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Weekly scheduling models for traveling therapists

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ABSTRACT

This paper presents a series of models that can be used to find weekly schedules for therapists who provide ongoing treatment to patients throughout a geographical region. In all cases, patient-appointment times and visit days are known prior to the beginning of the planning horizon. Variations in the models include single vs. multiple home bases, homogeneous vs. heterogeneous therapists, lunch break requirements, and a nonlinear cost structure for mileage reimbursement and overtime. The single home base and homogeneous therapist cases proved to be easy to solve and so were not thoroughly investigated. This left two cases of interest: the first included only lunch breaks while the second added nonlinear overtime and mileage reimbursement costs. For the first case, 40 data sets were solved, each consisting of either 15 or 20 therapists and between roughly 300 and 540 patient visits over five days. For each instance, we were able to obtain the minimum cost of providing residential healthcare services using a commercial solver. The results showed that CPU time increases more rapidly than total cost as the total number of visits grows. For the second case, which was much more difficult, it was necessary to develop heuristics to find good solutions quickly. Results for 5- through 20-therapist instances are presented and compared to the linear programming relaxation lower bounds. In the first of two parametric analyses, the tradeoff between the number of therapists on staff and the cost of providing service was examined. In the second, a similar tradeoff was explored between cost can the number of home bases used by the therapists.

1. Introduction

Home healthcare is the business of providing professional healthcare services in the patient's place of residence. These healthcare services include nursing, physical therapy, speech therapy, occupational therapy, medical treatments, and general assistance to the infirm [11]. As the population ages, the need for healthcare professionals grows. The Census Bureau projects that by 2030 there will be more than 70 million Americans aged 65 and older, more than twice their number in 1995. By 2040, one out of every five Americans will be over 65. The number of "old old," aged 85 and older, is projected to triple or quadruple [16]. There are now more than 10,000 home healthcare organizations in the U.S. alone. This number will continue to increase at an accelerated rate leading to greater competition between provider organizations. To remain profitable, these organizations must find new ways to better manage their human resources. A critical aspect of this effort is the derivation of cost-efficient schedules for up to a week at a time for their therapists. This involves constructing travel routes and assigning patients to therapists while taking into account a number of operational and logical constraints [3]. In fact, effective staff planning and scheduling must aim at cost minimization.

In this paper, we present a range of models that can be used to solve the weekly therapist scheduling problem and investigate the two most detailed. The objective of the models is to minimize the total cost of providing residential healthcare services for up to a week at a time without violating availability constraints, the requirement for lunch breaks, and patient-appointment times. We use the term "residential healthcare" as a generalization of "home healthcare" to reflect the fact that patients can be treated at locations other than their home. The type of organization that we have in mind is an independent agency that contracts with therapists to work on an hourly basis. Costs include wages for treatment and drive time, mileage reimbursement, and a premium for overtime. Because of different training levels and experience, therapists get paid at different rates. Travel costs arise from the fact that therapists must often travel for several hours between various locations to see their patients on any day of the week. Indeed, it is shown in a report of The National Association for Home Care and Hospice

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that healthcare providers drive nearly 5 billion miles each year [16]. It's important to minimize the cost of the travel time.

In the next section, we review the literature related to residential healthcare scheduling. In Section 3, a description of the operational procedures of our collaborating organization is provided that includes scheduling issues and cost structure. The problem statement and models are given in Section 4. In Section 5, we present two simple heuristics that proved to be extremely effective. This is followed in Section 6 with an example and the presentation of our computational results for 40 randomly generated data sets that include either 15 or 20 therapists and upwards of 540 visits per week, and 100 instances with 5 to 20 therapists and up to 650 visits per week. We also present two independent parametric analyses which demonstrate that as the number of available therapists increases and as the number of their home bases increases, total costs decrease linearly. The data sets reflect the actual demand faced by Key Rehab, a Midwestern rehabilitation services company that provides physical, occupational, and speech therapy. We close with a summary of the work and suggestions for future research.

2. Literature review

The problem discussed in the paper is posed in the context of residential healthcare delivery but it is not unique to that industry. More generally, we are solving a vehicle scheduling problem with time windows and multiple depots. There is a vast quantity of literature on algorithms for the multiple depot vehicle scheduling problem (MDVSP), which was first introduced by Carpaneto and Dell'Amico [7]. They present a branch and bound algorithm for the MDVSP which is based on an additive lower bound and the use of dominance criteria. Ribeiro and Soumis [13] improved Carpaneto's results by introducing a new formulation of the MDVSP as a set partitioning (SP) problem with side constraints whose continuous relaxation could be solved by column generation. They showed that the continuous relaxation of the SP formulation provides a much tighter lower bound than the additive bound procedure. Binaco et al. [5] studied the same problem using a similar approach. However, in addition to column generation, they describe a procedure for computing a lower bound to the MDVSP that is based on heuristically solving the dual of the continuous relaxation of SP without using the SP matrix. The dual solution obtained is used to reduce the number of variables in the SP in such a way that the resulting problem can be solved by standard branch and bound techniques. Dell'Amico et al. [9] aimed to minimize a weighed combination of the number of vehicles used and overall operational costs for the MDVSP. They designed a new polynomial-time heuristic that always guarantees the use of the minimum number of vehicles. Extensive computational results on test problems involving up to 1000 trips and 10 depots are reported.

The multiple depot crew scheduling problem (MDCSP) which is quite similar to our residential healthcare problem is an extension of the MDVSP. In that case, each crew is required to return to their starting depot within imposed limits on both the elapsed time and the working time of any duty. Boschetti et al. [6] developed a bounding procedure based on Lagrangian relaxation and column generation. Their procedure is an effective alternative to classical column generation as it is not affected by the typical degeneration drawbacks in solving the linear relaxation of the master problem with a standard LP code.

With respect to residential healthcare routing and scheduling, the literature is much sparser. Cheng and Rich [8] considered healthcare staff planning with full-time and part-time workers. They developed two mixed-integer linear programming formulations which, like us, included lunch break constraints. A two-phase heuristic was implemented and numerical results were presented for small data sets with up to 2 full-timers, 2 part-timers and 10 patients. Bertels and Fahle [4] present the core optimization components of PARPAP which is an optimization and planning tool for highly constrained staff routing problems, again for residential healthcare. A combination of linear programming, constraint programming and heuristics is used. Their model is flexible enough to accommodate many of the components of real-world problems.

Different than others who aim to minimize total cost, Steeg and Schröder [15] choose the objective of minimizing the number of nurses that visit patients during the day. Their model combines the nurse rostering problem with a periodic vehicle routing problem. Their algorithm first applies constraint programming to compute an initial feasible solution and then calls an adaptive large neighborhood search heuristic to improve the results.

3. Description of operations

Therapists that provide rehabilitation services can be divided into three categories: physical, occupational and speech. Physical therapists are healthcare professionals who diagnose and treat individuals of all ages. Their patients range from newborns to the very old who have medical problems or other health-related conditions, illnesses, or injuries that limit their ability to move and perform functional activities to the degree that they would like in their daily lives. Physical therapy is performed by either a physical therapist (PT) or sometimes by a physical therapist assistant (PTA) acting under their direction. Occupational therapists work with individuals who suffer from a mentally, physically, developmentally, or emotionally disabling condition. They provide treatments that develop, recover, or maintain a person's daily living functions. Speech and language pathologists assess, diagnose, treat, and help to prevent disorders related to speech, language, cognitive-communication, voice, swallowing, and fluency. Because the problem decomposes by therapist type, we only consider PTs and PTAs in this paper.

Therapists who contract to work 40 h per week are classified as "full-time"; otherwise, they are "part-time" and work on a fixed pre-defined schedule. For example, a specific part-timer may work Tuesday morning and all day Thursday. Full-timers are typically, but not always, available five days a week between 8:00 am and 5:30 pm; however, they are not necessarily given schedules that fully cover this interval each day. On a low demand day, for example, they might be assigned a set of patients in the morning only. PTs and PTAs could be either full-timers or part-timers, but the wages of the former are usually higher so if the aim is cost minimization, it is better to schedule part-timers first whenever possible.

In this paper, we focus on patients who have fixed appointment times which means that the number of treatments each week for a patient and the start and end time of the treatment are precisely defined. Patients can be treated at hospitals, nursing centers, medical lodges, clinics or their home. Most of the patients need one or two treatments weekly with a handful requiring daily visits (in some cases by PTs only). Each treatment lasts from 15 min to an hour.

The above factors imply that the problem has both a routing and scheduling aspect that must be considered. Given the information on therapist availability, wages and classification, and patient-appointment times, the objective is to develop a weekly schedule for each therapist that minimizes the total cost of providing residential healthcare services while satisfying a collection of hard constraints that are discussed in the remainder of this section. These are standard throughout the industry. An overview of the issues relevant to providing rehabilitative therapy is shown in Fig. 1 (adapted from Ref. [4]).