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A multistage approach for an employee timetabling problem with a high diversity of shifts as a solution for a strongly varying workforce demand

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ABSTRACT

This work deals with the employee rostering problem at the airport. Such problems, related to the time varying demand of the transport services, use many (e.g., about a hundred) diverse shifts to cover the workforce demand during the day. Together with the strict constraints, given by the collective agreement, the problem becomes difficult to solve. Algorithms commonly used for solving the usual employee rostering problems produce poor quality rosters, which are unusable in practice. This paper suggests a three stage approach allowing one to solve the employee rostering problems where a huge set of different shifts is used to satisfy the coverage requirements. The solution is based on the problem transformation to a simpler problem, thereupon, an evolutionary algorithm is used to determine a rough position of the shifts in the roster. Afterwards, the maximal weighted matching in the bipartite graph is applied as the inverse transformation of the problem and the final roster is obtained by the optimization based on a Tabu Search algorithm. This multistage approach is compared to other approaches. Furthermore, an evaluation methodology was proposed in order to make a complex and fair comparison. Its objective is to verify the contribution of the particular stages used in the different approaches applied on the different personnel scheduling problems.

1. Introduction

This paper deals with a scheduling problem at the airport belonging to the domain of employee timetabling problems (ETPs), also called employee rostering problems or personnel scheduling problems. The main difference between this problem and the most known problem from this domain, the Nurse Rostering Problem (NRP) [1], lies in the number of different shifts needed to satisfy a *personnel demand*, i.e., the number of employees needed at the specific time interval of the day. An illustrated example for both problems is shown in Fig. 1, where the upper one is typical for the NRP and the lower one corresponds with the ETP typical for airports. The personnel demand, given by the statistical data from the previous planning horizons, is represented by the gray area. One is able to satisfy the personnel demand expressed by the number of required shifts to be assigned to the employees on the certain day. This ensures a *shift coverage model* (see [2]) depicted by a bold black line that corresponds to the coverage by {early, late, night} shifts in Fig. 1 for both problems.

On the other hand, the personnel demand of the ETP from the transport services, e.g. at airports, is usually more dynamic (see the bottom chart in Fig. 1). This is caused by the traffic peaks that are even different on various days during the week. The personnel demand is, very often, expressed in time intervals of the day in order to cover it as precise as possible. This *time interval coverage* model (see [2]) is depicted by white bars bordered by a black line. There are two ways how to deal with the coverage given by time intervals. Either the time intervals can be considered as independent tasks, or these tasks can be joined together and modeled as shifts, for more details see Section 1.1. In our case, we have an already given set of shifts (created on the base of the time interval coverage model) which allows one to cover the personnel demand very accurately (see bottom of Fig. 1). This set not only consists of shifts with different start and finish times, but also contains split shifts and on-call shifts. The split shift facilitates covering the traffic peaks during the day, while the on-call shift is used as an alternative for employees' sick leaves and other unanticipated causes.

The objective of this paper is to solve the employee timetabling problem with a fixed and enlarged set of shifts. We denote this problem as the Employee Timetabling Problem with a High Diversity of shifts (ETPHD). The ETPHD is not only specific by a large variety of shifts, but also by its set of constraints.

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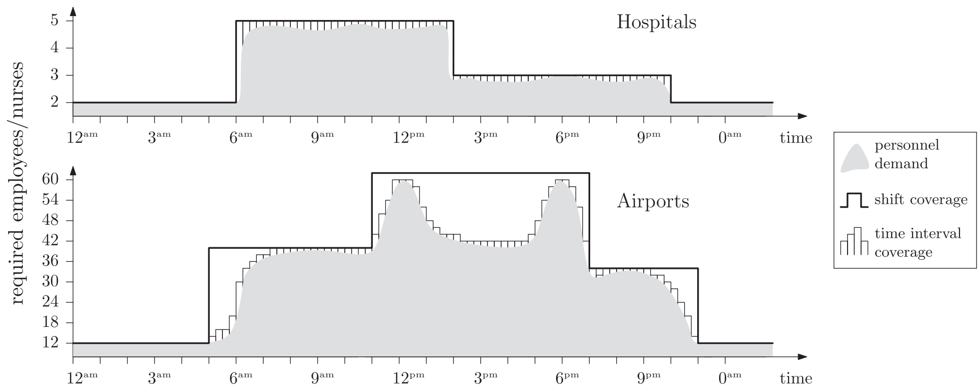

Fig. 1. Different coverage models for employee timetabling problems in hospitals and airports.

The constraints that make this problem more complex are the so-called *block constraints*. These constraints (described in detail in Section 2.1) are a generalization of the restrictions limiting the number of consecutive working days.

1.1. Related works

The problem addressed in this paper belongs to the employee timetabling area. Summaries of the approaches for solving problems from the employee timetabling/rostering domain are published in [1,3]. The most studied part of ETPs belongs to the health care branch [4,5]. In terms of the NRP classification proposed in [6], our ETPHD can be categorized by ASBI | TVNO | PLGM.

The following two paragraphs are focused on the methods used to handle the common NRPs, where the shift coverage model is used. These problems can be solved optimally by an *Integer Linear Programming* (ILP) [7]. However, this method provides the solution in a reasonable amount of time in the case of small instances only, i.e., a very limited set of shifts, a tiny set of employees and a simple set of constraints. Unfortunately, these assumptions are not usually kept for real data instances. Therefore, the ILP is used more often for simplified nurse rostering subproblems [8]. This problem can also be modeled as a Constraints Satisfaction Problem, solved by constraint programming techniques [9]. A hybrid approach from the domain of the declarative programming was presented in [10] on a simplified NRP where the authors proposed an automatically implied constraint generation. By this hybrid technique, the ratio of the solved NRPs can be increased.

The optimal approaches are usually unable to obtain the final solution in a reasonable amount of time when more difficult NRPs are considered. In this case, heuristic approaches are applied or the solved NRP is separated into its subproblems. These subproblems can be solved by different approaches (optimal or heuristic) to attain suboptimal solutions of the problem. One of the most applied metaheuristic approaches for NRPs is a *Tabu Search Algorithm* (TSA). A two stage approach to this problem is described in [11] where, in the first step, a feasible solution with respect to hard constraints is found and, in the second step, a TSA based optimization is used. A similar stage separation is described in [12] where the comparison of two approaches (TSA and *Memetic Algorithm* (MA)) for the optimization stage was presented. In a general way, TSA is faster than MA, but its computation time depends considerably on the previous initialization stage.

The papers relevant specifically to our ETPHD (not only to NRP) are described in this paragraph. There are two models from the coverage constraints point of view discussed beneath Fig. 1. The first one is the shift coverage model used typically in most of the NRPs. The second one is the time interval coverage model considering a time scale smaller than days, e.g. hours, minutes. This model occurs in ETPs having the highly dynamic services from the time point of view, e.g. call centers (see a complex survey [13,14]). In this case a *tour/sub daily scheduling problem* [15,16] or a *break scheduling problem* [17] is handled. A tour is designed like a group of consecutive tasks (e.g., different types of the work, breaks). The arbitrary tasks in the tour can be moved or swapped. Nevertheless, in the case of our ETPHD the shifts are assigned to the roster in an atomic way, i.e., the shift cannot be separated into its tasks. Also, the time interval coverage model is considered in a (*minimal*) *shift design problem* [18,19]. The objective is to determine how to design a set of shifts in order to cover the personnel demand (see the motivation Fig. 1) as precise as possible. However, this problem is not a part of our ETPHD described in this paper (the output of the shift design problem is used as the input of the ETPHD).

The comparison of different coverage models (shift coverage and time interval coverage) is presented in [2] and confirms that the time coverage model is more efficient from the overcoverage point of view than the shift coverage model. The time coverage model is transformed to the shift coverage model so that the personnel demand is fulfilled by different combinations of shifts, i.e., the shift design problem is solved. The main dissimilarity to our paper lies in the number of shifts, which is up to 10 shifts in [2], while our ETPHD takes into account the strictly given set of shifts enlarged to dozens or hundreds of shifts.

1.2. Contribution and outline

In this paper, we introduced a multistage approach for handling ETPHD. The basic idea lies in a transformation of the 'enlarged' set of shifts to a simpler one. The transformed timetable is initialized by an evolutionary algorithm (the first stage) and the problem instance is transformed back by an algorithm based on matching in the bipartite graph (the second stage). The objective of these stages is to determine the rough position of the blocks of shifts. The final roster is obtained during the optimization based on the TSA (the third stage). This stage uses our adaptation of the TSA suggested in [12]. The contributions of the paper are (a) a transformation, based on a mapping of the shifts into the group of shifts, allowing one to solve the ETPHD described in Sections 3 and 5, (b) an ILP model of the ETPHD presented in Section 3, (c) an algorithm for the first stage based on an evolutionary algorithm (EA) shown in Section 4 and (d) a proposed cross evaluation methodology used to verify the contribution of the particular stages used in the different approaches applied on the different personnel scheduling problems (described in Section 6.4).

The paper is organized as follows: Section 2 outlines the motivation problem at the airport. Section 3 explains the problem transformation to the problem with a reduced set of shifts and shows its ILP model. The transformed problem is solved in Section 4 by an EA. The inverse transformation is described in Section 5. The experiments and performance evaluation are summarized in Section 6 and the last section concludes the work.