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A memetic algorithm for a home health care routing and scheduling problem

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ABSTRACT

This work addresses a home health care routing and scheduling problem with time window and synchronization constraints. Each patient is associated with a period of availability according to their preferences while some visits may require the presence of two staff members simultaneously, which requires the synchronization of two visits. In this paper, the problem is studied with hard and soft patients time window and synchronization constraints. We developed a mixed integer programming model and a memetic algorithm featuring two original crossover operators. Experiments are conducted on benchmark instances from the literature as well as new instances based on real life data from a home health care provider in France. The results highlight the efficiency of the memetic algorithm since it provides great results while being flexible to the instance type. Indeed, the memetic algorithm is efficient whether the problem is studied with hard or soft time window and synchronization constraints, various caregivers qualification or several home health care offices.

1. Introduction

The vehicle routing and scheduling problem (VRP) is an extensive research area in the operations research field. Vehicle routing and scheduling problem consists in establishing a valid schedule for each vehicle given a fixed number of vehicles available at the depot and a set of customers to be serviced during a specific time window while minimizing, for instance, the total traveling time of the vehicles. Temporal constraints are frequently considered using time window restrictions for vehicles or customers to serve. However, dependencies between vehicles have been less studied. Dependencies occur when two vehicles have to serve the same customer in a specific order or at the same time, which happens in many practical cases including home health care. Consequently, these two constraints have received less attention in the literature when they are considered together. Moreover, they have been mostly studied in the case of hard time window and same time arrival for two dependent vehicles.

Both exact methods and heuristics have been studied on a large variety of problems. Several surveys have been presented such as Bräysy and Gendreau [1] who focused on metaheuristics or Laporte [2] who studied exact and approximate approaches. Generally speaking, the existing literature is now divided into two categories depending on the main optimized criteria: those that minimize costs (work, transport, …) and others that minimize time (travel, work, …).

Home health care structures provide care for the elderly or patients with chronic diseases. Different types of cares are performed depending on the need of the patients. Health care teams are often composed of auxiliary nurses and nurses to provide the full range of cares required such as personal cleaning, injections, bandage and much more.

Nowadays, the planning and scheduling of the home health care staff are performed manually by a coordinating nurse. This complex task often requires an extensive time to obtain a valid schedule which respects all the constraints (availability of patients, staff working time window, …). Since this task is performed every day (for planning the next day or the coming weekend), there is an important axis of improvement in order to improve the quality of the resulting schedule.

Due to the growing demand for home health care as reported by Bertrand [3], organizations providing home health care services are willing to optimize their activities in order to meet the increasing demand. Consequently, research on this problem has appeared by the end of the 20th century focusing on the different variants of the problem as compared by Fikar and Hirsch [4].

An overview of the characteristics and constraints considered in the following cited publications is provided in Table 1.

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Table 1
Constraints and assumptions considered in the related works on scheduling and routing of home health care service. The care demand can be either deterministic (Det.) or stochastic (Stoch.).

Reference	Nurse TW		Patient TW		Nurse's skills	Continuity of care	Synchronized visits		Care demand	
	Hard	Soft	Hard	Soft			Hard	Soft	Det.	Stoch.
Afifi et al. [5]	X		X				X		X	
Allaoua et al. [6]	X		X		X				X	
Bertels and Fahle [7]		X		X	X				X	
Braekers et al. [8]		X		X	X	X			X	
Bredström and Rönnqvist [9]	X		X		X	X	X		X	
Cheng and Rich [10]	X		X						X	
Eveborn et al. [11]	X		X		X	X	X		X	
Hiermann et al. [12]	X		X		X				X	
Issaoui et al. [13]	X				X				X	
Kergosien et al. [14]	X		X		X		X		X	
Lanzarone and Matta [15]					X	X				X
Liu et al. [16]			X			X			X	
Mankowska et al. [17]			X		X		X		X	
Rasmussen et al. [18]	X		X				X		X	
Shi et al. [19]			X							X
Trautsamwieser and Hirsch [20]		X		X	X	X			X	
Wirnitzer et al. [21]					X	X			X	
Yalçındağ et al. [22]									X	

In the context of the vehicle routing problem applied to the home health care problem, Cheng and Rich [10] consider the vehicle routing problem with time window (VRPTW) including multiple depots. By considering both full-time and part-time nurses, they have optimized the cost related to the working hours. As full-time nurses work overtime and part-time nurses are paid for each hour of work, their objective is to minimize the amount of overtime and part-time work scheduled. The home health care problem with multiple depots has also been studied by Allaoua et al. [6] who have split the problem into two sub-problems: a set-partitioning-like problem and a multi-depot traveling salesman problem with time window (MDTSPTW) for the routing part. They suggest a matheuristic for solving large instances. Some authors have focused their attention on the trade-off between the costs (coming from work and transports) and the patient convenience such as Issaoui et al. [13] and Braekers et al. [8]. In that case, the problem is modeled using multiple objective functions to be solved. In addition, particular attention on the continuity of care has been paid by Wirnitzer et al. [21]. They have sought ways to minimize the number of different nurses assigned to each patient on a monthly planning period. Liu et al. [16] have also taken into account the continuity of care in their mathematical model considering the lunch break requirements.

Another characteristic of the home health care problem is the qualification of the caregivers. Indeed, all care cannot be performed by the same type of caregivers. Therefore, it is necessary to define the qualification of caregivers to provide care. In their work, Hiermann et al. [12] have considered five kinds of caregivers : community service worker, visiting nurse, home-care nurse, advanced home-care nurse and medical nurse.

Moreover, Lanzarone and Matta [15] have proposed a solution to the assignment problem under the continuity of care that minimizes nurses' maximum overtimes. In opposite to Yalçındağ et al. [22] who perform the assignment of patients to caregivers according to a deterministic demand, Lanzarone and Matta [15] address the problem of assigning newly admitted patients by taking into account the stochasticity of new patient's demand. Recently considered, the uncertainty of the demand has also been studied by Shi et al. [19] who consider uncertain demand as a fuzzy variable to represent the quantity of drugs to deliver for each patient.

Besides, the concept of the penalty costs in the case of soft time window is subject to different representations depending on the researcher's choices. As an example, Bertels and Fahle [7] have modeled the cost function for the non-satisfaction of the soft constraints as a factor proportional to the earliness or the lateness of the vehicle to the patient's home. For each job, a penalty is applied if the vehicle arrives too early or too late. The sum of the penalties is then weighted in order to be added to the total travel time needed for the objective function. Also, Trautsamwieser and Hirsch [20] have studied the home health care problem with soft time windows on both nurses and clients. They used a metaheuristic based on Variable Neighborhood Search (VNS) to solve some randomly generated instances and real life instances provided by the Austrian Red Cross.

In this paper, the presence of the synchronization constraint between vehicles that is found frequently in the home health care application has to be pointed out. While most publications in the literature on the vehicle routing problem consider time window, the presence of synchronization constraints is uncommon. Synchronization constraints imply that some visits require multiple staff members at the same time. Therefore, the schedules of some staff members have to be synchronized (without mentioning previously which staff members are implied) at some point during the day. Eveborn et al. [11] consider these constraints in the routing and scheduling of a health care structure in Sweden. They developed a decision support system to aid the planners to quickly generate a valid and optimized schedule. In order to solve the synchronization constraints, the common technique is that the visits which require multiple staff members are handled by splitting those visits into two and then constraining the time those visits have to be performed. Similarly, Bredström and Rönnqvist [9] suggested a mathematical programming model for the vehicle routing and scheduling problem with time window and synchronization constraints as well as an optimization based heuristic. They tested the performance of their approaches on a set of data with a different number of customers, vehicles, synchronized visits and time window sizes. These data have later been also used by Afifi et al. [5] to test the performance of their simulated annealing based algorithm with a local search procedure. They showed that the local search procedure was efficiently adapted to handle the synchronization constraints. Classified by Drexl [23], different types of synchronization constraint do exist in the literature. Regarding the home health care problem, the synchronization constraint belongs to the type of operation synchronization, either as an operation synchronization with precedences or as an exact operation synchronization. These two types of synchronization have been considered by Kergosien et al. [14] in their integer linear program, in the branch-and-price algorithm of Rasmussen et al. [18] or in the adaptive variable neighborhood search algorithm