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A harmony search algorithm for nurse rostering problems

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ABSTRACT

Harmony search algorithm (HSA) is a relatively new nature-inspired algorithm. It evolves solutions in the problem search space by mimicking the musical improvisation process in seeking agreeable harmony measured by aesthetic standards. The nurse rostering problem (NRP) is a well-known NP-hard scheduling problem that aims at allocating the required workload to the available staff nurses at healthcare organizations to meet the operational requirements and a range of preferences. This work investigates research issues of the parameter settings in HSA and application of HSA to effectively solve complex NRPs. Due to the well-known fact that most NRPs algorithms are highly problem (or even instance) dependent, the performance of our proposed HSA is evaluated on two sets of very different nurse rostering problems. The first set represents a real world dataset obtained from a large hospital in Malaysia. Experimental results show that our proposed HSA produces better quality rosters for all considered instances than a genetic algorithm (implemented herein). The second is a set of well-known benchmark NRPs which are widely used by researchers in the literature. The proposed HSA obtains good results (and new lower bound for a few instances) when compared to the current state of the art of meta-heuristic algorithms in recent literature.

1. Introduction

Nurse rostering problems (NRPs) are highly constrained combinatorial problems which are difficult to be solved to optimality [8]. Scheduling the nurses at healthcare organizations is a challenging task. Extra care needs to be taken as personnel of healthcare organizations consume about 40% of hospital budgets [46]. Bad or inflexible duty roster can affect the personal life of staff nurses, increase job dissatisfaction, and thus result in high staff turnover. These have a direct impact on the nursing services provided to patients [14,46]. Based on the literature in NRPs, a lot of big healthcare organizations around the world still construct nurses' duty roster manually [14,20,45]. This raises the challenge for researchers to propose and investigate automated solution methodologies to solve this problem.

Various methods have been proposed to solve NRPs, including exact methods, meta-heuristics and others [14]. Although exact methods (mathematical based models) can obtain optimal solutions, they showed to be highly inflexible in solving large scale optimization problems due to the computational time required. Meta-heuristic approaches which are able to produce solutions of good quality for difficult combinatorial optimization problems within a reasonable computational time are thus usually preferable as the solution methodology [14]. Meta-heuristics refer to the approaches that mimic some of the natural and artificial phenomena that combine "rules of thumb" and randomness to solve difficult problems [15,49].

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Well-known examples of meta-heuristic algorithms include genetic algorithms (GAs), simulated annealing (SA), tabu search (TS), to name a few [49]. During the last few decades, meta-heuristic approaches and their hybrids have been successfully applied to solve NRPs [14].

NRPs have gained the interest of many researchers for more than four decades [14]. Several comprehensive surveys [14,17,24] have reviewed a large number of published papers on NRPs. NRPs are well known over-constrained problems [24,50]. They are very difficult to solve manually due to their nature of large number of often conflicting objectives that must be taken into consideration while constructing the duty roster, i.e. different types of nurses, different shift types, different coverage demand of shifts each day, popular/unpopular shifts and many more issues [14,46]. Many optimization algorithms have been proposed to solve NRPs with different constraints. Some showed to be superior in solving some of the instances but not the others. Various population based and local search based meta-heuristic algorithms developed to solve NRPs include GAs [2,43], TS [11,21], SA [31,42] and many others [14]. In [13], the performance of scatter search algorithm and memetic algorithm (population based) were better compared to variable neighborhood search and tabu search algorithms (local search based) when tested against the presented benchmark datasets. This encouraged us to investigate the use of other population based methods for NRPs.

In this work, we adapt harmony search algorithm (HSA), which was developed by Geem et al. [29] to solve combinatorial optimization problems, to solve NRPs. It mimics the analogy of the natural process of musical improvisation that searches for suitable musical notes. The idea is adapted in the search process for solving optimization problems [29]. HSA can be categorized as a recent evolutionary algorithm and showed to be efficient in solving difficult optimization problems such as university course timetabling [3], vehicle routing [30], and many others [23,25,39,51,54].

Compared to the traditional optimization methods, HSA has some features that motivate our investigation to solve NRPs. These include [37]: (i) HSA has few parameters that need to be tuned and thus could be easily adapted to different NPRs or instances. These parameters do not require too much tuning effort to obtain high quality solutions [53]. (ii) HSA is a stochastic random search method. (iii) HSA overcomes the drawback of building block theory of GAs by considering all existing solutions, whilst GAs consider only two solutions (parents) in reproduction [53]. To our knowledge, there is only limited published work on HSA to solve NRPs [4], where a basic HSA has been evaluated on only the small instances established by the International Nurse Rostering Competition 2010 (INRC2010). How HSA will perform on large or complex NPRs instances has not been investigated. In addition, the parameter values of HSA in [4] were arbitrary chosen. It is well known that the performance of many population based methods is highly dependent on its parameter values [22]. Therefore, the aim of this work is to address research issues in applying HSA to NRPs by intensive investigations on suitable parameter values and performance evaluation on a large number of instances of problems with different size and complexity.

In order to reduce the gap between practical problems and academic theories, a real world dataset obtained from a large hospital in Malaysia (UKMMC) is used to assess the performance of the proposed HSA. The performance of HSA is also evaluated on the nurse rostering benchmark problems (www.cs.nott.ac.uk/~tec/NRP/) [18]. Computational results on both problems demonstrate the efficiency and effectiveness of the proposed HSA in producing high quality solutions in a shorter time compared to a basic genetic algorithm for the UKMMC problem, and obtaining good results compared to some existing meta-heuristic algorithms for the same benchmark NRPs. For more resources and application areas of HSA, please refer to [35,52].

The rest of the paper is organized as follows. Section 2 presents the problem description. The proposed harmony search algorithm is presented in Section 3. Section 4 presents the computational results and analysis. Finally, concluding remarks are presented in Section 5.

2. Problem description

NRPs can be defined as allocating the workload to the available staff nurses at healthcare organizations to meet the operational requirements [14]. More precisely, given a set of nurses of specific categories, a set of pre-defined periods (shifts) on a working day, and a set of working days; the aim is to assign each nurse to specific planning periods satisfying some constrains (known as hard and soft constraints). Hard constraints are mandatory whereas soft constraints can be violated if necessary [14,24]. The quality of the generated roster can therefore be assessed based on how many soft constraints have been satisfied. Due to the variety in hard and soft constraints, which are different from one organization to another, the modeling and implementation process present to be challenging tasks, as a unique general mathematical model to accommodate all related constraints does not exist [8,14,24,47]. As a result, different instances require different implementations and configurations in designing the algorithms. There are, however, a group of problems represented with a common XML structure but associated with different constraints and objectives [18]. Some effort has also been made in the literature to construct relatively general frameworks [19]. Therefore, in this work we have attempted to solve real world and benchmark NRPs because we believe that HSA can be applied to solve a wide range of NRPs. The descriptions of the two problems concerned are provided as follows.

2.1. The UKMMC nurse rostering problem

To bridge the gap between academic research and real world practice, this work considers eight different rostering problem scenarios faced by UKMMC, see Table 6 in Section 4.1. UKMMC is a Malaysian public hospital with more than 1400 nurses working around the clock [32]. In this section, the list of hard and soft constraints, the evaluation function and