Flight Gate Allocation: Modells, Methods and Robust Solutions

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Abstract We consider the problem of assigning flights to airport gates. We examine the general case in which an aircraft serving a flight may be assigned to different gates for arrival and departure processing and for optional intermediate parking. Restrictions to this assignment include gate closures and shadow restrictions, i. e. the situation where certain gate assignments may cause blocking of neighboring gates. The objectives include maximization of the total assignment preference score, a minimal number of unassigned flights during overload periods, minimization of the number of tows, maximization of a robustness measure as well as a minimal deviation from a given reference schedule. We discuss exact as well as ejection chain based solution procedures which are based on modelling as resource constrained project scheduling problem or as a clique partitioning problem.

Keywords airport gates · robustness

1 Introduction

Due to the rapid growth of air transport traffic, how to efficiently allocate gates at airports to coming or outgoing flights has become one of the most important problems which managers of airlines and airports have to concern about. The problem, which can be modelled as a scheduling problem, is often referred to as flight gate scheduling or gate assignment problem. Gate scheduling is concerned with finding an assignment of flights or aircraft to terminal and ramp positions (gates), and an assignment of the start and completion times of the processing of a flight at its position. It is a key activity in airport operations. With the increase of civil air-traffic and the corresponding growth

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of airports in the past decades, the complexity of the task has increased significantly. At large international airports, several hundreds of flights must be handled per day. The task is further complicated by frequent changes of the underlying flight schedule on the day of operation, such as delays or aircraft changes. Gates are scarce and expensive resources. Increasing the resource supply involves a time-consuming and costly re-design of terminal buildings or the ramp and is usually not feasible in the short run. It is therefore of great economic importance for an airport or terminal operator to use the available gates in the best possible way. The gate assignment influences the quality of passenger service in manifold ways, e.g., through the required walking distances. Another problem well known to many passengers is that arriving flights sometimes have to wait on the ramp before traveling to their final position, because the assigned gate is still occupied by another flight, a situation often caused by a poor gate assignment or by failure to adapt an initial assignment to updates of the flight schedule. The gate assignment also affects other ground services. A good assignment may reduce the number of aircraft tows required and may lead to reduced setup times for several ground service activities on the ramp as well as in the terminal. The problem of finding a suitable gate assignment usually has to be addressed on three levels. Firstly, during the preparation of seasonal flight schedule revisions, the ability to accommodate the proposed flights must be examined. Secondly, given a current flight schedule, daily plans have to be prepared before the actual day of operation. Thirdly, on the day of operation, the gate schedule must be frequently altered to accommodate updates or disruptions in the flight schedule (reactive scheduling).

The main input for gate scheduling is a flight schedule with flight arrival and departure times and additional detailed flight information, including pair-wise links between successive flights served by the same aircraft, the type of aircraft, the number of passengers, the cargo volume, and the origin or destination of a flight, classified e.g. as domestic or international. The information in the flight schedule defines the time frame for processing a flight and the subset of gates to which it can or should be assigned, taking into account, e.g., aircraft-gate size compatibility, access to governmental inspection facilities for international flights, etc. It is worth pointing out – from a practical point of view – one of the most important issues of gate scheduling: a gate schedule should be insensitive to small changes of input data; in other words schedule flexibility is required. Obviously, the input data of any flight gate scheduling problem is subject to uncertainty and may change over time. Input data uncertainty in gate scheduling may have several reasons: 1) flight or gate breakdown, 2) flight earliness or tardiness, 3) emergency flights, 4) severe weather conditions, 5) errors made by staff and many others. For example, a tardy arrival of one aircraft may generate a chain of delayed arrivals for other aircraft which have been assigned to the same gate. In the worst case, this may lead to a “domino effect” and finally require a complete rescheduling, a situation which is highly undesirable. Gate scheduling is a task which arises daily. The schedules are commonly determined day by day. As it is desirable for passengers and flight crews that a given flight is assigned to the same gate throughout the week, the previous day’s schedule is often used as a reference schedule to ensure that repeating flights are as far as possible assigned to the same gate on each day.

2 The Problem and Recent Methods

While at the airport, an aircraft goes through the three stages of (1) arrival processing, (2) optional intermediate parking, depending on the length of the ground time, and (3) departure processing. In contrast to previous models, these stages are considered as separate entities that can potentially be assigned to different positions if necessary or advantageous. The aircraft may then have to travel between the assigned arrival, parking, and departure positions. In addition to assigning the three stages to positions, the start and completion times of processing at a position, which can vary within certain time windows, have to be assigned. Previous optimization based (e.g. Haghani and Chen [17] as well as Mangoubi and Mathaisel [21]) as well as knowledge based approaches (e.g. [16]) have usually modelled the problem by representing the arrival, parking, and departure stages as a single entity to be assigned to the same position. The objective function most frequently used is the minimization of walking distances for arriving, transferring, and departing passengers. The problem then becomes similar in structure to a quadratic assignment problem. However, for many airports, this modelling approach leads to an over-simplification that does not adequately reflect the original decision problem. The key idea behind our models is to look at the problem as a special multi-mode resource constrained scheduling problem [15] integrating constraint propagation [14], with a multi-criteria objective function as well as a representation as a clique partitioning problem, see [13]. The goals include the maximization of a total flight-gate preference value, the minimization of the number of tows, and the minimization of deviations from a reference gate plan. The constraints of the model include minimal arrival and departure gate times, the continuous assignment of an aircraft to a gate or tow tractor during its ground time, the consideration of towing durations and connection times, sequence dependent setup times between two aircraft served at the same gate, wing tip proximity or shadowing restrictions between aircraft at neighbouring gates, as well as the temporal un-availability of gates for certain aircraft types. In practice, a good solution to the problem can prevent congestion and inconvenience at the airport. A number of analytical models have been developed that help airport authorities more effectively assigning daily flights to gates. For example, Braaksma [7], Babic et al. [1], Mangoubi and Mathaisel [21], Vanderstraetan and Bergeron [22], Bihr [2], Zhang et al. [26], Cheng [9], Yan and Chang [23], Haghani and Chen [17], Bolat [5, 6], and Yan and Huo [24]. For a more detailed introduction we refer to [12].

Mathematical models of assigning flights to gates have been presented e. g. in [10], [11], [19], and [8]. A detailed survey has been presented in [12]. However, a robustness goal has hardly been included in these approaches. Considering buffer time in between two activities at a gate has been proposed by [18] and [5].

As already mentioned, the deterministic gate assignment problem can be modeled as a quadratic assignment problem or a linear integer program. Up to now, the most popular idea of incorporating robustness into gate scheduling is applying buffer times. For example, Hassounah and Steuart [18] show that planned buffer times could improve schedule punctuality. Yan and Chang [23] and Yan and Huo [24] use in their static gate assignment problems a fixed buffer time between two continuous flights assigned to the same gate in order to absorb the stochastic flight delays. In [23] Yan and Chang develop a multi-commodity network flow model. Moreover, they use Lagrangian relaxation with sub-gradient optimization and some heuristics to solve the gate assignment problem. In [24] Yan and Huo formulate a dual objective 0-1 integer programming model for the aircraft position allocation. The first objective tries to minimize passenger walking time while the second objective aims at minimizing passenger waiting times. The authors argue that, e.g. during peak hours, an aircraft might have to wait for an available gate, and hence passengers have to wait on the aircraft until a gate is available. A simulation framework is proposed in [25] by Yan et al., which is not only able to analyze the effects of stochastic flight delays on static gate assignments, but can also evaluate flexible buffer times and real-time gate assignment rules.

Recently some authors try to take into account the dynamic character of the gate assignment problem. A delayed departure may delay the arrival of another aircraft scheduled to the same gate, or require the flight to be reassigned. When gate idle times are distributed uniformly among the gates, the probability that the delayed departure will still be earlier than the arrival of the next flight is maximized [20]. One of the first attempts to realize an approach aiming at robust schedules is due to Bolat [3–6]. The author proposes to utilize gates as uniformly as possible to provide schedule robustness to small changes of input data. Furthermore, mathematical models and (optimal and heuristic) procedures are proposed to provide solutions with minimum dispersion of idle time periods for the gate assignment problem.

3 The Clique Partitioning Problem

We are concerned with the question of assigning a number of flights, or activities, to a number of gates or alternatively to a dummy gate. Given real life data from airports that work to capacity, feasible assignments might not exist. Thus, a dummy gate with unrestricted capacity is introduced. A flight activity can be an arrival, a parking or a departure activity of an aircraft. Each activity may be assigned to a different gate which would be handled in real life by towing the aircraft. We define the number of flight activities to be assigned by n and the number of gates without the dummy gate by m. Every activity and every gate is represented by a vertex of a complete graph.
Clique partitioning (CPP) is the problem of partitioning the set of vertices of a complete edge-weighted graph into a non-defined number of subsets (cliques) such that the sum of the weights of all clique edges is maximized. Thus, we will choose appropriate edge weights for this complete graph in order to find a clique partition satisfying some restrictions and maximizing certain objectives. Our goal is then to find such a clique partition with a maximum weight. The CPP is an NP-complete problem. Therefore exact algorithms are usually not applicable for real life problems where $n > 800$ and $m > 100$ are common. However, there exist efficient heuristics for solving the CPP.

Further restrictions are included as follows:

Gate Closures: Gates may be closed for certain flight activities. These restrictions are motivated by aircraft that are too big for some gates, or by other technical factors such as gates that exclusively serve national or international flights. However, flight activities can always be assigned to the dummy gate. If a gate k is closed for flight activity i we choose $w_{ik} := -\infty$ as edge weight.

Overlapping: Each gate, except the dummy gate, can serve at most one flight activity at a time. Therefore any two flight activities may not be assigned to the same gate if they either have an overlapping ground time or if their ground time intervals are so close that the gate setup time cannot be maintained. For all such pairs of activities i and j we set $w_{ij} := -\infty$ for the edge weight of the corresponding vertices.

In practical applications one can also find so called shadow restrictions, which prohibit specific assignments of two flight activities to specific gates. A major reason for the shadow restrictions is that two big aircraft cannot be assigned to neighbor gates without touching wing tips. Consequently these restrictions do not apply to the dummy gate and only apply for flight activities which overlap.

The objective for the flight gate scheduling problem consists of several weighted objectives. The weights for each objective were determined by airport and airline managers using e. g. priority classifications for aircraft or gates.

Preference Score: For every feasible assignment of a flight activity to a gate there is a preference score. These preference scores take into account priority rules, e. g. for bigger aircraft or for favored gates. They are determined by airport or gate managers.

Tows: As mentioned before, a flight activity corresponds to an arrival, a parking, or a departure of an aircraft. If two succeeding activities (i. e. the arrival and the parking activity or the parking and the departure activity of an aircraft) are assigned to different gates, then a tow is necessary. It is desirable to keep the number of tows low, or in other words to keep the number of succeeding activities that are assigned to the same gate high.

Robustness: Small flight delays are very common. Therefore it is not only reasonable to force overlapping flight activities to be assigned to different gates, but also flight activities separated by a very small time buffer.

Another objective of practical importance is the minimal deviation from a reference schedule: A subset of the flight activities appears on a daily basis. I. e. on the previous day there might have been a flight activity with the same origin and arrival time or the same destination and departure time as today assigned to some gate. It is desirable to assign such a flight activity to the same gate as it has been on the day before. If we are just concerned with a one period model, i. e. only the assignment of the previous day is given and we are not concerned about the fact that today's assignment could be a reference schedule for the following day, then it is easy to insert the objective of minimal deviation from the previous days' assignment.

The addition of the reference schedule objective to the flight gate scheduling problem is reasonable: On the one hand it favorably meets the passenger satisfaction by means of a more concise gate schedule and on the other hand it eases routines of the airport staff. However, considering a reference schedule changes the existing problem. For all other objectives and restrictions it is realistic to assume that they are completely independent from decisions made on previous days and that they do not influence decisions on the following days. As long as a reference schedule objective is not included, it is therefore reasonable to understand the flight gate scheduling problem as a one period assignment problem, which has to be solved on a daily basis. Since today's assignment largely affects the reference schedule objective of tomorrow's flight gate scheduling problem, we usually are facing a multiple period problem.

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