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Solving the gate assignment problem through the Fuzzy Bee Colony Optimization

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ABSTRACT

In the field of Swarm Intelligence, the Bee Colony Optimization (BCO) has proven to be capable of solving high-level combinatorial problems, like the Flight-Gate Assignment Problem (FGAP), with fast convergence performances. However, given that the FGAP can be often affected by uncertainty or approximation in data, in this paper we develop a new metaheuristic algorithm, based on the Fuzzy Bee Colony Optimization (FBCO), which integrates the concepts of BCO with a Fuzzy Inference System. The proposed method assigns, through the multicriteria analysis, airport gates to scheduled flights based on both passengers' total walking distance and use of remote gates, to find an optimal flight-to-gate assignment for a given schedule. Comparison of the results with the schedules of real airports has allowed us to show the characteristics of the proposed concepts and, at the same time, it stressed the effectiveness of the proposed method.

1. Introduction

Several serious problems are linked to airport operations, including the use of runways capacity, flight delays, environmental pollution due to noise and gas emissions, and safety. Many pieces of research have thus dealt with managing congestion and allocating scattered capacity, as well as mitigating the external costs related to noise, emissions, and to safety/risk. Among these problems, the so-called Flight-Gate Assignment Problem (FGAP) studies the assignment of the subset of available terminal or ramp positions, called gates, to each flight (aircraft), minimizing passengers' inconveniences and/or maximizing the operational efficiency of the airport. The complexity of this task has continuously increased with the increase of civil air traffic so that in the FGAP modeling exact algorithms are rarely used while the use of metaheuristics has now become increasingly widespread.

In this paper, we consider a Flight Gate Assignment Problem that assigns airport gates to scheduled flights based on passengers' daily flow data. The objective of the problem is to minimize (i) the total walking distance that passengers walk to catch their connection, and (ii) the number of flights assigned to remote terminal gates. We formulate this problem as a bi-criteria optimization problem. Since the analytical solution of this problem is rather complex, we design a metaheuristic approach, based on the Bee Colony Optimization. A computational experiment has been conducted and the results are presented and analyzed.

The paper is organized as follows: in the next section, a synthetic survey of previous works presented in the literature is proposed. In Section 2, we describe the mathematical formulation of GAP and the relevant objective functions. In Section 3,

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we explain the Bee Colony-based Optimization method (BCO), and verify its effectiveness in solving the FGAP. In Section 4, we consider two cases of Italian international airports as a test bed for the proposed method, reporting results of the sensitivity analysis. Finally, in Section 5 some concluding remarks are given.

2. A synthetic survey of models for the flight-gate assignment problem

Models for FGAP have been extensively studied mainly from two different points of view: the airport operators and the passengers' points of view. Following the first one, Hassounah and Steuart (1993) took into account stochastic flight delays to improve the performance of static gate assignment; Yan and Chang (1998) and Yan and Huo (2001) used a fixed buffer time between two contiguous flights assigned to the same gate, in order to absorb the stochastic flight delays. Gu and Chung (1999) designed a genetic algorithm, which generates effective solutions by calculating minimum extra delayed time schedules. Bolat (2000) proposed mathematical models and heuristic procedures to provide solutions with the minimum dispersion of idle periods for the FGAP. Yan et al. (2002) proposed a simulation framework, which can not only analyze the effects of stochastic flight delays on static gate assignments but also evaluate flexible buffer times and real-time gate assignment rules. Li and Xu (2012) maximized the utilization of the available gates and terminal through an immune genetic algorithm; Dorndorf et al. (2008, 2012) modeled the flight-gate assignment problem as a clique-partitioning problem. Şeker and Noyan (2012) considered the gate assignment problem under uncertainty in flight arrival and departure times and developed stochastic programming models. Yan and Tang (2007) minimized the flights delay through a heuristic approach. According to the passengers' point of view, Babic et al. (1984) minimized the walking distance of passengers through the branch and bound algorithm. Mangoubi and Mathaisel (1985) took into account transfer passengers, using the LP relaxation and greedy heuristics. Bihr (1990) proposed a simplified formulation of the gate assignment problem, minimizing the walking distance for fixed arrivals in a hub through a 0–1 integer program. Wirasinghe and Bandara (1990) integrate into terminal design process the cost of delays to minimize intra-terminal travel; Haghani and Chen (1998) tried to increase the customer satisfaction by minimizing the passenger walking distance between gates. Xu and Bailey (2001) used a Tabu Search algorithm for a single slot, minimizing the overall walking distances to get connecting flights. Ding et al. (2004) too used the Tabu Search to study the case in which the number of flights exceeds the number of gates. Instead, Lam et al. (2002) developed an intelligent agent to solve the FGAP; Drexl and Nikulin (2008) optimized their multicriteria objective using simulated annealing. Wei and Liu (2009) carried out a fuzzy model and an optimization algorithm; Prem Kumar and Bierlaire (2014) set up a mixed 0–1 integer program with a linear objective function and constraints.

As for the types of approach, the FGAP has been formulated through a wide variety of models: Bard et al. (2001) introduced an integral minimum cost network flow model, which reconstructs the operating programs of airlines in response to delays, transforming the routing problem in a time - based network, where the total time horizon is divided into distinct periods. Under some slight conditions, an optimum of the new model corresponds to the optimal solution of the original problem.

Another popular approach uses the rule-based expert systems: these systems assign flights to gates based on specific rules. For this kind of approach, it is necessary to identify all the rules, ordered by importance and listed appropriately. Initially, Baron (1969) combined optimization and rule-based approaches; then, Hamzwawi (1986) introduced a rule-based system for simulating the assignment of gates to flights, and evaluated the effects of particular rules on gate utilization. Srihari and Muthukrishnan (1991) used a similar approach for solving the FGAP, even describing how to apply the sensitivity analysis. Cheng (1997) integrated mathematical programming techniques into a knowledge-based gate assignment system to provide partial parallel assignments with multiple objectives.

A class of methods can be broadly categorized as "heuristic" algorithms since they do not yield an "exact" optimal solution. Hu and Di Paolo (2009) proposed an improved Genetic Algorithm applied to the FGAP, considering a multi-objective function; Cheng et al. (2012) carried out a comparison of performances of different metaheuristics (Genetic Algorithm, Tabu Search, Simulated Annealing) applied to the FGAP. The drawback of these metaheuristics is that they could generate infeasible solutions that a carefully designed fitness function should properly penalize. The proposed BCO algorithm overcomes this drawback since it builds the final solution always generating partial feasible solutions and improving them over iterations. Thus, in this way, the efficiency of the optimization procedure can be increased.

3. Mathematical formulation

In this section, we establish the mathematical model for the FGAP. First, let us list the input data:

N is the number of flights arrived at or departed from the airport during the planning day;
M is the number of gates available at the airport, including remote gates;
$f_{j,o}$ is the number of passengers transferring from flight j to the baggage claim area;
$f_{o,j}$ is the number of passengers transferring from check-in area to flight j;
$f_{j,r}$ is the number of passengers transferring from flight j to flight r;
$w_{i,o}$ is the walking distance between gate i and baggage claim area;
$w_{o,I}$ is the walking distance between check-in area and gate i;