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Stakeholders' Tolerance-based Linear Model for Home Health Care Coordination

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Abstract: With aging populations and increasing life expectancy, Home Health Care (HHC) has become an alternative treatment modality for the elderly who want autonomy and well-being as they live longer and longer. Facing this rise in demand, the organisation and coordination of HHC institutions has become increasingly complex and difficult. This paper addresses a short-term Home Health Care Routing and Scheduling Problem (HHCRSP), formulated by Mixed Integer Linear Programming (MILP). The proposed model considers tolerance-based soft constraints in view of both patients and caregivers, with the aim of maximising the total satisfaction of all HHC stakeholders. The problem is solved by the commercial solver CPLEX. We adopt a real dataset extracted from an existing HHC institution. The numerical result on 10 generated instances shows the efficient computing performance for an optimal solution for small and medium-large sizes.

Keywords: Mixed Integer Linear Programming, Home Health Care Routing and Scheduling Problem, Tolerance, Soft Constraints

1. INTRODUCTION

With aging populations and increasing life expectancy, home-based health care has become increasingly common in European healthcare delivery as a response to the soaring number of "frail" persons who require monitoring and care management on a long-term basis. For example, in France, and according to the National Institute of Statistics and Economic Studies[1], Home Health Care (HHC) has become much more systematic for people up to the age of 85. HHC organisations, including health (medical and para-medical) and social services (i.e., catering, cleaning), provide for the needs of patients to allow continuity of independent living at home, regardless of age or disability. Accordingly, home care services are complex processes, which represent the chain of various activities achieved by several stakeholder trades (i.e., nurses, physicians, professional caregivers, etc.), to follow each patient's progression and fulfill their needs at their homes (Lamine et al., 2014a).

As outlined in several research works (Drugbert et al., 2018; Lamine et al., 2019; Zhang et al., 2019b, 2020), HHC organisations are facing many challenges, mainly in terms of coordination and continuity of care. In both cases, the problem seems to be related to how care activities are distributed and managed among the different participants involved in such processes (Lamine et al., 2014a,b).

These challenges have increased the interest of research on the organisation of HHC, with consideration of the satisfaction of the care practitioner during service delivery, and the comfort of the patient while care is being administered.

Considering this context, our research addresses decision-making support for the organisation of HHC. In particular, we investigate the operational coordination of caregivers to ensure that the home-based care services requested by patients are fulfilled. This problem is known as the Home Health Care Routing and Scheduling Problem (HHCRSP) in the Operation Research community (Fikar and Hirsch, 2017; Restrepo et al., 2020). The goal is to guarantee the satisfaction of all stakeholders by specifying constraints identified by both patients and caregivers. In this respect, we present a mathematical model with consideration of various and complex stakeholder-oriented constraints. Moreover, all the formulated soft constraints are limited by the requested tolerances from stakeholders. The satisfaction rates are reduced in response to each violation of a constraint. Finally, the optimum solution is generated through CPLEX[2] by sending the caregivers with the maximisation of total satisfaction rates.

This paper is structured as follows: Firstly, we review recent work on the HHCRSP. Then we highlight the originality of our investigation in section 2. Section 3 specifies the context and the concept of our problem based on an HHCRSP conceptual model. Section 4 describes the

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[1] Population projections: www.insee.fr/en/statistiques/2496228

[2] IBM CPLEX Optimizer: www.ibm.com/analytics/cplex-optimizer

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notation and mathematical formulation of the problem. In section 5, we illustrate the results of the experimentation with the CPLEX solver, based on a real dataset extracted from an existing HHC institution. In section 6, we conclude this research work and give our outlook for the future.

2. STATE OF THE ART

Originally, the HHCRSP was an extension of the Vehicle Routing Problem (VRP). The complexity and the variability of business constraints, along with the diversity of HHC institutions, make the problem hard to solve (Restrepo et al., 2020). In addition, among the variations of VRP, the Vehicle Routing Problem with Time Windows (VRPTW) is the most studied in HHCRSP (Torres-Ramos et al., 2014). This concept of a time window is applied to represent the flexibility of both demand (requested service intervals) and offer (range of work time). Overall, (Fikar and Hirsch, 2017) highlight the Operations Research (OR) models developed recently for the HHCRSP. Based on this systematic review of the work, our literature review will focus on short-term planning; in particular, the daily planning horizon. This formulation takes into account the satisfaction of all stakeholders in the HHC system, with the considered constraints and objective functions as well as approaches for resolution.

Mixed integer linear programming (MILP) is widely applied as mathematical formulations in the HHC context. (Torres-Ramos et al., 2014) consider the constraints related to patients, such as respect of the time window (TW) and maximum caregiver workload, without the consideration of tolerance when constraints are saturated. The study of (Di Mascolo et al., 2014) investigates caregiver synchronisation regarding the execution of one care service, with a hard TW restriction of all stakeholders. In contrast, the soft TW of demands and the synchronisation constraint are considered in the work of (Decerle et al., 2017). The service's inter-dependencies, combined with the patient's hard TW, are included in the MILP model proposed by (Mankowska et al., 2014). In the recent work of (Nasir and Dang, 2018), 3 hard TWs are considered in the demand-flexible MILP daily model : service start TW, caregiver work and break TW. Similarly, (Xiao et al., 2018) introduce a model with flexible, hard TW-based lunch break requirements. In terms of the formulation of the HHCRSP under uncertainties, in (Naji et al., 2017), a robust-MILP was proposed with consideration of services' hard TW and their uncertain processing time.

Generally, the objective function defined in the formulated MILP model, considering satisfaction for both patients and caregivers, is in minimising total travel costs and the overtime cost of human resources. Total travel is minimised in the model of (Parragh and Doerner, 2018). In (Lin et al., 2018), total caregiver overtime costs and travel costs are minimised. Several terms are simultaneously minimised in (Nasir and Dang, 2018, 2019): travel costs, caregiver hiring costs and patient waiting costs.

Three resolution approaches are aimed at solving these problems with an MILP-based formulation. (1) The exact methods embedded in the solver (e.g. CPLEX, Gurobi): this approach finds optimal solutions for problems with a reasonable size and generally encountered difficulties when dealing with large use cases; therefore we focus not only on the applied solver but also on the maximum size of the problem being tested. (2) The approximated method is based on a metaheuristic algorithm; the goal being finding a solution approximating an exact method but in a more timely manner. (3) The mixed method is the combination of (1) and (2). As for (1), CPLEX is used in (Di Mascolo et al., 2014; Nasir and Dang, 2018) to solve the test problem having at most 16 or 20 services to be performed respectively. Gurobi is used in (Xiao et al., 2018) for the problem with 23 services maximally. As for (2), a memetic algorithm is applied in (Decerle et al., 2017), a harmony search is introduced in (Lin et al., 2018), a neighbourhood search is used in (Parragh and Doerner, 2018) and simulated annealing is used in (Zhang et al., 2019a). As for (3), the model introduced by (Nasir and Dang, 2019) is solved jointly through CPLEX and a neighbour search.

In this paper, we propose a mathematical model for the HHCRSP with consideration of business constraints in the view of both patients and caregivers to achieve a maximisation of total satisfaction regarding all stakeholders in the HHC system. We translate this satisfaction in a personalised way with regard to the profiles of stakeholders; each one (caregiver or care beneficiary) has his or her own referential acceptability when temporal constraints are not satisfied. The main contributions of this paper are: all the considered temporal constraints will be soft and controlled by the tolerance given by the stakeholder, for example the tolerance threshold of patient waiting time. The application of a regression system will present the tendency of the satisfaction rate to decrease when the constraint is violated.

The formulation of our problem is based on MILP and then solved by CPLEX. We adopt a real data set extracted from an existing HHC institution. As shown in previous studies, the exact method is to be able to solve the problem with small size; in our experimentation, we will show the computing performance of our formulated model for the problem with medium and medium-large sizes.

3. PROBLEM DESCRIPTION

The problem addressed in this paper is providing a solution to the HHCRSP on the daily horizon, by deciding on the detailed rounds of all the active caregivers in the HHC institution. We propose an HHC daily plan, based on a mathematical model that maximises the total satisfaction of all HHC stakeholders. From the patient's point of view, the patient satisfaction rate is the result of the function which is composed of the total waiting time for the requested care services and the non-respect of the inter-operation time between the 2 requested care services. From the caregiver's point of view, the caregiver satisfaction rate is generated by the same function as the patient's but with these components: overtime work after completing the work round and the sum of the weight indicator value regarding the set of performed care services. Subsequently, we detail the mentioned concepts and the relevant elements to compose these 2 sets of satisfaction rates through a business oriented conceptual model, the satisfaction function and the retained assumptions in our formulation.

3.1 HHCRSP Conceptual model

Patient Every working day, the patients and their requests must be registered into the database of the HHC structure. Each patient may request more than one care service per day. The multiple availability of a patient is denoted by the soft time windows with respect to each request. Each patient is characterised by their ID, their physical address, the inter-operation time, 2 tolerances and 2 satisfaction rates respectively in the case that waiting time and non-respect of inter-operation time occur. A set of patients' physical addresses will be translated into an itinerary matrix, which denotes the necessary travel time from one patient to another in a bird's-eye view without consideration of routing and traffic, taking 20 km/h as the average speed in a downtown area.

Care service Each care service is characterised by its ID, a duration of treatment, a set of demanded specific skills and a weight indicator to reflect the care service's difficulty in terms of operation, where 1 denotes the easiest and 6 denotes the hardest. The time window of each care service represents the expected earliest and latest start times.

Caregiver Caregivers (nurses, physical therapists, care assistants, etc.) are available to treat patients within their maximum workload. Each caregiver has a number of skills which indicate whether he or she can perform the requested care service or not. In addition, incompatibilities such as allergies between caregiver and patient also exist. In order to explain the relationship between offer and demand considering qualification and incompatibility, a feasibility matrix is adopted where 1 denotes that a caregiver is capable of performing a care service, 0 otherwise. Furthermore, each caregiver has a maximum workload, a tolerance and a respective satisfaction rate in the case of the workload being exceeded.

Fig. 1 illustrates the key concepts with their characteristics of our HHCRSP through a conceptual model.

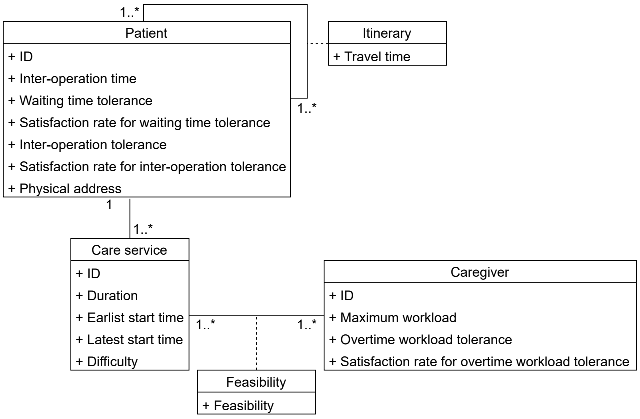


Fig. 1. HHCRSP conceptual model

3.2 Satisfaction rate based on linear regression function

As mentioned before, the main contribution of our work is the optimisation of the total satisfaction of all the HHC stakeholders (registered patients and caregivers per working day). We tolerate temporal constraint violations such as waiting time, and a lack of inter-operation time on the patients' side and overtime on the caregivers' side. Based on the tolerance violation value and the respective satisfaction rate provided by the stakeholders, a linear regression function is applied for modeling the relationship between the satisfaction rate, which is a scalar response, and the value reflecting a temporal constraint violation.

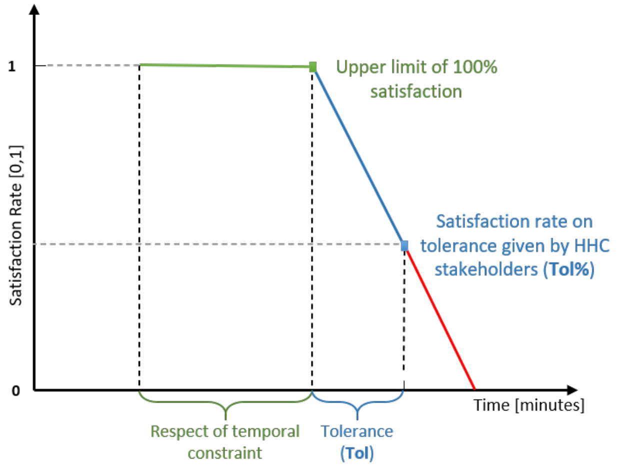


Fig. 2. Illustration of HHC stakeholder satisfaction based on a linear regression function

Fig. 2 schematises the linear regression function for generating HHC stakeholder satisfaction rates. Taking the "patient inter-operation time" constraint as an example, the satisfaction rate will be 100% (1 in integer) when the requested inter-operation time is respected. Once the constraint is violated, a linear function is applied which is in the form of :

$$\mathbb{RATE}\% = \frac{\frac{Tol\%}{100} - 1}{Tol} \cdot violation + 1 \tag{1}$$

This function $\mathbb{RATE}\%$ is applied to generate the satisfaction rate related to the temporal violation value, where Tol is the tolerance of a stakeholder (refer to parameters α_p, β_p, γ_k accordingly) regarding non-respect of the temporal constraint, $Tol\%$ is the satisfaction rate of the stakeholder (refer to parameters α_p^*, β_p^*, γ_k^* accordingly) with respect to his tolerance Tol. The result of $\mathbb{RATE}\%$ is in the range of [0,1].

3.3 Assumptions

We assume that each caregiver must leave and return to the office at the beginning and the end of his work round. For caregiver work rounds, we don't consider their breaks or unexpected events such as illnesses, routing difficulties, or holidays. If the caregivers arrive early at a patient's residence, they have to stand by until the expected availability of the patient (earliest start time window of one demand) is reached.

4. MATHEMATICAL MODEL DESCRIPTION

In this section, we illustrate our MILP-based model of the problem. Firstly, the explanation of the parameters and variables. In the model, the temporal data are in minutes and the rate data are in percentages. Then, we detail the objective function and the considered constraints.

4.1 Parameters

- P: set of patient, with the index $p \in [0, m]$ and where m denotes the number of patients.
- Υ: set of patient who requests more than one care service, with the index $q \in [0, l]$ where l denotes the number of patients with multiple requests and $\Upsilon \subseteq P$.
- K: set of caregiver, with the index $k \in [1, n]$ and where n denotes the number of caregivers registered in the HHC structure per day, who are available to perform the daily care services.
- C: set of care services requested by P, with the index $i, j, v \in [0, r]$ and where r denotes the number of care services requested by m patients.
- N: set of nodes, $N = C \cup \{0\}$ with the index $i^*, j^*, v^* \in [0, r^*]$ where r^* denotes the number of nodes. In the view of the caregiver, $\{0\}$ denotes the HHC structure. In the view of the patient, $\{0\}$ denotes the temporal starting and ending point of all the care services (or one care service) requested by a patient.
- M: a considerably large positive constant applied to the end of the time frame.
- $[e_i, l_i]$: time windows requested by the patient for the care service i.
- dif_i: difficulty in treating a care service i, $dif_i \in [1, 6]$
- $duration_{i^*}$: execution time of node i^*; the value is worth 0 for node 0.
- $dist_{i^*j^*}$: travel time between node i^* and j^*.
- δ_p: inter-operation time between 2 care services requested by patient p.
- α_p: tolerance of patient p when the latest start time of the requested care services is delayed.
- α_p^*: satisfaction rate of patient p with respect to α_p where $\alpha_p^* \in [0, 100]$.
- β_p: tolerance of patient p when the δ_p is not respected.
- β_p^*: satisfaction rate of patient p with respect to β_p where $\beta_p^* \in [0, 100]$.
- ξ_k: maximum workload of the caregiver k per day.
- γ_k: tolerance of caregiver k when the maximum workload is exceeded.
- γ_k^*: satisfaction rate of caregiver k with respect to γ_k where $\gamma_k^* \in [0, 100]$.
- d_{pi}: demand matrix between patient p and care service i, equals 1 denotes p request i, 0 otherwise.
- $feas_{ki}$: feasibility matrix between caregiver k and care service i requested by one patient, equals 1 denotes k is able to perform i, 0 otherwise.

4.2 Decision variables

- $X_{i^*j^*k} = \begin{cases} 1 \text{ if caregiver } k \text{ moves from } i^* \text{ to } j^* \\ \quad \text{for providing care service} \\ 0 \text{ otherwise} \end{cases}$
- $Y_{ik} = \begin{cases} 1 \text{ if caregiver } k \text{ performs care service } i \\ 0 \text{ otherwise} \end{cases}$
- $Z_{i^*j^*p} = \begin{cases} 1 \text{ if patient } p \text{ requests care service } i^* \\ \quad \text{then } j^* \\ 0 \text{ otherwise} \end{cases}$
- $Start_i$: start time of care service i.
- W_i: waiting penalty time in case of delay in the latest start time of care service i.
- R_{ijq}: lacking inter-operation time between care service i and j requested by patient q.
- O_k: real workload of caregiver k.
- $Over_k$: overtime work of caregiver k.
- G_k: total difficulty of the care services performed by caregiver k.
- $\mathbb{W}_p$: satisfaction rate with respect to the set of waiting time for care services requested by patient p.
- $\mathbb{R}_q$: satisfaction rate with respect to the set of lacking inter-operation time between the care services requested by patient q.
- $\mathbb{O}_k$: satisfaction rate with respect to the overtime workload of caregiver k.
- $\mathbb{G}_k$: round difficulty coefficient of caregiver k.

4.3 Objective function

Our objective function aims to maximise the set of $\mathbb{W}_p$, $\mathbb{R}_q$ with $p \in P$, $q \in \Upsilon$ from the patient's perspective, and the set of $\mathbb{O}_k$, $\mathbb{G}_k$ with $k \in K$ from the caregiver's perspective.

For the purpose of indicator normalisation, we calculate the ratio between the value of the second part and its upper limit to ensure that the result is in the range of [0,1].

$$maximise \quad \frac{\sum_{p \in P} \mathbb{W}_p + \sum_{q \in \Upsilon} \mathbb{R}_q + \sum_{k \in K} \mathbb{O}_k + \sum_{k \in K} \mathbb{G}_k}{n \cdot 2 + m + l} \tag{2}$$

4.4 Constraints

Constraint (3) ensures that each care service is performed by caregiver k exactly one time and each service is completed by exactly one caregiver.

$$\sum_{k \in K} Y_{ik} = 1 \quad \forall i \in C \tag{3}$$

Constraint (4) ensures the correct assignment of caregiver and care service.

$$Y_{ik} \leq feas_{ki} \quad \forall i \in C, \forall k \in K \tag{4}$$

Considering the view of the caregiver, constraints (5) & (6) ensure that each service allocated to caregiver k has one predecessor and one successor.

$$\sum_{j^* \in N : j^* \neq i} X_{ij^*k} = Y_{ik} \quad \forall i \in C, \forall k \in K \tag{5}$$

$$\sum_{i^* \in N : i^* \neq j} X_{i^*jk} = Y_{jk} \quad \forall j \in C, \forall k \in K \tag{6}$$

Considering the view of the patient, constraints (7) & (8) ensure that the requested care services have the executing sequence.

$$\sum_{j^* \in N : j^* \neq i} Z_{ij^*p} = d_{pi} \quad \forall i \in C, \forall p \in P \tag{7}$$

$$\sum_{i^* \in N : i^* \neq j} Z_{i^*jp} = d_{pj} \quad \forall j \in C, \forall p \in P \tag{8}$$

Constraints (9) & (10) ensure that all caregivers start and finish at the HHC structure.

$$\sum_{i^* \in N} X_{0i^*k} = 1 \quad \forall k \in K \tag{9}$$

$$\sum_{i^* \in N} X_{i^*0k} = 1 \quad \forall k \in K \tag{10}$$

Constraints (11) & (12) ensure that the set of care services requested by patient p start and finish at the temporal starting and ending point (the point is described in the definition of N).

$$\sum_{i^* \in N} Z_{0i^*p} = 1 \quad \forall p \in P \tag{11}$$

$$\sum_{i^* \in N} Z_{i^*0p} = 1 \quad \forall p \in P \tag{12}$$

Constraint (13) ensures that each care service has to start after the earliest start time requested by patient.

$$Start_i \geq e_i \quad \forall i \in C \tag{13}$$

Constraint (14) ensures that the pair of care services performed by the same caregiver must be one after another.

$$\begin{aligned} &Start_i + duration_i + dist_{ij} \leq \\ &Start_j + M \cdot (1 - \sum_{k \in K} X_{ijk}) \quad \forall i, j \in C : i \neq j \end{aligned} \tag{14}$$

Constraint (15) ensures that the pair of care services requested by the same patient must be one after another, respecting soft inter-operation time.

$$\begin{aligned} &Start_i + duration_i + \sum_{q \in \Upsilon} (\delta_q - R_{ijq}) \\ &\leq Start_j + M \cdot (1 - \sum_{q \in \Upsilon} Z_{ijq}) \quad \forall i, j \in C : i \neq j \end{aligned} \tag{15}$$

Constraint (16) determines the value of the waiting time of care service i.

$$W_i = \max(start_i - l_i, 0) \quad \forall i \in C \tag{16}$$

Constraint (17) determines the workload of caregiver k.

$$O_k = \sum_{i^* \in N} \sum_{j^* \in N : i^* \neq j^*} (dist_{i^*j^*} + duration_{j^*}) \cdot X_{i^*j^*k} \tag{17}$$

Constraint (18) determines the overtime workload of caregiver k.

$$Over_k = \max(O_k - \xi_k, 0) \quad \forall i \in C \tag{18}$$

Constraint (19) determines the difficulty of the care services performed by caregiver k.

$$G_k = \sum_{i \in C} Y_{ik} \cdot dif_i \quad \forall k \in K \tag{19}$$

Based on the linear regression function (1), constraints (20) - (23) calculate respectively patient p's two satisfaction rates $\mathbb{W}_p$ and $\mathbb{R}_p$, and caregiver k's satisfaction rate $\mathbb{O}_k$ and difficulty coefficient $\mathbb{G}_k$.

$$\mathbb{W}_p = \frac{\sum_{i \in C} (\frac{\frac{\alpha_p^*}{100} - 1}{\alpha_p} \cdot W_i + 1) \cdot d_{pi}}{\sum_{i \in C} d_{pi}} \quad \forall p \in P \tag{20}$$

$$\mathbb{R}_q = \frac{\sum_{i \in C} \sum_{j \in C : i \neq j} (\frac{\frac{\beta_p^*}{100} - 1}{\beta_p} \cdot R_{ijq} + 1 \cdot Z_{ijq}) \cdot d_{qi} \cdot d_{qj}}{\left(\sum_{i \in C} d_{qi}\right) - 1}$$

$$q \in \Upsilon \tag{21}$$

$$\mathbb{O}_k = \frac{\frac{\gamma_k^*}{100} - 1}{\gamma_k} \cdot Over_k + 1 \quad \forall k \in K \tag{22}$$

$$\mathbb{G}_k = \min\left(1, \frac{G_k}{\frac{\sum_{i \in C} dif_i}{r}}\right) \quad \forall k \in K \tag{23}$$

Constraints (24) - (29) ensure that $\mathbb{W}_p$, $\mathbb{R}_q$, $\mathbb{O}_k$, $\mathbb{G}_k$ are respectively continuous variables in [0,1] and non-negative variables.

$$\mathbb{W}_p \in [0, 1] \quad \forall p \in P \tag{24}$$

$$\mathbb{R}_q \in [0, 1] \quad \forall q \in \Upsilon \tag{25}$$

$$\mathbb{O}_k \in [0, 1] \quad \forall k \in K \tag{26}$$

$$\mathbb{G}_k \in [0, 1] \quad \forall k \in K \tag{27}$$

$$Start_i \geq 0 \quad \forall i \in C \tag{28}$$

$$R_{ijp} \geq 0 \quad \forall i, j \in C : i \neq j, \forall p \in P \tag{29}$$

5. EXPERIMENTATION

5.1 Data set generation

The data set was extracted from an existing HHC institution. We generated 10 instances and submitted them to a CPLEX solver to complete our experimentation. We tested the computing time as well as the performance in terms of the 4 components of objective function reflecting the HHC stakeholders' satisfaction formulated in the model. The experimental test ran on a computer with Intel(R) Core (TM) i7-7500U CPU 2.90GHz and 16.0 GB RAM under the Windows 10 operating system. The run time limit was set at 4000 seconds for each execution.

In all the instances, we randomly generated stakeholder satisfaction parameters and care services difficulties. On the caregiver's side: $\gamma_k \in [50, 100]$, $\gamma_k^* \in [30, 50]$, $\xi_k = 600$ according to the regulation of the end user's institution. On the patient's side: $\delta_p \in [20, 60]$, $\alpha_p \in [30, 60]$, $\alpha_p^* \in [30, 50]$, $\beta_p \in [1, 20]$, $\beta_p^* \in [30, 50]$. The difficulty of each care service was $dif_i \in [1, 6]$.

As in Table 1, we categorised the instances into 3 groups: S (Small size, 10-30 services), M (Medium size, 35-50 services), ML (Medium-Large size, 55-70 services). The name of the instance in the first column shows the detail size of each instance. Index s denotes the number of requested care services, index p denotes the number of patients, index mp denotes the number of patients having multiple demands and index k represents the number of registered caregivers. For example, "S_s13_p6_mp6_k3" is a small-size instance, having 13 care services requested by 6 patients; these 6 patients require several services ($\geq$2). These demands will be performed by 3 caregivers.

5.2 Numerical results

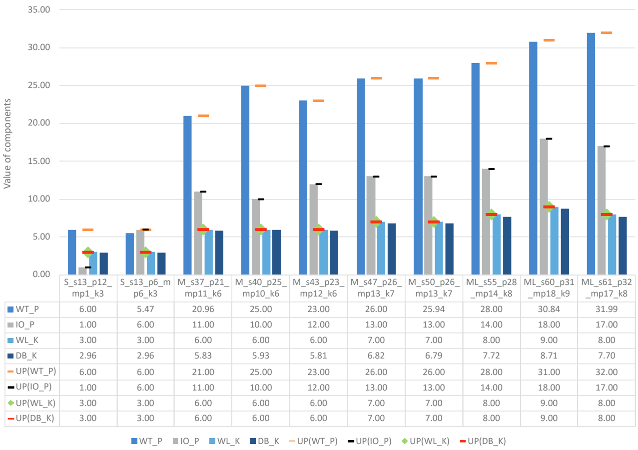
The general numerical results are shown in Table 1. We focus on the global performance in terms of computing time in seconds (CPU), and the gap between upper limit (UP) and retained objective function (OF) regarding the studied instances.

These results demonstrate the performance of our model in reaching the optimum solution for each real dataset-based instance (gap $\approx$ 0); the computing time is satisfying although the dimension only goes up to the medium-large size.

Then, in Fig. 3 we demonstrate the detailed results in terms of the 4 satisfaction components concerning the solution of each instance: waiting time (WT_P), respect of inter-operation time (IO_P), overtime workload (WL_K),

Table 1. General experimental results

Instance	OF	UP	gap(%)	CPU(s)
S_s13_p12_mp1_k3	0.9979	0.9979	0.00	0.4
S_s13_p6_mp6_k3	0.9684	0.9694	0.10	1.2
M_s37_p21_mp11_k6	0.9954	0.9991	0.39	10.6
M_s40_p25_mp10_k6	0.9984	0.9992	0.08	20.4
M_s43_p23_mp12_k6	0.9959	0.9989	0.30	20.8
M_s47_p26_mp13_k7	0.9966	0.9988	0.22	11.1
M_s50_p26_mp13_k7	0.9949	0.9993	0.44	134.1
ML_s55_p28_mp14_k8	0.9952	1.0000	0.48	280.0
ML_s60_p31_mp18_k9	0.9934	0.9994	0.60	149.2
ML_s61_p32_mp17_k8	0.9954	1.0000	0.46	236.8



	S_s13_p12_mp1_k3	S_s13_p6_mp6_k3	M_s37_p21_mp11_k6	M_s40_p25_mp10_k6	M_s43_p23_mp12_k6	M_s47_p26_mp13_k7	M_s50_p26_mp13_k7	ML_s55_p28_mp14_k8	ML_s60_p31_mp18_k9	ML_s61_p32_mp17_k8
WT_P	6.00	5.47	20.96	25.00	23.00	26.00	25.94	28.00	30.84	31.99
IO_P	1.00	6.00	11.00	10.00	12.00	13.00	13.00	14.00	18.00	17.00
WL_K	3.00	3.00	6.00	6.00	6.00	7.00	7.00	8.00	9.00	8.00
DB_K	2.96	2.96	5.83	5.93	5.81	6.82	6.79	7.72	8.71	7.70
UP(WT_P)	6.00	6.00	21.00	25.00	23.00	26.00	26.00	28.00	31.00	32.00
UP(IO_P)	1.00	6.00	11.00	10.00	12.00	13.00	13.00	14.00	18.00	17.00
UP(WL_K)	3.00	3.00	6.00	6.00	6.00	7.00	7.00	8.00	9.00	8.00
UP(DB_K)	3.00	3.00	6.00	6.00	6.00	7.00	7.00	8.00	9.00	8.00

Fig. 3. Experimental result: stakeholders' satisfaction

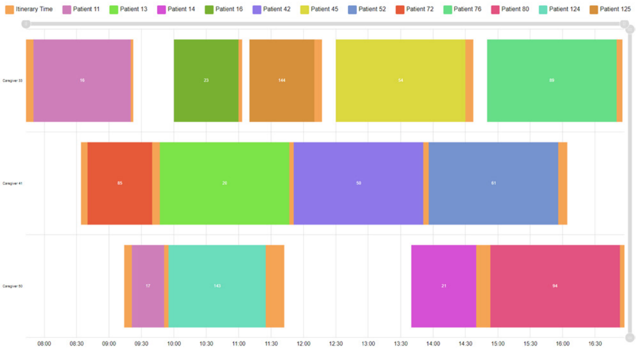


Fig. 4. Solution visualisation of S_s13_p12_mp1_k3

difficulty balance (DB_K) and the gap between their respective upper limits (UP). This demonstration shows the retained solution for each instance that achieved the maximisation of all stakeholders' satisfaction, by comparing with each component's upper limit.

For the purpose of visualisation, the solution of use case S_s13_p12_mp1_k3 is shown as an example in Fig. 4. The solution visualisation is care service oriented by each line, which represents a set of care services performed by a caregiver. Note that each care service is identified by ID, start time and duration. The orange zone shows travel time between the residences of the patients. The interval between arrival time and starting operation time denotes the standby event in case the caregiver arrives earlier. The color of the care services represents those who requested the service.

6. CONCLUSION AND RESEARCH PERSPECTIVES

This research work addresses an MILP model for solving the HHCRSP on the daily planning horizon. To consider the satisfaction of all HHC stakeholders, which has rarely been taken into account in previous work, we took various constraints into account from two perspectives: patients and caregivers. The test is based on a real operational dataset and the obtained optimum solution for each instance is generated though the use of CPLEX. The numerical results show a significant increase in performance in terms of the modeled satisfaction criteria in comparison with the ideal result. In addition, our MILP model is able to address the problem in a medium-large dimension within a short computing time (up to 236.8 seconds in the use case: ML_s61_p32_mp17_k8).

In future, the study should be conducted in a continuous experiment with a large instance, to see the limitation of the model in terms of CPU performance. Additionally, it will be interesting to develop several approximated methods based on a metaheuristic algorithm, in order to investigate the field of comparisons between exact and approximated methods. This environment will enable us to draw conclusions on these comparisons from experimental studies regarding our formulated HHCRSP.

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