Theoretical aspects of multicriteria flight gate scheduling: deterministic and fuzzy models

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Abstract This paper addresses the airport flight gate scheduling problem with multiple objectives. The objectives are to maximize the total flight gate preferences, to minimize the number of towing activities, and to minimize the absolute deviation of the new gate assignment from a so-called reference schedule. The problem examined is a multicriteria multi-mode resource-constrained project scheduling problem with generalized precedence constraints or time windows. While in previous approaches the problem has been simplified to a single objective counterpart, we tackle it directly by a multicriteria metaheuristic, namely Pareto Simulated Annealing, in order to get a representative approximation of the Pareto front. Possible uncertainty of input data is treated by means of fuzzy numbers.

Keywords Airport gate assignment · Multiple criteria optimization · Project scheduling · Time windows · Pareto simulated annealing · Fuzzy flight gate scheduling

1 Introduction

Scheduling problems arising in practice almost always have a multiple criteria nature, a fact which was indicated in Panwalkar et al. (1973) for the first time. Nevertheless until recently, research in scheduling continued to deal mainly with single objective problems and, hence, scheduling theory and multicriteria optimization so far have developed separately. One of the first attempts to improve the situation and to incorporate multicriteria approaches into scheduling theory was done in T’Kindt and Billaut (2002). In this research, it has been shown that a solution which is optimal with respect to one single objective might be arbitrarily bad with respect to other criteria and thus will be unacceptable for the decision maker. Having one solution as output of single objective optimization may not be sufficient for finding a solution which is most preferred by the decision maker. Instead, one should try to produce a tuple of efficient solutions which are both well approximated and representative to give a decision maker more freedom in his or her choice. So it can be generally concluded that any problem arising in practice can hardly be properly solved without multicriteria optimization techniques. Nowadays this is commonly accepted, a fact which will stipulate scheduling research within the multiple criteria framework.

Due to the growth of air transport traffic (it has roughly doubled since the early 1980s) techniques for managing and allocating airport and airline resources in a dynamic operational environment effectively and efficiently have gained an ever-increasing interest. Strong competition between airlines and the demand of passengers for more comfort have lead to complex planning problems that require new models and methods. The scheduling problems nowadays faced by airport and airline managers are even more complicated than most other traditional scheduling problems. Classical flight
gate scheduling deals with assigning aircraft to their terminal stand positions, which are known as ‘gates’. We refer the reader to Dorndorf et al. (2006) where a comprehensive survey of existed models and solution techniques is presented.

The most recent models represent the flight gate scheduling problem (FGSP) as a quadratic assignment problem (QAP) with multiple objectives (see, e.g., Ding et al. 2004a, 2004b, 2004c; Xu and Bailey 2001; Yan and Huo 2001), or as a resource- and time window-constrained project scheduling problem (RCPSP; see, for instance, Dorndorf 2002). It should be emphasized, that these two distinct models generally highlight two different strategies adopted in the major airports of the United States and the European Union, respectively. While these models have been developed for different application domains both adopt multiple criteria. Moreover, both are very hard to solve even in the single objective case. Therefore, for practical purposes, it seems to be promising to combine different well-known metaheuristic approaches (simulated annealing, tabu search, genetic algorithms) providing a good approximation of optimal solutions with acceptable running times with multicriteria optimization concepts. In Drexl and Nikulin (2008), for example, such an approach has been developed for FGSP modeled as QAP with multiple objectives. In this paper, we elaborate such an approach for FGSP modeled as RCPSP with multiple objectives.

The paper is organized as follows. In Sect. 2, the problem is formulated mathematically. In Sect. 3, a survey and synthesis of algorithms developed for RCPSP type models is given. Section 4 presents a detailed description of a particular multicriteria procedure, namely Pareto Simulated Annealing. Section 5 is devoted to the concepts of fuzziness, fuzzy numbers and fuzzy arithmetic. In Sect. 6, we show how the deterministic problem can be transformed into a fuzzy counterpart problem. We present the way of basic problem parameters’ fuzzification based on observed explicit distributions of earliness and tardiness. The modified version of the Pareto Simulated Annealing is discussed.

2 Mathematical model

2.1 General description

Traditionally, a well-constructed flight gate assignment must satisfy two restrictions:

- no two aircraft may be assigned to the same gate simultaneously, i.e., one gate can process only one aircraft at the same time,
- every flight must be assigned to exactly one gate, that is, an aircraft cannot be moved or reassigned to another position once it has been located at a terminal gate.

Note that the models with such strict restrictions represent the strategy adopted for United States airports. This strategy considers arrival, departure and intermediate parking stages as a single non-split entity to be assigned to the same position.

In the model presented in this paper, we relax the assumption that a flight has to be assigned as a whole to one and only one gate. The model uses a fairly large number of apron stands for passenger embarking and disembarking reflecting scarce terminal space. As indicated above such a model covers the situation encountered frequently at European airports.

Sometimes, special constraints are introduced mainly because of a particular airport configuration. The most commonly used such constraint is that any two large-type aircraft cannot be assigned to neighboring gates. Below we will refer to such constraints as ‘shadow’ restrictions.

The mathematical formulation of the problem we consider in this paper was originally proposed in Dorndorf (2002). The purpose of the model is to assign three possible aircraft activities (arrival; optional intermediate parking, the length of which depends on the ground time; departure) to the available airport flight gates and to schedule start and completion times of the activities at the positions.

The model has several new ingredients:

- First, the activities are modeled separately and, hence, can potentially be assigned to different positions. The aircraft can be moved to another position using tow tractors, a procedure which is called towing.
- Second, in contrast to the standard objective function commonly used (which minimizes passenger walking distance), a multiple objectives formulation is introduced. As indicated above, three objectives were considered to be the most important:
  - maximization of total flight-gate preferences,
  - minimization of the number of towing activities,
  - minimization of the absolute deviation of the new gate assignment from a so-called reference schedule.

The first and second objective are oriented towards convenience for airport services, whereas the third objective takes into account passenger comfort. The overall goal is to optimize all the objectives simultaneously. In fact, the multiple criteria nature of the problem makes it very unlikely that a so-called ideal optimal solution which simultaneously optimizes all objectives does exist, and can be found and verified in reasonable time. Therefore, one has to determine a solution that provides an appropriate compromise between all the different objectives while assuring a set of hard constraints.

In the following subsection, a mathematical formalization of the problem is presented.