Simulation Modelling Practice and Theory 74 (2017) 134–151

Contents lists available at ScienceDirect

Simulation Modelling Practice and Theory

journal homepage: www.elsevier.com/locate/simpat

A multi-agent system based on reactive decision rules for solving the caregiver routing problem in home health care

Eric Marcon[a], Sondes Chaabane[b,*], Yves Sallez[b], Thérèse Bonte[b], Damien Trentesaux[b]

[a] DISP, EA 4570, University of Lyon and INSA-LYON, 69621 Villeurbanne, France
[b] LAMIH UMR CNRS 8201, University of Valenciennes and Hainaut-Cambrésis, 59313 Valenciennes, France

ARTICLE INFO

Article history:
Received 13 October 2016
Revised 8 February 2017
Accepted 15 March 2017

Keywords:
Distributed approach
Home health care
Caregiver routing problem
Local decision rule
Multi-agent system

ABSTRACT

Home Health Care (HHC) services are growing worldwide. HHC providers that employ their caregivers have to manage operational decisions such as assigning patients to caregivers and planning the caregivers' routes. Centralized "off-line" approaches are generally used to deal with both these problems. In this paper, we solved the caregiver routing problem in a dynamic and distributed way using a Multi-agent system (MAS) to simulate caregiver behavior. Four decision rules were developed for the caregivers: NPR (Nearest Patient Rule), NRR (No-wait Route Rule), SRR (Shortest Route Rule), and BRR (Balanced Route Rule). These decision rules were implemented and tested on a multi-agent platform to assess their performances. We designed an experimental plan based on case studies that represent different sizes of HHC provider inspired from real-world examples. The results obtained show the relevance of using local decision rules to plan the caregiver's route.

1. Introduction

Over the last decade, Home Health Care (HHC) services have significantly increased [1]. HHC provides care outside hospital by a team of medical professionals and is presented as an alternative to traditional hospitalization. HHC offers intensive support and care such as daily living services, complex care services, and social and psychological assistance. Patients generally require HHC following a stay in hospital because they still require acute medical care.

The organization of HHC involves two main issues: "medical" decisions and "organizational" decisions. This paper considers the second issue and, more precisely, operational management problems related to human and material resources scheduling. In this case, HHC managers have to solve two operational-level sub-problems: (1) patient-caregiver assignment (denoted "assignment problem") and (2) determining the caregiver's route (denoted "routing problem"). For each patient admitted, solving the assignment problem consists in allocating a caregiver for each care service required while respecting certain constraints (caregiver's skills, order of care, caregiver's availability, etc.) [2]. The caregiver routing problem involves defining the most suitable route for each caregiver to visit assigned patients while minimizing certain factors (waiting time, travel distance, etc.), and taking into account constraints linked to the other caregivers [3,4].

The assignment and routing problems are generally large, complex problems because of the human resources and patients involved, the type and quantity of care received by patients, and the temporal dependency between the care activities

* Corresponding author.
E-mail address: sondes.chaabane@univ-valenciennes.fr (S. Chaabane).

http://dx.doi.org/10.1016/j.simpat.2017.03.006
1569-190X/

and the human resources. In addition, unexpected events can occur resulting in uncertainty and disruptions requiring action in real-time. Typically, traffic jams, road accidents, and weather conditions should be taken into account when designing a real-world routing problem [5]. In this context, HHC managers need decision support systems capable of solving large real-world situations in reasonable time and providing good solutions in a dynamic environment with numerous time constraints [6].

To meet HHC managers' expectations, this paper addresses the "routing" problem in a dynamic context with uncertainties and random events. The main contribution of this paper is to provide a new way of solving a large caregiver routing problem using the caregiver's ability to dynamically design his own route. The proposed approach was simulated to demonstrate its performance according to five properties: efficiency, pertinence, scalability, robustness, and implementability.

The remainder of the paper is organized as follows. A literature review is presented in Part II. In Part III, a global framework is described to solve the problems considered. The dynamic routing problem and the four decision rules used by the caregivers to choose their next patient are detailed in Part IV. The multi-agent simulation platform used to assess the performance of the proposed approach and the simulation protocol are presented in Part V. The simulation results are presented and discussed in part VI. Part VII highlights the relevance of the proposed decision rules. Finally, our conclusions and some future lines of research are provided in the last section.

2. Literature review

As mentioned in the introduction, two operational-level sub-problems have been identified: (1) the "assignment problem" and (2) the "routing problem". The literature related to "assignment" and "routing" problems in HHC has been enriched over the last few decades and has recently been reviewed [7,8]. These reviews highlight a large number of papers from the Operational Research community and their main subject is the optimization of the daily planning of health care services with the hypothesis that the patient care plan is the same each day. Related studies suggest different ways of solving these problems based on MILP [9,6] or original heuristics [10–12]. Recently, Nickel et al. [13] propose a heuristic to address the medium-term and short-term planning problem. In other studies, authors have focused on one of the two sub-problems in particular. Yalçındağ et al. [4] focus on the assignment problem, but travel time estimators were added to the model to take routing plan constraints into account. Lanzarone and Matta [2] define an assignment policy based on the cost of home care services. Hertz and Lahrichi [14] propose two MILP-based approaches to assign caregivers to patients in Canada, of which the aim is to balance the workload of the nurses and avoid long journeys. Lanzarone and Matta [15] propose a new assignment approach to cope with random events such as new patient demands and nurse workload. In the literature, the routing problem is largely tackled as a "Travelling Salesman Problem with Time Windows (TSPTW)" approach for designing the caregiver's route using MILP [3] and/or heuristic [16,17] approaches for a static, deterministic problem. The main limitation of these approaches is the computational time required to reach a solution, and in most cases, it is hypothesized that the routing problem is static and deterministic. The decisions are made in an off-line centralized manner with no feedback from real-time situations. No on-line decisions can be made to cope with unexpected events.

The literature review in [18] presents multi-agent systems as an alternative to solve optimization problems in distributed, complex, large, and heterogeneous contexts. The Multi-Agent System paradigm allows distributed approaches to be modeled where several entities (requesters) require services from other entities (providers). In the field of Home Health Care, for example, requesters would be patients and providers would be caregivers. In recent years, MAS have gained tremendously in popularity, providing solutions to transport planning and scheduling problems in healthcare systems in general, and in the management of home health care operations in particular. Recently, Bichindaritz et al. [19] presented advanced methodologies and case studies in health care using MAS and artificial agents. In the field of home care, the project K4Care (Knowledge-Based HomeCare eServices for an Ageing Europe) must be more particularly highlighted [20,21]. This project aims to improve assistance for elderly patients suffering from chronic diseases or disabled persons. A multi-agent system constitutes the heart of the K4Care platform and deals with problems such as negotiation of meetings and task assignment for care providers. More recently, [22] considered home-care staff scheduling and task assignment decisions in a dynamic context with conflicting objectives. The authors propose a system framework incorporating intelligent agents to represent the various actors (manager, supervisor, patient, nurse, resource, and scheduler), internet services, wireless networks, and mobile devices. The different agents in this model are controlled by a manager agent located in the home health care center and there is no direct interaction between caregivers and patients. The software platforms of these MAS approaches are distributed, but the decision mechanism remains "off–line". In fact, the agents are controlled by a central manager agent located in the HHC and the route planning for the caregivers is generated "off-line". To the best of our knowledge, only Itabashi et al. [23] propose an "on-line" distributed support system for the home care scheduling problem using a multi-agent system. Clients and caregivers are equipped with PDAs and can communicate with the HHC support system. The latter has a database and contains three types of agents (interface agent, scheduler agent, and helper agent). A negotiation mechanism among agents, associated with clients and caregivers, is used to execute autonomously the care schedule. The patients and caregivers use PDAs to confirm the schedules established by the agents. However, care schedules are drawn up centrally at the home care center.

The main parameters of assignment and routing problems are the following: (1) the number of human resources involved; (2) the large number of assisted patients; and (3) the large number of care services provided to the patients and the temporal dependency between the care activities and the human resources. These parameters are static and allow us to