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► To cite this version:

Didier Gourc, François Marmier, Paul Gaborit. An approach based on tabu search technique for solving a multi time window home healthcare scheduling problem. MOSIM 2014, 10ème Conférence Francophone de Modélisation, Optimisation et Simulation, Nov 2014, Nancy, France. hal-01166693

HAL Id: hal-01166693

<https://hal.science/hal-01166693v1>

Submitted on 23 Jun 2015

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AN APPROACH BASED ON TABU SEARCH TECHNIQUE FOR SOLVING A MULTI TIME WINDOW HOME HEALTHCARE SCHEDULING PROBLEM

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ABSTRACT: *In this article, we present a framework for solving a real-world multi time-windows home-healthcare scheduling problem. The goal of our approach is to assign homecare workers to interventions and to generate tours taking into account multi time-windows preferences. Our approach, based on a tabu search technique, is applied to a real-world problem. Then, results are presented and discussed.*

KEYWORDS: *home healthcare, scheduling, tabu search, nurse rostering, capability.*

1 INTRODUCTION

Since a few years, the demand for solutions of home healthcare grows up in France as in other countries (Shepperd & Iliffe 2005). These solutions can be addressed to elderly patients for long stays but also for shorter stays of post-operative period. This development is one of the possible responses to relieve the congestion in hospitals and to reduce the costs of care (Afrite et al. 2007, Raffy 1994). Moreover, this kind of structures is compatible with the increasing preferences of patient (Sentilhes-Monkam 2006) for giving priority to the quality of life and comfort in a familiar environment. The home healthcare becomes a more and more frequent alternative of a hospitalization or a placement in a specialized establishment.

The implementation of these new organizations brought specific problems of coordination of distributed actors (doctors, specialists, physiotherapists, nurses, nurse's aides, ...), of information exchanges, of traçability of the information and the management of the schedules. The literature review of the problems associated to the homecare is proposed by (Bashir et al. 2012). The authors also propose an analysis of the situation in several countries (Europe, USA, Canada).

Healthcare staff have to operate at patient homes and to travel from patient to patient. So, home healthcare schedule is difficult because many constraints have to be evaluate and take into account like visiting time windows, travel times, qualifications required for operating healthcare acts. Most of the time, shifts and

tours are planned manually which can be very problematic for several reasons. The quality of the shedule is very dependant of the experience of the planner and can be difficult to evaluate predictively. Usually, the human planner do not calculate criteria (economic, duration,...) that could help to evaluate and compare several solutions in order to propose the best one. Furthermore, producing home healthcare schedule can be a very time-consuming task that reduces the availability time of the human planner for other tasks.

Healthcare workers are in charge of realizing acts for patients at their home. Every actor is allocated to a tour which describes the orderly list of acts to be realized, and thus patients to visit, over a specific period. For each day tours are pre identified (their number and their amplitude) according to the capacity of the home care structure and the number of patients. A tour is characterised by a start time and a end time. The tours amplitude are determined, apriori, in order to cover the totality of the day.

According to their skills, home healthcare workers are assigned to tours for performing various acts at home patients. Facing the evolution of the economic context, the structures of homecare have to optimize the use of their resources and to optimize their costs while maintaining a very high level of quality. In this article, we are interested in the problem of scheduling acts and generating tours taking into account many specific constraints. Based on tabu search technique, the selected approach aims to optimize the total travel times and to minimize the tours duration.

The article is structured as follows. The literature review is discussed in Section 2. In Section 3, we develop the formal problem description. Next, our general solving approach, as well as the objective function formulation, are presented in Section 4. Then, an application case and computational results on this example are presented and analysed in Section 5. Finally, we conclude our work and give an outlook on future work.

2 LITERATURE REVIEW

Research in the field of home-healthcare problems started around 2000.

(Ernst, Jiang, Krishnamoorthy, Owens & Sier 2004) propose an important annotated bibliography synthesis on computational methods for rostering and personnel scheduling. The authors classify articles, more than 700 references, according to the type of problem addressed, the domain of application and the methods used. (Rinder et al. 2012) present a systematic literature review of the application of industrial engineering methods in healthcare scheduling.

It also exists in the literature, articles relative to the economic planning of the activities or the actors within the framework of structures of care at home (Bashir et al. 2012). They are interested, in particular, in the economic planning of the tours of the nurses. The schedule of a nurse is generally composed by a sequence of tasks which are different some of the others and which have different durations. Between these tasks, it is possible to find not worked periods of time. On the basis of this definition of the schedule (Ernst, Jiang, Krishnamoorthy & Sier 2004), the constraints relative to the economic planning of the tasks of the nurses are classified in constraints of sequence, schedule and final solution. The final solution is represented by the sum of the schedules.

(Bertels & Fahle 2006) propose a hybrid setup for a hybrid scenario: combining heuristics for the home health care problem. The requirement is to design rosters that consider both the staff rostering and vehicle routing components while minimising transportation costs and maximising the preferences of the patients and nurses (Ernst, Jiang, Krishnamoorthy & Sier 2004). The paper contains a discussion of integrated approach using Linear Programming (LP), Constraint Programming (CP) and heuristic solution methods.

(Akjiratikar et al. 2007) propose an original approach using an algorithm of Particle Swarm Optimization to build the schedule of the homecare actors. This algorithm combines a global exploration of the space of the solutions and a procedure of local search to refine the solution by an analysis of the neighborhood.

In (Brucker et al. 2010), an original method, to build the schedule of every actor by decomposing the problem into two phases, is proposed: first the construction of the possible 'shifts sequence' respecting the constraints of sequence are elaborated, then the construction of the schedules for every actor respecting the constraints of 'schedule and roster' are selected.

(Rasmussen et al. 2012) develop a solution for a home care crew scheduling problem. The problem definition, tackled by the authors in this article, is composed with temporal dependencies between interventions. They present five type temporal dependencies: synchronisation, overlap, minimum difference, maximum difference and min+max difference.

Some others works are related to multimodal home healthcare scheduling problem (Hiermann et al. 2013). This stream of work aim to take into account the modality of routes in the process of determining and assigning nursing tasks to homecare staff. Healthcare actors can use different modes of transportation (cars, public transportation, foot, bicycle, ...). The choice of one of this mode of transportation influences the travel times. The authors compare four metaheuristics: variable neighborhood search, a memetic algorithm, scatter search and a simulated annealing hyper-heuristic.

In this field, numerous works, concern problems where interventions have to be performed in a single preferred time windows. In our work, we address a multi time windows scheduling problem.

Preliminary results of our work based on a previous version of the algorithm have been presented in (Gourc et al. 2013). Furthermore, enhanced features have been developed concerning the multi time-window problem and so on concerning the ability to assign interventions to tour according the capabilities proposed by workers. According to real world practices, an investigation of the influence of capability workers, required to perform the interventions, on the scheduling practices have been done. So, the major contributions of this article concern a detailed formulation of this specific problem, an extended presentation of our global resolution method and the analysis of the results obtained with this approach on a real-world case.

3 THE MULTI TIME-WINDOWS HOME-HEALTHCARE SCHEDULING PROBLEM

The problem deals with finding an assignment of health actors (nurses, care assistant, orderly, ...) to healthcare interventions and scheduling tours for visiting the patients while minimizing violation of healthcare constraints and the total travel time. This

scheduling problem aims to generate tours that efficiently utilize resources minimizing the total travel times, as well as satisfying individual preferences (like as much as possible).

3.1 Problem definition

Health interventions. Let define the set of patients $\mathcal{P} = \{1, \dots, p, \dots, P\}$ who have to be taken care of in a home healthcare structure. For each patient a set of health interventions to be done are described. $\mathcal{I}_d = \{1, \dots, i, \dots, I\}$ denotes the set of health interventions that have to be done the day d .

An health intervention i is characterised by:

- a set $\mathcal{W}_i = \{1, \dots, w, \dots, W\}$ of preferred time window. Each preferred time window is characterised by $[s_{ri}, e_{ri}]$ with s_{ri} the earliest possible start time and e_{ri} the latest possible end time for this window
- an estimated duration time dur_i
- the capabilities required to perform it $\mathcal{C}_i = \{1, \dots, c_i, \dots, C_i\}$
- the patient p concerned by this intervention with its home address

For an health intervention i , one of the aims of the planner is to generate the planned start time and the planned end time s_{pi} and e_{pi} .

Pre-allocated interventions. In addition to healthcare interventions, we also consider specific jobs (e.g. team meetings, administrative works, etc.) that are assigned to a fixed location and a fixed time. A pre-allocated intervention is modelised as a specific intervention for which the assignment is already realized.

Capabilities. Capabilities represent aptitudes whose are endowed the health workers and that could be needed to perform the interventions.

The set of available capabilities is $\mathcal{C} = \{1, \dots, c, \dots, C\}$. This set of capabilities and their definition can be specific for each home-healthcare structure, this could refers, to diseases, pathologies or feature of the acts to do (like alzheimer, end-of-life care, nursing, ...) and so on.

Tours. Each day, available health workers can only work within a specific time windows. The set of tours $\mathcal{T}_d = \{1, \dots, t, \dots, T\}$ to be planned the day d are in accordance with availability and capabilities of health workers. A tour t is characterised by: the available total time window $[s_t, e_t]$ with s_t the start time and e_t the end time of the tour and the proposed set of required capabilities $\mathcal{C}_t = \{1, \dots, c_t, \dots, C_t\}$, $\mathcal{C}_t \subseteq \mathcal{C}$.

Travel times matrix. A travel times matrix TM is used to represent estimated travel time between each couple of patients of the healthcare structure and others specific points of interest that are necessary to consider. Among these points of interest, we define usually the localisation of the healthcare structure, or another point of interest, from where healthcare workers start their tour and to where they go to close the tour. Others points could be considered. The travel times matrix is not symmetric, travel time from the point a to the point b is not necessary the same that the travel time from b to a . In some situations, due to road infrastructure the trip between these two points may require to use two itineraries different according to the circulation way. Travel time is expressed in minutes.

3.2 Constraints

Constraints. Constraints are broken into two classes: hard constraints and soft constraints. Hard constraints must be satisfied to obtain feasible solutions. The hard constraints are:

- all interventions plan ahead for a day d must be assigned to a tour of this day d
- each intervention i must be assigned to exactly one tour t
- intervention which requires specific capabilities must be assigned to a tour endowed with all the capabilities required
- for a tour and at one time, there can be only an intervention performed
- starting times of two consecutive interventions i_1 and i_2 are calculated according their duration and the travel time. If i_1 is planned before i_2 , $s_{i_2} = e_{i_1} + tm$ where tm is the travel time from the residence of the involved patient in the intervention i_1 to the residence of the involved patient in the intervention i_2
- start and end time of the specific jobs must be strictly planned in the desired schedule

Soft constraints are desirable but not obligatory, and thus can be violated.

The soft constraints are:

- start and end time of a planned intervention should lie within the specified time windows
- the planning solution should minimize the interventions planned out of the duration time of the tours

- time interval between two visits to the same patient must respect a determined duration (for example 3 hours)
- planned tours of a period must be balanced in terms of duration
- planned tours of a period must be balanced in terms of work hardness

Solution. A solution s is composed of the planned tours t_d for each day of the study period, for instance a week. $s = \{t_1, t_2, \dots, t_n\}$. Several tours can be associated to a day. Each tour lists the interventions to be realized with a specific arrangement allowing to determine the planned start and finish time of each intervention.

3.3 Objective function and criteria used for evaluating the solutions

Two classes of criteria are identified to evaluate each solution generated. The first class is composed of three criteria that are the most important weight in the evaluation process. These criteria aim to validate the realism of the evaluated solution. The second class of criteria addresses characteristics of the evaluated solution that have to be optimized in realist solutions.

| Term | Weight | Meaning |
|---------------------|----------|----------------------------------|
| First class | | |
| c_1 | | time windows respect |
| c_2 | | planned tour overtime |
| c_3 | | time interval between two visits |
| Second class | | |
| c_4 | α | travel time |
| c_5 | β | overtime equilibrium |
| c_6 | γ | hardness equilibrium |

Table 1: Criteria used to evaluate solutions

Time Windows Respect (TMR) quantifies the deviation from the desired time window for each intervention. For each intervention, the most closely preferred time window with the time window of the planned intervention are identified. When the intervention is planned and for each preferred time windows characterising this intervention, we propose to generate the sum of the delay and the advance for this intervention. Among these values, the minimum is selected to characterize the criteria of time window respect for this intervention. The global time window respect, associated to the planned solution which is composed of all the planned interventions, is obtained by adding the elementary time window respect (see equation 1).

In figure 1 four specific situations are illustrated : situation 1 to situation 4. Each situation expresses a

possible schedule for a specific intervention to plan. Three preferred time windows was identified : w_1 , w_2 and w_3 . The table 2 illustrates the calculation to perform the TMR indicator. For each situation, early and delay indicators are calculated for each preferred time window. For instance, for the preferred time window w_1 , the situation 1 is 0 minutes early, it starts after the beginning of early start of the preferred time window, and it is 0 minutes late because it finishes before the end time. The partial TMR indicator for this preferred time window is evaluated as 0, illustrating that this planned intervention respects this preferred time window. A same calculation for the preferred time window w_2 generates a partial TMR with a value of 13. This higher value illustrates that this situation don't respects the preferred time window w_2 , and the planned intervention is 13 minutes later.

$$c_1 = \sum_i \min_w \max(0; s_{ri} - s_{pi}) + \max(0; e_{pi} - e_{ri}) \quad (1)$$

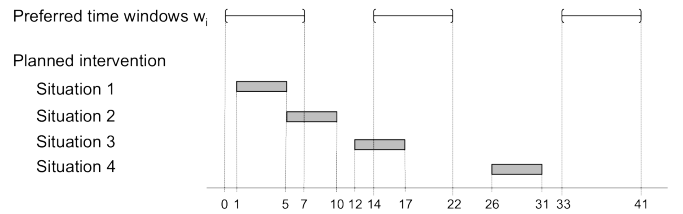


Figure 1: Example of planned interventions

| Preferred windows planned intervention | w1 | w2 | w3 |
|---|-------------------|--------------------|--------------------|
| Situation 1 | | | |
| Early | $\max(0; 0 - 1)$ | $\max(0; 14 - 1)$ | $\max(0; 33 - 1)$ |
| Delay | $\max(0; 5 - 7)$ | $\max(0; 5 - 22)$ | $\max(0; 5 - 41)$ |
| TMR | 0 | 13 | 32 |
| Situation 2 | | | |
| Early | $\max(0; 0 - 5)$ | $\max(0; 14 - 5)$ | $\max(0; 33 - 5)$ |
| Delay | $\max(0; 10 - 7)$ | $\max(0; 10 - 22)$ | $\max(0; 10 - 41)$ |
| TMR | 3 | 1 | 28 |
| Situation 3 | | | |
| Early | $\max(0; 0 - 12)$ | $\max(0; 14 - 12)$ | $\max(0; 33 - 12)$ |
| Delay | $\max(0; 17 - 7)$ | $\max(0; 17 - 22)$ | $\max(0; 17 - 41)$ |
| TMR | 10 | 2 | 21 |
| Situation 4 | | | |
| Early | $\max(0; 0 - 26)$ | $\max(0; 14 - 26)$ | $\max(0; 33 - 26)$ |
| Delay | $\max(0; 31 - 7)$ | $\max(0; 31 - 22)$ | $\max(0; 31 - 41)$ |
| TMR | 24 | 9 | 7 |

Table 2: Example of calculating time windows respect

Planned tour overtime quantifies the deviation from the working time planned for all tour. It is calculated in minutes.

$$c_2 = \sum_t \max(0; dur_{rt} - dur_{pt}) \quad (2)$$

where dur_{rt} is the daily working time considering all tour available and dur_{pt} is the working time resulting of the solution generated. Additional hours of work should be considered as overtime, the healthcare organisation wants to reduce this number.

Time interval between two visits quantifies the respect of a number of hours minimum between two visits at the same patient. For instance, when a patient needs two visits per day or more, the second visit at the patient have to be done at least m units of time after the first one.

$$c_3 = \sum_{s \in S} \min(0; m - \text{dist}(c)) \quad (3)$$

where S is the set of all intervention couples for the patient p and $\text{dist}(c)$ is the time interval between these two interventions.

Travel time quantifies the sum of all the travel times planned to realize the interventions of the day d . This criteria have to be the smallest. It is calculated as the standard deviation at the average of the overtime for the planned tours.

Overtime equilibrium quantifies workload balance among healthcare workers which is modelised as the likeness of the overtime of all healthcare workers in the planned solution. It is calculated as the standard deviation at the average of the overtime for the planned tours. This criteria has to be the smallest in order to minimize the difference of overtime in each tour.

Hardness equilibrium quantifies the likeness of the hardness of all healthcare workers in the planned solution. It is calculated as the standard deviation at the average of the hardness for the planned tours. The tour hardness is based on the french AGGIR grid. This criteria has to be the smallest in order to minimize the difference of hardness in each tour.

The last three criteria are aggregated with a linear function in order to consider them in the solution evaluation process in the same time. cr is the aggregated criteria which is obtained by the equation 4.

$$cr = \alpha \times c_4 + \beta \times c_5 + \gamma \times c_6 \quad (4)$$

The valuation of the parameters α , β and γ has been done according to weights of the criteria c_4 , c_5 and c_6 in order to balance their influences. The values for these parameters represent the relative importance that the home healthcare structure affects to each of them.

4 NEIGHBORHOOD SEARCH

In the proposed approach we use a tabu search technique for exploring the solution space. For this, three different types of neighborhoods generation are introduced for:

- Shift intervention: shifts an intervention from one tour to another tour. The intervention is positioned at an aleatory place in the new tour.
- Swap intervention: swaps two interventions with each other, so that the tour of the first intervention is assigned to the second intervention and vice versa.
- OrOpt insertion: moves an intervention from one position to another in the same tour.

The shift and swap techniques used in our model for generating neighbors take into account the capability of the interventions and the tours. Only realist neighbors, according to the point of view of the adequation between the required capabilities for an intervention and the capabilities endowed by the tour, are generated and thus evaluated.

One of the originality of the proposed approach concerns the manner of the criteria are used in the neighborhood algorithm resolution. During an iteration of the neighborhood algorithm the best solution is identified in a two passes approach. First, criteria of the first class are evaluated according to the order they has been presented in the Table 1: c_1 is considered before c_2 which is considered before c_3 . Then, criteria of the second class are aggregated in a single value with a linear function (equation 4) for ranking the realist solutions identified. The algorithm to compare two solutions is presented in Algorithm 1. The best solution identified at this iteration is selected to perform the next iteration of the neighborhood algorithm. The best solution obtained within all the resolution process is memorized.

A mark of each of the evaluated solutions is memorized in order to detect cycles in the neighborhood algorithm. A cycle is identified when a sequence of evaluated solutions is upper than the size of the tabu list. When this situation occurs, the algorithm generates randomly a new solution which is used to carry on the resolution process.

5 APPLICATION CASE AND COMPUTATIONAL RESULTS

This study is realized in the context of the project PlaS'O'Soins which is funded by the french program ANR/TECSAN. Partners of this project gave us real-world dataset that are used for evaluating the proposed solutions and to compare it with the solution planned by the structure for this instance.

Patients are distributed geographically in a zone around the healthcare structure. The dataset is composed of 54 patients.

Disponibility of healthcare actors may induce a num-

Algorithm 1 Compare two solutions

Require: two one-day solutions: s_i and s_j

Ensure: the best one-day solution

```

if  $c_1(s_i) <> c_1(s_j)$  then
    return the solution with the best criteria  $c_1$ 
else
    if  $c_2(s_i) <> c_2(s_j)$  then
        return the solution with the best criteria  $c_2$ 
    else
        if  $c_3(s_i) <> c_3(s_j)$  then
            return the solution with the best criteria  $c_3$ 
        else
             $cr \leftarrow \alpha \times c_4 + \beta \times c_5 + \gamma \times c_6$ 
            return the solution with the best criteria  $cr$ 
        end if
    end if
end if
    
```

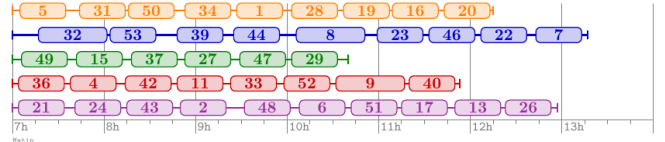


Figure 2: Morning tours generate by human

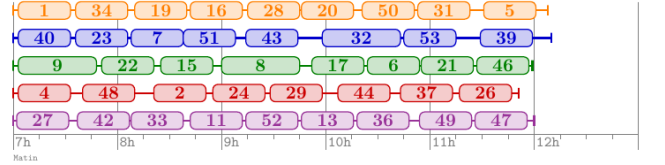


Figure 3: Morning tours generated by our approach

ber of tours different for each day (# tours). Each tour can be categorised.

The dataset instance used for this experiment is composed of interventions to plan related to an entire week of seven days. The number of interventions and the number of tours to schedule are given in Table 3.

| | day1 | day2 | day3 | day4 | day5 | day6 | day7 |
|--------------------------|------|------|------|------|------|------|------|
| morning 7h-12h | | | | | | | |
| # interventions | 41 | 43 | 40 | 43 | 41 | 43 | 29 |
| # tours | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| afternoon 14h-17h | | | | | | | |
| # interventions | 4 | 3 | 4 | 3 | 4 | 3 | 3 |
| # tours | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| evening 17h-19h30 | | | | | | | |
| # interventions | 23 | 23 | 23 | 23 | 23 | 23 | 19 |
| # tours | 5 | 5 | 5 | 5 | 5 | 5 | 5 |

Table 3: Dataset dimensions

Unfortunately, we are not able to make the dataset publicity available due to data protection issues.

Examples of plannings for the morning tours are represented in figures 2 and 3. The figure 2 presents the solution obtained by a human scheduler, tours are not balanced. One of them, the tour #3, is very short while some of others are taller than the tour #3 and exceed the limit. The solution generated by our algorithm is described in the figure 3.

In these figures, each horizontal chain represent a specific tour, from upper to lower #tour1 to #tour5. The time line is associated to the horizontal axe. The boxes illustrate the planned time window for each intervention, the number inside the box is the intervention number. The travel time between two successive interventions is represented by the line between the boxes.

Table 4 illustrates the value of several criteria that are used to evaluate solutions. The obtained progress

on each of the criteria is presented in table 4, in the column labelled gain, comparing the human solution and the algorithm solution.

| Criteria | Manual scheduling | Planner | Gain (%) |
|-----------------|-------------------|---------------|----------|
| c_1 (minutes) | 145 | 1 | 99% |
| c_2 (minutes) | 306 | 172 | 43% |
| c_3 (minutes) | 68 | fully respect | 100% |
| c_4 (minutes) | 476 | 362 | 24% |

Table 4: Compared results

CONCLUSION

In this work, we presented an approach to tackle a multi time window home healthcare scheduling problem. The proposed approach, based on a tabu search technique, is developed and applied to a real-world case. Some of the computational results are presented in the paper. In our computational results, we see that the proposed approach produces best results than human approach. This results are obtained in reasonable time.

For future work, we plan to extend several characteristics of the problem definition. First, we want to integrate the required job qualifications in the intervention description. So, we can schedule tours for an home healthcare structure that utilize different kind of health actors (nurse, nurse’s aide, doctor, ...). Second, connected visits will be implemented in order to schedule for example interventions needing more than one actor to perform them.

ACKNOWLEDGMENTS

This work was supported by the French National Research Agency and the project PlaS’O’Soins which globally presented in (Bastide et al. 2014). PlaS’O’Soins is a project of the Program entitled “Technologies for health and autonomy (TecSan)”. The authors express their gratitude to Nicolas Salatgé for his contribution to the software deployment.

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