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Optimization for gate re-assignment

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ABSTRACT

Disruptions such as adverse weather, flight delays and flight cancellations are a frequent occurrence in airport operations. A sophisticated gate assignment plan can be easily disrupted and serious consequences might be caused. Therefore, an efficient gate re-assignment methodology is of great importance for the airline industry. In this paper, we propose *an efficient gate re-assignment methodology* to deal with the disruptions, in which the objective function is to minimize the weighted sum of the total flight delays, the number of gate re-assignment operations and the number of missed passenger connections. Two multi-commodity network flow models are built for the pure gate re-assignment problem and the gate re-assignment problem with connecting passengers. Recognizing the inherent NP hard nature of the gate re-assignment problem, two heuristic algorithms are proposed to solve the models efficiently. The proposed models and algorithms are tested based on real-world data of a large U.S. carrier and computational results reveal that the proposed methodologies can provide high quality solutions within a short computational time.

1. Introduction

A good gate assignment plan plays an important role in utilizing gates efficiently and improving passengers' satisfaction. However, disruptions such as adverse weather, flight delays, flight cancellations, etc. are a frequent occurrence and a sophisticated gate assignment plan is easily disrupted (Zhang et al., 2015, 2016). Serious consequences might be caused if an efficient gate re-assignment plan is not available after the disruptions. Therefore, efficient and effective methodologies for the gate re-assignment problem after the disruptions are of great importance to maintain high service quality.

In the U.S. airline industry, gates are leased to airlines and thereby the airlines are responsible for planning gate operations, which is referred to as an airline-specific gate system (Tang and Wang, 2013). Some Asian airports have also adopted the airline-specific gate system. The alternative gate system, used in European and some Asian airports, is the airport-specific gate system, where the gates belong to airports and the airports are responsible for planning the gate operations. In this study, we are focusing on gate operations in the U.S. airline industry, specifically, the gate re-assignment problem in the airline-specific gate system. In the context of the U.S. airline industry, gate controllers of the airlines are in charge of the gate re-assignment planning. Inputs to gate re-assignment planning are the updated flight schedule and the current gate assignment plan. In the updated flight schedule, flights might be delayed or cancelled, which implies that the current gate assignment plan might not be feasible. Once infeasibility is detected by the gate controllers, a gate re-assignment pro-

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cess is triggered. In current practice, the gate re-assignment process is mostly conducted manually by the experienced gate controllers. They adjust the current gate assignment plan with some computer aided tools, mostly focusing on visualization.

Two main objectives are typically taken into consideration: minimizing total flight delays and minimizing the number of gate re-assignment operations. Flight delays are incurred due to holding either arrival or departure flights of an aircraft. In the gate re-assignment problem, an aircraft corresponds to one arrival flight and one departure flight. If an aircraft is held on the ground waiting for an available gate, holding time is defined as the delay of the arrival flight. If an aircraft is held at a gate to wait for late connecting passengers, holding time is defined as the delay of the departure flight. The total flight delays are defined as the summation of all flights' delays. The number of gate re-assignment operations indicates the number of aircraft not assigned to their initially planned gate.

Furthermore, gate related constraints, such as a gate can only accommodate certain aircraft types and two large aircraft cannot be assigned to two adjacent gates simultaneously, must be satisfied in the gate re-assignment process.

When the number of aircraft involved is low, the gate controllers can efficiently produce a gate re-assignment plan by trying different options. As the number of aircraft involved increases, the number of possible combinations is increasing significantly. It becomes hard to produce a gate re-assignment solution efficiently. Therefore, the airport gate controllers are in need of systematic optimization methodologies to help them efficiently solve the gate re-assignment problem.

In this research, we propose a novel optimization methodology for the gate re-assignment problem with four different options considered: (1) *Re*-assigning an aircraft to an alternative gate (including the parking area); (2) Delaying an aircraft's gate arrival time in parking to wait for an available gate; (3) Delaying an aircraft's push back time to wait for late transfer passengers; (4) Towing an aircraft to a parking area if there is a long waiting time between the arrival and departure flight. Two multi-commodity network flow models are formulated to consider the pure gate re-assignment problem and the gate re-assignment problem with connecting passengers, respectively. In addition to the two aforementioned objectives (minimizing total flight delays and the number of gate re-assignment operations), minimizing total passenger transfer distance and the number of missed passenger connections are included in the objective function. In both models, each gate is considered as a commodity and thus corresponds to one network. In each gate's network, a feasible sequence of aircraft assigned to it is defined as a flow in the network.

The first model can be efficiently solved by a commercial MIP solver, such as CPLEX. However, it is very challenging to solve the second model efficiently by a commercial solver due to its size and the quick response requirement. Therefore, two heuristic algorithms are proposed to solve the second model. The first heuristic algorithm is a guided diving heuristic algorithm based on general upper bound branching, in which at each iteration, multiple aircraft are selected and each of them is fixed to a gate clique based on the linear relaxation solution. If every aircraft is already assigned to a gate clique, the restricted mixed integer programming (MIP) model is then directly solved by a commercial MIP solver. In some situations, the length of the re-assignment time window might be very long and the first heuristic algorithm cannot produce a solution within the pre-specified timeframe. The second heuristic algorithm, a variable rolling horizon algorithm, is then proposed to deal with these situations. It decomposes the whole time window into multiple overlapping intervals with each interval corresponding to a problem of smaller size, which can be efficiently solved by the guided diving heuristic algorithm. Computational results revealed that the proposed algorithms can solve all instances within 5 min with the largest optimality gap smaller than 13%.

In literature, there are already several studies focusing on the gate re-assignment problem (Gu and Chung, 1999; Yan et al., 2009; Yan et al., 2011; Tang, 2011; Tang et al., 2010; Maharjan and Matis, 2011; Gosling, 1990; Srihari and Muthukrishnan, 1991; Jo et al., 1997; Su and Srihari, 1993; Cheng, 1997). However, few of them consider connecting passengers within their model formulations and solution algorithms. In a hub-and-spoke network, there are many passengers connecting at hub airports. A gate re-assignment plan ignoring connecting passengers has two negative impacts on the connecting passengers: (1) Delay of the arrival flight can make it impossible to catch another departure flight; (2) Transfer time for a passenger can increase causing insufficient time for the passenger to move from the arrival gate to another departure gate. If a connecting passenger misses his or her connection, high cost (compensation cost, passengers' goodwill loss cost, etc.) is incurred for both airports and airlines. Therefore, it is essential to consider connecting passengers in the gate re-assignment problem to minimize the number of missed passenger connections, and thereby, to minimize the total gate re-assignment cost. To the best of our knowledge, Maharjan and Matis (2011) considered the transfer passengers in their gate re-assignment model. However, there are two limitations of their study. First, it only considered minimization of the passengers' transfer distance but ignored probabilities of missed passenger connections. If a passenger misses his or her connection, the transfer distance is irrelevant; second, a quadratic model was proposed but no algorithm was provided to solve the model. Recognizing the gap between practical requirements in the industry and current gate re-assignment methodologies, we realize that an efficient methodology for the gate re-assignment problem fully considering factors of connecting passengers is highly desired in the industry.

To fill this gap, we propose a novel methodology for the gate re-assignment problem. Our contributions can be summarized as follows:

(1) A more efficient multi-commodity network flow model is built for the gate re-assignment problem;
(2) An extended multi-commodity network flow model is built where minimizing the passenger transfer distance and minimizing the number of missed passenger connections are both considered;
(3) A diving heuristic algorithm and a rolling horizon algorithm are proposed to efficiently solve the proposed model.