Preference Nurse Scheduling with Squeaky Wheel Optimisation

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1 Introduction

We refer to the construction of schedules for a ward of nurses in a hospital. In general, nurse scheduling methods can be classified into three types. In **cyclic scheduling**, a series of working patterns are generated and rotated among all nurses from one planning period to the next one (e.g. [1]). In **self-scheduling**, nurses choose the shift they want in each day provided that enough places are available and no conflicts with management and contractual regulations occur (e.g. [2]). In **preference scheduling**, cyclic and self-scheduling are combined where individual nurses' preferences are considered but not necessarily enforced (e.g. [3]). This method is more flexible than cyclic scheduling and it is also fairer than self-scheduling because all nurse's preferences are considered simultaneously. A number of algorithms for nurse scheduling have been proposed. These include mathematical programming, meta-heuristics, knowledge-based systems and others, see [4, 5] for comprehensive reviews of nurse scheduling literature. We propose an approach based on squeaky wheel optimisation [6] that also incorporates ideas from multi-neighbourhood search [7] and great deluge [8] to tackle a real-world nurse scheduling problem following the preference scheduling method. We carry out experiments on seven instances of the Queen's Medical Centre (QMC) nurse scheduling problem in Nottingham, UK. In the QMC problem, each nurse expresses his/her preferences for working shifts and days off for the planning period in an individual preference schedule (hence our decision for using a preference scheduling approach). A ward of 20-30 nurses should be scheduled over a period of 28 days with three shifts (early, late, night). Nurses work full time or part time and a number of additional constraints and regulations exist. A full description of the QMC nurse scheduling problem and the data sets used here are available at: `http://www.cs.nott.ac.uk/~kxl/research/QMC/qmc.html`

2 Squeaky Wheel Optimisation Approach

Squeaky wheel optimisation uses three iterative steps: construct, analyse and prioritise [6]. First, generate a solution using a greedy algorithm. Second, analyse the current solution to identify trouble spots in the solution. Third, prioritise the trouble spots and use this information when the greedy algorithm constructs the new solution. In our implementation, each step works as follows:

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Construct. Starting with day 1, a greedy heuristic assigns nurses to the early shift until the coverage demand is met, then the late shift and night shifts are scheduled in turn. This process is repeated for every day until a ward schedule is completed. At every point, the heuristic looks at the individual preference schedules to decide which nurse to assign. The heuristic also checks that no hard constraint is violated during the schedule construction.

Analyse. For each day in the current schedule, we calculate the penalty due to soft constraints violations. This penalty becomes the blame factor, which identifies 'poor' parts of the solution. This phase identifies good and bad scheduled days.

Prioritise. Using the blame factors from the previous step, we order the days in the schedule in a prioritised list from the most penalised to the least penalised. The aim is to have the badly scheduled days at the top of the list ready to be repaired by the construction phase.

Repair. Starting from the top of the prioritised list, we attempt to reduce the penalty in each day using swaps of shifts. A high penalty on a given day is because not enough nurses are assigned or because undesirable shift sequences (e.g. day after night) occur. Then, the repair process is embedded in the next constructive phase, which tries to build a better schedule by scheduling the badly scheduled days first. In our first implementation, the repair process consists of selecting the best of a number of local swaps of shifts between two days for the same nurse. These swaps are focused on badly scheduled days and are only accepted if they improve the current solution. We further improved our algorithm by modifying the repair step as follows. Firstly, we use multi-neighbourhood search [7] to select the move to be applied while still accepting improving moves only. We implemented eleven moves based on three basic ones: assign shift (assign a shift to the nurse's schedule in a free day), change shift (change the type of shift assigned) and swap shift (swap the shifts between two nurses for a given day). We call this algorithm variant SWO+NS. Secondly, we incorporate the idea, from the great deluge algorithm [8], of accepting non-improving swaps provided the detriment in within a threshold, such threshold is reduced as the search progresses. We call this algorithm variant SWO+NS+GD. An improvement to the basic squeaky wheel optimisation algorithm has also been proposed elsewhere [9].

3   Experiments and Results

We constructed 10 schedules for each of the seven data sets from March to September 2001 and each run took 100,000 iterations. Table 1 shows a summary of our results comparing SWO, SWO+NS and SWO+NS+GD. For each algorithm we show: 1) the overall preference satisfaction (PrefSat) which gives the percentage of all nurses' preferences that are met in the final ward schedule, 2) the total penalty due to the violation of soft constraints (SCP), and 3) the total computation time in seconds to find the best solution. The table also shows in columns 2 and 3, PrefSat in the manually constructed solution and SCP in the initial constructed schedule. The best values are indicated in bold. From the first implementation, SWO obtains very good schedules in short computation time. After incorporating the multiple neighbourhoods in the repair procedure, better preference satisfaction and lower soft constraints penalty are achieved in three instances while the computation time increases but is still below 30 seconds. When the great deluge acceptance criterion is incorporated, better preference satisfaction is achieved in two instances and in the other five instances the preference satisfaction is very close to

the best values found before. Moreover, SWO+NS+GD produces the best results in terms of soft constraint violation in all instances. In summary, our experiments provide evidence that our squeaky wheel implementation generates high quality schedules and the two proposed modifications to the repairing step in this algorithm help to obtain better results in our problem.

Table 1: Summary of results applying squeaky wheel optimisation with concepts from multi-neighbourhood search and great deluge to the seven instances of the QMC nurse scheduling problem.

Dataset	PrefSat	SCP	SWO			SWO+NS			SWO+NS+GD		
	Man.Sol.	Ini.Sol.	PrefSat	SCP	t(s)	PrefSat	SCP	t(s)	PrefSat	SCP	t(s)
Mar01	45.4%	819	**88.2%**	0	12	86.0%	0	12	82.0%	**0**	63
Apr01	80.5%	953	82.0%	266	16	**85.2%**	205	21	75.2%	**205**	66
May01	31.6%	1875	81.9%	618	14	64.5%	1434	21	**89.5%**	**577**	63
Jun01	82.4%	1801	88.6%	1468	12	73.0%	1604	25	**90.8%**	**1409**	72
Jul01	16.0%	2005	89.1%	1734	14	**92.0%**	1543	29	84.3%	**1473**	52
Aug01	47.3%	786	86.1%	330	14	**87.9%**	300	15	84.9%	**40**	45
Sep01	29.2%	1129	**88.8%**	619	13	87.5%	577	22	85.5%	**495**	68

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