Business Planning for Home Care and Services

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ABSTRACT: *In this paper, we are interested in the organization of home care activities. We focus on the planification of the accompaniments of a set of people by a SESSAD (Service d'Education Spéciale et de Soins A Domicile - Special Education Service and Home Care). This planification implies deciding conjointly on the schedule of each care and on routing of the professional caregivers. To organize this planning we need to know who will do this work, where it will be done, and how to organize the schedule to reduce travel costs and to maximize the satisfaction of patients. This type of subject has been already approached by close problems but not too much around the dimension of multi-period in the planification. First of all, the basis of the model are inspired by the literature. Then, a case study analysis is necessary to study the needs as well as the solutions that can be provided. Finally, a tool is presented to respond to our problems, combining the literature as well as the field aspect, as well as to list the future advances needed in this field.*

KEYWORDS: *Multi Period Vehicle Routing Problem, Scheduling, Staff transportation, Home Capacity, Routing, HHCRSP*

1 INTRODUCTION

Our topic proposes to focus on activity planning for home care and services. The preferred field of analysis is that of SESSAD (Service d'Education Spéciale et de Soins A Domicile - Special Education Service and Home Care). The accompaniment of a person by a SESSAD can include specialized medical acts and re-education (physiotherapy, speech therapy, psychomotricity, occupational therapy). SESSAD educators and specialized teachers can also provide specific assistance to the patients with a disability, either in the form of the class, either individually or in small groups outside the classroom. Accompaniments take place in several living areas (home, school, etc.). To organize these accompaniments, it is necessary to answer several questions: Who carries out the accompaniment (Assignment)? Where will the accompaniment take place (Location)? How can the accompaniments be best linked to reduce the number of journeys and maximize the presence of professionals with the users (Routing). The work is carried out with a close link to the field study.

This one concerns tours by speech and language therapists (SLTs) in the Lyon region (France). Indeed, children in need of hearing treatment can acquire this care from their school. The notion of routing of professionals is then consequent. Whether at the level of employees or patients, there are considerable constraints in matching schedules. The importance of optimizing the routes is not only have the benefit of reducing costs but also be able to meet as much demand as possible.

In this paper, we formulate the problem as a mixed integer linear program to solve the study. This paper is organized as follows: a short literature review is given in section 2. The description of the case study and formulation of the problem is presented in section 3, followed by the mathematical model in section 4. Section 5 contains the results of the simulation and a conclusion based on these results with new perspectives for future research are exposed in section 6.

2 Literature Review

Since the 2000s, planning in health has been studied in many aspects. There are many different resources on this subject, Cissé et al. (2017) lists a large part of them, which makes it possible to observe how each criterion has been explored. We are able to use this review to find articles whose objectives and constraints are as close as possible to the subject. A Multi Period Vehicle Routing Problem (MPVRP) deals with transport costs (Archetti, et al., 2015) and planning (Wen, et al., 2010) objectives. As this model is as close as possible to the expectations of the one being sought, the bases are similar. MPVRP models can have dynamic or static structures, this concept have to be studied in order to decide which one is the most appropriate. A case study in Sweden was presented by Wen, et al., (2010) to show the benefits on the ground that such a study can bring. This case study corresponds to the distribution of orders from a depot to a set of customers over a multi-period time horizon. They modeled the problem using a dynamic multi-period vehicle routing problem, and solved it by means of a three-phase heuristic. This study allowed them to submit good quality results within reasonable running times.

The Home Health Care Routing and Scheduling Problem therefore corresponds to the resolution of transport costs and planning objectives for a type of staff. We are aware that exact methods explode in computation time when the data set becomes important. Heuristics are then good means to find good solutions. Martinez, et al.,(2018) exposes one of them in Home Health Care and Scheduling Problem by combining an algorithm and a MILP. Its context being close to ours, albeit with some differences, is a good basic inspiration. The multidisciplinary aspect is questioned in staff scheduling problems where there is a routing problem with an importance on the quality of service (Abounacer, et al., 2009).

The Vehicle Routing Problem with Time Windows (VRP-TW) consists in taking into account the moments of availability of the customers. These customers can receive services only during these time windows (Tellez, et al., 2020). In general, time windows in an HHCRSP are unique each day. As with the above, the parameters are a start time, and an end time on which the employee can intervene. These are called non-block scheduling (Conforti, et al., 2010). A schedule is generated on a daily time slot. There is then another way of looking at availability, that of block scheduling, where the day is divided into homogeneous blocks of time, each representing a processing time slot (Conforti, et al., 2008).

Our problem here is very close to an MPVRP. However, our specificity are at the level of availability periods. Instead of having availability data represented by a "start" to an "end", we have slots over the day. This make it possible to put several periods of availability on the same day.

3 Problem description

3.1 Description

A collaboration with a SESSAD of the OVE Foundation, an association dealing with speech and language therapy services in the Lyon area, has been realized. The latter does not have a decision-making tool to help it draw up its tour schedules, so there is a fairly considerable potential for improvement. The model to be developed meet the objectives and constraints of this association. The goal of this model is to optimize employees' travel time, while keeping a small waiting time.

We consider a set of patients requiring weekly services at their school sites. We thus work on a time horizon of one week, which is close to the functioning of the association. We have a set of employees in order to meet the demand. Each employee has different qualifications. In order to respond to a request, the employee need to have the necessary skills to perform the service. Indeed the services are not identical and require certain skills to carry them out. Hard time windows have to be respected in order to match employee and patient schedules.

In Figure 1, we can see the disparity and complexity of employee and patient locations. In this example we have 12 SLTs (grey stars) and 100 patients (black markers). When the locations are the same, only one point is shown on the map, which explains why the number of points is lower than the total number of patients.

Figure 1 – Zoomed-in overview of our case study without the two most distant patients

3.2 Formulation

We decided to model this problem as a vehicle routing problem with time window (VRP-TW). The problem has a G(R,T) graph with the locations of SLTs and patient treatment as nodes (R), and the paths between them as arcs (T). We used a discrete time approach where time is divided into time-slots in order to respect what is done in practice. Each patient requires a certain demand (frequency and skill) that can be achieved by different professionals as well as hard time windows. Employees do not have the same employment contracts, therefore they do not have the same working time capacities, either in terms of the number of days in the week or the number of working hours per day. We must then succeed in finding a match between the schedules of professionals and patients, while making sure that the employee destined for a certain patient has the right skills. It should also be noted that each employee leaves home at the beginning of the tour and must finish this one at home.

As previously mentioned, the objective is to optimize travel time while minimizing waiting time. It should be noted that waiting time represents the delay between the employee's arrival at the patient's location and the beginning of the service.

The notations used in the model are summarized in Table 1.

We group resources (professionals and patients) in a single set R in order to create distance matrices between them.

Data	
Notation	**Definition**
P	Set of patients
E	Set of employees
$R = E \cup P$	Set of all resources
D	Set of days
S	Set of services
W	Set of time slots
$T_{r_1 r_2}$	Travel time between resources r_1 and r_2
Dem_{rs}	Request of patient r in service s
$Avai_{rdw}$	Availability of ressource r on day d on time window w
QE_{es}	Qualification of employee e on service s
$TTime$	Treatment time
$WTime$	Size of a time slot
$MTime$	Margin time to arrive at a patient
K_r	Minimum number of days required between two treatments for resource r
$\|D\|$	Time Horizon
M	Big M

Table 1 – Notation for the Model

4 Mathematic model

4.1 MILP

Variables

- $X_{r_1 r_2 edw}$: equal 1 if employee e takes the path r_1 to r_2 on day d on time window w — boolean
- Y_{erd} : arrival time of employee at resource location r on day d — int+
- Tf_{ed} : End time of employee e on day d — int+
- v_e : number of visits made by employee e — int+

Objectives

$$OptTrav = min \sum_{r_1 \in R} \sum_{r_2 \in R} \sum_{e \in E} \sum_{d \in D} \sum_{w \in W} X_{r_1 r_2 edw} * T_{r_1 r_2} \quad (1)$$

$$OptWaitT = min \sum_{e \in E} \sum_{d \in D} (Tf_{ed} - Y_{eed}) - \sum_{r \in R} \sum_{s \in S} Dem_{rs} * TTime - OptTrav \quad (2)$$

Constraints

$$\sum_{r_2 \in R} \sum_{e \in E} \sum_{w \in W} X_{r_2 r_1 edw} \leq 1 \quad \forall r_1 \in R, d \in D \quad (3)$$

$$\sum_{r \in R} \sum_{w \in W} X_{eredw} \leq 1 \quad \forall e \in E, d \in D \quad (4)$$

$$\sum_{r \in R} \sum_{e_2 \in E, e_2 \neq e_1} \sum_{w \in W} X_{e_1 r e_2 dw} = 0 \quad \forall e_1 \in E, d \in D \quad (5)$$

$$\sum_{r \in R} \sum_{w \in W} X_{reedw} \leq 1 \quad \forall e \in E, d \in D \quad (6)$$

$$\sum_{r \in R} \sum_{e_2 \in E, e_2 \neq e_1} \sum_{w \in W} X_{r e_1 e_2 dw} = 0 \quad \forall e_1 \in E, d \in D \quad (7)$$

$$\sum_{r_1 \in R} \sum_{r_2 \in R} X_{r_1 r_2 edw} \leq 1 \quad \forall e \in E, d \in D, w \in W \tag{8}$$

$$\sum_{r_1 \in R} \sum_{r_2 \in R} \sum_{w \in W} X_{r_1 r_2 edw} \leq M * \sum_{r \in R} \sum_{w \in W} X_{eredw} \quad \forall e \in E, d \in D \tag{9}$$

$$\sum_{r_1 \in R} \sum_{r_2 \in R} \sum_{w \in W} X_{r_1 r_2 edw} \leq M * \sum_{r \in R} \sum_{w \in W} X_{reedw} \quad \forall e \in E, d \in D \tag{10}$$

$$Y_{p_1 ed} + TTime + T_{p_1 p_2} \leq Y_{ep_2 d} + M * \sum_{w \in W} (1 - X_{p_1 p_2 edw}) \quad \forall e \in E, p_1 \in P, p_2 \in P, d \in D \tag{11}$$

$$Y_{eed} + T_{ep} \leq Y_{epd} + M * (1 - \sum_{w \in W} X_{epedw})) \quad \forall e \in E, p \in P, d \in D \tag{12}$$

$$Y_{epd} - T_{ep} \leq Y_{eed} + M * (1 - \sum_{w \in W} X_{epedw}) \quad \forall e \in E, p \in P, d \in D \tag{13}$$

$$(w * \sum_{r \in R} X_{rpedw} * WTime) - MTime \leq Y_{epd} \quad \forall e \in E, p \in P, d \in D, w \in W \tag{14}$$

$$Y_{epd} \leq M(1 - \sum_{r \in R} X_{rpedw}) + \sum_{r \in R} X_{rpedw} * w * WTime + MTime \quad \forall e \in E, p \in P, d \in D, w \in W \tag{15}$$

$$Y_{er_1 d} \leq M * \sum_{r_2 \in R} \sum_{w \in W} X_{r_2 r_1 edw} \quad \forall e \in E, r_1 \in R, d \in D \tag{16}$$

$$X_{rpedw} \leq Avai_{pdw} * Avai_{edw} \quad \forall e \in E, d \in D, w \in W : w \neq 0, r \in R, p \in P \tag{17}$$

$$X_{eped0} \leq Avai_{pd0} * Avai_{ed0} \quad \forall e \in E, d \in D, p \in P \tag{18}$$

$$\sum_{e \in E} \sum_{r \in R} \sum_{d \in D} (X_{rpedw} * QE_{ps} * Avai_{edw} * Avai_{pdw}) \geq Dem_{ps} \quad \forall p \in P, s \in S \tag{19}$$

$$\sum_{w \in W} (X_{p_2 p_1 edw} + X_{p_1 p_2 edw}) \leq 1 \quad \forall e \in E, p_1 \in P, p_2 \in P, d \in D \tag{20}$$

$$\sum_{w \in W} X_{rredw} = 0 \quad \forall e \in E, r \in R, d \in D \tag{21}$$

$$\sum_{r_2 \in R} \sum_{w \in W} X_{jr_1 edw} = \sum_{r_2 \in R} \sum_{w \in W} X_{r_1 jedw} \quad \forall e \in E, r_1 \in R, d \in D \tag{22}$$

$$M * (1 - \sum_{r \in R} \sum_{w_2 = w}^{|W|-1} X_{predw_2}) \leq M * (1 - \sum_{r \in R} X_{rpedw}) \quad \forall e \in E, p \in P, d \in D, w \in W \tag{23}$$

$$\sum_{r_2 \in R : r_2 \neq r_1} \sum_{e \in E} \sum_{f = d}^{d + K_{r_1}} \sum_{w \in W} X_{r_1 r_2 efw} \leq 1 \quad \forall r_1 \in R, d \in [0, .., |D| - K_{r_1}] \tag{24}$$

$$\sum_{r \in R} \sum_{e \in E} \sum_{d \in D} \sum_{w \in W} X_{rpedw} = \sum_{s \in S} Dem_{ps} \quad \forall p \in P \tag{25}$$

$$Y_{erd} + \sum_{w \in W} (X_{reedw} * (T_{re} + TTime)) \leq Tf_{ed} \quad \forall e \in E, r \in R, d \in D \tag{26}$$

$$\sum_{r \in R} \sum_{p \in P} \sum_{d \in D} \sum_{w \in W} X_{rpedw} = v_e \quad \forall e \in E \tag{27}$$

$$\sum_{r \in R} \sum_{d \in D} \sum_{w \in W} X_{rpedw} \leq M * \sum_{s \in S} (QE_{es} * Dem_{ps}) \quad \forall p \in P, e \in E \tag{28}$$

$$X_{r_1 r_2 ed} \in \{0, 1\} \quad \forall r_1 \in R, r_2 \in R, e \in E, d \in D \tag{29}$$

$$Y_{er_1 d} \in \mathbb{N} \quad \forall r_1 \in R, e \in E, d \in D \tag{30}$$

$$Tf_{ed} \in \mathbb{N} \quad \forall e \in E, d \in D \tag{31}$$

$$v_e \in \mathbb{N} \quad \forall e \in E \tag{32}$$

The first objective in (1) is to find the shortest travel time to be achieved while respecting all constraints. The second objective (2) is to minimize the waiting time. Constraints (3),(4),(5),(6),(7),(8),(9) and (10) enforce the logical feasibility of a vehicle routing problem. (3) prevents multiple visits to the same patient on the same day, (4) and (6) control the number of departures and arrivals from employee locations. Constraints (5) and (7) check the departure and arrival locations of employees, like depart from home, maximal one visit per day per patient and return to the right location. Constraint (8) prevents the employee visiting more than one patient at the same time. With (9) and (10) the employee is obliged to leave and return home if he or she goes on a tour. The respect of time window is controlled by (11),(12),(13),(14),(15) and (16). The continuity of the hours of passages during the tour is managed by (11). (12) and (13) control the departure time of employees. Constraints (14) and (15) enforce patient arrival times. Matching of availability between patients and employees is given by (17) and (18). Constraint (19) verifies that demand is being met with the right employee skills. The avoidance of subtours between patients or on themselves is achieved by (20) and (21). The flow is maintained using (22) and (23). Patients must have a certain number of days between their sessions, this is expressed by the constraint (24). Constraint (25) ensures that the number of visits carried out is equal to the total demand. Employee's end time of work is determined by (26). Constraint (27) determine the number of visits made by an employee. An employee may see a patient only if he or she is qualified by (28). Constraints (29),(30),(31) and (32) determine the areas of variable definitions.

5 Experiments

5.1 Solution approach

For this study we use the CPLEX 12.8.0 application to run our model.

We also need to determine the Big M used in these experiments. It takes this form: $M = max \sum_{r \in R} \sum_{d \in D} \sum_{w \in W} (Avai_{rdw} * w * WTime)$

The waiting time has to be controlled, so that we do not have unsuitable schedules. To do this, after having found the optimal travel time, we put this travel time in constraint and return to the waiting time as a second objective. We then make a lexicographical approach: $Lexmin(OptTravel, OptWaitT)$.

5.2 Instances

With the help of OVE's data, we have generated instances that take into account the current schedules of the speech language therapists (SLT's), the average time of a treatment (45 min), the demand of the patients as well as their availability rate. Using this availability rate, which depends on the level of education of the patient, we have created an individual instance for each SLT in order to bring the visits close to the optimum, linking the availability of patients (which is more complex in real time).

The sum of those individual instances constitutes the global instance where data are presented in Table 2.

Number of SLT's	$\|E\| = 12$
Number of patients	$\|P\| = 100$
Time Horizon	$\|D\| = 5$
Number of services	$\|S\| = 3$
Travel time matrix	$T_{r_1 r_2}$
Demand matrix	Dem_{rs}
Availiability matrix	$Avai_{rdw}$
Treatment time	$TTime = 45$
Size of a time slot	$WTime = 60$
Margin Time	$MTime = 5$
Rest time matrix	K_r
Big M	M

Table 2 – Data of global instance

We decided to test different subunits because the global instance is too big and also to see how the model performs. For example, 10 SLTs need to manage more than 3.5 million binary variables and more than 6 million constraints. Each subunit tested by the model includes a subset of SLTs and their patients who were previously associated by OVE foundation. The choice of the mix of SLTs is random. We first look at the travel time saving as a function of the number of SLTs per instance, then we analyse these results by associating them with other considerations in order to judge when this model is relevant.

Instances with several SLTs thus take the same characteristics as the individual instances (availability, distance...).

In Table 3, we can look at the individual performances for SLTs 1,2 and 3. This approach, which separates decision for each SLT, is relevant to the current approach used by SESSAD managers. In that case, patients are already assigned to professionals. On a second time, we used an integrated approach where several SLTs are regrouped to make a global decision in which allocation and routing decisions have to be made. Using our work, we bring these 3 SLTs (and their 27 patients) together and we can compare the results in Table 4. We notice that on this instance a saving of travel time, working time and waiting time is achieved.

SLT	Number of patients	Travel Time	Working Time	Waiting Time
1	9	125	1223	423
2	10	174	1196	482
3	8	89	733	194

Table 3 – Individual performance on SLT's 1,2 and 3

SLT's Instance	Travel Time	Working Time	Waiting Time
Separated approach 1+2+3	388	3112	1059
Integrated approach (1,2,3)	266	2707	776
Gain of the integrated solution	31%	13%	27%

Table 4 – MILP performance on SLT's 1,2 and 3

5.3 Travel time reduction

In this study, we have 12 SLTs with a total of 100 patients. We evaluate the travel time saving of an instance (*OptTrav*) by comparing it to the sum of the travel times of SLTs working individually with their patients (*SumTrav*). This rate is calculated as follows : $1 - OptTrav/SumTrav$.

Each type of test (number of SLTs) has five instances.

With the results in Table 5 and the Figure 2, we can see that the gain in travel time increases almost linearly with the number of SLTs regrouped in the global decision. However, the compilation time increases exponentially when the number of SLTs exceeds 6 (Figure 3). Thus it is unthinkable to run the programme on all 12 SLTs at the same time. We have to find a smart way to cluster these 12 SLTs and run the program on them. Having a low compilation time with 6 SLTs and a linear travel time saving, it would be wise to divide the 12 employees into two groups of 6.

number of SLTs	Average travel time reduction	Average compilation time (min)
3	22%	1
4	28%	1
5	29%	1,6
6	35%	4,4
7	37%	21,2
8	39%	101,2
9	41%	299,6

Table 5 – Results of travel time performances

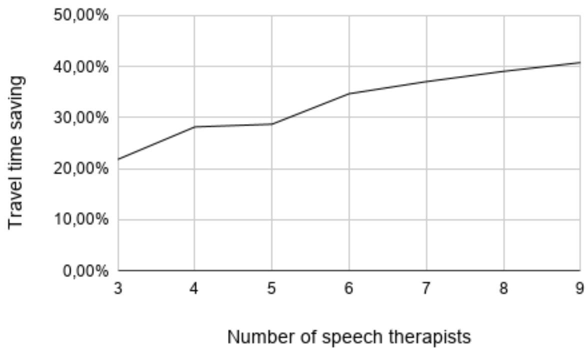

Figure 2 – Travel time saving according to the number of SLTs

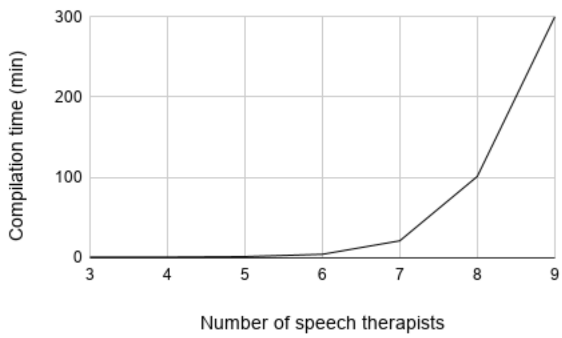

Figure 3 – Compilation time according to the number of SLTs

5.4 Working time reduction

As before, the reduction of working times is obtained by comparing the time found by the MILP ($OptWorkT$) and the sum of the individual times ($SumWorkT$). The result is represented by the operation : $1 - OptWorkT/SumWorkT$. The same goes for the waiting time.

These results were collected after running the model on the two objectives, in a lexicographical way, as presented in section 5.

As we can see in Table 6, only the results of the instances of 3 to 6 SLTs are presented. This is due to the compilation time which is even longer during the second MILP.

We can see that we reduce not only the travel time, but also working time and waiting time. We can't find a trend as marked as the one on travel time, but we can say that this program allows us to gain on all the aspects presented.

We also looked at trends in outcomes by taking outcomes no longer by number of SLTs but by number of patients or demand. These results did not show anything conclusive which led us to present the results in this way.

number of SLTs	Working time reduction	Waiting time reduction
3	7%	14%
4	6%	7%
5	5%	7%
6	5%	6%

Table 6 – Results of working time performances with the second objective

6 Conclusion

This study was able to show the potential benefit of using an integrated approach compared to the separated approach that is in place today. The research work helps to reduce the travel times of SLTs' tours. Its performance increases according to the size of the instance, especially in relation to the number of SLTs. Having a 5-dimensional problem, calculation times explode when the number of SLTs exceeds 6, so it is recommended to use this program for at most 6 SLTs. A solution to overcome this constraint would be to use a cluster algorithm for up to 6 SLTs to best fit the 12.

It would also make sense to make a Pareto front between optimising travel time and optimising waiting time. It may be that by degrading travel time, much more waiting time could be saved. It all depends on the goal. Another area for improvement would be to balance the workload among SLTs. Not having the same contracts in terms of hours per week, a balanced workload between employees would be valuable to the manager to avoid overloading or underloading someone.

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