internal failures (see Clausen et al., 2010). Among others, examples for perturbations are: severe weather, technical reasons, late or absent crew. Recent overviews of airline disruption management can be found in Kohl et al. (2007) and Clausen et al. (2010). When a perturbation takes place then the airline has to reschedule its flights. Common objectives are related to minimizing some delay performance measurements. For instance, the airline tries to reduce the maximum delay that would result from rescheduling (e.g., see Ball and Lulli, 2004).

Luo and Yu (1997) classify schedule perturbations at airports into three categories. The first category contains all perturbations caused by temporary capacity shortages whereas the second contains schedule disruptions resulted by permanent capacity shortages. The third category includes all schedule perturbations that are a result of a sudden change of capacity access. Our research falls into the third category. We consider perturbations that are caused by a so called *ground delay program* (GDP). Normally, a GDP is caused by bad weather conditions. A GDP, once it is issued by the *Federal Aviation Administration* (FAA), changes the accessibility of an airport over a specific period of time. In simple terms, the FAA proposes new arrival slot assignments to the airline for all affected flights by the GDP. However, the proposal is not at the airlines best interest in meeting internal objectives. But the airline is able, under some circumstances, to use the new arrival slots in a more efficient way. For instance, they might interchange slot assignments of arriving flights so that passengers can make

* Address: Wirtschaftswissenschaftliche Fakultät, Universität Augsburg, Universitätsstraße 16, 86159 Augsburg, Germany.
E-mail address: jens.brunner@wiwi.uni-augsburg.de

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their transfer connections. Due to legal reasons, these arrival slot swaps occur only internally at a given airport. In general, rescheduling will incur additional cost for the airline.

We use mathematical programming and present a model that can be used by the airline to reschedule their flights when a GDP is issued. We define four types of cost that might occur: Arrival delay cost from arrivals at the GDP airport, departure delay cost from departures at the GDP airport, misconnection cost from transfer passengers/crews at the GDP airport, and flight cancelations. Note that the misconnection cost can only be calculated when the arrival slot assignments are available. If slot assignments are not known then the misconnection cost cannot be calculated in advance. Consequently, in the literature a quadratic objective function has been used to consider misconnection cost (e.g., see Bard and Mohan, 2008). Our main contribution is the formulation of a linear integer programming model for the flight rescheduling problem including all types of cost. Furthermore, we present several model extensions that are of practical value. Using real-world data we verify the linear programming formulation to solve the flight rescheduling problem. Optimal assignments can be found within seconds and final solutions are superior to findings published in literature. In follow up experiments, we consider passenger connections as well and show that even then the formulation is able to find high quality solutions quickly.

The remainder of the paper is structured as follows. In the next section, we review the relevant literature and characterize our problem in the context of the literature. In Section 3, we describe the problem and then present the full new linear integer programming model. We also discuss the incorporation of two common performance measures into the formulation. In Section 4, we illustrate the computations using a real-world example with 71 flights affected by a GDP. We investigate the effect of different parameter setting on the final assignments and extend the input data by passenger connections. We discuss the results and highlight implications for airline management. We close with a summary of the results and some suggestions for further research in Section 5.

2. Literature

Handling perturbations based on random events in an airlines schedule has attracted some research in the past. Jarrah et al. (1993) tackle the schedule perturbation problem with temporarily capacity shortages with network models. The research falls into the first category of schedule perturbations (see Luo and Yu, 1997). The objective is either to minimize cancelations or delays. They apply a specialized algorithm to solve the network models.

Teodorovic (1985) studied disruptions that result from bad weather conditions. He developed a network formulation to model the problem with its dependencies. Minimizing the number of aircraft was the main objective. He proposed a simple dynamic programming heuristic. Vasquesz-Marques (1991) developed a software tool for American Airlines. The goal is to minimize ground delays. The basic modeling idea is similar to a traveling salesman problem. Aircraft are cities and the visiting sequence determines the new slot assignments to aircraft.

A similar problem to the one studied in this paper is the *ground holding problem* (GHP). The objective is to assign optimal ground delays in order to tackle capacity bottlenecks at some destination airports. The problem of minimizing the expected ground and airborne delay at a single airport is tackled in Andreatta and Romanin-Jacur (1987). The authors use a GHP formulation and develop a polynomial dynamic programming procedure. A major result of their work is that large savings can be achieved when uncertain capacity is considered. Mukherjee and Hansen (2007) consider also a single airport GHP and model it as a dynamic stochastic integer programming model. One major finding is that the choice of ground delay cost has a significant effect on the allocation policy. Furthermore, the authors develop an approach that enables arrival slot exchanges between airlines under the collaborative decision making initiative, which has been introduced by the major airlines in the US and the FAA to improve air traffic flow management. Related work that considers trading arrival slots between airlines during a GDP is given in Vossen and Ball (2006). The trading mechanisms allow airlines to optimize their cost functions.

A GHP with deterministic airport capacities is studied by Terrab and Odoni (1993). A minimum cost flow model is used to determine the optimal delay cost. The landing sequence is created based on a priority rule regarding the marginal delay cost of an aircraft. Extending the work, the authors investigate the stochastic capacity problem. Other related work is given in Richetta and Odoni (1993, 1994), and Rossi and Smriglio (2001). Integer programming models that take into account ground delays, airborne delays, and flight cancelations are studied by Vranas et al. (1994). In related work the research group developed a model that is used to update the delays when new information comes in Vranas et al. (1994b).

More recently Ball and Lulli (2004) look at the definition of the flight set in a GDP. The set is defined on the distance to the affected airport. The authors present several approaches for setting the distance parameter optimally. They investigate the effects on the test statistics: unrecoverable delay, average delay, and maximum delay.

Luo and Yu (1997) present an integer programming formulation for a GDP that either minimizes the maximum delay of outbound flights or the number of delayed aircraft which have a delay above some threshold value. They derive valid inequalities to improve convergence. To solve the problem the authors present a heuristic procedure to find high quality solutions. The performance of the procedure is evaluated by solving a real-world problem. In subsequent work, Luo and Yu (1998) present several models with different objectives like minimizing canceled or delayed flights as well as minimizing the maximum delay. A similar problem is studied in Bard and Mohan (2008). They present a new model that incorporates flight delays and missed connections. Since they failed to state the model without using a quadratic objective function for the missed connection cost, they use a dynamic programming formulation to model the problem. They include a branch and