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The use of meta-heuristics for airport gate assignment

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ABSTRACT

Improper assignment of gates may result in flight delays, inefficient use of the resource, customer's dissatisfaction. A typical metropolitan airport handles hundreds of flights a day. Solving the gate assignment problem (GAP) to optimality is often impractical. Meta-heuristics have recently been proposed to generate good solutions within a reasonable timeframe. In this work, we attempt to assess the performance of three meta-heuristics, namely, genetic algorithm (GA), tabu search (TS), simulated annealing (SA) and a hybrid approach based on SA and TS. Flight data from Incheon International Airport are collected to carry out the computational comparison. Although the literature has documented these algorithms, this work may be a first attempt to evaluate their performance using a set of realistic flight data.

1. Introduction

A metropolitan airport has more than fifty gates and handles hundreds of flights a day for thousands of passengers. Gate assignment is a complicated problem as it deals with a wide range of interdependent resources including aircrafts, gates, gate facilities, and crews (Dorndorf, Jaehn, & Pesch, 2008). Improper assignment may result in flight delays, poor customer services, and inefficient use of gate facilities. Typically gates are first pre-assigned to the scheduled arriving and departing aircrafts ahead of time to ensure a smooth operation. This is commonly known as the gate assignment problem (GAP). Although GAP produces only a static schedule, it provides a basis for making last-minute changes to handle operational uncertainty caused by unexpected events such as flight delays, machine failures, and severe weather conditions.

Many GAP models and solution methods have been developed in the literature. Static and stochastic models are formulated. Exact and heuristic solution methods are proposed. The use of exact solution methods is certainly preferable. However, Obata (1979) argues that these exact methods are unable to solve realistic problems. Hence, heuristic methods have been extensively studied. Recent research focuses on meta-heuristics.

In this research, we adopt a GAP model commonly used in the literature and examine the use of meta-heuristics. Specifically, we consider genetic algorithm (GA), simulated annealing (SA), tabu search (TS), and a hybrid approach based on SA and TS. To assess the performance of these meta-heuristics, we collect flight data from Incheon International Airport (ICN). ICN is a busy hub in East Asia and provides a practical case for our computational comparison.

Although these meta-heuristics have been well documented in the literature, they have not been comprehensively compared to one another in terms of solution quality and computational efficiency. Also, all the previous studies use generated data to test their algorithms. In this work, we compare the three well-known meta-heuristics and a hybrid approach together using a common set of realistic flight data. To the best of our knowledge, this is a first attempt.

This manuscript is organized in this way. We will provide a literature review in the next section. Section 3 discusses a common GAP model. Section 4 presents the three GAP meta-heuristics, namely GA, SA, TS and a hybrid approach. In Section 5, we describe our flight data collected from ICN. One week data is used to evaluate these algorithms. Section 6 provides concluding remarks.

2. Literature review

Many solution packages (e.g., Avient, Quintiq, and Sabre) are commercially available to support airport operations. These packages typically have a gate management module for airport staff to assign aircrafts to different gates. The software developers of these systems do not provide the details of their algorithms in the literature. However, they claim that their modules take into account all GAP applicable rules and constraints such as arrival patterns, airline rules, airline preferences, and ground operations, etc. They also assure that their systems are able to handle last-minute changes and disturbances.

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2.1. GAP formulations

We may classify GAP models into two types: *static models* and *stochastic and robust models*. Typically, a static assignment is prepared a week or even a month ahead of time. This assignment considers only deterministic factors (such as airport layout, number of flights and number of passengers) but not stochastic factors (such as flight cancellations and delays). In most cases, airport operators need to assign all the aircrafts to the gates in the terminal and try to accommodate the traveling needs of all passengers while keeping a smooth ground operation.

A static assignment may become infeasible if there are flight delays, changes in weather conditions, or machine breakdowns. Obviously, sudden changes and disturbances are inevitable. However, if the assignment is robust enough, it will help the operators react to these events quickly. Therefore, stochastic and robust GAP models have been studied extensively as well.

Fig. 1 shows an overview of GAP objective functions used in both static and stochastic models. A common objective of many models is to minimize the walking distance of all the passengers (e.g., Babic et al., 1984; Braaksma, 1977; Haghani & Chen, 1998; Mangoubi & Mathaisel, 1985; Sherali & Brown, 1993; Xu & Bailey, 2001). Minimization of objectives such as total passenger waiting time (e.g., Lim, Rodrigues, & Zhu, 2005; Yan & Huo, 2001), the number of unassigned aircrafts (e.g., Ding, Lim, Rodrigues, & Zhu, 2005; Lim & Wang, 2005), idle time (e.g., Bolat, 1999, 2000, 2001), flight delays (e.g., Gu & Chung, 1999; Yan & Tang, 2007), buffer time (e.g., Yan, Shieh, & Chen, 2002), gate conflicts (e.g., Lim & Wang, 2005), and total passenger connection time (e.g., Pintea et al., 2008) are also used. In some cases, these objectives are simultaneously considered in a multi-criterion model (e.g., Dorndorf, Jaehn, & Pesch, 2008; Drexl & Nikulin, 2008; Hu & Di Paolo, 2009; Yan & Huo, 2001).

Hard and soft operating restrictions may be used to model constraints. Soft constraints model ground operating rules and airline's preferences relevant to a specific operation. Typical hard constraints may be used to describe these situations such as:

- Every aircraft is assigned to one and only one gate. However, some models (such as Ding et al. (2005)) allow embarkation and disembarkation at an airport's apron.
- No two aircrafts are assigned to the same gate at the same time. This non-linear constraint makes the problem harder to solve.
- A large aircraft at a certain gate may prevent the neighboring gates from accepting aircrafts exceeding certain size. The existence of this constraint depends on the gate layout of an airport.
- An aircraft cannot be assigned to certain gates due to the lack of gate facilities. This constraint may be used for an airport with different facilities at different gates.

2.2. Solution methodologies

The solution methodologies of GAP can be mainly divided into two categories: optimization and expert system approaches. Within optimization, it can be further classified into exact methods and heuristics. The exact methods may use a branch-and-bound framework or its variants. However, many researchers are working on heuristics for their computational efficiency. Fig. 2 shows an overview of the solution methodologies.

2.2.1. Expert system approaches

Expert system is a software system that stimulates the performance of human experts. A database, which contains rules generated by human knowledge in a specific problem domain, is used to provide suggested solutions. A system operator may adjust existing rules or input new rules to improve the capability of the system to handle different problem situations and produce better solutions.

Brazile and Swigger (1988) develop a constraint satisfaction expert system called GATES using Prolog. GATES consists of two logic levels. The first level produces an initial schedule, and the second level adjusts the schedule in response to unexpected events such as flight delays, changes in weather conditions and facility failures. To make a decision, GATES uses permissive rules and conflict rules. The permissive rules determine when it is appropriate to consider a particular gate for an aircraft while the conflict rules decide when a particular aircraft cannot be assigned to particular gates. Brazile and Swigger construct knowledge and procedures used by experienced ground controllers and implement GATES for New York John F. Kennedy International Airport. It is reported that GATES creates gate assignments in about 30 s which is much faster than human experts.

Later, Gosling (1990) designs an expert system which also adapts to delays and equipment changes. Moreover, it considers constraints imposed by available facilities and personnel to handle aircrafts, and the consequences on downstream operations of a particular assignment decision. Gosling suggests that it is better to integrate the expert system with an operational database. This is done by Su and Srihari (1993). They develop a knowledge based gate assignment advisor using an approach similar to Gosling's. They integrate the inference process with an operational database that allows end users to modify the knowledge base. Su and Srihari claim that their approach improves the flexibility of the system.

Although an expert system approach can handle more complicated constraints in realistic operations, it lacks optimization capability. Cheng (1997) proposes a knowledge-based gate assignment system which integrates with optimization techniques. Cheng divides the problem into several smaller problems and uses a linear

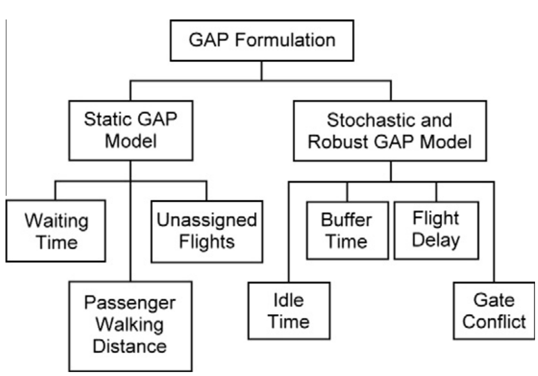

Fig. 1. Overview of GAP objective functions.

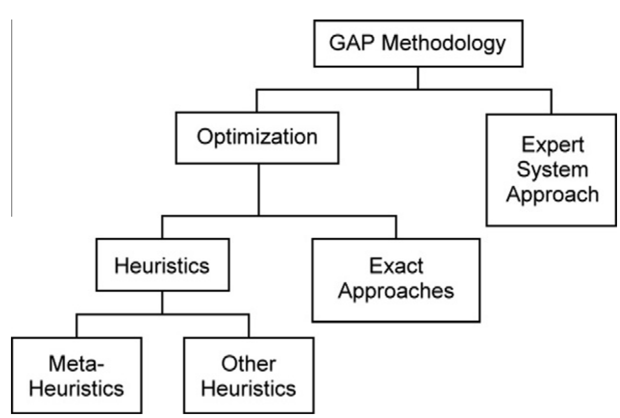

Fig. 2. Overview of solution methodologies.