Computers & Industrial Engineering 56 (2009) 1232–1242

Contents lists available at ScienceDirect

Computers & Industrial Engineering

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

Medical doctor rostering problem in a hospital emergency department by means of genetic algorithms

Javier Puente *, Alberto Gómez, Isabel Fernández, Paolo Priore

Polytechnic School of Engineering – Gijón, Business Administration Department, University of Oviedo, Spain

ARTICLE INFO

Article history:
Received 30 August 2007
Received in revised form 15 April 2008
Accepted 14 July 2008
Available online 31 July 2008

Keywords:
Timetabling
Rostering
Genetic algorithms
Health services
Medical staff

ABSTRACT

Organising shifts, or work rosters, is a problem that affects a large number of businesses where employees are subject to some kind of work rotation. Researchers in the fields of Operations Research and Artificial Intelligence have resorted to several different optimisation systems to solve the problem. The motivation for the medical-staff shift-rotation research presented in this paper stems from the needs of an actual hospital emergency department (HED) and from the observed growing staff of these services in Spain. The problem approach, which has been hardly dealt with in the literature, intends to automate the creation of time-tables by applying genetic algorithms (GAs) in an actual HED. HEDs work organisation becomes different because of the combination of shifts and 24-h duties. After knowing the HED workers' requirements (which will allow to identify the hard and soft constraints imposed to the problem) and after defining the adequate encoding to be used in the solutions, a heuristic-schedule builder –designed ad hoc to satisfy the hard constraints – produces an initial population of feasible solutions. Afterwards, iteratively, GA obtains new generations of feasible individuals, thanks to the use of a specific crossover operator, based in the exchange of whole work weeks, that operates together with a repair function. Once the optimum is reached, the results obtained are discussed as a function of the degree of satisfaction of the constraints under which the system operates and of the adaptability of the system as the constraints vary.

1. Introduction

The aim of designing good rotation schemes is to build up work schedules intended to both comply with the policies laid down by an organisation and satisfy personnel preferences which in turn has critical implications for staff morale, quality of service delivery and resource utilization (Burke, Causmaecker, Petrovic, & Berghe, 2006). To most service and industrial organisations, it is critically important to have qualified staff on duty at the right time since this is a large determinant of service organisation efficiency and customers' requirements satisfaction (Felici & Gentile, 2004; Thompson, 1995). Hence, a broad research attention has been given in literature to a great variety of personnel rostering problems (Ernst, Jiang, Krishnamoorthy, Owens, & Sier, 2004a; Ernst, Jiang, Krishnamoorthy, & Sier, 2004b), but since they are complex and highly constrained problems (Glover & McMillan, 1986) there is no all-encompassing solution for every single problem. Each case is unique according to its own constraints and characteristics (legal regulations, personnel policies, personnel preferences and priorities, hospital policies, objectives in rostering, etc.).

The task of periodically producing a duty roster begins with the consideration of both a number of resources (workforce, usually) and a set of features to be considered in order to make optimal use of these resources (structure of the work: shift types, holidays, hard and soft constraints to be satisfied, etc.). Contingent on the problem type at hand, the sequence chosen for applying each feature may become crucial so as to satisfactorily solving the problem.

An initial approach to solving the above-mentioned problem implies the utilization of mathematical programming (MP) – linear programming, goal programming, single-objective MP, multi-objective MP – (Bailey, 1985; Beaumont, 1997; Warner, 1976). MP can most certainly be applied to simple cases involving a small number of staff restrictions. However, in many instances, it does not work entirely satisfactorily or it is not even applicable when applied to more complex cases.

Alternative and more recent approaches are mostly based on constraint programming and heuristics and meta-heuristics procedures. (Ernst et al., 2004a,b) identified 28 different categories of methods that have been used on personnel scheduling problems including: constraint logic programming, constructive heuristics, expert systems, genetic algorithms, integer programming, set partitioning, simple local search and simulated annealing. In general terms, these techniques provide good quality solutions in

* Corresponding author. Tel.: +34 985 18 19 96; fax: +34 985 18 20 10.
E-mail addresses: jpuente@uniovi.es (J. Puente), albertogomez@uniovi.es (A. Gómez), ifq@uniovi.es (I. Fernández), priore@uniovi.es (P. Priore).

0360-8352/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.cie.2008.07.016

the sense that they satisfy most of the conditions stipulated at the outset even though they may not be the best. However, these techniques entail the following drawbacks:

- Optimal (or near-optimal) solutions cannot be generated by the mere evaluation of a polynomial function. Furthermore, the range of possible solutions is too extensive for a non-directed search method to work efficiently.
- Advanced search techniques that employ heuristic methods to downsize the range of possible solutions cannot be guaranteed to find an optimal (or near-optimal) solution.
- The problems involving time planning are complicated by the details of each particular case, and such constraints should be included in the definition of the search domain.
- Real-life time planning problems often include constraints that cannot be represented in the search algorithm with any degree of real precision.

Yet despite such drawbacks, a plethora of applications of heuristic techniques has risen in the last years. Among them, genetic algorithms as optimisation tools, based on the concepts of natural evolution and survival of the fittest, have proved their ability to evolve near-optimal solutions to nonlinear optimisation problems, in different fields on operations research. A wide review of GA applications can be checked in Kobbacy, Vadera, and Rasmy (2007). These applications refer to four mayor categories: design, process-planning & control, quality-maintenance-fault diagnosis, and Scheduling. Rostering problems are included in this last category.

GAs were first employed in the scheduling category so as to tackle with the problem of time-tabling by Colorni, Dorigo, and Maniezzo (1990). Since then, they have helped to provide further breakthroughs in the rostering field (see Aickelin & Dowsland, 2000; Jan, Yamamoto, & Ohuchi, 2000; Kawanaka, Yamamoto, Yoshikawa, Shinogi, & Tsuruoka, 2001), the most important of them being documented in Burke, Causmaecker, Berghe, and Landeghem (2004). However, as previously mentioned, other heuristic techniques have been applied in order to solve the problem; for example, Brusco, Jacobs, Bongiorno, Lyons, and Tang (1995) have applied simulated annealing and local search to generate duty rosters in the airline industry. Dowsland (1998), Valouxis and Housos (2000), Chiarandini, Schaerfand, and Tiozzo (2000), Bellanti, Carello, Della Croce, and Tadeo (2004) among others have utilized tabu search.

Most publications on rostering related to health care area (specifically in hospitals), focus on the nurse scheduling problem (NSP). Nurse rostering can be defined as the problem of placing resources (nurses), subject to constraints, into slots in a pattern. The pattern denotes a set of legal shifts defined in terms of work that needs to be done (Wren, 1996). A wide variety of constraints can be imposed on rosters depending on the legal, management, and staffing requirements of individual organisations. Nurse rostering problems have been solved using a variety of different mathematical and artificial intelligence methods. Since Bailey, (1985) who used mathematical programming techniques to generate nurse rosters optimised with respect to staffing costs, under-staffing costs, and shift pattern penalties, a number of meta-heuristic approaches have been explored including genetic algorithms (Aickelin & Dowsland, 2004), simulated annealing (Bailey, Garner, & Hobbs, 1997), tabu search (Bester, Nieuwoudtand, & Van Vuuren, 2007; Dowsland, 1998), and hyper-heuristics (Burke, Kendall, & Soubeiga, 2003). More recently, Aickelin, Burke, and Li (2007) have proposed a new memetic evolutionary algorithm to achieve explicit learning in rule-based nurse rostering, and Burke, Curtois, Post, Quand, and Veltman (2008) have proposed a hybrid heuristic ordering and variable neighbourhood search to optimise the solution of the problem. A comprehensive survey of scheduling techniques can be seen from Cheang, Li, Limand, and Rodrigues (2003) and Burke et al. (2004).

The nurse rostering problem has been widely studied since the seventies (probably owing to the important growth of this group among hospital staffs). In the same way, it is worth a bigger attention on the study of the rostering problem within the group of the doctors in a hospital emergency department (HED) because of some reasons:

- In the first place because of the growth of this group during the last years. In Spain the mean growth has been 2%, which represents, nowadays, a total amount of 6240 doctors. This represents, approximately, 7% of the medical staff in hospitals (MSCa, MSCb).
- In the second place, the necessity of decreasing risks related to erroneous medical decisions. These decisions stem from the fatigue related to this group's way of working – high number of continuously worked hours and work scheduling instability – (Gander, Purnell, Garden, & Woodward, 2007; Whitt, Harvey, McLeod, & Child, 2007).
- What is more, HED's work system could be exported to any other health service, or even to other non-health sectors with similar features (for instance, attended survey services).

This paper deals with an actual medical-staff rostering problem in which monthly schedules are requested. The study tackles the fact that there is an important difference with the nurse rostering problem. In Spain, the doctors who work in a HED, work in two different ways, combining shifts (morning, afternoon and night) and 24-h duties. Next section starts describing the shift roster problem at the analysed HED; the structure of the personnel in the service is detailed, as well as the different ways of working (shifts and duties). In Section 3 the procedure by which the hard and soft constraints are to be satisfied by the monthly schedule is detailed, and the relevance of each one of these constraints is also analysed. In Section 4, the main features of the genetic algorithm proposed to solve the problem are commented. Section 5 shows the results obtained for two different weighting criteria. The satisfaction of the constraints in both scenarios is statistically analysed and discussed. Finally in Section 6 the conclusions of the paper are listed, marking out the main contributions of the paper.

2. Description of the medical doctor-shift rostering problem

Establishing duty rosters for the medical staff of a real HED is a challenging tailor-made task that does not respond to the general pattern given the complexity of such a department's structure. This complexity is due to a number of factors, such as the variability and unpredictability of patient demand, the range of the services offered (factor which is in turn reliant on the category of the hospital, and therefore on the hospital's catchment area), the work mode (shifts, duties, or a combination of both), the type of labour contract (full time or part time, etc.), and the kind of work that is undertaken (general emergencies, outpatient service, mobile intensive care units, emergency care with other departments).

This study focuses on shift management for the HED of a second category Spanish hospital, category given by its 500-bed capacity. The HED has 11 beds for general emergencies, and 13 beds for patients under observation. Medical workforce is a combination of some staff with permanent contracts, and others with temporary ones, as described in next paragraphs: