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A two stage heuristic algorithm for the integrated aircraft and crew schedule recovery problems

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ABSTRACT

Airline disruptions incurred huge cost for airlines and serious inconvenience for travelers. In this paper, we study the integrated aircraft and crew schedule recovery problem. A two stage heuristic algorithm for the integrated recovery problem is proposed. In the first stage, the integrated aircraft recovery and flight-rescheduling model with partial crew consideration is built. This model is based on the traditional multi-commodity network model for the aircraft schedule recovery problem. The objective of this model also includes minimization of the original crew connection disruption. In the second stage, the integrated crew schedule recovery and flight re-scheduling model with partial aircraft consideration is built. We proposed a new multi-commodity model for the crew schedule recovery. The main advantage of such model is that it is much more efficient to integrate the flight-scheduling and aircraft consideration. New constraints are incorporated to guarantee that the aircraft connections generated in the stage 1 are still feasible. Two stages are run iteratively until no improvement can be achieved. Experimental results show that our method can provide better recovery solutions compared with the benchmark algorithms.

1. Introduction

Airline scheduling has always been the important topic both in academic research and industrial application because it is essential for profit, service level, competitiveness of airline in the competing market. On-time performance of airlines schedule is a key factor in maintaining satisfaction of current customers and attracting new ones. However, airline planned schedules are often subjected to numerous irregularities such as adverse weather, air traffic congestion, aircraft mechanical problems, crew member's absence, propagated delay from upstream, and longer passenger embarking and disembarking time (Ball, Barnhart, Nemhauser, Odoni, & Laporte, 2007). Delay and cancellation of flights are commonplace in today air services. Most disruptions in airline are attributed to two main causes (Bratu & Barnhart, 2006): (1) airline resource shortages and (2) airport and airspace capacity shortage. The huge loss caused by airline disruption has attracted researchers from industries and academy to study airline schedule recovery problem which aims to re-allocate and re-schedule resources to minimize the recovery cost.

Airline schedule recovery problem is similar to the airline schedule planning problem. However, it is exacerbated by three aspects. First, the airline schedule recovery is dealing with operations within recovery time window. Typically, the period of the recovery time window is set as one day (Yu & Qi, 2004). However, the scope of airline scheduling problem is much longer (one month or several months) (Belobaba et al., 2009); Second, the requirements of computing efficiency are different. The airline schedule planning is typically generated several months in advance and therefore there is no immediate computing requirement. However, a near-real time solution is usually required for the airline schedule recovery problem. Third, more complicated crew regulations and recovery options are considered, for example, the crew can be deadheaded, the rest regulation can be violated if more rest is assigned after the duty, etc. The complexities of recovery problem make providing a good recovery solution in short response very challenging task.

Solving the whole airline schedule recovery problem in an integrated model is intractable in computational efficiency because its huge solution space and complex problem structure. In practice, a sequential manner is adopted in the airline schedule recovery. First the aircraft schedule is recovered because the aircraft is the most valuable and scarce resources for the airline; second the crew schedule recovery and finally the passenger schedule recovery.

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The sequence of the crew schedule recovery and the passenger schedule recovery might be swapped in some implementations. The sequential manner typically results in suboptimal, or even infeasible solutions since there is little interaction between the three stages. Therefore, an iterative approach is adopted. For example, when solving the crew schedule recovery, the aircraft schedule is also modified to get a feasible crew schedule recovery solution (Petersen, 2012). Such modification is usually conducted manually. Considering the numerous number of combinatorial possibilities, finding a feasible solution is still challenging and therefore the solution quality is usually sacrificed.

Integrated approaches for more than one stage have demonstrated to provide higher quality solution in airline scheduling problems (Papadakos, 2009; Sandhu & Klabjan, 2007) and there is similar expectations for the airline schedule recovery problems. However, research studying the integrated airline schedule recovery problems is much less compared to the integrated airline scheduling problems. More attention is deserved for the solution methodologies of the integrated airline schedule recovery problems. In this paper, an integrated recovery problem simultaneously considering aircraft and crew is studied. Airport landing capacity, departing capacity and gate availability are explicitly incorporated when making re-scheduling decision, which can facilitate airline efficiently allocating scarce airport resource. A two-stage heuristic algorithm is proposed to solve this integrated model efficiently. The main idea of our model is to decompose the whole integrated model into two smaller models. In the first model, the integrated aircraft schedule recovery, flight re-scheduling and partial crew consideration are considered. In the second model, the integrated crew schedule recovery, flight re-scheduling and partial aircraft consideration are considered. The second model is built based on the first model's solution. For each stage, the efficient model is built. The two stages are run iteratively until no improvement can be achieved. This algorithm can better trade-off between the solution quality and computational performance. Experimental results show this algorithm can efficiently solve integrated airline recovery problem for data set with 351 flights, 134 crews and 70 aircrafts. All the instances can be solved within 2 min and it is sufficient for the practical requirements.

The main contributions of our study can be summarized as follows:

(1) A new two stage heuristic algorithm is proposed for the integrated aircraft and crew schedule recovery problem.
(2) Based on the traditional multi-commodity network model for the aircraft schedule recovery, we propose a new model to incorporate partial crew consideration in the stage 1.
(3) A new multi-commodity network model is proposed for the crew schedule recovery problem in stage 2. To our knowledge, there is no such network model proposed in the literature for the crew schedule recovery problem.

The following part is organized as follows: Section 2 is a literature review related to airline scheduling and airline recovery. Section 3 presents the problem description and the multi-commodity network model for the integrated airline recovery problem. Section 4 illustrates the heuristic algorithm to solve integrated airline recovery problem. Section 5 provides the experimental results of the algorithm. Section 6 is the conclusion and future research plan.

2. Literature review

The applications of optimization techniques for the airline scheduling problems have been extensively studied for several decades. Numerous approaches have been proposed to solve flight scheduling, aircraft routing problem, crew scheduling problem, integrated scheduling problems and so on. We refer the interested readers to Barnhart (2003) and Lan, Clarke, and Barnhart (2006) and reference therein for the details of airline scheduling problems.

Although airline schedules are generated elaborately, typical schedules are hard to be operated normally because various disruptions, such as mechanical failures, adverse weathers, and crew absence. Huge loss is caused by the disruptions and therefore more and more attention has been attracted to propose disruption management approaches for the airline recovery problems. For a general review about airline recovery, we refer to Clarke (1998), Clausen, Larsen, Larsen, and Rezanova (2010) and Ball et al. (2007). Following part is detailed literature review for the various recovery problems.

2.1. Aircraft recovery

Initially, a lot of attention has been attracted to aircraft recovery problem mainly because aircraft is the most scarce resource for airlines. Teodorović and Guberinić (1984) pioneered aircraft recovery problem in which one or more aircrafts are unavailable. The objective is to minimize passenger delays by reassigning or re-timing original flights. A sequential heuristic algorithm is proposed to construct flight routes for each aircraft. Branch-and-bound idea is adopted to find a solution. The drawback of this study is that aircraft maintenance requirements are completely ignored. Based on this study, Teodorović and Stojković (1990) and Teodorovic and Stojkovic (1995) incorporated airport curfew and crew consideration into aircraft recovery.

Jarrah, Yu, Krishnamurthy, and Rakshit (1993) represented two network models aiding flight cancellation and delay decision making. Based on this work, Cao and Kanafani (1997) further proposed a quadratic zero-one programming model to integrate flight cancellation and delay decision making.

Yan and Yang (1996) proposed an airline recovery approach based on time–space network in which nodes are characterized as departure nodes and arrival nodes, while arcs are characterized as flight arcs, ground arcs and overnight arcs. Four different models are represented to deal with different incidences. In order to facilitate flight delay decision making, several flight copies with series delay levels are added into network. Yan and Tu (1997) extended this work to multi fleet recovery problem. Yan and Lin (1997) extended this method to deal with airport closure problem.

Thengvall, Bard, and Yu (2000) solved the aircraft grounding problem based on network model with side constraints. Similar to Yan and Yang (1996), flight delays are considered by adding a series of flight delay arcs. Protection arcs are incorporated to penalize deviation from original routes. Thengvall, Yu, and Bard (2001) further compared three multi-commodity network models, which are the pure network with side constraints, the generalized network and the discretized time-band network with side constraints for aircraft recovery following a hub closure disruption.

Jonathan, Gang, and Michael (2001) modeled aircraft recovery on time band network. In this model, flight departures or arrivals within a time band are aggregated into one node in the time–space network. A relaxed model can be built based on the time-band network. The algorithm is run as follows: relaxed model is first solved, if solution is not integral, mix integer programming solver is called to find integer solution. Based on integer solution, aircraft recovery solution is generated, if no feasible solution can be found, decrease time band width and re-calculate model. The solution quality of this approach highly depends on width of time band.

Eggenberg et al. (2007) proposed a column generation approach to solve aircraft routing problem, in which master problem is modeled as a set partitioning problem with side constraints and pricing