A Two-Stage Stochastic Home Healthcare routing and scheduling Problem

[(1)]Khaoula Besbes and [(2)]Issam Nouaouri

[(1)] *Department of Resarch & development, HIGHFI, France*

[(2)]*Univ. Artois, EA 3926 LGI2A, F-62400, France*

Abstract

The home healthcare services (HHCS) are defined as medical and paramedical services delivered to patients at home for a limited period, which can be extended depending on patients' needs. They provide continuous and coordinated healthcare at patients' homes. The aim is to improve life conditions of patients and reduce the congestion of hospitals. The HHCS contribute to increase the costs of the healthcare system. For healthcare organizations, it is critical to assign caregivers to patients and devise reasonable visiting routes to save total operational cost and improve the service quality. However, some special constraints make the problem hard to solve. For example, patients' service times are usually stochastic due to their varying health conditions; caregivers are organized in a hierarchical structure according to their skills to satisfy patients' demands.

In this paper we propose a two-stage stochastic model for a home healthcare routing and scheduling problem. We search to assign caregivers to patients during a planning horizon while considering the patients' availability, and the caregivers' skills. Furthermore, we take into account the uncertainty of the time service required to give cares to the patients.

Keywords: home health care; stochastic service times; skill requirements; uncertainty ; two-stage stochastic programming

1- Introduction

Budget crisis in the public hospital and population aging are likely to lead to a substantial increase in demand for home health care services (HHCS). According to the « Haut Conseil pour l'Avenir de l'Assurance maladie » in France, the average day in the HHCS was counted to cost 196 euros compared to 703 euros in Hospital. The HHCS are growing in many industrialized countries, particularly in U.S where more than 4.7 million patients received healthcare services at their home [6] and in France where 4,6 million days has been devoted in 2015. In Europe, between 1% and 5% of the total public health budget is spent on HHCS [5]. In France, the report of "l'Inspection Générale des Affaires Sociales (IGAS), 2010 " shows that the HHCS is considered as a complex system and hard to manage it due to the high number of actors (patients, healthcare structures, associations, nurses, physicians, etc.). Unexpected events increase the difficulty to manage efficiently the HHCS. This complexity often causes dissatisfaction of different actors mainly patients and caregivers.

In this context, the scheduling and routing of HHCS is considered as usefulness and challenging problem. It is one of the major issues considered in the literature [4]. The problem is known as a vehicle routing problems (VRP). It consists of assigning caregivers to patients and scheduling working times while taking into account time and resource constraints.

In this paper, we address a HHC scheduling and routing problem with stochastic service times and skill requirements. A two-stage stochastic model is proposed to formulate the problem in which the expected penalties for early and late arrivals at patients are considered. Such a stochastic model seeks a solution which is appropriately balanced between some alternative scenarios identified based on the historical data.

2- Problem description

We are given a set of caregivers and a set of patients. Patients are classified into several types according to their required skills. Caregivers are also divided into several levels according to their owned skills to fulfill the requirements.

The problem consists in determining a set of routes with minimum total cost in order to visit all patients and satisfy their skill requirements. Four kinds of cost are considered in it: travel cost, fixed cost, service cost and penalty for early and late arrival costs. From the point of view of companies, travel cost, fixed cost and service cost are indeed paid by them.

However, the penalties for early and late arrivals are to measure how late caregivers arrive at patients which is related to the service satisfaction level of patients.

Moreover, what makes the problem more challenging is that patients' service times, related to their health conditions and to the caregivers' skills, are usually not deterministic. Thus, in the planning of HHC services, we should consider and tackle such source of uncertainty.

Objective functions:

Two objectives are considered. The first objective function can simultaneously minimize companies' cost and maximize the service satisfaction level of patients, and the second objective function maximizes the affinity between patients and caregivers.

Model constraints:

- Each patient needs only one visit in one day.
- Each visit of a patient has a minimum level of skill required. To describe skill constraints, we assign different dummy demands and capacities to patients and caregivers, respectively.
- Each visit of a patient has a probabilistic service time depending on a given scenario, and a time window in which the service has to start. In case of unavailability, especially due to the stochastic nature of the time service, we assume that all patients' time windows are soft and can be violated by paying appropriate penalties. The penalty structure associated with soft time windows essentially allows serving a patient at any point of the planning horizon. Therefore, any early or late arrival is permissible at a cost.
- For each caregiver, for each workday, the fixed cost and the service cost per unit time incurred, increase with his level.
- Each caregiver can only visit a given maximum number of patients due to his limited work time.
- After a working time, a break is mandatory. The break duration, as well as the desired time window for the break can be specified in advance.
- All routes start and end within the HHCS center.

3- Proposed approach

A mathematical model is proposed based on two-stage stochastic programming, whose deterministic equivalent is formulated as a mixed integer linear programming (MILP). The first-stage decisions concern the definition of the assignment variables. In this stage we search to minimize the total fixed cost of the caregivers while considering their skills.

The second-stage decisions refer to the precedence variables and the arrival time variables over the periods of the planning horizon, which are directly influenced by the first-stage decisions and the realizations of the uncertain parameters. The randomness and the uncertainty of the model refer to the service time, namely the time required by each caregiver, depending on his skill, to give the different cares to the patient.

The service time is modeled as a random variable that follows a known probability distribution. The probability distributions of the scenarios are expected on the basis of previous experiences or HHC center's historical data.

4- A real case study

To illustrate the application of the Home Health Care assignment problem under uncertainty, we use real data provided by a HHC center in the north of France. The model consists of 51 daily potential patients, and an average of 3 caregivers for each 8 patients.

In the stochastic program, the scenarios of the uncertain parameters are generated from the distribution function derived from the real data. The model is solved by ILOG CPLEX optimization Studio 12.7.

Fifteen scenarios are generated for two-stage stochastic programming and all 15 scenarios are used individually for deterministic model. The stochastic solution is not optimal in general for any of the individual scenarios.

The results and analysis indicate that our two-stage stochastic model is suitable for Home Health Care assignment problem. The computation time of the model is quite consistent within a given problem size, but it can easily increase with the growing problem size. The use of heuristic methods can help to decrease CPU time, which is one of our future research topics.

5- Conclusion

In this paper, we developed a two-stage stochastic model for the assignment problem in Home Health Care. The model involves the most important constraints needed in caregiver planning such as patients' availability, caregivers' skills, caregivers' lunch breaks, a maximum limit on the number of daily visited patients, and so on. Furthermore, we take into account the randomness of the time required to give cares to patients. The proposed method was applied to a real life problem instances.

The results are very encouraging as the model offers the possibility to obtain good quality solutions in very reasonable time.

6- References

[1] Bertels S, Fahle T. A hybrid setup for a hybrid scenario: combining heuristics for the home health care problem. Comput Oper Res 2006;33(10):2866–90.

[2] Braekers K, Hartl RF, Parragh SN, Tricoire F. A bi-objective home care scheduling problem: analyzing the trade-off between costs and client inconvenience. Eur J Oper Res 2016;248(2):428–43.

[3] Errahout A, Kharraja S, Corbier C. Two-stage Stochastic Assignment Problem in the Home Health Care. IFAC-PapersOnLine, 2016 ; 49-12 ; 1152–1157.

[4] Fikar C, Hirsch P. A. Home health care routing and scheduling: A review. Comput Oper Res 2017; 77 ; 86–95.

[5]Genet N, Boerma W, Kroneman M, Hutchinson A, Saltman RB, editors. Home care across Europe—current structure and future challenges. European Observatory on Health Systems and Policies, World Health Organization, Oslo, Norway; 2012.

[6] Harris-Kojetin L, Sengupta M, Park-Lee E, Valverde R. Long-term care services in the United States: 2013 overview. National Center for Health Statistics Vital Health Stat 2013;3:37.

[7] Hiermann G, Prandtstetter M, Rendl A, Puchinger J, Raidl G. Metaheuristics for solving a multimodal home-healthcare scheduling problem. Cent Eur J Oper Res 2015;23(1):89–113.

[8] Trautsamwieser A, Gronalt M, Hirsch P. Securing home health care in times of natural disasters. OR Spectr 2011;33(3):787–813.

[9] Trautsamwieser A, Hirsch P. Optimization of daily scheduling for home health care services. J Appl Oper Res 2011;3(3):124–36.

[10] Shi Y, Boudouh Y, and Grunder O. A Home Health Care Routing Problem with Stochastic Travel and Service Time, IFAC PapersOnLine 2017; 50-1; 13987–13992 .

[11] Yuan B, Liu R, Jiang Z. A branch-and-price algorithm for the home health care scheduling and routing problem with stochastic service times and skill requirements. Int J Prod Res 2015;53(24):7450–64.