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A novel heuristic approach for solving aircraft landing problem with single runway

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ABSTRACT

Nowadays, airlines administrations are more willing to utilize optimization tools to control air traffic due to considerable increases in volume of air transports. A challenging problem in the field of air traffic is how to optimally schedule landing time of aircrafts and assign them to different runways such that early and late landing costs are minimized. This problem is called aircraft landing problem (ALP). This paper proposes a novel decomposition based heuristic by solving two sub-problems for the ALP with single runway. In the first sub-problem, we apply the adaptive large neighborhood search (ALNS) algorithm to find a sequence of aircrafts. The solution found in the first sub-problem will be sent to the second sub-problem, to check for the feasibility of the solution using CPLEX solver. A set of benchmark problem are taken from the OR library for the purpose of comparison with other existing approaches. The computational results exhibit that the proposed algorithm is capable of finding the best known optimal solution for all the instances.

1. Introduction

Over the past few decades, with the development of airline industries, the use of air transport including passenger, freight and leisure services has remarkably increased. For instance, the world's busiest airport, Hartsfield-Jackson Atlanta international airport has individually handled total of 96 million passengers including enplaned, deplaned and in-transit passengers in the year of 2012 (Tragale, 2012). In the same year, Hong Kong International airport, recognized as the world's busiest airport in terms of cargo traffic, has transported about 4.1 million tons of cargo (Marcell, 2012). Air transport has definitely established itself as one of the most popular means of transportation due to its reliability, speed, safety and convince. However, as the usage of air transport increases, new challenges such as managing air traffic, air pollution, etc. arise. From the air traffic point of view, an accurate aircraft scheduling decision may efficiently eliminate the bottleneck associated with airport operations. Additionally, it can prevent incurring extra costs into the airline industries. There is generally a cost associated with early landing for each aircraft which flies faster than its most economical speed due to the waste of fuel. Likewise, there is a cost associated with the late landing. Depending on the value of delay, there might be a considerable number of passengers that miss their connecting flights. This delay might postpone the next flight that has been scheduled prior. There are other possible costs yields from delays, such as extra maintenance costs, ground crew rescheduling, loading costs of passengers and so on. According to the report of Federal Aviation Administration (FAA) airlines lose approximately 22 billion dollar annually due to only flight delays in the United States (Jasenka, 2009). Hence, it is really crucial for the airlines to carefully investigate for the best sequence of aircrafts in which each aircraft lands with the least deviation from its target landing time. This problem is known as the aircraft landing problem (ALP). The aim of solving this problem is to minimize the total deviation costs from target landing time including earliness landing costs and lateness landing costs. The ALP can be considered for either single or multiple runways. The assumptions of ALP in this paper are as follows:

- There is only single runway for the landing.
- The target landing time of each aircraft is predetermined and bounded by its earliness and lateness landing times.
- To avoid collision between airplanes, separation time is considered for every pair of aircrafts.

The ALP can be considered to be some type of routing and scheduling problems such as vehicle routing problem and machine scheduling problem. Let's consider the single machine scheduling problem (SMSP) with a set of jobs that has to be processed on a single machine, then ALP can be viewed as an SMSP with a sequence setup time where the aircraft represents job and runway

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represents machine, and there is a release time, processing time and latest finished time associated with each job. Similarly, it can be viewed as a vehicle routing problem (VRP) where aircraft and runway are equivalent to customer and vehicle respectively. It can be easily seen that the ALP is an NP-hard problem, since the SMSP and VRP have been proven to be NP-hard (Beasley et al., 2000).

A few exact methods have been applied to solve the ALP. Beasley et al. (2000) presented a mixed integer programming model for the ALP. They reduced the solution search spaces by adding 6 kinds of valid inequalities constraints into the original mathematical model and a tree search heuristic based approach employed to solve the ALP. Pinol and Beasley (2006) proposed scatter search (SS) and Bionomic algorithm for solving the ALP for both single and multiple runways. Bencheikh et al. (2011) proposed an ant colony algorithm for solving ALP with multiple and single runways. In this paper, we propose a novel decomposition based heuristic approach to deal with ALP. In the first sub-problem (*scheduling problem*), we apply the adaptive large neighborhood search (ALNS) algorithm to find a sequence of aircrafts, and in second sub-problem (*feasibility problem*), the feasibility of solution generated by the scheduling problem is examined using the CPLEX solver.

The rest of this paper is structured as follows: In Section 2, ALP is presented. Section 3 describes the proposed solution approach for the ALP. Section 4 is dedicated to the computational results. Finally conclusion is given in Section 5.

2. The aircraft landing problem

In this section, we describe aircraft landing problem (ALP), its decision variables, its objective function, and its constraints in more detail. The solution to the single runway ALP is the sequencing and scheduling of aircrafts that are going to be landed in a single runway of airport.

2.1. Decision variables

The ALP contains four decision variables. The first decision variable is the landing time for every aircraft. It is clear than the aircraft landing time must be non-negative. The second decision variable called as sequence decision variable (δ_{ij}) which is a binary decision variable and defined to be 1 if aircraft i lands before aircraft j, and 0 otherwise.

2.2. Objective function

The objective function is to minimize the average delay which includes lateness and earliness of aircrafts landing.

2.3. Constraints

- *Runway usage*: Each runway can be used by at most one aircraft at a time so either aircraft i lands before aircraft j or vice versa.
- *Time window constraint:* Based on operational and technical consideration such as limited fuel, airspeed, etc., each aircraft has a maximum and minimum allowable air-borne time which has to be treated as hard constraints.
- *Separation time:* This constraint ensures that there is a separation time between two consecutive aircraft landings.

3. Adaptive large neighborhood search heuristic for ALP

The ALP is known as an NP-hard problem (Beasley et al., 2000) and hence only small instances of the problem can be solved using exact methods. Hence, researchers are motivated to apply heuristics to deal with it. The ALNS was first introduced by (Ropke and Pisinger, 2006) which extends the large neighborhood search algorithm introduced by Shaw (1997). Hewitt et al. (2010) used the ALNS framework to solve the capacitated fixed charge network-flow problem. The capacitated arc-routing problem with stochastic demands was solved by (Laporte et al., 2010). Coelho et al. (2012) applied the ALNS to solve the inventory routing problem with transshipments. Cumulative capacitated vehicle routing problem was solved with this framework by Glaydston and Laporte (2012). Cordeau et al. (2010) proposed a method to use the ALNS framework to solve a technician scheduling problem. Multi-item dynamic lot sizing problem was solved using ALNS by Muller et al. (2012). The main features of the ALNS algorithm will be discussed in detail below.

In this paper, we provide decomposition based adaptive large neighborhood search heuristic. We spilt the aircraft landing problem into two sub-problems: I) *scheduling problem*: ALNS is applied to find a sequence of aircrafts by using various destroy and restore operators described later. The sequence generated by ALNS fixes the binary decision variables δ_{ij} which in turn eliminate the need for Eq. (2) which reduces a considerable number of constraints and binary decision variables. The number of binary decision variables for an ALP is computed by $P(P-1)$. Let us consider an ALP with 100 aircrafts, and then solving the scheduling problem can take care of 100 constraints of Eq. (2) and 100*99 binary decision variables. II) *feasibility problem*: After fixing all binary decision variables, the remaining problem reduces to feasibility problem that contains Eqs. (4) and (10). The feasibility problem solves the ALP for the continuous decision variable x_i using CPLEX solver. Please see the mathematical model of ALP given in Appendix for more details.

3.1. Initialization

The initial solution is produced randomly by generating a string of aircrafts with size of $1 \times P$, where P represents the total number of aircrafts. The initial solution approach does not impact the quality of solution or the computation time of the rest of the algorithm since as a rule ALNS can easily recover from a poor initial solution (Demir et al. 2012).

3.2. Adaptive weight adjustment

The roulette-wheel mechanism is used to select the different destroy and restore operators. Initially, all destroy and restore operators are given equal weights. Let ω_i be the weight assigned to each operator and if there are h operators, the probability of selecting one operator is $p_j = \omega_j / \sum_{i=1}^{h} \omega_i$. During the course of algorithm, the weights are updated by the following equation $\omega_i = (1-\eta)\omega_i + \eta\pi_i/\vartheta_i$. Let π_i and ϑ_i be the score and the number of times the operator i has been used. $\eta \in [0,1]$ is called the reaction factor, and controls how quickly the weight adjustment reacts to the change in the operator's performance. At the end of each iteration, the score π_i is updated as follows:

$$\begin{cases} \sigma_1 & \text{if the operator finds a new best solution} \\ \sigma_2 & \text{if the operator finds a new solution better than the current one} \\ \sigma_3 & \text{if the solution is not better than the current solution but still accepted} \end{cases}$$