Taking patients’ wishes into account for daily planning in the Home Health Care context
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Abstract: We consider here the daily planning of human resources for home health care. We give a mathematical formulation of the problem, as a mixed integer linear program integrating real-world constraints, such as disjunction, synchronization and precedence between tasks. Our objective is to optimize several indicators of patients’ satisfaction, regarding time of care and the caregivers’ gender. We assess the performance of the MILP with some data generated in order to fit the specifics of the practical problem.

Keywords: Home Health Care, routing and scheduling, daily planning, temporal constraints, MILP

1. INTRODUCTION

Home Health Care offers an alternative or an extension to traditional hospitalization. It consists in delivering medical and paramedical services to patients at home. Although applicable to a wide variety of pathologies, the Home Health Care relates more largely to postpartum care, palliative care, and neuro-degenerative diseases associated with aging. Thus, in part because of the aging of population, the Home Health Care has experienced strong growth in recent years.

While allowing potential reductions in hospitalization costs, the Home Health Care also gives raise to a number of additional organizational difficulties, compared to a conventional hospital service, such as routing and scheduling of caregivers. The aim is to decide which caregiver visits which patient, at what time, respecting a set of constraints.

Besides the cost aspect, the Home Health Care being a service to persons, service quality is defined, among others, by the level of patient’s satisfaction. Several criteria are possible to measure this satisfaction, such as respect for the wishes of patients regarding their provision of care. These wishes are usually difficult to meet, and often ignored in a schedule established “by hand”.

Our study addresses the routing and scheduling problem, by focusing on the human aspect, and specifically on patient’s satisfaction.

This paper is organized as follows: Section 2 presents related studies and define our problem, relating it with the literature. We then propose in Section 3 a mathematical formulation of our problem using linear programming with mixed variables. Section 4 presents the data generation and Section 5 the experiences and results of this modeling.

2. LITERATURE AND PROBLEM DESCRIPTION

The good effective functioning of a Home Health Care Center (HHCC) implies the resolution of several problems, such as resource dimensioning, partitioning patients and resources into districts, based on geography and / or on skills needed to treat patients, admission of patients and their assignment to one or more caregivers, and finally the scheduling and routing of human and material resources. We are interested here in the scheduling and routing problem of HHCC staff (i.e. deciding which human resource visits which patient at what time). In the literature, we find different variants of this problem. The main differences among the papers are the considered objectives, the constraints that are taken into account, and the methodology used for solving the problem. Readers can refer to Fikar and Hirsch (2017), or Cissé et al. (2017) for some recent reviews of existing OR models applied to Home Health Care Routing and Scheduling problem.

Within the planning problem, we can distinguish the problem of short-term planning (about a day or half a day), the problem of planning in the mid-term (about one or two weeks) or long term (about a month or more). We focus here our attention on the papers, published in journals and considering short term planning. Tables 1 and 2 summarize the objectives pursued in the planning, and the constraints that are taken into account in these papers.

2.1 Literature analysis for the daily planning problem

Table 1 shows that, almost all the articles aim at minimizing the transportation costs. However, the majority of the articles use a multiple objective, expressed as a weighted sum of several criteria, which do not necessarily have the same unit. To the best of our knowledge, only Ait Haddadene et al. (2016) and Braekers et al. (2016)
considered the trade-off between costs and satisfaction and proposed methods based on the e-constraint approach and enumerating the Pareto frontier. In our paper, we aim at maximizing the patients' satisfaction, by minimizing a sum of penalties.

The characteristics of the schedules are summarized in Table 2. Most of the articles take into account the diversity of the caregivers’ skills, generally under the shape of strong constraints. In general, a set of skills is assigned to each caregiver, and a set of necessary qualifications to every visit. We notice however that in practice, instances contain a limited number of different skills (2 or 3). Almost all the articles dedicated to the planning impose a hard time window for the task execution. Only a very few of them consider temporal constraints or patient preferences. In our paper, we aim at overcoming some limitations observed in the literature, especially those concerning the temporal constraints and the patient preferences.

2.2 Problem description and positioning

The problem considered in this article is the daily planning of the caregivers tours. We take into account constraints that are commonly considered, as the working schedules of caregivers, the adequacy between the staff skills and the qualifications required by the care, and time windows imposed for some cares. Temporal constraints between
tasks, which are important in practice and approached by relatively few works, are also considered. More precisely, in this article we take into account constraints of disjunction, synchronization, precedence and strict precedence.

Unlike the majority of the articles in the literature, the objective is not the tour minimization (total distance or duration), nor the balancing of the working time, but is the maximization of the patients’ satisfaction. For that, two different criteria are taken into account:

- Respect for time windows desired by the patients: a patient can give a time window in which he/she prefers to receive the visits from the caregivers.
- Respect for the patients’ wishes for the caregivers’ gender: a patient can express a preference concerning the gender of the caregiver for some of the cares. In the literature some methods allow to model the wishes of gender thanks to the notion of qualification but none takes into account the gender as a particular constraint.

These criteria are modeled by soft constraints, with a penalty associated with their violation. The objective is to minimize the sum of these penalties in order to optimize the satisfaction of the patient. The performance of our solution is checked on generated testing data the closest possible to reality.

3. MODEL DESCRIPTION

3.1 Assumptions and definitions

Periods We consider a time horizon of 1 period of half a day.

Caregivers We consider several kinds of caregivers, corresponding to different levels of skills (which may correspond to nurses, auxiliary nurses, or other caregivers). A caregiver may perform all the tasks for which the required qualification is lower or equal to his/her skill level. All caregivers must begin and end their tour at the HHCC. Working hours may vary according to the caregivers, but are always continuous intervals. The gender of each caregiver is known.

Tasks A number T of tasks must be performed by caregivers. A task is a care for a given patient, performed by exactly one caregiver. Each task has a defined duration. A qualification is defined for each task corresponding to the minimal level of skill required by the caregiver to realize this task. Some tasks may have a time window. This time window could be a hard time window corresponding to a medical constraint, or a soft time window corresponding to a patient’s wish. For the hard time window, the task must start and end within this time window. For the soft time window, if the task starts before this time window or finishes after this time window, a penalty is applied. A wish of gender can be associated with some tasks. If this wish of gender is not respected a penalty is applied.

Patients The travel time between patients and caregivers. A patient may express wishes for tasks regarding, specifically:
- a preference on the gender of a caregiver may be associated with a task.
- a desired availability time window can be associated with a task. These time windows are continuous intervals. Let us define these time windows by soft time windows.

Each patient can need one or several task(s) by period. When two tasks are defined for the same patient on the same period, they can be of several type:
- disjunction: both tasks cannot overlap, the order is irrelevant;
- synchronization: both tasks start at the same time; In this case, these two care cannot be realized by the same caregiver, two caregivers are simultaneously required at the patient’s home.
- precedence: both tasks cannot overlap and must be performed in a certain order.
- strict precedence: both tasks must be sequenced directly in a certain order. One starts immediately after the end of the other.

3.2 Data and parameters

- K : Set of caregivers.
- P : Set of patients.
- T : Set of tasks.
- Demandp : set of tasks for the patient p.
- D : Set of depots. D = {0,τ}
- S : Set of nodes. S = T ∪ D.
- E set of arcs. E = \{(i,j) ∈ D : i ≠ j \} \ {((j,0) : j ∈ T} \ {(j, 0) : j ∈ T}
- Tdys : set of couple of tasks for which a disjunction has been defined.
- Tsync : set of couple of tasks for which a synchronization has been defined.
- TpreceS : set of couple of tasks for which a precedence has been defined.
- TpreceE : set of couple of tasks for which a strict precedence has been defined.
- Kt = {k ∈ K : Qualif(k) >= Qualif(t)}: set of caregivers who can perform task t
- Travelsij: Travel time between tasks i and j.
- Duree: Duration of task t
- C_Genk: Gender of caregiver k (0 for Female and 1 for Male)
- T_Genk: Wish of gender for task t (0 for Female, 1 for Male, -1 for not specified gender)
- [alk, bk]: Working time window of caregivers k
- [αt, βt]: Hard Time window of task t (αt =-1 and βt = -1 if t does not require a hard TW).
- [et, lt]: Soft Time window of task t (et =-1 and lt =-1 if t does not require a soft TW).
- CG: Gender costs.
- CT: Soft Time Window costs.
- M: a big constant settled to the end of the time horizon.

3.3 Variables

Assignment variables
\[ y_{tk} = \begin{cases} 
1 & \text{if caregiver } k \text{ performs task } t \\
0 & \text{otherwise.} 
\end{cases} \]
\[ z_{ijk} = \begin{cases} 
1 & \text{if caregiver } k \text{ performs task } i \text{ then } j \\
0 & \text{otherwise.} 
\end{cases} \]
\[ \lambda_t = \begin{cases} 
1 & \text{if the soft TW of task } t \text{ is not respected} \\
0 & \text{otherwise.} 
\end{cases} \]
\[ \gamma_t = \begin{cases} 
1 & \text{if the wish of gender for task } t \text{ is not respected} \\
0 & \text{otherwise.} 
\end{cases} \]

Scheduling variables

- \( t : \) Starting time of task \( t \).

3.4 Model

\[
\min CG \sum_{t \in T} \gamma_t + CT \sum_{t \in T, \alpha_t \neq -1} \lambda_t
\]
Subject to:

\[ \forall t \in T, \sum_{k \in K_t} y_{tk} = 1 \] (2)
\[ \forall t \in T, \forall k \in K_t, \sum_{i \in D(\tau)} z_{tik} = \sum_{i \in E(\tau)} z_{tik} \] (3)
\[ \forall k \in K_t, \sum_{t \in T} z_{0tk} = 1 \] (4)
\[ \forall k \in K_t, \sum_{t \in T} z_{trk} = 1 \] (5)
\[ \forall t \in T, \forall k \in K_t, \sum_{i \in D(\tau)} z_{tik} = y_{tk} \] (6)
\[ \forall t_1, t_2 : t_1 \neq t_2 \in T, \sum_{i \in D(\tau)} \text{time}_{i} + D\text{urr}_{i} + \text{Travel}_{i,t_2} \leq \text{time}_{t_2} + M * (1 - \sum_{k \in K_t} \text{z}_{t_1t_2k}) \] (7)
\[ \forall t \in T, \forall k \in K_t, \text{a}_{k} + \text{Travel}_{a_{k}} - b_{k}(1 - \text{z}_{t_{0}k}) \leq \text{time}_{t} \] (8)
\[ \forall t \in T, \forall k \in K_t, \text{time}_{t} + D\text{urr}_{t} + \text{Travel}_{t} \leq b_{k} + M(1 - \text{z}_{t_{0}k}) \] (9)
\[ \forall t \in T : \alpha_t \neq -1, \alpha_t \sum_{k \in K_t} y_{tk} \leq \text{time}_{t} \] (10)
\[ \forall t \in T : \alpha_t \neq -1, \text{time}_{t} + D\text{urr}_{t} \leq \beta_t \sum_{k \in K_t} y_{tk} \] (11)
\[ \forall t \in T : \varepsilon_t \neq -1, \varepsilon_t(1 - \lambda_t) \leq \text{time}_{t} \] (12)
\[ \forall t \in T : \varepsilon_t \neq -1, \text{time}_{t} + D\text{urr}_{t} \leq \varepsilon_t + M \lambda_t \] (13)
\[ \forall t \in T : T_{Gen_{t}} = 0, \sum_{k \in K_t} y_{tk}C_{Gen_{k}} = \gamma_t \] (14)
\[ \forall t \in T : T_{Gen_{t}} = 1, \sum_{k \in K_t} y_{tk}(1-C_{Gen_{k}}) = \gamma_t \] (15)
\[ \forall (t_1, t_2) \in T_{sync}, \text{time}_{t_1} = \text{time}_{t_2} \] (16)
\[ \forall (t_1, t_2) \in T_{sync}, \forall k_1 \in K_{t_1}, k_2 \in K_{t_2} : k_2 \neq k_1, y_{t_1k_1} + y_{t_2k_2} \leq 1 \] (17)
\[ \forall (t_1, t_2) \in T_{precE}, \text{time}_{t_1} + D\text{urr}_{t_1} = \text{time}_{t_2} \] (18)
\[ \forall (t_1, t_2) \in T_{precS}, \text{time}_{t_1} + D\text{urr}_{t_1} \leq \text{time}_{t_2} \] (19)
\[ \forall (t_1, t_2) \in T_{dus}, \text{time}_{t_1} + D\text{urr}_{t_1} \geq \text{time}_{t_2} \] (20)
\[ \forall t \in T, \forall k \notin K_t, \sum_{i \in D(\tau)} z_{tik} = 0 \] (21)
\[ \forall t \in T, \forall k \notin K_t, \sum_{i \in D(\tau)} z_{tik} = 0 \] (22)
\[ \forall t \in T, \gamma_t \in \{0, 1\} \] (23)
\[ \forall t \in T, \lambda_t \in \{0, 1\} \] (24)
\[ \forall t \in T, \lambda_t \in \{0, 1\} \] (25)
\[ \forall i \in T, \forall j \in T, \forall k \in K_t, z_{ijk} \in \{0, 1\} \] (26)
\[ \forall t \in T, \text{time}_{t} \geq 0 \] (27)
\[ \forall t \in T, \text{time}_{t} \geq 0 \] (28)

The objective function (1) minimizes a weighted sum of the penalties associated with the non-satisfaction of the patient’s wishes (gender and time windows). Constraint set (2) ensures that each task is completed by exactly one caregiver with the required skill level. Constraint set (3) is the classical constraint set of preservation of flow. Constraint sets (4) and (5) ensure that each caregiver starts and ends his/her working day at the HHCC. Constraint sets (6) set \( y_{tk} \) to 1 if one the variables \( z_{tik} \) has been assigned to 1, that is to say if the caregiver \( k \) performs, during his/her tour, the task \( t \). Constraint set (7) ensures that if a pair of tasks \( (t_1, t_2) \) is performed by the same caregiver \( k \) then task \( t_1 \) must end before task \( t_2 \), starts, and without overlapping. The assumption regarding the respect of the triangle inequality for travel time is used here. Constraint sets (8) and (9) ensure that caregivers’ working time windows are respected. Constraint sets (10) and (11) ensure that the planning respects the tasks’ time windows, when defined. Constraint sets (12) and (13) ensure that if the desired soft time window of a patient for a task \( t \) is not respected, the decision variable corresponding to the non satisfaction of this wish \( \lambda_t \) is equal to one. Constraint sets (14), (15) ensure that if the gender preference of the patient for a task \( t \) is not respected, the decision variable corresponding to the non satisfaction of this wish \( \gamma_t \) is equal to one. Constraint sets (16), (18), (19), (20) ensure that scheduling variables are assigned according to synchronization, strict precedence and precedence and disjunction constraints. Constraint sets (17) ensure that if two tasks must be synchronized, these two tasks will be performed by two different caregivers. Constraint sets (21) and (22) ensure that a task of a tour cannot be assigned to a caregiver with an insufficient skill level.

4. DATA GENERATION

We generate randomly the instances, by respecting a number of rules stemming from constraints of the problem observed in practice. We assume that regular care are performed in the morning (in practice, afternoon is frequently dedicated to episodic cares). We shall thus consider that a period represents a morning constituted of 300 minutes, numbered from 0 to 300. In all our instances, we consider
Table 3. Working hours (in minutes) for the caregivers

| Probability | Beginning | End |
|-------------|-----------|-----|
| 0.4         | 0         | 300 |
| 0.15        | 0         | 240 |
| 0.15        | 60        | 300 |
| 0.1         | 0         | 180 |
| 0.1         | 120       | 300 |
| 0.05        | 180       | 300 |
| 0.05        | 0         | 120 |

Table 4. Desired (soft) time windows for the tasks (in minutes)

| Probability | Beginning | Probability | Duration |
|-------------|-----------|-------------|----------|
| 0.2         | 0         | 0.2         | 60       |
| 0.2         | 30        | 0.2         | 90       |
| 0.2         | 60        | 0.2         | 120      |
| 0.2         | 90        | 0.2         | 150      |
| 0.2         | 120       | 0.2         | 180      |

Table 5. Performance of the MILP - resolution

| Problem     | ISolved | avRTime | minRTime | maxRTime |
|-------------|---------|---------|----------|----------|
| (20;2;11;25) | 91      | 24.9    | 0.9      | 464.0    |
| (20;2;12;25) | 92      | 32.2    | 1.5      | 593.3    |
| (20;3;11;25) | 35      | 38.5    | 1.6      | 549.4    |
| (20;2;12;25) | 87      | 56.9    | 1.4      | 800.6    |
| (30;2;16;36) | 47      | 308.7   | 0.1      | 899.6    |
| (30;2;18;36) | 76      | 437.1   | 8.0      | 1801.0   |
| (30;3;16;36) | 44      | 317.6   | 13.9     | 317.6    |
| (30;3;18;36) | 48      | 160.8   | 9.9      | 643.0    |

ISolved: % of instances solved within 30 minutes
avRTime: average resolution time in seconds
minRTime: min resolution time in seconds
maxRTime: max resolution time in seconds

For all the instances, the percentage of gender wishes is about 10% of wish for a female caregiver, and 2.5% of wishes for a male caregiver.

5. EXPERIMENTS

To assess the performances of the MILP, we used the solver IBM ILOG CPLEX and the modeling language IBM ILOG OPL.

The program was tested on instances generated in a random way so as to remain close to reality. The MILP was tested on instances of various size and characteristics, following the generation rules described above. To be applicable in practice, the MILP must be solved within a reasonable time period. Here, we stop the execution after 30 minutes of running time.

In the remainder of the article, instances are referred to in the following way (P; Q; K; T), with:

- P number of patients,
- Q number of qualifications,
- K number of caregivers,
- T number of tasks

In tables 5 and 6, results obtained on various sizes of instances are presented. For each size shown in the tables, we generated 80 instances, by varying the proportion of temporal constraints (10 or 20%), the proportion of hard time windows (10 or 20%), and the proportion of soft time windows (30 or 40%).

We observe that instances with 20 patients are solved within one minute and instances with 30 patients within 5 minutes. Remember that the tested instances have at least 10% of temporal constraints, 10% of hard time windows, and 30% of soft time windows.

If we consider now the obtained results, we can observe that, in most cases, the gender preferences are satisfied, and that the soft time windows are satisfied in more than 80% of the cases. If we compare the obtained results to those obtained with a MILP aiming at optimizing the travel time, we can observe that the travel time is around 20% greater than the optimal one. Moreover, when optimizing the travel time, we could never satisfy the soft time windows, and satisfy the gender preferences only in around 70% of the cases.
We proposed a new mathematical model for the daily planning problem in a HHCC focusing on the patients’ satisfaction to overcome some limitations identified in the previous articles in the literature. The experiments show that the proposed MILP gives rather good results for the problem of daily planning, considering the patients’ satisfaction, and without degrading too much the travel time.

A challenging future issue would be to have a bi-criteria approach to emphasis simultaneously the two contradictory criteria: patients and caregivers’ satisfaction and costs.

REFERENCES

Ait Haddadene, S., Labadie, N., and Prodhon, C. (2016). A GRASP × ILS for the vehicle routing problem with time windows, synchronization and precedence constraints. *Expert Systems with Applications*, 66, 274 – 294.

Akjiratikarl, C., Yenradee, P., and Drake, P. (2007). PSO-softTWPref: % of non satisfied soft time window preferences. *GenderPref*: % of non satisfied Gender preferences. *tory criteria: patients and caregivers’satisfaction and costs.

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REFERENCES

Ait Haddadene, S., Labadie, N., and Prodhon, C. (2016). A GRASP × ILS for the vehicle routing problem with time windows, synchronization and precedence constraints. *Expert Systems with Applications*, 66, 274 – 294.

Akjiratikarl, C., Yenradee, P., and Drake, P. (2007). PSO-based algorithm for home care worker scheduling in the UK. *Computers & Industrial Engineering*, 53(4), 559–583.

Begur, S., Miller, D., and Weaver, J. (1997). An integrated spatial DSS for scheduling and routing home-healthcare nurses. *Interfaces*, 27(4), 35–48. doi: 10.1287/inte.27.4.35.

Benzarti, E., Sahin, E., and Dallery, Y. (2013). Operations management applied to home care services: Analysis of the districting problem. *Decision Support Systems*, 55(2), 587–598.

Bertels, S. and Fahle, T. (2006). A hybrid setup for a hybrid scenario: combining heuristics for the home health care problem. *Computers & Operations Research*, 33(10), 2866–2890.

Blais, M., Lapierre, S.D., and Laporte, G. (2003). Solving a home-care districting problem in an urban setting. *Journal of the Operational Research Society*, 54(11), 1141–1147.

Brekers, K., Hartl, R., Parragh, S., and Tricoire, F. (2016). A bi-objective home care scheduling problem: Analyzing the trade-off between costs and client inconvenience. *European Journal of Operational Research*, 248(2), 428–443.

Bredström, D. and Rönqvist, M. (2008). Combined vehicle routing and scheduling with temporal precedence and synchronization constraints. *European Journal of Operational Research*, 191(1), 19–31.

Cissé, M., Yalçұdagu, S., Kergosien, Y., Sahin, E., Lenté, C., and Matta, A. (2017). Or problems related to home health care: A review of relevant routing and scheduling problems. *Operations Research for Health Care*, in press.

Evøeborn, P., Flisberg, P., and Rönqvist, M. (2006). Laps carean operational system for staff planning of home care. *European Journal of Operational Research*, 171(3), 962–976.

Fikar, C. and Hirsch, P. (2017). Home health care routing and scheduling: A review. *Computers & Operations Research*, 77, 86–95.

Hertz, A. and Lahriri, N. (2009). A patient assignment algorithm for home care services. *Journal of the Operational Research Society*, 60(4), 481–495.

Issaoui, B., Zidi, I., Marcon, E., and Ghedira, K. (2015). New multi-objective approach for the home care service problem based on scheduling algorithms and variable neighborhood descent. *Electronic Notes in Discrete Mathematics*, 47, 181–188.

Liedler, A., Mooke, D., Koole, G., and Stolletz, R. (2015). Task scheduling in long-term care facilities: A client-centered approach. *Operations Research for Health Care*, 6, 11 – 17.

Mankowska, D., Meisel, F., and Bierwirth, C. (2014). The home health care routing and scheduling problem with interdependent services. *Health Care Management Science*, 17(1), 15–30.

Mutingi, M. and Mbohwa, C. (2013). Home healthcare worker scheduling: A group genetic algorithm approach. *Lecture Notes in Engineering and Computer Science*, 1, 721–725.

Mutingi, M. and Mbohwa, C. (2014). Multi-objective homecare worker scheduling: A fuzzy simulated evolution algorithm approach. *IEE Transactions on Healthcare Systems Engineering*, 4(4), 209–216.

Rasmussen, M., Justesen, T., Dohn, A., and Larsen, J. (2012). The home care crew scheduling problem: Preference-based visit clustering and temporal dependencies. *European Journal of Operational Research*, 219(3), 598–610.

Redjem, R. and Marcon, E. (2016). Operations management in the home care services: a heuristic for the caregivers routing problem. *Flexible Services and Manufacturing Journal*, 28(1-2), 280–303.

Shi, Y., Boudouh, T., and Grunder, O. (2016). A hybrid genetic algorithm for a home health care routing problem with time window and fuzzy demand. *Expert Systems with Applications*, 72, 160 – 176.

Yalçұdagu, S., Matta, A., Sahin, E., and Shanthikumar, J.G. (2016). The patient assignment problem in home health care: using a data-driven method to estimate the travel times of care givers. *Flexible Services and Manufacturing Journal*, 28(1-2, SI), 304–335.

Yuan, B., Liu, R., and Jiang, Z. (2015). A branch-and-price algorithm for the home health care scheduling and routing problem with stochastic service times and skill requirements. *International Journal of Production Research*, 53(24), 7450–7464.