

Novel Meta-heuristic Approaches to Nurse Rostering Problems in Belgian Hospitals

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Introduction

- Due to the increasing pressure of work in hospitals around Belgium, nurse rostering system is deployed among hospitals which help to produce rosters which employ resources more efficiently.
- While doing so there are several factors to be considered while assigning nurse rosters to personnel members.
- The current approach concentrates on short term problems while assigning specific tasks to a sufficient number of qualified nurses, such as:

Introduction

- Number of Personnels in the ward.
- The required qualifications of nurses.
- Definition of shift types.
- etc.

Apart from these factors listed, some problems that are usually not considered but affect the solution strategies are:

- Shift time divided over several nurses.
- Nurses assigned to different wards temporarily during emergencies.
- Certain preferences by personnel members.
- etc.

Introduction

All these problems have been addressed by many scientists, personnel managers and schedulers over a number of years. Although due to the emergence of larger and more constrained problems has presented a real problem for researchers.

For this, a flexible planning system should incorporate as much knowledge as possible to provide the personnel manager or head nurse satisfying all the objectives of personnel

Problem Description

Automated nurse rostering assistance
developed in Belgian health care
Organizations refer as ANROM
(Advanced Nurse Rostering Model).

		Start	End
M	morning shift	06:45	14:45
L	late shift	14:30	22:00
N	night shift	22:00	07:00

- Hospitals are organized in wards with fixed activities, usually a settled location, and, for the most part, they have a permanent team of nurses.
- Personnel members in a ward belong to skill categories.
- People with more experience or who have taken some exams, can be substitutes for higher skill categories.

Problem Description

- A shift type is a predefined period with a fixed start and end time in which personnel members can be on or off duty.
- Different part time contracts require a large variation in start and end times and in duration. Planning periods for nurse rostering vary from a couple of days to a few months.
- Cyclical rosters are not common at all, it is important for individual employees to know their schedule some time in advance.
- Long term scheduling should not be too detailed because the personnel requirements and preferences fluctuate and are not predictable in the long term.

	Mon	Tue	Wed	Thu	Fri	Sat	Sun
P1	M	M	L	L	N		
P2	N		N	L	L		
P3	M	M	M	M	M	M	M
P4	M		L	N	N	N	
P5	M L	L	L	L			

Figure 1: Roster example for 5 people (P1,..., P5) and 1 week; M, L, and N being the shift types introduced in Table 1

Problem Description

- The roster, in which the shift assignments are stored, is called the schedule.
 - Assignment assigned to units as entities of minimum allocation in a schedule.
 - They are mainly introduced to express and evaluate the soft constraints on the personnel's schedules.
-
- Hard and Soft Constraints:
 - Hard constraints are those that must be satisfied at all costs.
 - Soft constraints are those which are desirable but which may need to be violated in order to generate a workable solution.

Problem Description

- All the shift types specified in the personnel requirements have to be assigned to a personnel member.
- One person cannot be assigned twice to the same shift on the same day.
- Shifts can only be assigned to people of the right skill category.
- The real-world situation addressed in this case incorporates a high number of soft constraints on the personal schedules.
- It is highly exceptional in practice to find a schedule that satisfies all the soft constraints.
- The aim of the search algorithms is to minimize the penalties due to violations of these constraints.

Problem Description

- The list of Soft constraints can be divided into 3 categories:

1. Certain constraints hold for the entire hospital.

- For example:
 - Minimum time between two assignments.
 - Allow use of an alternative skill category in certain situations.

2. Another set of soft constraints is the same for all the people with the same contract (full-time, half-time, night nurses, etc.). Values are set by the users.

- For example:
 - Maximum number of assignments in the planning period
 - Minimum/Maximum number of consecutive days

3. When individual personnel members have an agreement with the personnel manager or head nurse, then certain constraints can be implemented.

- For example:
 - Day off; shifts off
 - Requested assignments

Solution Framework

- The search heuristics for solving the ANROM model are driven by an evaluation function that estimates the quality of schedules.
- Since hard constraints have to be satisfied at all costs, only soft constraint violations contribute to that quality.
 - A solution that does not meet a hard constraint does not qualify as a feasible solution
- The evaluation method makes use of a simple algorithm and requires very little memory and computation time.
 - This is useful for evaluating intermediate solutions while exploring the large search space.
- Hard constraints have to be satisfied at all costs, so only soft constraint violations contribute to the quality of a solution.

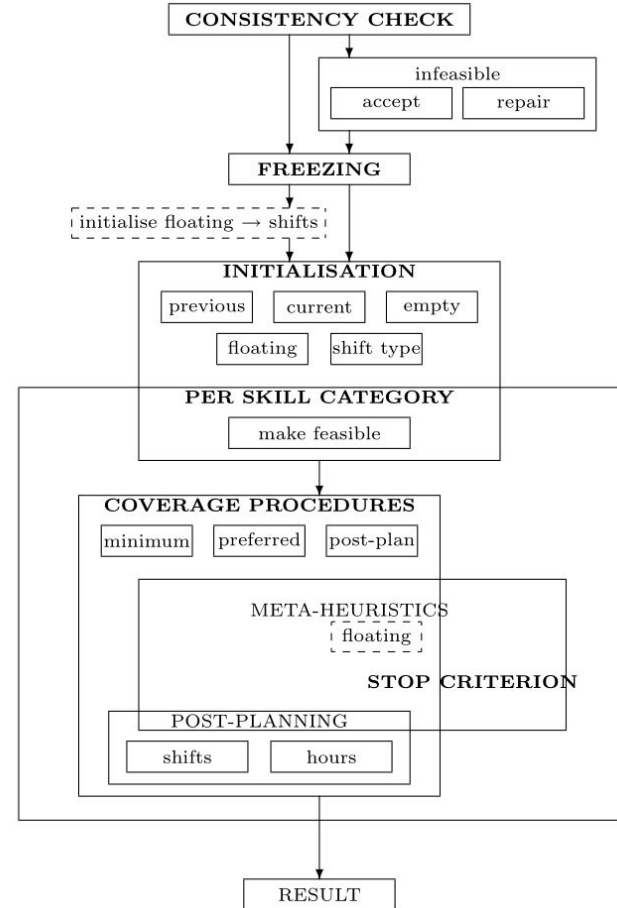
Solution Framework

- The procedure takes into account the characteristics of the soft constraints (cost parameters, tolerable deviations, restrictions on consecutiveness) in a modular way.
 - It is easily extendible and provides a very structural technique for incorporating new constraints that appear in real world problems.
 - This functionality assists the user with the interpretation of the quality of the result.
- The modular nature of the approach allows the system to provide some feedback.
 - Basically what this means is that after every step or (module) in the process, the user can provide feedback to adjust the result of that module

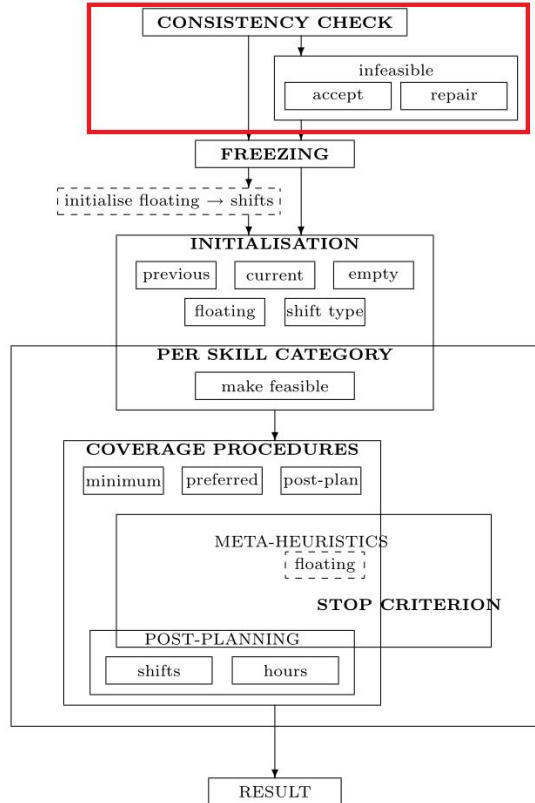
Planning Procedures

The algorithm has been split up into separate procedures or modules. This is done to allow each hospital to have the option to modify results of each procedure in order to have more control over the end result.

- Each procedure is highlighted in bold in the chart.
- Smaller boxes that are on the same level indicate alternatives or options.



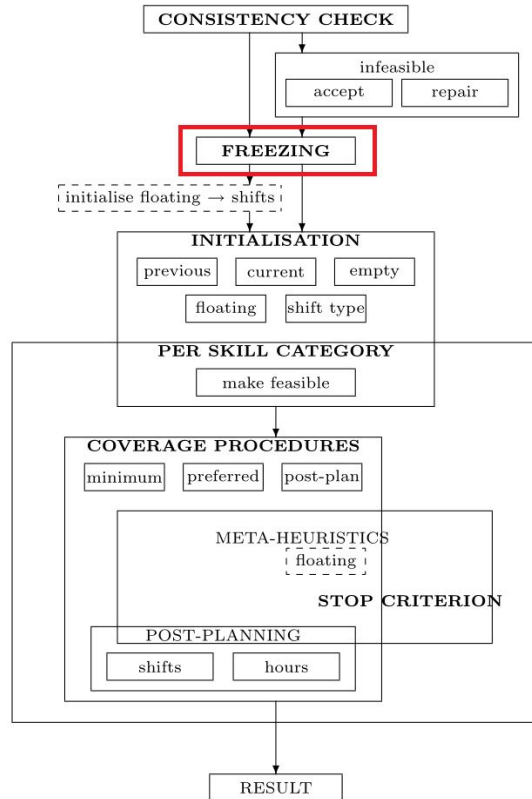
Planning Procedure: Consistency Check



When the hard constraints are so strict that no feasible solution exists, planners can opt to relax them.

Either the user can accept the solution by relaxing the requirements when necessary or then can deliberately choose to violate the soft constraints that were checked.

Planning Procedure: Freezing parts of the schedule

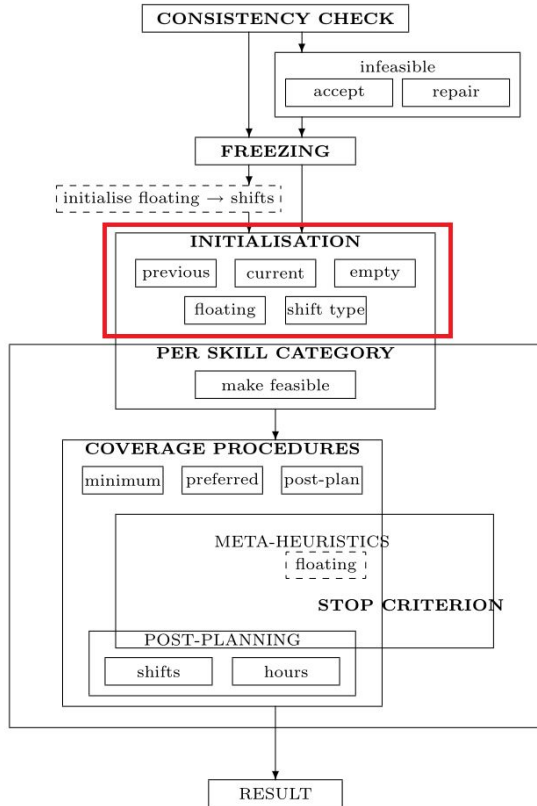


The search space for rostering algorithms can be restricted for various reasons.

- This means that we can prevent the algorithm from modifying certain parts of the schedule.
 - Some hospitals prefer interaction and they schedule the timetables of certain nurses manually.
 - Personal preference of hospital staff.
 - During emergencies, hospital staff have to be reassigned.

No matter which parts of the schedule are frozen, the evaluation procedure considers the entire schedule.

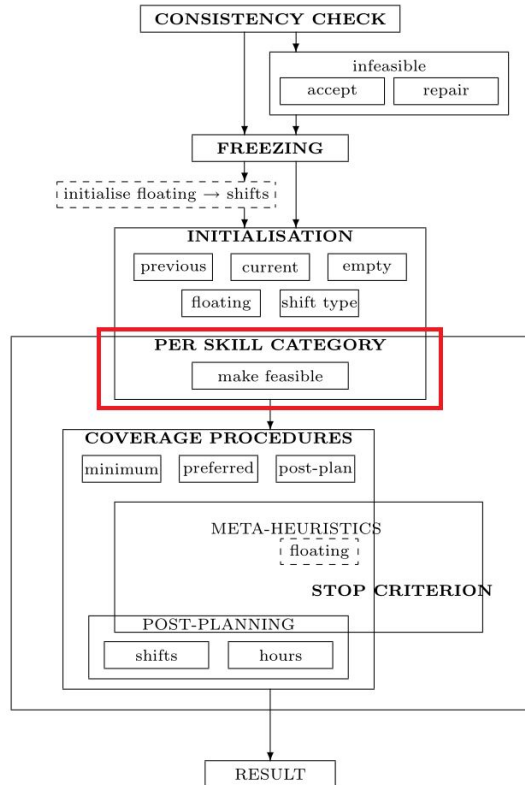
Planning Procedure: Initialisation



The initialisation of the scheduling algorithm consists of two phases for creating a feasible initial solution.

1. The input is loaded and planners can make a choice among a random initial schedule or an initial schedule that is copied from the previous or current planning period (if that exists).
2. The schedule is made feasible by randomly adding or removing assignments until the hard constraints are satisfied.

Planning Procedure: order of skill categories



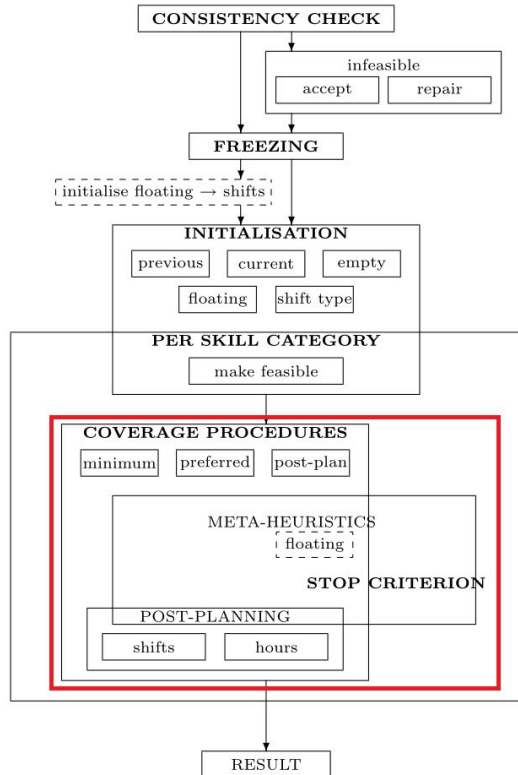
Each skill category is scheduled separately in this model.

- This is done because number of personnel belonging to each skill category is often considerably smaller than the entire staff which means the number of shifts to assign is much lower.
- After the planning for one skill category has stopped, the algorithm moves on to the next skill category and temporarily freezes the already assigned shifts.

Planning Procedure: Time interval requirements

- Time interval requirements provide an alternative way of expressing the coverage needs.
- Hospitals define a large number of shift types that match different activities and enable many kinds of part time work.
- With this option, we concentrate on an advanced formulation of requirements in terms of intervals of personnel coverage.

Planning Procedure: Coverage Procedures



In practice, the number of required personnel on a certain day is not completely strict.

- This algorithm can be modified to only satisfy a few of the hard constraints instead all of them
 - Instead of strictly setting the hard constraints, this option allows a range in which the hard constraints are considered to be satisfied.
- The algorithm can also add additional hours any shift at this stage in order to satisfy the requirements.

Meta-Heuristics and Hybrids

- Method that applies the problem characteristics to dynamically modify the environments of the search heuristics.
- Search space can be improved by combining short sighted search as well as greedy search in a wider environment.

Meta-Heuristics and Hybrids - Personnel Rostering

- The meta-heuristics for the nurse rostering problems change neighborhoods if they cannot find better solutions after a number of iterations.
 - Must satisfy hard constraints
- The cost function is the driving force for the heuristics, but can remain blind for improvements if it is unable to interpret certain problem characteristics.
- Environments were designed to find such improvements:
 - Single shift-day neighborhood.
 - Soft constraint related neighborhoods.
 - Swapping large sections of personal schedules.

Single Shift-day Neighborhood

- Simplest environment contains solutions differing from current solution by moving one assignment to another nurse's schedule.

	Mon				Tue				Wed				Thu			
Head Nurse		(D)				(D)				(D)				(D)		
Nurse A, HN	(E)	↓		↑	(E)	↓		↑	↑	↓	(L)	↑	↑	↓	(L)	
Nurse B	↓			↑	↓			(N)	↑		↓		(N)	↑	↓	
Nurse C	↓			(N)	↓			↓	(E)		↓	↓	(E)		↓	

- Ex: 4 Nurses with 4 different shift types (Early: E; Day: D; Late: L; Night: N). The arrows show the only possible moves without violating the hard constraints.
 - Nurse A is able to replace Head Nurse while Nurse B & C cannot.

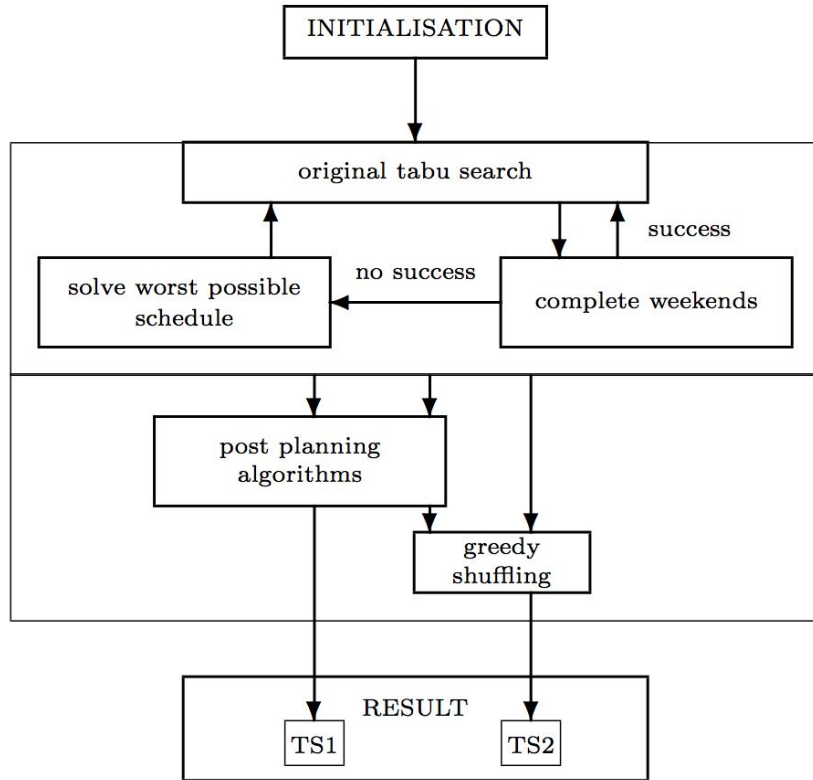
Soft Constraint Related Neighbors

- Planners with practical experience were often more concerned with soft constraints rather overall solution quality
 - Only soft constraints are addressed.
- Environments look at weekend constraints, alternative qualifications, personal preferences, etc..

Swapping Large Sections of personal schedules

- Unlike the previous two, this set of neighborhoods looks at schedules that are substantially different from their current solution.
- Instead of moving single shift types, all the assignments in a longer period are switched.
 - A single day or a number of days that equals half the planning period
- A similar environment is called the greedy shuffle
 - Consists of possible shuffles between any set of two people.
- Drawbacks: large neighboring solutions and iterations, thus requiring large amounts of computational time.

Hybrid Tabu Search



- Tabu search for personnel scheduling
 - A combination of tabu search with the environment generating neighborhoods.
- Useful considering:
 - The soft constraint on full weekends
 - Improving the worst personal roster
 - All the large improvements between two personal rosters
- Practical use:
 - Choice between algorithm generating schedules fast - **Fast Planning - TS1**
 - More thorough schedule when final solution is required - **Thorough Planning - TS2**

Memetic Algorithms

- Makes use of crossover operators to copy desirable characteristics of previous generations as well as mutations for the random diversity.
- Consider a population with N individuals that match the hard constraints.
 - The quality of a roster is determined by the sum of the qualities of all individual rosters.
 - Crossover operators will copy full personal rosters to the next generations.

Various Memetic Algorithms

- Simple Memetic Algorithm
 - Applies on each newly created individual.
 - The first child is obtained by copying the best personal schedules from both parents.
 - All other personal schedules are copied randomly from both parents.
 - Assignments are added or removed randomly until the constraints are met.
- Diverse Memetic Algorithm
 - Based on the Simple Algorithm, however the planning order of skill categories is randomly chosen in the local search step
- Memetic Algorithm with crossover
 - A random assignment unit is generated for each person in the schedule and at that point, personal schedules from 2 parents are combined.

Various Memetic Algorithms

- Memetic Algorithm that copies the Best x Assignments
 - Selects the assignments that induce the highest increase in violations when removed and is passed on to the child iteration.

Combination of Tabu Search and Evolutionary Algorithms

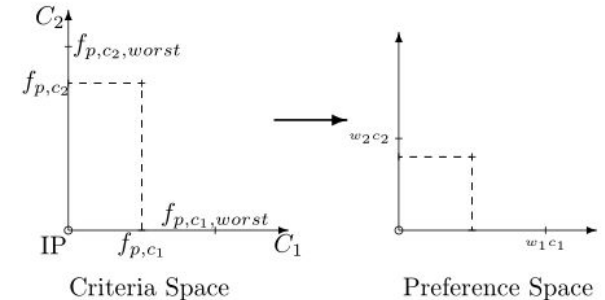
- Various algorithmic variants has been explored with combining tabu search and evolutionary methods.
- Multistart TS with random planning order
 - Enables a direct comparison between table search, memetic algorithms and hybrids.
- Memetic algorithm with improved local search
 - Uses thorough planning algorithm to the best solution obtained by the memetic algorithm.
- Switch
 - Accepts all solutions that remain within the minimum-preferred requirements interval.
 - New generations are created by adding or removing assignments in the parent schedules.

Multi Criteria Approach

The authors also implemented a multi-criteria approach which applies 'compromise programming', which is based on the concept of the distance to an ideal point.

This is done by creating a best possible result which the algorithm can produce and mapping it on a chart. Then comparing it to the actual result generated by the algorithm and measuring the distance between the two on the chart.

The smaller the distance, the better the schedule.



Conclusion

- The time for automatic schedule generation can be tailored to suit the time available by selecting appropriate search heuristics.
- The proposed solution method provides an unbiased way of generating the schedules for all the personnel members.
- It enables simple verification of the constraints, helps redefine unrealistic hard constraints and thus leads to an overall higher satisfaction among the personnel, as is manifest in many applications.
- Moreover, other sectors require the evaluation of constraints on locations, equipment, etc that are irrelevant in nurse rostering.