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A heuristic approach for solving an integrated gate reassignment and taxi scheduling problem

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ABSTRACT

Capacity limitation of airport ground operation is one of the major limiting factors in air traffic operation. The congestion on the gate and taxiway causes severe delay and propagate effect on the flight schedule. This paper considers the problem of integrated gate reassignment and taxiway scheduling, in which complex constraints related to runway restriction, gate allocation and taxiway conflict are all incorporated when determining the schedule. To solve this problem, we propose a novel heuristic approach. First, all possible aircraft schedules are enumerated by disretizing the waiting time along the path. Then, the cost is evaluated for each schedule and the conflict detection is conducted to generate constraint sets. Finally, we propose a set partition model, in which each decision variable denotes a candidate schedule that takes into account the possible constraints when generated. This method is compared with a sequential method that solves gate reassignment and taxiway scheduling problem separately. Computational results highlight the strength of our method.

1. Introduction

According to International Civil Aviation Organization (ICAO), nearly 3.2 billion passengers utilized air transport for their business and tourism needs. Correspondingly, aircraft departures reached 33 million globally in 2014. Under such huge air traffic volume, most of the hub airports are already operating at or close to capacity (Clare and Richards, 2011), and a large scale of delay on the airport surface is observed. Moreover, air traffic demand is forecasted to grow annually at a rate of 5%. Therefore, the surface delay is expected to exacerbate in future. To alleviate airport surface delay, one straightforward way is to expand current infrastructure at the airport, which is however costly and hard to be completed in short-term. Another option is to utilize optimization approaches to efficiently schedule surface movements. There are three key components within airport surface management, namely, *runway scheduling problem* (**RSP**), *gate assignment problem* (**GAP**) and *taxi scheduling problem* (**TSP**). Among them, RSP attracts most attention with various techniques and tools being developed to efficiently meet different requirements and objectives. Whereas, this shifts the bottleneck further to taxiway and apron areas, which have not been fully considered in the literature. To fill this gap, GAP and TSP are the major focuses of this paper. GAP is one of the most important and complicated airport management topics. The dedicated planning for gate assignment is to find an assignment of flights as well as start and completion times for processing an aircraft, which usually completed one day before operation. TSP determines the routing and scheduling of aircraft on the taxiway, using gate pushback time and runway landing time as input for departures and arrivals respectively.

In current practice, airports utilize complicated decision support tools to efficiently manage airport surface movements. If no flight delay occurs, the pre-determined surface schedule can run smoothly. However, due to the uncertainty resulting from unexpected events such as adverse weather, malfunction of aircraft, and passenger boarding and former disembarking process, the actual landing time for arrivals and pushback ready time for departures divert frequently from the planning time. These delays may be propagated as secondary delays to other flights in the network. In such case, the initial surface schedule might be non-optimal or even infeasible, which is required to be adjusted or recovered. In most occasions, such adjustment is conducted manually by

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experienced managers. However, considering the severe congestion of airport, exploring a feasible schedule is already challenging, let alone the optimal solution. Therefore, it necessitates an efficient optimization approach to re-schedule gate assignment, which is known as *gate reassignment problem* (**GRP**), and corresponding taxiway movement for disrupted flights.

In the literature, most research dealt with taxiway (Marin, 2006; Balakrishnan and Jung, 2007; Atkin et al., 2010a, 2012; Ravizza et al., 2014; Godbole et al., 2016; Guepet et al., 2016) and gate (Ernst et al., 1999; Beasley et al., 2000, 2001; Bianco et al., 2006, Brentnall, 2006; Pinol and Beasley, 2006; Dorndorf et al., 2007; Balakrishnan et al., 2010, Bennell et al., 2011; Yu et al., 2011; Salehipour et al., 2013; Ghoniem et al., 2014; Briskorn and Stolletz, 2014; Bouras et al., 2014; Lieder et al., 2015, Faye, 2015; Sabar and Kendall, 2015; Ghoniem et al., 2015, Bennell et al., 2016; Yu et al., 2016; Zhang and Klabjan 2017) separately. Based on these approaches, GRP and TSP are typically solved in a stagewise manner (Malik et al., 2010). However, one can easily find the tight interactive relationship between gate and taxiway operations, which indicates that the integrated consideration in most cases can lead to better solutions. There are several research attempts along this direction. Atkin et al. (2010b, 2012), Stergianos et al. (2015) considered gate operation together with only a small extension on nearby ramp area. Maharjan and Matis (2012) built a multicommodity network flow model to solve the GAP, where the expected travel time between runway and gate is incorporated. The potential negative impact of gate holding on the free access of arriving flights to the terminals was pointed out by Kim and Feron (2014), which investigated the gate assignment on the departure metering. The departure process was built as a queuing model that consists of a take-off model and taxi-out time estimates. Interferences between aircraft movements at ramp area were incorporated into the objectives of gate assignment model by Kim et al. (2013), where the taxi time is calculated based on the shortest path between runway and gate. In the above three research, potential conflicts on taxiway are neglected. Neuman and Atkin (2013) pointed out the importance of taking into consideration possible conflicts at taxiway, while only the area around the gates was considered in the experiments.

To the best of our knowledge, there is no paper explicitly considering the gate reassignment and taxi scheduling simultaneously. To fill this gap, we consider the *integrated gate reassignment and taxi scheduling problem* (**IGRTSP**). The complexity of IGRTSP comes from three major aspects: (i) each sub-problem alone is an NP-hard problem. TSP needs to determine both the aircraft routing and timing issues on taxiway segments, modeling the conflicts presented between the aircraft using the limited capacity on the airport surface. Note that in a practical situation, there are usually more than one alternative taxiway paths for each aircraft between runway and gate, and this enlarges solution space. GRP considers various possibilities on delay time and gate compatibility issues, resolving the gate and apron conflict; (ii) the taxiway operation and gate allocation are tightly linked and interacting with each other, which makes it challenging to explore an optimal solution for both sides; (iii) the problem is strongly dynamic in nature. In a practical situation, due to the exact ready time for pushback for departure flights and landing time for arrival flights are generally known only less than 1 h (60 min) in advance, which requires an efficient methodology to obtain fast solutions.

To solve IGRTSP in real-time, in this paper, we propose an efficient heuristic approach. The major contributions are listed as follows:

- Comprehensive practical constraints at the airport are considered, which makes our solution more practical in reality.
- An efficient heuristic for IGRTSP is proposed.
- Extensive numerical studies are conducted to validate the high efficiency and effectiveness of the integrated model over the sequential model.

This paper is organized in the following manner. In Section 2, we describe the background of IGRTSP. In Section 3 the heuristic approach is described in detail. Section 4 is the numerical study. Section 5 concludes the paper and provides some future directions for research on this topic.

2. Problem description

In this section, we present a formal specification of IGRTSP. There are three major infrastructures at the airport used by the aircraft: *gate* distributed around the terminal area, *taxiway* connecting the runway and gate area, and *runway* for take-off and landing. Gates are used for aircraft parking, passengers disembarking and embarking, which are important as they connect the air-side and land-side. Therefore, the assignment of gates affects not only the ramp operations, but also the passengers' satisfaction. After being pushed back from the gates, aircraft then move on the taxiway and forward to the runway for take-off. In this paper, the whole airport surface area is modeled as a graph, where nodes denote the gate, runway entry and exit, and taxiway intersections, and arcs denote the taxiway segments. As taxiway segments usually can only accommodate space for one aircraft, possible conflict on taxiway should be detected and resolved in advance. The path of an arriving aircraft starts from the runway exit, and ends at a gate through the taxiway segments, and the path of a departing aircraft starts from its gate, and ends at the runway entry point through the taxiway segments.

IGRTSP aims to find a best taxi and gate schedule for flights which complies with the runway schedule as well as the restrictions associated with gates and taxiway. For a departure, the output schedule specifies the approaching path from its gate to the allocated runway entry, with the waiting position and corresponding duration. For an arrival, the output schedule additionally specifies its final gate. The objective is to minimize the fuel cost, gate (for arrivals) and runway (for departures) delay, and gate swap cost. Runway delay is defined as the extended time with respect to the target take-off time for departures. Gate delay is defined as the extended time with respect to the target gate reaching time for arrivals. Taxi time is the actual time taken by aircraft on the taxiway with engines on, including the waiting and moving time. If an arriving aircraft is reassigned to a gate that is different with the original gate, a swap cost is incurred. In this paper, the swap cost is assumed to grow linearly with the total number of passengers on the aircraft.

We assume the aircraft traveling speed on the taxiway is constant. On taxiway, only one aircraft can move simultaneously as a taxi lane is essentially a single line and allows one-way traffic at any time instant. When there is a conflict ahead anticipated, the aircraft will wait on the taxiway segment (arc) rather than the intersection (node). Note that runway scheduling is not considered in this paper, the reference runway time serves as an input for optimization process. Specifically, for an arriving aircraft, the landing time on the runway is known. After landing, the aircraft must immediately leave the runway to taxiway, to avoid the influence on the following aircraft from the air. The target gate reaching time is obtained by assuming aircraft moving on the shortest path without any stops to the original assigned gate. A maximum delay limit is set for each aircraft to prevent overlong individual delay. For a departing aircraft, the expected push-back/gate clear time is known and the reference runway time serves as the target runway time.