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A survey of the literature on airline crew scheduling

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ABSTRACT

As the airline industry is ever expanding, companies are increasing their fleet sizes to obtain greater market shares. Moreover, as the airlines seek more growth, the complexity and size of the airline crew scheduling problem, which is one of the major planning problems in the industry, is also increasing. For this reason, companies dedicate resources to solve this problem, and lease software at great expense from external sources. Rigorous mathematical models and algorithms are used in solving these problems. This paper presents a survey of airline crew scheduling problems, and their proposed solutions from the literature. As a conclusion, prospective studies will be proposed and discussed with the aim of developing better solutions for airline crew scheduling problems in the future.

1. Introduction

The increase in demand for rapid transportation in recent years has led to the establishment of many airline carriers and the increase in capacity for existing airline carriers (establishment of new aircraft fleet networks). The increase in the number of fleets has led to the increase in number of cockpit and cabin crew, ground crew, etc., and therefore, increasing the costs drastically. Thus, in recent years, airline companies have begun to set up departments of operational research in order to address their most fundamental problems (Rushmeier and Kontogiorgis, 1997; Ulucan and Eryiğit, 2004).

Airline operations consist of flight scheduling, aircraft scheduling, crew scheduling (crew pairing and crew rostering), revenue management, gate assignment as well as managing irregular operations. For this reason, the output of one stage is the input of another stage (Bazargan, 2004). The airline crew scheduling, which is one of the planning problems, is one of the most sophisticated problems encountered when dealing with airline operations. In this paper, airline crew scheduling problem is examined.

In most cases, a planning problem is applied at the strategic level while a scheduling problem is operational due to the consideration of detailed timing factors. Thus, scheduling is usually more complicated. In addition, unlike the fuel expense, operational cost can be controlled (Anbil et al., 1992). Airline crew scheduling is one of the most comprehensive of crew scheduling applications, given the economic size and impact.

In this study, crew scheduling problems are examined in detail, with a view to provide cost savings for airline companies. The crew scheduling problem is generally considered a difficult optimization problem (NP-hard) that must be solved under numerous constraints (Deveci and Demirel, 2016). The optimization techniques have been used in the literature in various application areas. Some of these studies are related to neural networks (Coban, 2014), genetic algorithms (Elsayed et al., 2014; Akbari et al., 2017) and particle swarm optimization (Yare and Venayagamoorthy, 2010; Aksu and Çoban, 2013). A preliminary analysis of this study was performed by Deveci and Demirel (2015).

In this paper, the studies regarding crew scheduling problem with which all the airline companies deal with are examined in detail. The important findings obtained from these studies, the methods used in problem solving, the size of the problem, real or randomly generated data, flight data, airline company, the formulation types and other related information for the problem are all presented. Furthermore, promising studies for this problem is also presented.

The rest of the paper is organized as the following. In Section 2, the airline crew scheduling problem is described. The set partitioning and set covering formulations are explained in Section 3. Section 4 presents details of the solution methodologies for airline crew scheduling problem. The results and discussion are presented in Section 5. Finally, in Section 6, the conclusion of this study and recommendations for future research are presented.

2. Airline crew scheduling

Airline crew scheduling can be defined as the assignment of flight crew (cockpit and cabin) to scheduled flights, so as to ensure that the crew needed for all flights are covered. The following are some of the key

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performance indicators used to evaluate the output of the processes at this stage; total person-days, number of overnight stays, deadhead times, and ground time. It is highly desired that the values of these parameters be as low as possible. Therefore, optimization methods play a crucial role in the determination of critical cost indicators.

Due to the difficulty of solving the airline crew scheduling problem, it is generally divided into two sub problems that consist of crew pairing problem (CPP) and crew rostering problem (CRP); however, ideally, it should be one integrated problem and model. The main reason for decomposing the problem, is that the integrated problem is too large to be handled simultaneously for large airlines. Furthermore, when the crew rostering problem takes into consideration crew member preferences on crew pairings, these pairings must be computed beforehand. In addition, these two problems are planning-type problems. CPP and CRP are considered separate, but related problems, and, both can be solved similarly methods (Valdes and Andres, 2010). The some of these methods used for solution are two-level decomposition-based matheuristic (Doi et al., 2018), memetic algorithm (Demirel and Deveci, 2017; Deveci and Demirel, 2018), neighbourhood search approach (Agustin et al., 2017), randomized heuristics (de Armas et al., 2017), genetic algorithms (Deveci and Demirel, 2016; Chen and Chou, 2017; Mohamed et al., 2017), optimization-driven algorithm (Özener et al., 2017), and branch-and-price heuristics (Quesnel et al., 2017).

There are three basic reasons for breaking down the crew scheduling problem into two sub-problems. First, the objectives of the two sub-problems are different, and, secondly, it is difficult to calculate crew rostering prior to generating crew pairings. Thirdly, the rules that crew are obliged to follow, are specified under two different headings: pairing and rostering (Soykan and Erol, 2016).

2.1. Crew pairing problem

The objectives of crew pairing problem (CPP) are to minimize costs by complying with all legal criteria (crew-duty time and rest periods), covering all flights on the flight schedule, and ensuring optimum use of all resources to produce high quality solutions (Ulucan and Eryiğit, 2004).

Crew pairing stands for a series of flights, namely round-trips, starting and ending at the home base (Rushmeier et al., 1995; Zeghal and Minoux, 2006). Crew pairing is also the cost-determining phase of the crew scheduling. For airliners, the crew pairing optimization of flight scheduling is vital since this process is used for minimizing the operational crew costs while maximizing the efficient use of the crew. An acceptable crew pairing must meet the legal restrictions of SHGM (Directorate General of Civil Aviation), FAA (Federal Aviation Administration) rules and special restrictions laid down by the airliners. Considering these restrictions and rules, the main purpose of the optimization is to determine the most cost effective crew pairing comprising of all the flights in the flight schedule. Fig. 1 shows a pairing that comprise of two duties and a two-day crew pairing, showing duty periods, connection time within duty periods, brief, debrief, overnight rests, sign-in, sign-out times, duty summary, and trip summary. This figure shows a pairing that begins and ends at the IST (Istanbul) Airport, a local-airline home base in Turkey. Some definitions of the CPP as follows (Bazargan, 2010; Demirel and Deveci, 2017):

Flight(flight leg or leg): Timeperiod between aircraft take off and raicraft landing.

Duty: Period comprising one or more flight legs, including the briefing time, which is the preparation period for the duty, and the debriefing time, which is the preparation period of the aircraft for the next flight crew.

Deadhead (DH): If a crew member flies as a passenger by occupying a passenger seat, this flight is called as deadhead flight for that crew member. Deadhead is a factor that should be minimized, as it reduces passenger capacity, and the efficiency of crew utilization (Zeren and Ozkol, 2016).

Limits that need to be respected in order to ensure that a duty or crew pairing is legal are composed of rest period, connection time, flight time and duty time. *Connection times* for a duty period must be within a certain range (minimum and maximum). *Total flight time* referring to the time spent in a duty period, *block time* referring to the flight times during a duty, and the number of flight legs must not exceed the given range. A certain period of time is also allocated for *briefing* before each duty period and *debriefing* at the end of each duty period. Four-day planning horizon consist of 41 flights is shown Fig. 2 for a flight schedule. This figure shows the duties and pairings which are generated from these flights. Each pair consists of four duties as in this figure.

2.2. Crew rostering (assignment) problem

After the crew-pairing phase is solved, the crew-rostering phase, the second fundamental sub-process, needs to be solved. Crew rostering is also one of the important problems in airline operations (Kohl and Karisch, 2004). During this phase, flight crew rostering is done in accordance with the requirements of the crew pairings made in the previous phase. The financial impact of the crew rostering process on total crew costs is lower as compared to the impact of the crew pairing process. The rostering process aims to achieve a more balanced workload distribution among the flight crew. This allows for fair flight plans to be produced in the interest of flight crews. Contrary to pairing, crew rostering problem can be done in various ways following different approaches (*bidline generation, rostering, and preferential bidding*) (Nissen and Haase, 2006; Kohl and Karisch, 2004; Römer and Mellouli, 2011; de Armas et al., 2016). In the first approach, while taking into account the needs and preferences of the crew, crew members are assigned to crew pairings equally between all flights. In the second approach, the seniority of the crew member is taken into account during the assignment (Orhan et al., 2010). When setting up this task schedule, the first approach is used in European countries, and the second in north American countries (Cappanera and Gallo, 2004; Qi et al., 2004). Certain North American companies do not implement single-stage crew rostering processes as described above. Instead, monthly crew planning (bidlines) is done, and, with the use of a seniority-based preference mechanism, the rostering processes are managed in accordance with the preferences of the flight crew. After the preference phase, an additional system allows for the exchange of monthly plans for flight crews (Zeren and Ozkol, 2016). The process of crew rostering is shown in Fig. 3. Crew pairings in Fig. 3 are assigned to specific crewmembers.

3. Set partitioning and set covering formulations

Airline crew scheduling can be modelled as a problem of set covering (SC) problem or set partitioning (SP) problem in the literature (Yan and Tu, 2002). Both of them are proven to be NP-complete (Garey and Johnson, 1979).

Each flight must be covered by at least one crew pairing. Furthermore, solutions of the problem in the SP model can be impossible, while a feasible solution could be found in the SC model. The set covering problem for the crew pairing problems can be defined as follows (Chu et al., 1997; Bazargan, 2004):

$\underline{Set\ covering\ for\ crew\ pairing:}$

$$Min(z) = \sum_{j=1}^{p} c_j x_j \tag{1}$$

$Subject\ to;$

$$\sum_{j=1}^{p} a_{ij} * x_j \geq 1 \qquad \forall i \in F \tag{2}$$

$$x_j \in \{0,1\} \qquad \forall j \in P$$

$$x_j = \begin{cases} 1 & if\ pairing\ j\ is\ selected; \\ 0 & otherwise, \end{cases}$$

$$a_{ij} = \begin{cases} 1 & if\ flight\ leg\ i\ is\ covered\ by\ pairing\ j; \\ 0 & otherwise, \end{cases}$$