Computers & Operations Research 38 (2011) 1400–1411

Contents lists available at ScienceDirect

Computers & Operations Research

journal homepage: www.elsevier.com/locate/caor

An evolutionary approach for the nurse rerostering problem

Broos Maenhout [a,*], Mario Vanhoucke [a,b]

[a] Faculty of Economics and Business Administration, Ghent University, Tweekerkenstraat 2, 9000 Gent, Belgium
[b] Operations and Technology Management Centre, Vlerick Leuven Gent Management School, Reep 1, 9000 Gent, Belgium

ARTICLE INFO

Available online 31 December 2010

Keywords:
Nurse rostering
Rerostering
Genetic algorithms

ABSTRACT

The personnel scheduler constructs a deterministic personnel roster that determines the line-of-work for each personnel member. When unexpected events disrupt this roster, the feasibility needs to be restored by constructing a new workable roster. The scheduler must reassign the set of employees in order to cover the disrupted shift such that the staffing requirements and the time-related personnel constraints remain satisfied. In this paper, we propose an evolutionary meta-heuristic to solve the nurse rerostering problem. We show that the proposed procedure performs consistently well under many different circumstances. We test different optimisation strategies and compare our procedure with the existing literature on a dataset that is carefully designed in a controlled and varied way.

1. Introduction

Operating systems typically have to operate in a dynamic and uncertain environment where unexpected events may occur. When these events lead to schedule disruptions and infeasibilities, rescheduling is necessary to update the activity schedule. A disruption in a personnel schedule is defined as an occurrence when an employee that is planned to work a specific task is unavailable to work the specified task due to e.g. unplanned absences or staff turnover.

In a report of the National Health Service (UK, 1999) it is indicated that in the health sector, disruptions have a dramatic effect on the budget for workforce staffing. In total 4% of the total resources spent on staffing are lost due to schedule disruptions [1]. Since uncertainty is considerable in healthcare applications and disruptions cannot be eliminated, decision support systems should be developed that adequately react to unexpected events. The rerostering problem is a scheduling type of problem with which most hospitals are confronted. In case of schedule disruptions, hospital units should resort to their own nursing resources to solve any schedule infeasibility. Only when the hospital unit cannot cope with the problem(s), they can typically call upon more expensive nursing staff resources external to the unit (e.g. hospital reserve pool, external interim nurses).

When contingencies and schedule disruptions occur, employees cannot perform their duties in accordance with the postulated schedule. In that case, deviations are required to the original schedule as tasks cannot be operated below a minimum number of required staff. Rerostering nursing staff is a reactive approach to cope with unexpected schedule disruptions in personnel rosters such that the schedule remains valid in accordance with the schedule requirements, i.e. the staffing requirements and the time-related constraints which guarantee the roster quality of the single personnel members. Typically, the goal of rerostering is to rebuild the schedule while minimising the number of deviations to the original schedule as deviations may not be very well accepted by the workforce.

Due to the frequency of schedule disruptions and the importance of rerostering in personnel rostering, we propose an optimisation tool for the nurse rerostering problem that revises and re-optimises a schedule for a set of heterogeneous nurses. In this paper, we gain insights and understanding in solving the nurse rerostering problem. We focus on the application of optimisation concepts that were found to be successful for the traditional nurse rostering problem and adapt these to meet the peculiarities (problem settings, objectives and constraints) of the rerostering problem. The personnel scheduling optimisation methods found in the literature provide excellent solutions to the nurse rostering problem. However, as uncertainty and absenteeism are inherent when dealing with personnel, these roster solutions may no longer be valid at certain moments. We discuss how to tailor these methods to the nurse rerostering problem from an algorithmic point-of-view.

The remainder of the paper is organised as follows. In Section 2, we give an overview of the relevant literature on heuristic optimisation procedures involving nurse (re-)rostering problems. A precise problem description and formulation is provided in Section 3, in which we discuss the typical settings, objectives and

* Corresponding author.
E-mail addresses: Broos.Maenhout@Ugent.be (B. Maenhout), Mario.Vanhoucke@ugent.be (M. Vanhoucke).

0305-0548/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.cor.2010.12.012

constraints of the problem. In Section 4, we discuss the proposed heuristic approach to solve the nurse rerostering problem. In Section 5, we discuss the algorithmic performance of all problem-specific features of our approach and compare the proposed optimisation procedure with the existing literature. In Section 6, conclusions are drawn and directions for future research are given.

2. Literature review

Most research papers in the personnel scheduling literature involve exact or heuristic procedures for the construction of a deterministic personnel schedule. An extensive overview of personnel shift scheduling problems can be found in Ernst et al. [2,3] and for the nurse rostering problem specifically in Cheang et al. [4] and Burke et al. [5]. In the following, we first go through the nurse rerostering literature and then we discuss the relevant (meta-)heuristic optimisation principles found in the general nurse rostering literature.

In contrast to the nurse rostering problem, the *nurse rerostering problem* has received limited attention in the staff scheduling literature. Moz and Pato [6] were the first to formulate the nurse rerostering problem as an integer multi-commodity flow model with the single objective of minimising the number of deviations from the original schedule. This single-objective version has been classified as NP-hard in Moz and Pato [7]. Moz and Pato [6] developed a constructive heuristic to reconstruct nurse rosters instantly. Furthermore, they developed various mathematical ILP formulations with additional constraints for the nurse rerostering problem in a multi-level acyclical network that are solved using CPLEX [6,8]. Recently, Moz and Pato [7] developed an indirect genetic algorithm approach to the nurse rerostering problem and tested their procedure on real-life data instances from Portuguese public hospitals. Their algorithm is composed of an improved constructive heuristic and a genetic algorithm. The constructive heuristic entails a sequential re-assignment of all tasks to nurses in various ways after a disruption has occurred. In the genetic algorithm, the encoding consists of two permutations, i.e. a permutation of the list of tasks and a permutation of the list of nurses. A new nurse roster is then generated by trying to assign each task to one of the nurses following the order of the nurse permutation and based on various rules of thumb which promote the feasibility and the quality of the nurse roster as best as possible. The individuals are then scored based on their similarity to the original schedule. A genetic algorithm (using selection, crossover and mutation operators) is then applied to the population of individuals to produce a new population. The authors developed several versions of the genetic algorithm, whose differences lay in the encoding of the permutations and in the genetic operators used for each encoding. Pato and Moz [9] formulated and solved a multiple objective approach to the nurse rerostering problem in order to map the trade-off between schedule similarity and the fairness among nurses. In their paper, they designed a bi-objective genetic heuristic based on the best performing optimisation principles found in Moz and Pato [7]. In Pato and Moz [9], however, the evolutionary approach operates on the Pareto optimal set of solution elements and the fitness function complies with the Pareto ranking of the respective decoded solutions. Knighton [10] proposed a network-based mathematical programming approach that also incorporates multiple objectives. The goal of this methodology is to respond to disruptions in a workforce schedule such that the number of deviations with respect to the original schedule is minimised and the management and employee preferences to work a particular shift on a particular day are satisfied as best as possible. In this respect, a decomposition-based heuristic algorithm is developed for the rerostering of a heterogeneous workforce over a multi-week period. A schedule is composed of combining multiple weekly nurse rostering problems that are constructed using a network-based linear program.

Related to the nurse rerostering problem, which is a shift scheduling problem, there are different other papers in the literature that cope with reconstructing personnel schedules e.g. the task-based crew recovery problem in the airline industry (for an overview see Clausen et al. [11]), the tour-of-duty rescheduling problem in the railway sector (e.g. Huisman [12]), the general days on/days off personnel replanning problem under annualised hours [13].

In the *nurse rostering problem* literature, problem descriptions and models vary drastically and depend on the characteristics and policies of the particular business environment. Hence, many objective function possibilities subject to a huge variety of constraint combinations are explored. Since nurse rostering problems have this multitude of formulations, many (meta-)heuristic procedures have been proposed to solve the nurse rostering problem in an acceptable computation time. Instigated by their flexible design, meta-heuristic approaches are considered to tackle most appropriately the nurse rostering problem in a real-world problem setting. Recent meta-heuristics described in the literature implemented successfully the ideas of creating and maintaining diversity in the population elements and the idea of exploiting variable neighbourhoods to diversify the search in the solution space. We can discern several local search-based and evolutionary meta-heuristic frameworks that are successfully implemented to solve the nurse rostering problem. In this respect, variable neighbourhood search is an important concept in heuristic optimisation that is successfully explored in recent years for the nurse rostering problem and boils down to the systematic change of neighbourhoods within a (local) search algorithm. Different papers combine different local search heuristics within a meta-heuristic framework and/or study the use of hyperheuristics that implement neighbourhoods to enhance the diversification step in the meta-heuristic search. We explore these principles in this paper to tackle the nurse rerostering problem adequately.

3. Problem definition and formulation

The problem under study is the nurse rerostering problem and can be stated as follows. A set of heterogeneous nurses N (i.e. set of nurses, index i ($i=1,\ldots,n$)) is scheduled on a periodically basis within a pre-defined period D (i.e. set of days in the scheduling period, index j ($j=1,\ldots,d$)). More precisely, these nurses are assigned to one of a set of possible shifts S (i.e. set of shifts, index k ($k=1,\ldots,s$), with the last shift s as the free day assignment). This assignment should satisfy on the one hand some (hard) time-related constraints that typically guarantee the (social) quality of a schedule for a single nurse. On the other hand, multiple (conflicting) goals can be postulated, e.g. minimising understaffing and overstaffing costs, minimising labour costs, maximising the nurse preferences and constructing employee schedules as fair as possible. The decision variables used for the nurse rerostering problem are the following:

x_{ijk} 1 if nurse i is scheduled to work on day j shift k,
0 otherwise.

Combining the decisions for all these assignment variables, each employee of the available nursing staff is assigned to an individual schedule, which is in line with the applicable nurse rostering policies and objectives. When coping with the nurse rerostering problem, the nurse rostering problem has already been solved. We denote these assignments stated in the original nurse