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Discrete Optimization

A three-stage mixed integer programming approach for optimizing the skill mix and training schedules for aircraft maintenance

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ABSTRACT

This paper presents a three-stage mixed integer programming approach for optimizing the skill mix and training schedule for aircraft maintenance workers. When all workers are trained for all skills, cheaper workforce schedules are possible. However, the training that is required to acquire all those skills can become very expensive. In the first and second stage, we therefore make a trade-off between the training costs and the resulting cheaper workforce schedule. As we assume that workers are unavailable to work during their training, the resulting schedules are only applicable in practice if the required training can be performed without endangering the current maintenance operations. In the third stage, we therefore want to find an optimal and feasible training schedule in order to obtain the desired skill mix with minimal costs. A computational experiment based on real-life data of an aircraft maintenance company not only demonstrates that our models succeed in finding good solutions within reasonable computation times, but also illustrates how the explicit incorporation of skills training in the scheduling process can lead to significant cost savings.

1. Introduction

In service industries, labor is often the largest expenditure for a company. An efficient scheduling of the workforce is therefore very important. This paper presents a three-stage mixed integer programming (MIP) approach for optimizing the skill mix and training schedule at an aircraft maintenance company. In this study, we only focus on the line maintenance which takes place at the gate or parking ramp between the arrival and departure of an aircraft. Line maintenance consists of on-call assistance and routine checks of the engines, the landing gear, etc. Since different aircraft have different features and can show different problems, only adequately skilled workers should be assigned to maintain certain flights. In fact, according to aviation legislation, each type of aircraft requires its own maintenance license. Consequently, skills and licenses are used as synonyms in this paper.

A good personnel schedule should make sure that all flights can be maintained with the available workers and their respective skills. Schedules based on the current (limited) skill pool can, however, be very expensive. Therefore, as a first step, we follow an integrated approach to build inexpensive personnel schedules and to design the optimal skill mix at the same time. The final step is to build the lowest cost training schedule that leads to this optimal skill mix. We illustrate our procedure using real-life data from an aircraft maintenance company.

Aviation industries are often characterized by a highly seasonal demand. Hence, the demand for aircraft maintenance also follows a seasonal pattern. Typically, aircraft maintenance companies have to build new workforce schedules twice a year, i.e., before the start of the winter as well as the summer season. A special feature of the aircraft maintenance business is the fact that every week the same set of flights must be maintained. These flight schedules are known months in advance of the start of a new season and contain information such as the STA (Scheduled Time of Arrival), the STD (Scheduled Time of Departure) and the workload. In this paper we also assume that the flight schedule specifies the required skill for each flight. An example of such a weekly flight schedule with skill requirements is shown in Table 1.

Once the demand for maintenance is known for the next season, the construction of an optimal workforce schedule for the next season can start. Fig. 1 visualizes this process. A detailed

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Table 1
Example of a weekly flight schedule.

Flight	Company	STA	STD	Workload (man-hours)	Skill
1	AA	Monday 22:05	Tuesday 07:45	4.00	A
...	...	...	...	...	
56	BA	Thursday 07:30	Thursday 11:40	6.00	A
...	...	...	...	...	
100	SN33	Saturday 05:30	Saturday 10:45	4.25	B

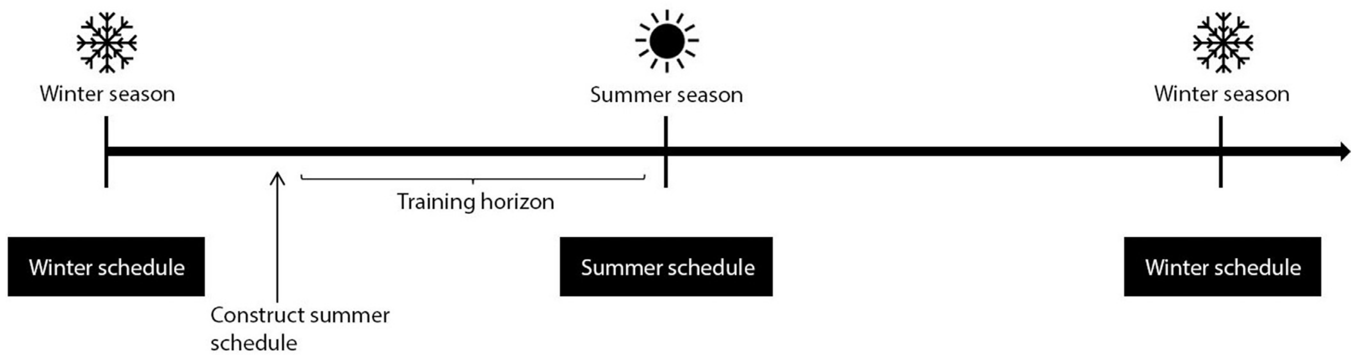

Fig. 1. Overview of the seasons.

description of the problem details and the specifics about the cycles, shifts and teams in the workforce configuration is given in Section 3.1.

In the example shown in Fig. 1, the company is currently operating based on the winter flight schedules and the winter workforce schedule. When the summer flight schedules become known, the company has to construct the summer workforce schedule. We distinguish between two important tasks in constructing an optimal summer workforce schedule.

The first task is to build an efficient schedule to make sure that all flights can be maintained with the available workers and their respective skills. We therefore have to make two major decisions. First, we have to decide on the scheduling of the shifts, and second, we have to assign the available workers to these shifts to make sure that all flights can be maintained in time with the available skills. These two decisions are integrated in the optimization model to build optimal workforce schedules.

The second task is to find the optimal skill mix. When the number of skills per worker is relatively small, too many workers would be needed to construct a feasible workforce configuration leading to very high costs. Using the current available workers and their current skills to construct the summer workforce schedule therefore only leads to a suboptimal result. Cheaper schedules can be obtained by training some of the workers. These higher skilled workers can then do some of the work for which they were not certified earlier. This can decrease the required number of staff and hence decrease costs. The workers that are not needed anymore to do the line maintenance can then be used somewhere else in the company such as in the heavy maintenance.

Because training can be very expensive, a trade-off must be made between cheaper rosters that require higher skilled workers and the training costs to obtain this higher skilled workforce. Therefore, these two tasks are incorporated in the same optimization model to build optimal workforce schedules. This model is presented in Section 3.1 and is referred to as the workforce scheduling model.

While the workforce scheduling model results in a decision about the optimal skill mix and the skills that must be trained, it does not specify when this training should take place. To build the lowest cost training schedule that results in the optimal skill mix, another optimization model is constructed in Section 3.3. This model takes into account that workers are unavailable to work during their training. The goal of this model is to schedule the training during the training horizon (see Fig. 1). Based on the current winter workforce schedule, this model decides who will be trained on each day in each week for each skill.

The remainder of this paper is organized as follows. Section 2 reviews the related literature. Section 3 describes the three-stage approach, while Section 4 presents computational results and managerial insights. Section 5 concludes this paper.

2. Literature review

Since several decades, aircraft maintenance has been a popular application area for operations research studies. Most of these studies address aircraft maintenance routing problems (e.g., Haouari, Shao, & Sherali, 2013; Liang, Chaovalitwongse, Huang, & Johnson, 2010; Liang & Chaovalitwongse, 2013), an important problem within the general framework of airline crew scheduling (Barnhart et al., 2003). Only a few have studied maintenance workforce or capacity scheduling problems. Beliën, Demeulemeester, and Cardoen (2012) describe the successful application of MIP for building aircraft maintenance workforce schedules. Van den Bergh, De Bruecker, Beliën, De Boeck, and Demeulemeester (2013) extend the work of Beliën et al. (2012) taking into account uncertainty in flight arrivals. Using a discrete event simulation model and data envelopment analysis, the generated rosters are evaluated on 5 parameters: cost, preferences, average number of flights maintained in time, average number of completions without preemption, and average tardiness. Keysan, Nemhauser, and Savelsbergh (2010) study the tactical and operational planning of scheduled maintenance for per-seat, on-demand air transportation. They present a MIP formulation for the general tactical capacity planning problem at an aircraft maintenance facility. None of these studies take individual skills and training into account.

Safaei, Banjevic, and Jardine (2011) study a real maintenance workforce-constrained scheduling problem in a steel manufacturing context in which maintenance jobs must be scheduled during the course of a predetermined planning horizon considering two conflicting objectives: skilled workforce requirement minimization and equipment availability maximization. The model incorporates skilled manpower availabilities but does neither opti-