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An ACO algorithm for a dynamic regional nurse-scheduling problem in Austria

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Abstract

To the best of our knowledge, this paper describes the first ant colony optimization (ACO) approach applied to nurse scheduling, analyzing a dynamic regional problem which is currently under discussion at the Vienna hospital compound. Each day, pool nurses have to be assigned for the following days to public hospitals while taking into account a variety of soft and hard constraints regarding working date and time, working patterns, nurses qualifications, nurses' and hospitals' preferences, as well as costs. Extensive computational experiments based on a four week simulation period were used to evaluate three different scenarios varying the number of nurses and hospitals for six different hospitals' demand intensities. The results of our simulations and optimizations reveal that the proposed ACO algorithm achieves highly significant improvements compared to a greedy assignment algorithm.

Keywords: Dynamic regional nurse scheduling; Ant colony optimization (ACO); Decision support system

1. Introduction

Policy makers are facing a situation in which there is an emerging global nursing shortage along with misdistribution and poor utilization of nurses [1]. Major contributors to the nursing shortage include: the aging population, the decline in enrollment at nursing schools, the changing work climate in hospitals

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and nursing homes, and the low image and salary associated with nursing [2,3]. The current situation is characterized by an increasing demand and a decreasing supply. For example, health care experts estimate a shortage of 400,000 registered nurses in the United States of America by 2020 [3]. Badelt et al. [4] forecasted that by 2030 the number of Austrians needing health care services would double based on a scenario for long life expectancy due to improved medical technologies.

This nurse shortage results in an increased competition for the nursing human resources available, both within and among countries [1]. Many nurses from less-developed countries emigrate to high-income countries due to better pay and career opportunities [1]. In recent years, many Chinese, Philippine, and Eastern European nurses have come to Austria. However, this number has still been too low to compensate for the existing shortage. First evidence of this shortage's negative consequences emerged in a number of nursing homes where several patients were left unattended by careless nurses. This led to an Austrian nursing scandal in autumn 2003.

Therefore, new strategies have to be developed to overcome the nursing shortage as well as the mis-distribution and poor utilization of nurses. One strategy includes the development of regional nurse pools to better compensate for the nursing shortage and to better utilize scarce human resources. Currently, the Vienna hospital compound is considering such a solution for covering temporary shortages in their hospitals.

Until recently, policy makers in hospitals solved nurse scheduling problems manually, which was a time consuming task [5]. This is why numerous models have been developed to investigate various aspects of specific nurse scheduling problems for over 40 years (cf. [6–9]). Warner [10] disclosed essential characteristics for decision support systems (DSS) in this field: coverage, quality, stability, flexibility, fairness, and costs. Another key issue for nurse scheduling comprises physical and mental consequences of night work, alternating shift plans, and work stretches, etc., [11,12].

In the early years of nurse and physician scheduling modeling, many mathematical programming approaches were applied to solve rather simple problems with few constraints and a single goal due to restricted computer technology (cf. [9,13,14]). Since the early 1980s, goal programming and multi-criteria approaches have emerged in the literature (cf. [15–18]). As real world problems are immense and deal with many constraints, heuristics (cf. [19–21]), and recently metaheuristics such as simulated annealing (cf. [22]), Tabu search (cf. [23–29]), and Genetic Algorithms (cf. [30–32]) have been developed to generate high quality nurse schedules in an acceptable computation time. Several artificial intelligence methods have been proposed to schedule duty rosters for physicians and nurses in recent years (cf. [33,34]).

The dynamic regional nurse scheduling problem tackled in this paper can be described as follows. The Vienna Hospital Compound consists of 15 public hospitals including nursing homes and serves the majority of Vienna's population [35]. Currently, this organization is considering the introduction of an organized pool of flexible nurses for the Vienna region to meet excess or uncovered demand for nurses. Periodically, for example daily, pool nurses have to be assigned for the following days to public hospitals while considering a variety of soft and hard constraints regarding working date and time, working patterns, nurses' qualifications, nurses' and hospitals' preferences, as well as costs. Decision makers can weigh all of these constraints in a cost function to express their assignment preferences such as more weight for salary costs and for uncovered demands.

We anticipated that simulated annealing or Genetic Algorithms were not the most efficient approaches for our problem because of the complicated form of the constraints, and verified this in our experiments for the case of simulated annealing. Due to the high complexity of the problem, we did not consider mathematical programming or goal programming methods such as [36]. On the other hand, the ant colony