Innovative Applications of O.R.

A cardinality-constrained robust model for the assignment problem in Home Care services

Giuliana Carello [a], Ettore Lanzarone [b],*

[a] *Dipartimento di Elettronica, Informazione e Bioingegneria, Politecnico di Milano, P.za Leonardo da Vinci 32, 20133 Milan, Italy*
[b] *Istituto di Matematica Applicata e Tecnologie Informatiche (IMATI), Consiglio Nazionale delle Ricerche (CNR), Via Bassini 15, 20133 Milan, Italy*

ABSTRACT

Home Care includes medical, paramedical and social services which are delivered to patients at their domicile rather than in hospital. Managing human and material resources in Home Care services is a difficult task, as the provider has to deal with peculiar constraints (e.g., the continuity of care, which imposes that a patient is always cared for by the same nurse) and to manage the high variability of patients' demands. One of the main issues encountered in planning Home Care services under continuity of care requirement is the nurse-to-patient assignment. Despite the importance of this topic, the problem is only marginally addressed in the literature, where continuity of care is usually treated as a soft-constraint rather than as a hard one. Uncertainty is another relevant feature of nurse-to-patient assignment problem, and it is usually managed adopting stochastic programming or analytical policies. However, both these approaches proved to be limited, even if they improve the quality of the assignments upon those actually provided in practice. In this paper, we develop a cardinality-constrained robust assignment model, which allows exploiting the potentialities of a mathematical programming model without the necessity of generating scenarios. The developed model is tested on real-life instances related to a relevant Home Care provider operating in Italy, in order to evaluate its capability of reducing the costs related to nurses' overtimes.

© 2014 Elsevier B.V. All rights reserved.

1. Introduction

Randomness in data and parameters is a common feature of several optimization problems. It arises in many applications, such as telecommunications, where uncertainty is usually associated with traffic demands, and health care, where a high uncertainty is related to patients' conditions and demands.

Indeed, uncertainty is inherent in many health care optimization problems and cannot be neglected, as it may have a significant impact on quality and feasibility of problem solution. For instance, in emergency vehicle location problems, uncertainty is associated with the availability of ambulances (Brotcorne, Laporte, & Semet, 2003), whereas in planning and scheduling operating room theaters uncertainty is due to surgery durations (Denton, Miller, Balasubramanian, & Huschka, 2010) or care demands in different specialties (Holte & Mannino, 2013). Uncertainty also occurs in managing Home Care (HC) services.

HC providers must synchronize the use of resources at patient's domicile, while usually delivering the service to a large number of patients in a vast territory. Furthermore, random events may affect service delivery, undermine feasibility of plans, and cause a high variability in nurses' workloads and, consequently, in the cost of service. One of the most critical and frequent of such events is a sudden variation in the amount of service required by patients, which is in general highly variable. Hence, managing human resources in HC services is a difficult task, which is made more complex by uncertain patient demands.

Different approaches are usually applied to deal with uncertainty in health care problems, such as probabilistic models or stochastic optimization approaches.

Recently, an innovative robust optimization approach, named cardinality-constrained approach, has been proposed in Bertsimas and Sim (2004) and already applied in several fields, such as portfolio optimization or network design. It allows to account for a certain degree of uncertainty with a reasonable computational effort, providing a trade-off between computational time and robustness. In addition, it can be tuned to take into account the specific degree of risk the decision maker accepts. Although the approach seems to fit well to many health care problems, and in particular to the HC

---

* Corresponding author. Tel.: +39 02 2369 9531.

E-mail addresses: giuliana.carello@polimi.it (G. Carello), ettore.lanzarone@cnr.it (E. Lanzarone).

planning, to the best of our knowledge it has not been applied to many health care problems so far.[1]

In this paper we present an application of the above mentioned robust approach to the nurse-to-patient assignment problem in HC, which is an interesting and meaningful example of health care optimization problem. The approach can be easily applied to the problem and proved to be able to produce good quality solutions with a reasonable computational effort. Hence, it is also worth being tested on other health care problems.

1.1. Problem description

HC consists of delivering medical, paramedical and social services to patients at their domicile rather than in a hospital. On the one hand this leads to a significant improvement in the quality of life for patients, as they continue to live at their home in a familiar environment. On the other hand it leads to considerable cost savings for the health care system, as hospitalization costs are avoided. HC is a relevant and growing sector in western countries, due to population aging, increase in chronic pathologies, introduction of innovative technologies, and pressure of governments to contain health care costs.

HC services involve different professional figures. Patients are usually assisted by nurses and, according to the case, may require also other figures, such as physiotherapist, physician, or psychologist. In some cases, they may require specific facilities to be brought and managed at home.

Hence, many resources are involved in delivering HC services, including nurses and other categories of operators, support staff and material resources. HC providers must carefully optimize limited human resources. In addition some features, such as the continuity of care and the risk of incurring in operator burnout, make the HC resource planning different from the planning problems that occur in other services within the health care domain. Besides, as HC patients have to be cared after for weeks, middle and long-term planning are key issues in providing a good quality of service, while keeping balanced personnel workloads over the whole considered time horizon.

In this work, we focus on the nurse-to-patient assignment under continuity of care. Continuity of care means that an HC provider assigns only one nurse to each patient, named the *reference nurse*, and the assignment is kept for a long period. Continuity of care is an important factor in service provision in all health care facilities (Haggerty et al., 2003; Heffernan & Husni, 2009). Two main aspects are preserved when continuity of care is pursued. On the one hand, continuity of care preserves the quality of service perceived by patients, as patients receive care from the same operator and do not have to continuously develop new relationships with new operators. On the other hand, potential loss of information among operators is avoided. Both these aspects are extremely important in HC, where the patient is assisted for a long period, patient's family and domestic context are involved in providing care, and, for palliative care, very serious pathologies are treated. Hence, many HC providers pursue continuity of care. However, continuity of care constraint limits service flexibility and, despite of quality of care, some providers do not adopt reference nurses to increase operational efficiency. In general, in order to guarantee a good tradeoff between quality and flexibility, continuity of care should be preserved at least for critical patients (e.g., palliative patients) or patients with particular needs. In other words, patients should

be classified according to their needs and continuity of care should be guaranteed for a subset of them.

Nurses are usually divided into districts depending on skills and territory. Patients are divided into classes, according to the type of service required (e.g., the main classification is between palliative and non-palliative patients), and nurses take care of patients they are skilled for. Furthermore, in large HC providers, nurses are divided into territorial groups and take care of patients who are resident in their territory. Districts are usually assumed to be independent in planning the assignments, i.e., each patient is cared for by nurses with a skill compatible to his/her pathology and working in his/her geographical area.

Each patient requires a number of visits per week from each professional figure, which is described by an uncertain parameter. Each operator has an amount of contracted working time per time period for providing visits. If the care volume exceeds the operator contract capacity, overtime has an extra cost that providers want to minimize. Hence, the assignment aims at reducing the visits that each operator provides above his/her contracted time.

1.2. State of the art

Home Care involves the management of several resources and must take into account many requirements and constraints. It is related to nurse rostering in hospitals (see Burke, De Causmaecker, Vanden Berghe, & Van Landeghem, 2004; Cheang, Li, Lim, & Rodrigues, 2003) as it deals with nurse management. However, HC management involves several issues which are not usually addressed in nurse rostering problems, such as the continuity of care (Haggerty et al., 2003) or the burnout risk (Borsani, Matta, Beschi, & Sommaruga, 2006), which make the HC nurse management peculiar. The main issues to be considered are the partitioning of a territory into districts, the dimensioning of human resources, the assignment of visits to operators (or patients to operators in case of continuity of care), the scheduling of nurses' duties and the routing optimization.

Literature about HC can be mainly divided into two groups: a first group deals with daily schedule of visits and routing of nurses, and a second group deals with staff planning and management in a mid-term and long-term perspective. The nurse-to-patient assignment under continuity of care analyzed in this paper is related to the mid-term management.

From a long-term point of view, the districting problem consists of grouping patients and nurses according to geographical and skill compatibility, usually aiming at balancing workload among different groups (Blais, Lapierre, & Laporte, 2003; Lahrichi, Lapierre, Hertz, Talib, & Bouvier, 2006).

Dimensioning of human resources consists of determining the number of operators, together with their skills, to meet patient demand in each part of the territory. Patient demand uncertainty may be taken into account (De Angelis, 1998). Funding has to be taken into account in dimensioning HC resources, as well (Busby & Carter, 2006).

The nurse-to-patient assignment problem consists of assigning personnel to visits in a fair way. Different features can be considered, such as the continuity of care and the uncertainty in patients' demands. It has been rarely studied as a stand-alone problem, i.e. not considering scheduling (Boldy & Howell, 1980), and, to the best of our knowledge, the assignment problem taking into account the continuity of care issue is only marginally addressed in literature (Borsani et al., 2006; Hertz & Lahrichi, 2009; Lanzarone, Matta, & Sahin, 2012). Besides, continuity of care is often considered as an objective rather than a strict requirement and, therefore, dealt with as a soft-constraint rather than as a hard one, see for instance Nickel, Schroder, and Steeg (2012).

---

[1] There are the only five papers (i.e., Banditori, Cappanera, & Visintin, 2013; Chan, Bortfeld, & Tsitsiklis, 2006; Denton et al., 2010; Holte & Mannino, 2013; Mannino, Nilssen, & Nordlander, 2012) found in September 2013 through a search on ISI web of knowledge and Scopus, referring to Health Care, among the papers citing Bertsimas and Sim (2004). However, none deals with HC management.