Multimodal Home Healthcare Scheduling using a novel CP–VND–DP Approach

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1 Overview

Healthcare services, especially home healthcare services (HHC), are of great significance in today's western world, where the average age is steadily increasing. HHC services are particularly popular, since patients prefer being nursed at home than at retirement homes. However, finding a good schedule is challenging:

- Nurses need to arrive at the patients' homes in certain **time windows**,
- Each service requires a **qualification** that the nurse must hold (e.g. a nurse for cleaning may not perform a medical service)
- The schedule should meet **preferences** of patients, nurses and employer
- All **legal and contractual issues** (such as sufficient resting periods) should be satisfied

We consider a real-world setting, where the objective is to find a schedule with *minimal travel time* (to reduce operational costs), such that *all* patients are assigned a nurse, satisfying as many side constraints from the above as possible. Our goal is to construct a flexible framework that generates efficient nurse schedules for different home care companies.

Real-world HHC problems are challenging for many reasons. First, the HHC problem constitutes a combination of two NP-hard problems: vehicle routing with time windows [4, 5] and nurse rostering [6]. Therefore, we need to employ a heuristic approach since exact solving methods can typically only tackle small instances. Second, real-world instances include many side constraints that vary greatly between different service providers (e.g. different nurse contracts). Hence we require a *flexible* solving architecture, where constraints can be easily added/removed. Third, to provide accurate schedules, it is crucial to use accurate travel time estimations, regarding *different modes of transport*. Therefore, we include travel time estimations from a large set of historical data for different transport modes (car, public transport, bike, foot) into our system.

2 A Hybrid Approach for Solving the HHC Problem

We propose a hybrid meta-heuristic for the HHC problem where constraints can be easily added and/or removed, and different transport modes are considered. The solution approach consists of three parts: (1) an initialization step, (2) an improvement phase and (3) a constraint checking and subproblem solution phase. Three core components are used during those steps: a *constraint programming* (CP) [11] formulation, a *variable neighborhood descent* (VND) [8] improvement phase and a *dynamic programming* (DP) [2] method.

1. Initialization Step First, an initial solution is generated using a CP approach, where we use an extension of the vehicle routing problem model from [11]. The advantages of using CP are threefold: first, the CP model is *flexible*, since constraints can be easily added and/or removed from the model. Second, CP is efficient in finding good first solutions, if adequate search strategies are chosen. Third, the CP model can be reused to check if a modified solution still satisfies all constraints.

2. Solution Improvement Second, the initial solution is improved by VND, a fast local search method, where various neighborhoods, which are generated by 'moves' such as '*swap-nurses*', are systematically searched for better solutions. Candidate solutions are verified by reloading the store of the CP model. This approach guarantees that the system is kept flexible, yet accurate, since constraints can be easily added/removed without any major implementation tasks.

3. Tour Planning Phase In a third step, we improve the tours of the schedule: as soon as all patients are assigned to a nurse, planning tours can be considered an independent subproblem, *a TSP with time windows.* First, we reduce the TSP with with time windows to a generalized TSP by applying the algorithm from Albiach et al [1]. Second, we solve the TSP using an extended DP-approach based on [9]. The main benefit of using DP is that we obtain an *exact* solution in little time due to the instance dimensions (limited number of nodes per tour).

Multimodality Nurses typically travel by (a combination of) different transport modes (car, bike, foot, public transport) which has an effect on the overall travel time. Currently, the transport mode of each nurse is given *in advance* and therefore constitutes a feature (such as *qualification*) that affects travel time. Thus, multimodality results in additional side constraints. The travel times are computed from time-dependent historical data for each transport mode. In future work, we want to *select* the best transport mode for each nurse.

3 Related Work

The main difference to other approaches lies within our objective to provide a *flexible* framework to tackle real-world HHC problems of different flavor. Hence, our hybrid setup is tailored to this requirement. Other meta-heuristical approaches [7, 3, 12, 10] use different setups and do not consider multimodality.

4 Discussion and Conclusions

In this abstract, we propose a new hybrid meta-heuristic to solve real-world HHC instances in a flexible framework for different homecare companies. The contributions of this work are twofold: first, we motivate a *flexible*, novel, hybrid approach to tackle HHC problems. Second, we introduce the issue of *multimodality* in HHC: in our current setting, we investigate the case where nurses select their preferred mode of transport in advance. However, we are interested in the extension of this problem, where we optimize the transport mode for each nurse wrt different objectives (minimization of travel time, travel costs, etc). Can we obtain better nurse schedules by additionally choosing the mode of transport for each nurse?

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