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Pattern-based decompositions for human resource planning in home health care services

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ABSTRACT

Home health care services play a crucial role in reducing the hospitalization costs due to the increase of chronic diseases of elderly people. At the same time, they allow us to improve the quality of life for those patients that receive treatments at their home. Optimization tools are therefore necessary to plan service delivery at patients' homes. Recently, solution methods that jointly address the assignment of the patient to the caregiver (assignment), the definition of the days (pattern) in which caregivers visit the assigned patients (scheduling), and the sequence of visits for each caregiver (routing) have been proposed in the scientific literature. However, the joint consideration of these three levels of decisions may be not affordable for large providers, due to the required computational time.

In order to combine the strength and the flexibility guaranteed by a joint assignment, scheduling and routing solution approach with the computational efficiency required for large providers, in this study we propose a new family of two-phase methods that decompose the joint approach by incrementally incorporating some decisions into the first phase. The concept of pattern is crucial to perform such a decomposition in a clever way. Several scenarios are analyzed by changing the way in which resource skills are managed and the optimization criteria adopted to guide the provider decisions. The proposed methods are tested on realistic instances. The numerical experiments help us to identify the combinations of decomposition techniques, skill management policies and optimization criteria that best fit with problem instances of different size.

1. Introduction

Human resource planning defines, over a given time horizon, the composition of the required workforce to meet the service goals of the system under study. In the literature, this planning process is classified under different categories: permanence centered planning, fluctuation centered planning, mobility centered planning and project centered planning [11]. This paper focuses on the short term planning process for mobility centered planning [6], where human resources (operators) travel to perform on-site service activities at customer places. For such services, innovative decision making methods are required to support the planning process.

Home Health Care (HHC) is a relevant example of such services that emerge as an increasingly promising alternative for providing health and social services to patients cared at home [16,19,22]. Many factors drive the demand for HHC. Among these, we can cite the actual demographic trends, the changes in the epidemiological landscape of diseases and the availability of new support technologies. In the HHC service process, that involves several types of operators (e.g., nurses, physicians, social workers, and home support workers), the human resource planning process is of particular interest. As such, the human resource planning process for Home Health Care (HRPHHC) consists of several decisions such as capacity planning, partitioning of the territory where the HHC service operates into districts, allocation of resources to districts, assignment of operators to patients (or to visits), scheduling and routing of operators [19,22].

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In this paper we focus on the last three levels of planning that are the assignment, scheduling and routing decisions. Given a planning horizon, a set of patients where each patient has a specific care plan (i.e. weekly care service requests asking for specific operator qualifications/skills), and a set of operators characterized by skills, the addressed HRPHHC problem asks to (i) assign the operators to the patients by taking into account the compatibility between requests and operator skills (assignment decisions), (ii) schedule the patient requests during the planning horizon (scheduling decisions), and (iii) determine the tour each operator has to perform on each day of the planning horizon (routing decisions). We consider variously skilled operators, various patient care requests, multiple planning period (which is usually a week) and continuity of care constraints (i.e., the assignment patient–operator is not changed during the whole planning horizon [17]).

In the state-of-the-art literature, the HRPHHC problem is usually solved in cascade: first operators are assigned to patients on a geographical basis so as to match the skills demanded by patient care requirements with skills owned by each operator; second, the routing of each operator is determined. Such *two-phase methods* generally deal with a daily planning horizon. In a more flexible way, the problem can be solved without decomposing the three levels of planning decisions, but jointly addressing assignment, scheduling and routing decisions over the given planning horizon. We refer to this as the *single-phase method*.

An innovative modeling device to combine the three levels of decisions has recently been proposed, where services are offered according to a set of a priori given *patterns*, i.e., possible schedules for patients' requests [9]. It has been shown that, by properly selecting the pattern generation mechanism, the single-phase method is able to compute very good quality solutions, near the optimal ones. Large amounts of time and memory resources may be required, however, in the case of large instances. Hence, the use of the pattern device coupled with a two-phase decomposition approach seems to be suitable for solving large scale HRPHHC instances by combining efficacy (solution quality) with efficiency (solution time). This represents the subject of this paper.

Precisely, the main contribution of this paper is the proposal of a new family of two-phase methods, based on patterns, where assignment, scheduling and routing decisions over the considered planning horizon are taken in two steps, as in the traditional two-phase methods. Such steps, however, are properly coordinated by means of the pattern mechanism introduced in Cappanera and Scutellà [9]. In this way the strength of the single-phase method is combined with the computational efficiency of the traditional two-phase approaches.

The pattern-based two-phase methods are investigated also computationally, by providing a comparative study among them. Specifically, since the proposed methods vary in terms of flexibility and efficiency, the goal is to identify the most effective and efficient ones. In addition, alternative objective functions based on operating cost minimization and on social equity criteria (i.e., balancing operator workloads) are compared under different conditions of skill management. The presented methods are indeed relaxations of the exact, single-phase approach in Cappanera and Scutellà [9]. Therefore, such an exact approach is considered in order to evaluate the solution quality guaranteed by the pattern-based two-phase methods.

Numerical analysis is carried out on realistic problem instances. Results show that some of the proposed two-phase methods provide a powerful tool to solve HRPHHC, leading to high quality solutions in a short computational time. In other words, they appear to be a very promising tool to address HRPHHC with both efficacy and efficiency, especially for large size instances. This finding is significantly important in practice where many HHC providers have to deal with large scale problems, characterized by several hundreds of patients located in a single district.

The paper is organized as follows. Section 2 provides a literature review on the short term HRPHHC. Section 3 describes the problem and also provides an overview of the methods presented in this work. Such methods are then detailed in Section 4. Results from an extensive experimentation are reported in Section 5. Finally, conclusions are drawn in the last section.

2. Literature review

The literature related to assignment, scheduling and routing problems in HHC services has been reviewed by two recent works [15,26]. Hulshof et al. [15] propose a taxonomic review on planning-related decisions in health care services, including HHC. Yalcindag et al. [26] review the assignment and routing problems in HHC. Among the existing works already mentioned in these papers, this section summarizes and classifies the most relevant ones. Papers are thus grouped based on the length of the planning period considered, the objective function used as well as constraints imposed. This enables us to point out the main differences of the problems studied in this paper with respect to those addressed in the literature. The solution approaches proposed by authors are also briefly presented.

Most of the existing literature is devoted to the daily HHC planning problems. Among these, Cheng and Rich [12] develop a daily scheduling problem as a multi-depot Vehicle Routing Problem (VRP) with time windows (MDVRPTW) that considers compatibility information between patients and operators. The problem is formulated as a mixed integer linear program. The objective is to minimize the total cost associated with the amount of overtime hours of full-time and part-time nurses. Meanwhile, this objective is pursued with respect to constraints such as visiting each patient exactly once, assigning each nurse to at least one patient, starting and ending at the operator's home, taking a lunch break within the given time interval and respecting the constraint of maximum nurse shift length. Since the problem is a complex combinatorial optimization problem, Cheng and Rich [12] develop a two-phase heuristic. The first phase falls into the parallel tour-building procedure category. The identified tours are then improved in the second phase using local search by adjusting assignments and inserting omitted patients.

Eveborn et al. [13] formulate the scheduling problem as a VRPTW with the set partitioning model and solve it heuristically by using a repeated matching algorithm. The objective is to minimize a total cost related to the travel time, scheduled hours, preferences, etc., while respecting the following constraints: time windows for visits, operators' skill requirements, and accomplishment of each visit by one operator.

Thomsen [23] addresses the daily scheduling problem as a VRPTW with shared visits (i.e., visits requiring two operators). The objective of this model is to minimize the total traveling cost and the number of visits that are carried out by non-reference care givers. The constraints of the model are as follows: respecting the visits' and operators' time windows, assigning at least one visit to each operator and starting/ending a shared visit at the same time. The model is solved by using a new insertion method that forms an initial solution for a variant of tabu search.

Akjiratikarl et al. [1] generate daily schedules by using the VRPTW. They minimize the total distance traveled with respect to visits' and operators' time windows and assignment of each visit to only one operator. The solution procedure incorporates the Local Improvement Procedure into the Particle Swarm Optimization technique to improve the identified solutions. The initial