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Carlos Rodriguez-Verjan, Vincent Augusto, Xiaolan Xie. Home health-care network design: Location and configuration of home health-care centers. *Operations Research for Health Care*, 2017, 10.1016/j.orhc.2017.09.001 . hal-01623131

**HAL Id: hal-01623131**

**<https://hal.science/hal-01623131>**

Submitted on 25 Oct 2017

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# Home Health-Care Network Design: Location and Configuration of Home Health-Care Centers

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January 2017

## Abstract

Home Health-Care (HHC) is a concept slowly expanding over time, introduced to reduce pressure on inpatient hospital beds by providing care to patients at home. Nowadays, HHC centers are able to undertake more technical complex care such as (but not limited to) end-of-life care, chemotherapy and rehabilitation. This article accomplishes two main objectives: (i) design a home health-care network by locating HHC centers across a territory, taking into account medical demand and costs of resources and facilities; (ii) optimally manage the activities of HHC centers by deciding on the outsourcing of critical processes for patient care. Two mixed-integer linear programs are proposed to solve these problems and propose strategic and tactical decisions. A practical case study is proposed on the Loire department (France) with various scenarios to test the robustness of the model depending on demand variation. The proposed method gives efficient plans for designing and managing HHC centers with cost-efficient solutions on both strategic and tactical level.

**Keywords:** Home health-care; location; allocation; cost analysis; resource management; strategic design; optimization

## 1 Introduction

Health-care systems efficiency optimization is beyond the scope of the hospital. The challenges of the twentieth century aim to connect health facilities in order to better understand and accompany patient's pathway throughout their care process on the long term. Health-care centers are now designed to collaborate within a network, and this requires a rigorous organization. Besides the quality of care provided to the patient, reducing costs remains a primary goal of health systems. Deficit of hospitals in most of European countries is an incentive to find new measures to cure "better" and "cheaper". Indeed, an ever aging population imposes health professionals a continuously increasing workload, even if resources are constant. Efficient health-care network organizations supported by modern information technology infrastructure can help solve this challenge.

Home Health-Care (HHC) is an important organization of health-care in developed countries, allowing patients to be treated at home when possible. Such approach is cost-efficient [Rodríguez-Verjan et al., 2012] if the HHC centers are wisely organized in a network, allowing traditional hospitals to free beds for acute care and avoid bed-blockers. Experiences of hospitalization at home are not so numerous. Technical care (such as chemotherapy, blood transfusion,

rehabilitation...), once devoted to hospital, might now be dispensed at home [Shepperd et al., 2009], but experiences remained local and isolated. Moreover, HHC centers usually have a fragile economic model, dependent on the characteristics of the local territory (type of population, type of demand, proximity with hospitals). It is difficult to establish economic viability of such facilities [Rischin et al., 2000, Goulet et al., 2001, Chataway et al., 2006]. Nevertheless, patient satisfaction is usually higher when admitted in HHC [Borras et al., 2001].

In this context it seems reasonable to design a home health-care network by taking into account the whole health-care landscape of the territory. Nowadays, no regional strategy is provided for the design and the control of home health-care networks although taking into account the adjustment between demand, resources and location seems crucial. To do so, the development of strategic and tactical decision aid tools is a good solution to optimize the location and demand allocation of HHC centers on a territory.

In this paper, we propose a new methodology for the design and economic viability assessment of home health-care centers on the regional level. Taking into account crucial health characteristics of a territory, we propose a comprehensive optimization model for designing a strategic plan for home health-care network through a net of centers working in collaboration, taking into account medical demand, cost of resources and activity balance between practitioners. An economic assessment of home health-care centers is also provided, taking into account the management of the operations of health-care activities on the tactical level. Such approach constitutes a rich scientific contribution since the provided literature review does not provide any model for the home health-care network organization.

The article is organized as follows. A literature review on home health-care organization optimization and evaluation is provided in Section 2. The proposed methodology for the strategic design of a HHC network and for the tactical management of HHC centers is detailed in Section 3. The first problem related to strategic HHC center location is described in Section 4. The second problem related to the tactical management of HHC activities is described in Section 5. Application to a real case study is provided in Section 6. Finally, conclusions and perspectives are developed in Section 7.

## 2 Literature review

Although HHC is developing in various countries due to the aforementioned increasing hospitalization costs coupled with an aging population, it benefits from little published research in comparison to classical health-care problems such as nurse rostering problem, operating rooms planning or hospital resource sizing. HHC organization is different from one country to another, as shown by the comparative work of [Chevreul et al., 2005]. In France, there is an important distinction between hospitalization at home and nursing at home, whereas other countries may only have low level of home care (United Kingdom), only HHC (Australia), or both types with a less clear distinction (Canada). Most obvious problems related to home health-care are connected to vehicle routing problem and human resource scheduling problem. Yalcindag et al. [2011] proposed a literature review on the topic. Most of these articles address the issue of finding the optimal way to treat the admitted patients.

Most of work related to the location of health-care centers are based on the covering problem. A comprehensive state of the art of location studies applied to the public sector is provided by Marianov and Serra [2001]. Preliminary studies [Toregas et al., 1971, Garey and Johnson, 1979] intends to locate health-care centers using an extension of the set covering problem. A literature review on algorithms used to solve the set covering problem can be found in [Caprara et al., 2000]. The maximum covering problem has also been extended for health-care in various situations. Eaton et al. [1985] propose a study to design an emergency network. A maximum covering model is used to evaluate various policies for the organization of emergency services.

Authors demonstrate that the method allows savings and reduces response time. In [Jia et al., 2007], authors define new concepts such as covering quantity and quality. Three solving methods are proposed, based on genetic algorithms, heuristics and Lagrangian relaxation. Finally, the literature related to ambulance location is rich. A state of the art is presented in [Brotcorne et al., 2003] where authors define three types of problems: (i) deterministic (no random factors), (ii) stochastic, and (iii) dynamic (re-location of ambulances over the planning horizon). In this paper, we propose a new approach to locate HHC centers while maximizing the coverage or the expected coverage.

The tactical management of HHC centers has also received little attention in the literature. In [Drake and Davies, 2006] authors proposed a review of relevant literature on the outsourcing of home care and its political drivers in the UK. Research has focused on Wales in general plus a few local authorities in England. Some works related to outsourcing in health-care are available. In [Nicholson et al., 2004], authors address the issue of managing inventory costs in a health-care setting and compare an in-house three-echelon distribution network vs an outsourced two-echelon distribution network using two scenarios. Authors conclude that outsourcing does not compromise the quality of care and allows inventory cost savings. In [Dalton and Warren, 2016], authors model outsourcing as trade-off of income vs control over production and discuss differences between the two approaches. Difference is not significant with fixed cost shocks. An extension of the model of nonprofit entrepreneurship [Glaeser and Shleifer, 2001] is proposed to include an outsourcing decision. In [Mariani et al., 2014], authors propose a representation of the current state of outsourcing in the Italian Healthcare System by focusing on satisfaction level of operators involved in outsourcing. Results show mixed satisfaction level depending on the status of the operator. Several studies are also related to the outsourcing of various component of health-care systems such as information systems [Lorence and Spink, 2004] or other very special activities within hospitals such as waste disposal processes or logistics. In this paper, we propose a methodological guide to help HHC managers to decide on the precise outsourcing of their operational process using exact optimization and extensive design of experiment approaches.

To the best of our knowledge, the strategic conception of a HHC network and its economical resource management has not been yet addressed in the literature. Most related papers refer to staff dimensioning in HHC [Rodríguez-Verjan et al., 2015] where stochastic demands were taken into account. The network configuration was analyzed in [Benzarti et al., 2013] by proposing solutions for the districting problem. The closest work related to the present article is presented in [Matta et al., 2014] where authors proposed a comprehensive approach to optimize the organization of home health-care centers. In this paper, we propose a new comprehensive methodology for two different stake holders: (i) high level decision maker (regional health agencies), by providing solutions for the strategic HHC location problem aiming at maximizing the covering of demand while taking into account traditional hospitalization; (ii) HHC center manager, by providing a cost-effective approach for the management of human resources in a HHC center once its location has been decided through a set of design of experiments.

### 3 Methodology for home health-care network design

The home health-care (HHC) strategic location problem and tactical configuration problem tackled in this paper consist in providing an efficient coverage over a territory for the medical demand, i.e. patients requiring medical care at home for various pathologies. The territory under consideration is composed of zones. For each zone, a demand is evaluated, corresponding to a number of patients suffering from a certain type of pathology. In this paper, activities performed by HHC centers are exclusively related to home care (such as visits to patients); patients are not supposed to travel to HHC centers. However, if HHC centers are unable to satisfy the demand for home care, these patients will be treated in traditional hospitals. Taking into account the

characteristics of the territory such as the capacity of hospitals and the possible locations for HHC centers, the proposed methodology consists in answering the following research questions: (i) Where should HHC centers be located across the territory? (ii) What are the resources needs (number and type of different resources) required to satisfy demand over a certain time horizon and across the territory? (iii) How should the management of activities (e.g. services provided) of each center be controlled?

Figure 1 illustrates the problem with the case study of the Loire department (France). In this example, the territory is divided into four demand zones, each zone having a certain demand for care depending on pathologies ( $P_1, P_2, P_3$ ). Several locations (red squares) are available for the opening of new HHC centers to satisfy the demand, each center having a certain number of resources available to visit patients at home (nurses, doctors, specialists). Finally, each HHC center may be managed in a different way and may choose to outsource its activities or not to ensure its economic viability.

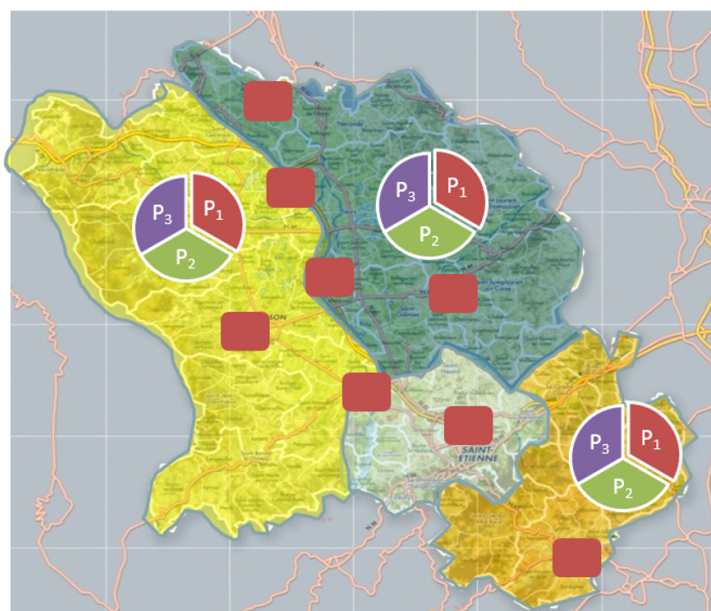


Figure 1: Home health-care network design example

The proposed methodology intends to design and optimize the HHC centers configuration across a territory in two steps:

1. **Strategic design the HHC network.** Taking into account the characteristics of the territory, a Mixed-Integer Linear Programming (MILP) model is provided to design the HHC network by deciding the location of centers, the composition of medical teams, and the assignment of demand. Collaboration between centers and hospitals is taken into account in this approach through the allocation of demand (Section 4).
2. **Tactical management of each HHC center.** Once the network has been designed, another MILP model is provided to determine the organization and the management of each center, taking into account the subset of demand assigned to it, in order to ensure economic viability. As a result we propose a decision aid tool for HHC managers taking into account the opportunity of outsourcing activities (Section 5).

The proposed approach is applied to design the HHC network on both strategic and tactical level. The methodology has been applied on various scenarios in order to take into account

the sensitivity of results against input data. Such experiment is provided in the case study in Section 6. A software has been implemented and extensively tested using real data.

The main contribution of the paper is a methodology that can be used by stakeholders such as HAH centers managers, but also health authorities such as regional health agencies. Purposes of proposed models are very different: (i) the *HHC multi-period location problem* has been designed for health authorities, and intends to define a strategic plan for health services deployment across a large territory and over a long time horizon, whereas (ii) the *tactical management of HHC activities problem* has been designed for HHC centers managers to be used on a shorter time horizon to ensure that each center adapt itself to the evolving market. The scope is very different for each problem: several years for the first ones, whereas the second one might be ran on demand depending on the dynamic of the territory. Another contribution lies in the design of a decision aid software for regional health agencies and HHC centers managers.

## 4 The strategic home health-care multi-period location problem

### 4.1 Problem description

The HHC center location problem can be modeled as an extension of a multi-resources, multi-facilities location problem. In this paper, HHC centers must be set on a territory to satisfy efficiently the demand. Opening centers and employing human resources decisions cannot be taken without considering special constraints such as: (i) care delivery authorization for certain pathologies (such authorization are delivered by health authorities and must be renewed periodically); (ii) medical human resources requirements (e.g. for delivering chemotherapy at home, at least a doctor and a nurse are required); (iii) demand evolution over time.

We consider a set of pathologies to be treated at home indexed by  $p \in P$ . Resources  $r \in R$  are required to treat the patients at home depending of their illness. Time horizon is discretized in time periods  $t \in T$ . Before stating the model, the following assumptions are made:

**Assumption 1 (Demand)** *The territory is divided into  $\bar{J}$  demand zones. For each zone  $j$ , pathology  $p$  and time period  $t$ , we define a demand quantity  $\delta_{jpt}$  modeling the number of patients requiring home care.*

**Assumption 2 (Resource requirements)** *Each pathology is linked with a resource requirement  $\tau_{pr}$  (number of units of resource  $r$  required to satisfy one unit of demand of pathology  $p$  in a time period).*

**Example 1** *Let us consider a small example with a territory having only one demand zone, one pathology and two time periods. Ten patients in this demand zone  $j = 1$  are suffering from breast cancer ( $p = 1$ ) in period 1; an increase is expected for period 2 with 15 patients. They may receive a chemotherapy at home; such treatment requires ten visits per month from one doctor ( $r = 1$ ) and one nurse ( $r = 2$ ). The doctor stays 15 minutes and the nurse stays 1 hour for each visit. In that example the demand quantity is defined as follows:  $\delta_{1,1,1} = 10$  and  $\delta_{1,1,2} = 15$ ; resources needs are  $\delta_{1,1,1} \times \tau_{1,1} = 10 \times 150$  and  $\delta_{1,1,2} \times \tau_{1,2} = 15 \times 600$  for time periods 1 and 2.*

**Assumption 3 (Authorization)** *Each pathology  $p$  requires a special authorization. Each authorization has a fixed cost  $\gamma_p$  and requires the employment of a minimal amount of human resources  $\eta_{pr}$ . Authorizations are given for a limited duration  $\alpha$  and should be renewed. In France, an authorization to deliver care at home is delivered by the local regional health agency and lasts five years. It is a legal requirement for every HHC center and allow health authorities to control and regulate the amount of home care delivered across the territory. It also ensures a certain level of quality of care through the minimal amount of human resources required.*

**Assumption 4 (Unsatisfied demand penalty)** *If a demand is unassigned, a penalty cost  $c_p$  is raised to model the negative impact on traditional hospitalization: each patient not treated by HHC must be hospitalized, which should be avoided.*

Assumptions 3 and 4 are introduced in the model to best balance the ratio of patients treated at home versus patients treated in traditional hospitals. Cost adjustment is important and will be studied in the following through design of experiments.

**Assumption 5 (Resources)** *Only human resources are considered in this study. Each resource has a capacity in terms of number of care actions  $q_r$  s/he can deliver, also denoted resource capacity or maximum load.*

**Assumption 6 (Costs)** *Costs are related to possible decisions. Opening a center in location  $i$  has a fixed cost  $f_i$ . Assigning resources has a cost related to demand and distance: traveling duration between demand zones and the main HHC facility represent an important cost. Such argument has been confirmed in [Triki et al., 2014]. Finally, each resource has a variable cost  $a_r$  (salary) and a fixed cost  $a_r^+$  (resp.  $a_r^-$ ) related to his/her employment (resp. departure).*

**Example 2 (Traveling distance)** *Let us consider a doctor from HHC center  $i$  visiting a patient in demand zone  $j$  (traveling duration  $d_{ij} = 30$  minutes). Let us assume work load of doctor related to the traveling distance is  $\xi_r = 10\%$ . In that case, resource requirement considering the distance is  $\xi_r \times d_{ij} = 33$  minutes.*

**Assumption 7 (Single sourcing)** *Each demand  $(p, j)$  is satisfied by at most one center. Demand zones have been defined by health authorities to be served by a sole health-care provider. This is why we actually consider a high number of demand zones in the case study.*

## 4.2 Formal model

The MILP model for the HHC location problem is defined as follows.

Indexes and sets:

- $T$ : set of time periods, indexed by  $t$ .
- $P$ : set of pathologies, indexed by  $p$ .
- $R$ : set of resources, indexed by  $r$ .
- $J$ : set of demand zones, indexed by  $j$ .
- $I$ : set of possible locations for centers, indexed by  $i$ .

Parameters:

- $\delta_{jp}$ : demand for pathology  $p$  in demand zone  $j$ .
- $q_r$ : resource capacity (maximum load) of resource  $r$ .
- $\xi_r$ : work load of resource  $r$  related to the distance between center and patients, depending on resource type.
- $\tau_{pr}$ : work load of resource  $r$  to give care for a patient suffering from pathology  $p$ . Hence, taking care of patient  $p$  in zone  $j$  by center  $i$  has a total work load  $\tau_{pr} + \xi_r d_{ij}$  for resource  $r$ .

- $\eta_{pr}$ : minimal amount of resource  $r$  required to get authorization for pathology  $p$ .
- $d_{ij}$ : distance between center location  $i$  and demand zone  $j$ .
- $f_i$ : fixed cost for opening a center in location  $i$ .
- $c_p$ : penalty cost for not serving pathology  $p$ .
- $\gamma_p$ : authorization cost for serving pathology  $p$ .
- $a_r$ : variable cost (salary) for resource  $r$ .
- $a_r^+$  (resp.  $a_r^-$ ): fixed cost to increase (resp. decrease) a resource quantity.

Decision variables:

- $Y_{it} = 1$  if center  $i$  is opened at time period  $t$ .
- $X_{jpit} = 1$  if demand type  $p$  of demand zone  $j$  is served by center  $i$  at time period  $t$ .
- $Z_{ipt} = 1$  if center  $i$  is authorized to serve demand type  $p$  at time period  $t$ .
- $N_{irt}$ : amount of resources  $r$  to employ in center  $i$  at time period  $t$ .
- $Q_{irt}^+$  (resp.  $Q_{irt}^-$ ): number of resource units of type  $r$  increased (resp. decreased) at the beginning of period  $t$  in center  $i$ .

Costs definition:

- $\sum_{it} f_i Y_{it}$ : opening cost of centers (cost related to the acquisition of a building and materials in chosen locations over the time horizon).
- $\sum_{pjit} \delta_{jp} d_{ij} X_{jpit}$ : demand assignment cost (cost related to the distance between the assigned resource and the demand zone for all centers over the time horizon).
- $\sum_{irt} a_r N_{irt}$ : total resource cost (cost related to the salary of all practitioners employed in all centers over the time horizon).
- $\sum_{i,r,t} (a_r^+ Q_{irt}^+ + a_r^- Q_{irt}^-)$ : total cost over the time horizon to increase or decrease resource quantities (e.g. base amount paid by a center to employ or dismiss a physician).
- $\sum_{ipt} \gamma_p Z_{ipt}$ : authorization cost (amount paid by all centers for serving a certain pathology over the time horizon).
- $\sum_{pjt} c_p \delta_{jp} \left( 1 - \sum_i X_{jpit} \right)$ : penalty cost (amount paid for not serving certain demand zones over the time horizon).



The mathematical problem is defined as follows:

$$\min \sum_{i,t} f_i Y_{i,t} + \sum_{t,p,j,i} \delta_{jpt} d_{ij} X_{jpit} \quad (1)$$

$$+ \sum_{t,i,r} a_r N_{irt} + \sum_{i,r,t} (a_r^+ Q_{irt}^+ + a_r^- Q_{irt}^-) \quad (2)$$

$$+ \sum_{t,i,p} \gamma_p Z_{ipt} + \sum_{t,p,j} c_p \delta_{jpt} (1 - \sum_i X_{jpit}) \quad (3)$$

s.t.

$$\sum_{p,j} (\tau_{pr} + \xi_r d_{ij}) \delta_{jpt} X_{jpit} \leq N_{irt} q_r \quad \forall i, r, t \quad (4)$$

$$\sum_i X_{jpit} \leq 1 \quad \forall j, p, t \quad (5)$$

$$\sum_j X_{jpit} \leq \sum_{t'=t-\alpha}^t Z_{ipt'} \quad \forall p, i, t \quad (6)$$

$$Z_{ipt} \leq Y_{it} \quad \forall i, p, t \quad (7)$$

$$\eta_{pr} \sum_{t'=t-\alpha}^t Z_{ipt'} \leq N_{irt} \quad \forall p, i, t, r \quad (8)$$

$$Y_{it} \leq Y_{i,t+1} \quad \forall i, t \quad (9)$$

$$N_{irt} = N_{irt-1} + Q_{irt}^+ - Q_{irt}^- \quad \forall i, r, t \quad (10)$$

$$Y_{it}, Z_{ipt}, X_{jpit} \in \{0, 1\} \quad \forall i, t \quad (11)$$

$$N_{irt}, Q_{irt}^+, Q_{irt}^- \in \mathbb{N}^* \quad \forall r, i, t \quad (12)$$

The first part of the objective function (1) is the sum of fixed costs related to the centers and the authorizations. The second part (2) is related to the variable and fixed costs of resources. The third part (3) models assignment costs and demand penalties.

Constraints set (4) is the capacity constraint. Constraints set (5) assigns a pathology of a demand zone to at most one center. Constraints set (6) forces to get the authorization when a demand is assigned. Constraints set (7) ensures no authorization can be given if the center is not opened. Constraints set (8) ensures the minimum quantity of resources is respected when an authorization is given. Constraints set (9) ensures opened centers cannot be closed. Constraints set (10) is the definition of the resources amount in the centers. Finally, constraints sets (11) and (12) defines the type of variables (binary and integer).

This problem is NP-hard, meaning it cannot be solve in polynomial time: if only one period is considered and if authorization costs, resource costs and penalty costs are set to zero, the well-known location-assignment problem appears, which is itself NP-hard [Garey and Johnson, 1979]. In this problem, we take decisions for the location of centers and the timing of their opening at the same time. It constitutes a scientific challenge because the complexity of the problem might be an obstacle depending on the scenario under study. As shown in the model performance analysis in the following, we observe that bigger instances cannot be solved to optimality within reasonable time.

In this problem, the opening of a HHC center on a possible location is possible anytime over the time horizon, however it is indeed impossible to close a center. This constraint has been added to ensure that centers are not opened for a short amount of time since some pathologies

are characterized by a quick variation of the demand over time. Also, social constraints are important: human resources should not be dismissed shortly after employment and center opening. The goal does not consist only in deciding on HHC centers location, but also in determining the best timing of their opening over the time horizon, and the best adjustment of overall health resources of the territory considering collaboration.

### 4.3 Model performance analysis

In this section we propose theoretical numerical tests to assess the performance of the model presented in the previous section. Random data sets are generated taking into account the real case study. Necessary information (volume of demand, pathologies, availability of resources, costs) have been extracted from relevant public databases. We generate demand zones located around main cities of the territory, as presented in Figure 3. The Loire department is presented in Figure 2. Demand zones have been randomly generated in an orthogonal coordinate system in order to easily calculate distances between zones and centers possible locations. Coordinates and distances are expressed in kilometers. Origin of the system has been randomly chosen centered on the *Saint-Bonnet-le-Château* city. Negative coordinates are not a problem in that case. Thirty data sets have been randomly generated for each scenario, using the intervals proposed in Table 1. Bounds of the intervals have been estimated with the help of health economists. Uniform distributions are used for all varying parameters. Distances have been calculated using the Floyd-Warshall algorithm [Floyd, 1962] to guarantee a geographical coherence.

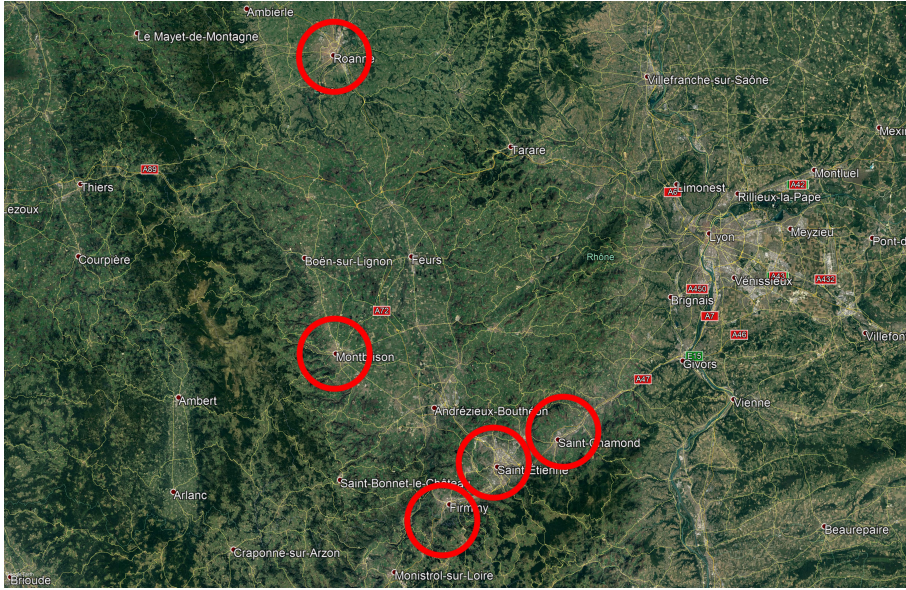


Figure 2: Map of the Loire department with its five main demand centers

Numerical tests have been performed using IBM ILOG CPLEX 12.0 on a computer with an Intel Dual-Core 2.2Ghz CPU. Scenarios and results are presented in Table 2. Configuration *a.b.c.d.e* means *a* possible locations, *b* demand zones, *c* pathologies, *d* resource types and *e* time periods. Optimization is stopped when either a gap limit (0.5%, 0.1% and 0.05%) or a time limit for the biggest instances (900 seconds) is reached. Average computational times are provided in the fourth column. Average final gaps are given in the fifth column. The last column indicates the ratio of instances for which the calculation was stopped due to the time limit.

Finding a solution with a gap lower than 1% is fast, but reaching an optimal solution may be long, especially for data sets IV and V. Computational time is highly impacted by the amount of demand zones and potential locations for HHC centers. For multi-period scenarios (VI-VII),

Parameter	Meaning	Value
$\delta_{jpt}$	Demand	[0 ; 80]
$q_r$	Maximum workload of a resource	[150 ; 190]
$\xi_r$	Workload related to distance	[0% ; 5%]
$\tau_{pr}$	Resource requirement for each pathology	[0.2 ; 2.5]
$\eta_{pr}$	Resource requirement for authorization	[0 ; 2]
$\alpha$	Validity length (time periods) of authorization	2
$a_r^+$	Resource employment cost	[3,000 € ; 6,000 €]
$a_r^-$	Resource dismissal cost	[3,000 € ; 4,500 €]
$\gamma_p$	Authorization cost	[100,000 € ; 125,000 €]
$c_p$	Penalty cost	$\infty$
$f_i$	Opening cost for a HHC center	[10,000 € ; 15,000 €]
$a_r$	Resource salary	[50,000 € ; 100,000 €]

Table 1: Parameter variation for random generation of test data instances

Scenarios			Results		
Id	Configuration	Gap/Time limit	Avg CPU (s)	Avg final gap	Stopped
I	5.50.5.5.1	0.5%	0.665	0.108%	0%
		0.1%	1.451	0.086%	0%
		0.05%	65.373	0.047%	0%
II	5.50.5.10.1	0.5%	0.665	0.149%	0%
		0.1%	5.538	0.088%	0%
		0.05%	131.429	0.049%	0%
III	5.50.10.5.1	0.5%	1.324	0.045%	0%
		0.1%	1.343	0.044%	0%
		0.05%	2.306	0.036%	0%
IV	20.50.5.5.1	0.5% / 900s	4.483	0.341%	0%
		0.1% / 900s	529.598	0.126%	40%
		0.05% / 900s	755.259	0.086%	77%
V	20.100.5.5.1	0.5% / 900s	6.754	0.255%	0%
		0.1% / 900s	685.141	0.136%	50%
		0.05% / 900s	831.883	0.120%	80%
VI	5.50.5.5.5	0.5% / 900s	4.512	0.287%	0%
		0.1% / 900s	291.802	0.090%	20%
		0.05% / 900s	891.725	0.077%	83.3%
VII	5.50.5.5.10	0.5% / 900s	14.395	0.351%	0%
		0.1% / 900s	613.671	0.123%	33.3%
		0.05% / 900s	860.821	0.113%	83.3%

Table 2: Results summary of the HHC location problem performance analysis

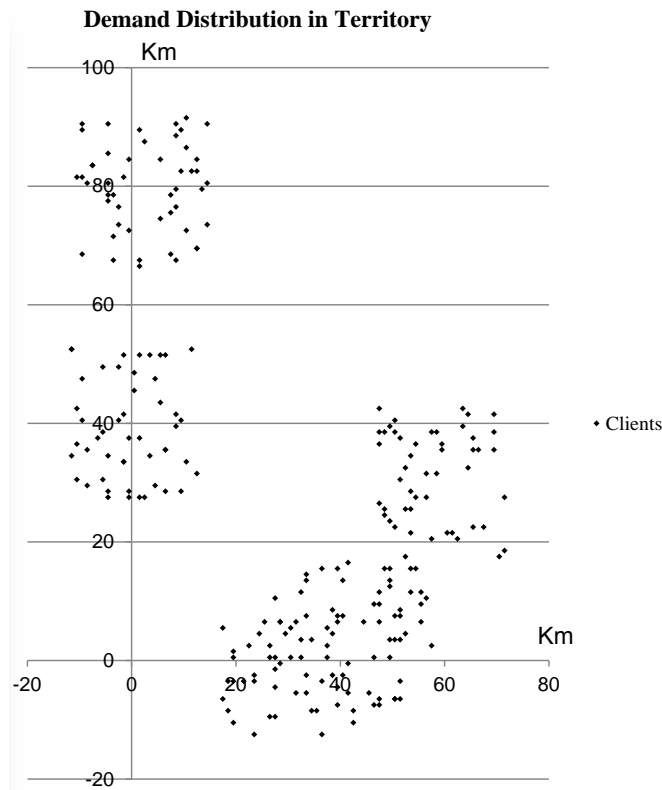


Figure 3: Demand zones generation example

time horizon length have also a high impact on quality of results. Other parameters (amount of pathologies, of resource types) have a low impact on optimization performance. Since we focus on a strategic optimization problem, long computational times are admissible. Further research on that point (construction of a meta heuristic for example) is out of the scope of the present paper.

## 5 Tactical management of home health-care activities

### 5.1 Problem description

In this section, we propose a direct extension of the HHC center location problem by taking into account the economic viability of the system. In this problem, we intend to ensure a tactical management of a HHC center, allowing to adapt itself to the evolving market. To answer the care demand, HHC centers should invest money in various processes. Five fundamental processes have been identified for HHC. Each process has a cost for the center which is different if the process is managed internally or if it is outsourced. Table 3 summarizes the processes and their features.

**Assumption 8 (Outsourcing)** *For the sake of quality of care, it is not possible to partly outsource care activities for a certain demand zone. This point has been extensively discussed with health-care practitioners since it was indeed theoretically possible to partly outsource certain care activities.*

**Assumption 9 (Refund of activities)** *HHC activities benefit a certain refund from the state (social insurance). It means that certain activities may have a better refund than others depending on state policies.*

<b>Id</b>	<b>Process name</b>	<b>External organization (outsourcing)</b>	<b>Internal organization (own resources)</b>
P1	Activity coordination	Not permitted	Coordination of care activities by the center.
P2	Medicines and supplies distribution	Use the town dispensaries network or external service providers. Each delivery has a cost.	Internal pharmacy and storage rooms are necessary. A fleet of vehicle is also required for the distribution.
P3	Consultation with a specialist	A hospital specialist is required for the consultation.	The center must have a specialist, inducing a fixed cost for salary.
P4	Care activities	The center hires freelance nurses.	The center employs nurses (fixed cost for salary).
P5	Waste collection and disposal	Same as P2.	Same as P2.

Table 3: HHC fundamental processes

**Assumption 10 (Authorization)** *In this problem,  $\eta_{pri}$  also depends on care process. It is the minimal amount of resources related to a process to ensure a certain level of care quality. Such amount is determined by health authorities and depends on the pathology.*

## 5.2 Formal model

The problem consists in deciding for a HHC center which processes will be outsourced or not. We propose two models (A) and (B) with two different objectives: model (A) intends to minimize the costs for the HHC center, whereas model (B) intends to maximize demand coverage.

Indexes and sets:

- $P$ : set of pathologies, indexed by  $p$ .
- $R$ : set of resources, indexed by  $r$ .
- $J$ : set of demand zones, indexed by  $j$ .
- $I$ : set of activity processes, indexed by  $i$ .

Parameters:

- $\delta_{jp}$ : demand quantity for pathology  $p$  in demand zone  $j$ .
- $d_j$ : distance between demand zone  $j$  and the HHC center under consideration.
- $q_r$ : resource capacity (maximum load) of resource  $r$ .
- $\tau_{pri}$ : workload of resource  $r$  in process  $i$  for pathology  $p$ .
- $\eta_{pri}$ : minimal amount of resource  $r$  in process  $i$  required to get authorization for pathology  $p$  in process  $i$ .
- $l_{jr}$ : amount of freelance resources  $r$  available in demand zone  $j$ .

- $\theta_j$ : transportation time inside demand zone  $j$ , used to approximate traveling time of resources inside a demand zone.

Costs parameters:

- $a_r$ : fixed cost for the salary of a resource  $r$ .
- $\gamma_p$ : fixed authorization cost for pathology  $p$ .
- $c_{ip}$ : variable cost per demand unit of process  $i$  for pathology  $p$  when outsourced.
- $b_{ip}$ : variable cost per demand unit of process  $i$  for pathology  $p$  when not outsourced. To calculate the costs of internal processes, we distinguish two types of sub costs: (i)  $b_{ip} \in R_0$  process cost depending on distance, and (ii)  $b_{ip} \in R_1$  for costs per demand unit.
- $f_{ip}$ : refund for process  $i$  of pathology  $p$ .
- $W$ : total budget of the center.

Decision variables:

- $X_{jpi} = 1$  if demand for service  $i$  related to pathology  $p$  in zone  $j$  is managed using employed resources (not outsourced).
- $Z_p = 1$  if the center pays the authorization to offer services related to pathology  $p$ .
- $N_r$  is the amount of resource units  $r$  employed by the center.
- $Y_{jpi} = 1$  if the service  $i$  related to pathology  $p$  in zone  $j$  is outsourced.

The mathematical model A is formulated as follows:

$$\begin{aligned} \max \quad & \sum_{i,p} f_{ip} \sum_j \delta_{jp} (X_{jpi} + Y_{jpi}) - \sum_{i,p} c_{ip} \sum_j Y_{jpi} - \sum_{i,p|b_{ip} \in R_1} b_{ip} \sum_j X_{jpi} \delta_{jp} \\ & - \sum_{ip|b_{ip} \in R_0} b_{ip} \sum_j X_{jpi} (d_j (1 + \theta_j)) - \sum_r a_r N_r - \sum_p \gamma_p Z_p \end{aligned} \quad (13)$$

s.t.

$$\sum_{j,p,i} X_{jpi} \delta_{jp} (\tau_{rpi} + (d_j (1 + \theta_j))) \leq q_r N_r \quad \forall r \in R_0 \quad (14)$$

$$X_{jpi} + Y_{jpi} = X_{jp0} \quad \forall j, p, i \quad (15)$$

$$X_{jpi} + Y_{jpi} = 1 \quad \forall j, p, i \quad (16)$$

$$X_{jp0} \leq Z_p \quad \forall j, p \quad (17)$$

$$\eta_{pr} Z_p \leq N_r \quad \forall r, p \quad (18)$$

$$\sum_{p,i} Y_{jpi} (\delta_{jp} \tau_{rpi}) \leq l_{jr} q_r \quad \forall j, r \quad (19)$$

$$X_{jpi}, Y_{jpi}, Z_p \in \{0, 1\} \quad \forall j, p, i \quad (20)$$

$$N_r \in \mathbb{N}^* \quad \forall r \quad (21)$$

The objective function intends to maximize the benefit of the center and is the sum of: (i) total refund; (ii) outsourcing cost; (iii) internal resources cost; (iv) salaries costs; and (v) authorization cost. Constraints set (14) ensures capacity is not exceeded. Constraints set (15)

ensures all services of a demand are accepted and served. Constraints set (16) ensures the center can serve a demand using both outsourced and internal resources. Constraints set (17) forbids the coordination for a pathology if unauthorized. Constraints set (18) ensures a minimal amount of resources. Constraints set (19) limits outsourcing. Finally, constraints sets (20) and (21) defines the type of variables (binary and integer).

If the objective is the maximization of the coverage under a fixed budget  $W$  (model B), the following modifications are required. The objective function is stated as follows:

$$\max \sum_{jpi} X_{jpi} \quad (22)$$

Cost information in equation (13) should become a constraint:

$$\begin{aligned} \sum_{ip} c_{ip} \sum_j Y_{jpi} + \sum_{ip|b_{ip} \in R_1} b_{ip} \sum_j X_{jpi} \delta_{jp} + \sum_{ip|b_{ip} \in R_0} b_{ip} \sum_j X_{jpi} (d_j (1 + \theta_j)) \\ + \sum_r a_r N_r + \sum_p \gamma_p Z_p \leq W \end{aligned} \quad (23)$$

Finally full coverage of demand is no longer required in model B. Constraints set (16) should be replaced the following set of constraints:

$$X_{jpi} + Y_{jpi} \leq 1 \quad \forall j, p, i \quad (24)$$

Numerical tests of the management optimization of HHC problem are presented along with the case study in the next Section. This model is intended to be run periodically by HHC centers managers to adjust the volume of outsourced activities. The process decomposition can be adjusted depending on the type of HHC center.

## 6 Case study

### 6.1 Data collection

Data collection consisted in gathering information if various databases such as demographic data, epidemiological data. The ATIH (Technical Agency for Hospital Information) information system was used to gather information related to the Loire department (Auvergne-Rhone-Alpes region, France), as presented in Figure 4. The territory is divided into demand zones. For each urban center, a demand zone is defined. Patients are supposed to be uniformly distributed on the area around those points. The demand quantity in each zone is proportional to the population density, as illustrated previously in Figure 3. All demand zones are detailed in Table 4.

For the Loire department, there have been 72,074 HHC care days in 2011 for 1,687 stays. Among all pathologies, two have been selected for our case study: (i) palliative care ( $p_0$ : 23,039 days (32%) and 582 stays (34%)) and (ii) pain management ( $p_1$ : 8,594 days (12%) and 297 stays (18%)). The demand parameter  $\delta_{jp}$  of the model is estimated using the following formula:

$$\delta_{jp} = D_p \frac{\pi_j}{\sum_j \pi_j} \quad (25)$$

where  $\pi_j$  models the population of demand zone  $j$  and  $D_p$  models the total demand for pathology  $p$  on the territory.

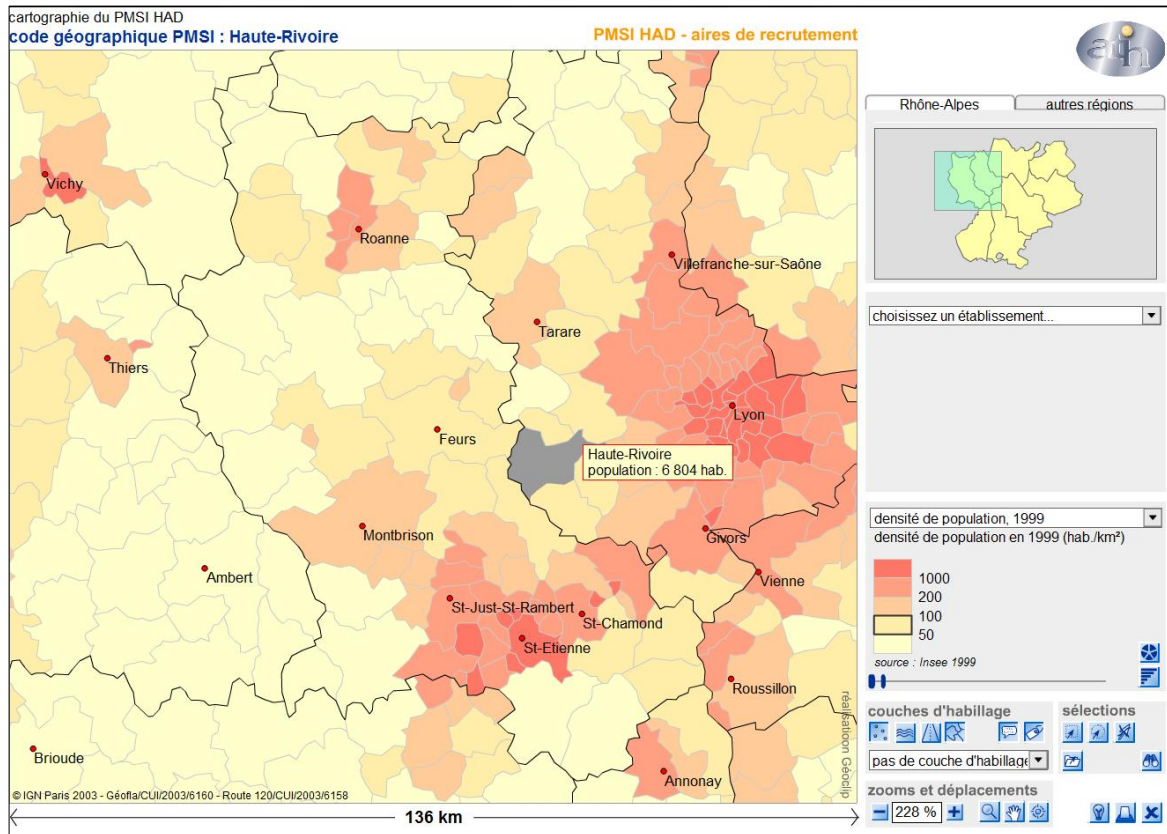


Figure 4: Geographical distribution of patients for the Loire department (from ATIH)

Resource requirements and related costs are also extracted from the ATIH information system, as presented in Table 5. For each resource type (nurse, carers, coordination staff, administrative staff and welcome staff) the salary has been estimated using national public function grids and indicators as presented in Table 6. For a pathology, utilization cost for each resource is known. For this point, we calculate the relative workload of each resource. By dividing the cost of a day of care by the daily cost, we obtain the daily workload of the resource per day of care (fourth column). Daily costs are also calculated. Finally, the workload is normalized among all resource types considered and the relative workload may be calculated. An estimation of the minimum amount of resources required to obtain the authorization has been calculated and presented in Table 20 in the appendices.

Finally, demand evolution can also be found in public databases. Figure 5 depicts demand evolution for both type of pathology in the Rhone-Alpes region from 2005 until 2011. It shows that (i) pain management care demand increases drastically since 2009 and (ii) the increase in palliative care slows down after 2010. In our case study, we use a time horizon of 7 periods and a demand evolution that fit the trend described in Figure 5, i.e. a rapid increase for  $p_0$  and a slow increase for  $p_1$ .



Zone	City	Pop. count	Zone	City	Pop. count
<b>01</b>	<b>Roanne</b>	<b>50 763</b>	<b>30</b>	<b>St-Chamond</b>	<b>37378</b>
02	Régny	3 121	31	Saint-Jean-Bonnefonds-2	3 045
03	Montagny	1 394	32	Saint-Paul-en-Jarez-2	3 084
04	Coutouvre	4 797	33	La Grand-Croix	9 448
05	Charlieu	7 256	34	L'Horme	4 639
06	Pouilly-sous-Charlieu	6 677	35	Lorette	4 843
07	Perreux	14 137	36	Sorbiers-2	3 699
08	Saint-Romain-la-Motte	3 631	<b>Total zones 30–36</b>		<b>66 136</b>
09	Ambierle	1 728	<b>37</b>	<b>St-Étienne</b>	<b>180 210</b>
10	Saint-Haon-le-Châtel	7 107	38	St-Genest-Malifaux	7 865
11	Pouilly-les-Nonains	6 864	39	Saint-Paul-en-Jarez-1	3 084
12	Riorges	10 074	40	Saint-Jean-Bonnefonds-1	3 045
13	Cordelle	1 552	41	Sorbiers-1	3 699
<b>Total zones 01–13</b>		<b>119 101</b>	42	La Talaudière	6 700
<b>14</b>	<b>St-Just-St-Rambert</b>	<b>13 954</b>	43	L'Etrat	3 682
15	Saint-Marcellin-en-Forez-2	1 687	44	Saint-Priest-en-Jarez	5 812
16	Sury-le-Comtal-2	2 402	45	Villars	8 494
17	Andrézieux-Bouthéon	15 094	46	Saint-Genest-Lerpt	5 672
18	Veauche	9 207	47	Roche-La-Molire	10 083
19	Saint-Galmier	11 374	48	Le Chambon-Feugerolles	14 090
20	Saint-Héand	3 722	49	La Ricamarie	8 438
21	La-Fouillouse-1	2 117	50	La-Fouillouse-2	2 117
<b>Total zones 14–21</b>		<b>59 557</b>	<b>Total zones 37–50</b>		<b>262 991</b>
<b>22</b>	<b>Feurs</b>	<b>15 349</b>	<b>51</b>	<b>Montbrison</b>	<b>26 643</b>
23	Rozier-en-Donzy	1 268	52	Saint-Bonnet-le-Courreau	1 009
24	Panissières	4 270	53	Saint-Georges-en-Couzan	1 846
25	Néronde	6 239	54	Sail-sous-Couzan	983
26	Chazelles-sur-Lyon	9 725	55	Saint-Jean-Soleymieux	3 760
27	Montrond-les-Bains-1	5 433	56	Montrond-les-Bains-2	5 433
28	Boen-1	4 848	57	Boen-2	4 848
29	Saint-Germain-Laval	6 017	58	Saint-Marcellin-en-Forez-1	1 687
<b>Total zones 22–29</b>		<b>53 150</b>	59	Sury-le-Comtal-1	2 402
			<b>Total zones 51–59</b>		<b>48 612</b>
					<b>Grand total</b>
					<b>609 547</b>

Table 4: Population count in the main urban zones of the Loire department

	Nurse	Carer	Coord.	Admin. staff	Welcome staff
$p_0$	66.1€(41.9%)	29.5€(18.7%)	34.4€(21.8%)	17.7€(11.2%)	10.1€(6.4%)
$p_1$	54.8€(41.1%)	20.4€(15.3%)	35.3€(26.5%)	16.6€(12.5%)	6.2€(4.7%)

Table 5: Cost of case study pathologies taken from national costs inquiry

## 6.2 Home health-care centers location

### 6.2.1 Single period special case

A design of experiments has been built in order to test the impact of the variation of two parameters: (i) the cost structure and (ii) the penalty cost (cost of giving traditional care in the hospital). Key performance indicators are:

1. Number of opened centers.
2. Number of treatments performed by the HHC centers or by the hospital.
3. Average/Maximum distance HHC centers-Patients.
4. Total cost per treatment performed by HHC centers.
5. Number of covered zones.

Resource type	Daily salary	Daily workload		Rel. workload	
		$p_0$	$p_1$	$p_0$	$p_1$
Nurse	194.47€	0.339	0.282	0.40	0.4
Carer	146.31€	0.202	0.139	0.24	0.20
Administrative staff	243.55€	0.141	0.145	0.17	0.21
Coordination staff (med. secretary)	162.98€	0.109	0.102	0.13	0.14
Welcoming staff (med. secretary)	162.98€	0.062	0.038	0.07	0.05

Table 6: Estimated relative workload for each resource type

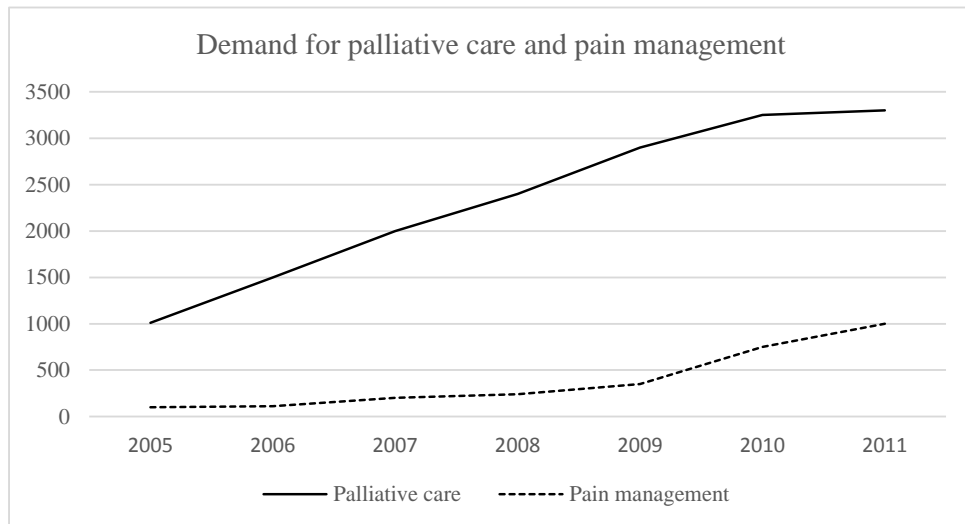


Figure 5: Demand for palliative care and pain management in the Rhone-Alps region between 2005 and 2011 (thousands of people)

Three different situations are analyzed using economic parameters of the model: (i) treatments are performed in traditional health-care systems such as hospitals: opening costs are high compared to resource costs; (ii) small centers (facilities with smaller resource capacity/low employment rate) are opened; (iii) opening and authorization costs are low compared to resource costs. The design of experiment is presented in Table 7: a scenario (labeled I–IX in the first column) is defined by a cost structure which has been established with the help of health economists (columns 2–5: opening cost, salary, authorization cost, penalty cost).

Results are presented in Table 8. Population covering is not affected by the cost structure (other than penalty cost); the three first scenarios are set to understand the impact of fixed cost change for center opening. The number of opened centers decreases with cost increase as predicted. A 90% reduction of opening fixed cost brings a 22% increase of number of opened centers and a 2.06% decrease of average distance between patients and centers.

Scenarios I, IV and V were formulated to evaluate the impact of resources cost variation. It is the most important cost in our model since it creates a variation up to 94% of treatment cost. Such cost also impacts the number of opened centers: when resource cost decreases, big centers may employ more human resources, which makes small centers useless (however average distance between patients and centers increase, up to 39% between scenarios I and V).

Scenarios VI and VII show that authorization fixed cost has no impact on performance indicators, which goes against stereotypes. A comparison between scenario I (where 18 centers are opened) and VI/VII (where 23 centers are opened) shows that the opening of more centers reduces the average distance between patients and centers. By comparing scenarios II and VI, we notice that a diminution of authorization cost allows the opening of a new center, improving at the same time territorial coverage.

The total cost of HHC centers is important in our cost structure. Such parameter has a great impact on covering indicators. The proposed design of experiment allows to find a value for that parameter having the lowest impact on HHC coverage. Such estimator is important for decision makers, and can be used as a threshold to know whether HHC centers may be opened on a new territory or not.

<b>Id</b>	<b>Scenario</b>	<b>Opening cost (€)</b>	<b>Salary (€)</b>	<b>Authorization cost (€)</b>	<b>Penalty cost (€)</b>
<b>I</b>	Base scenario	515,959	71,233	106,775	$\infty$
<b>II</b>	Impact of opening cost ( $\times 0.1$ )	51,596	71,233	106,775	$\infty$
<b>III</b>	Impact of opening cost ( $\times 0.01$ )	5,159	71,233	106,775	$\infty$
<b>IV</b>	Impact of salary ( $\times 0.1$ )	51,596	7,123	106,775	$\infty$
<b>V</b>	Impact of salary ( $\times 0.01$ )	51,596	712	106,775	$\infty$
<b>VI</b>	Impact of auth. cost ( $\times 0.1$ )	51,596	71,233	10,677	$\infty$
<b>VII</b>	Impact of auth. cost ( $\times 0.01$ )	51,596	71,233	1,067	$\infty$
<b>VIII</b>	Impact of penalty cost	51,596	71,233	106,775	100
<b>IX</b>	Impact of penalty cost	51,596	71,233	106,775	50

Table 7: Design of experiment for the single period case

## 6.2.2 Multi period case

The design of experiment presented in this section has been built to test the behavior of the model when several parameters vary over time: demand type, validity of authorizations, employment and dismissal costs. Scenarios settings are presented in Table 9. The first scenario is the base scenario. In that case, the demand for each time period and for each pathology is generated

Id	Number of open struct.	Number of unassigned treat.	Avg dist.	Max dist.	Avg cost per treatment	Nb covered zones	
						$p_0$	$p_1$
<b>I</b>	18	4 154	2.91	5.67	69 575	59	59
<b>II</b>	22	4 154	2.85	5.67	64 538	59	59
<b>III</b>	22	4 154	2.85	5.67	64 135	59	59
<b>IV</b>	12	4 154	3.47	6.07	9 891	59	59
<b>V</b>	8	4 154	4.04	6.98	3 790	59	59
<b>VI</b>	23	4 154	2.67	5.66	63 413	59	59
<b>VII</b>	23	4 154	2.67	5.66	63 324	59	59
<b>VIII</b>	22	4 154	2.85	5.66	64 538	59	59
<b>IX</b>	21	4 030	2.66	4.57	59 070	53	52

Table 8: Results for the single period case

according to Figure 5. Another key performance indicator is considered for the multi period case to evaluate the stability of employment of HHC center. The *stability factor* of human resources is calculated using the following formula:

$$\sum_{irt} (Q_{irt}^+ + Q_{irt}^-) / (|T| \times |I| \times |R|) \quad (26)$$

This factor is used to identify solutions having frequent employment and dismissal of resources. If the factor is close to zero, the scenario is stable. Taking into account the results, the stability factor is highly dependent on employment and dismissal costs, and on unused capacity (see scenarios VII and VIII). All stability factors have a low value and are close to zero, showing that resource capacity do not change drastically from one period to another.

Id	Scenario	Modified parameters
<b>I</b>	Base scenario	None
<b>II</b>	Demand increase	+5% each period
<b>III</b>	Demand decrease	-5% each period
<b>IV</b>	Authorization duration	$\alpha = 4$
<b>V</b>	Dismissal cost	$a_r^- \times 10$
<b>VI</b>	Dismissal cost	$a_r^- \times 100$
<b>VII</b>	Employment cost	$a_r^+ \times 10$
<b>VIII</b>	Employment cost	$a_r^+ \times 100$

Table 9: Design of experiment for the multi-period case

Results are presented in Table 10. Results of scenario II are close to the base scenario, only one additional center is opened. In scenario III, demand is decreasing in time: the unused capacity is higher than in the base scenario but the stability factor is lower. Since the demand is decreasing over the time horizon, too many resources are allocated. A longer authorization period in scenario IV allows HHC centers to treat more patients in the same period with a stable amount of resources.

Results of scenarios V and VI are proposed to observe the impact of dismissal cost variation. As expected, the unused capacity is lower when the cost is higher. Scenario VI has the lowest unused capacity. Distances between patients and centers are stable (average and maximum). The stability factor is higher in scenario VI than in scenario V but the total number of resources employed in scenarios V and VI are 4,220 and 4,647 respectively, meaning that even the high

dismissal cost does not prevent a high number of employments. Finally, the variation of the employment cost of resources (scenarios VII and VIII) leads to an increase of the unused capacity because it is less costly than employing new resources. The number of opened centers decreases as well as the number of unassigned treatments (which is the lowest for all scenarios).

<b>Id</b>	<b>Unused capacity</b>	<b>Number of open struct.</b>	<b>Number of unassigned treat.</b>	<b>Avg dist.</b>	<b>Max dist.</b>	<b>Avg cost per treatment</b>	<b>Stability factor</b>
<b>I</b>	1.061%	14	255	4.43	8.56	64 289	2.58
<b>II</b>	1.025%	15	245	4.35	8.68	64 471	2.50
<b>III</b>	1.618%	14	81	4.06	7.55	68 751	2.20
<b>IV</b>	1.059%	15	124	4.33	9.05	63 818	2.68
<b>V</b>	1.415%	16	679	4.18	7.55	63 582	2.71
<b>VI</b>	1.022%	15	152	4.20	7.55	63 582	2.88
<b>VII</b>	1.482%	16	175	4.11	7.55	63 110	2.90
<b>VIII</b>	1.349%	15	10	4.29	9.19	62 838	2.75

Table 10: Results for the multi-period case

### 6.3 Home health-care management

For the HHC management problem case study, we focus on a HHC center located in Andrezieux-Boutheon city, in the center of the Loire territory. To calculate the variable cost for each process and for each pathology (parameter  $b_{ip}$ ) we used the same database from the ATIH. The costs are presented in Table 11. The second column describes the daily cost outside of the center and the third column the average length of stay for each pathology in 2010. For each process, the cost are estimated such as the sum of all processes is equal to the treatment cost. Detailed values are presented in Table 23 in appendices. Parameters values are summarized in Table 12.

<b>Pathology</b>	<b>Daily cost</b>	<b>Average LOS (days)</b>	<b>Cost of treatment</b>
Palliative care ( $p_0$ )	262.4€	22.2	5 825.3€
Pain management ( $p_1$ )	358.5€	15.4	5 520.9€

Table 11: Input parameters for cost of treatments

<b>Parameter</b>	<b>Label</b>	<b>Value</b>
$\eta_{pri}$	Resources required for authorization	see Table 20
$q_r$	Capacity	see Table 21
$a_r$	Salary	see Table 21
$\tau_{pri}$	Resources requirement	see Table 22
$b_{ip}$	Internal variable cost	see Table 23
$\delta_{jp}$	Demand	[10,30]
$l_{jr}$	Available freelance resources	[0 ; 20]
$\theta_j$	Distance in a zone	[0.005 ; 0.025]
$R_1$	Variable costs depending on demand	$[I_0, I_2, I_3]$
$R_0$	Variable costs depending on distance	$[I_1, I_4]$

Table 12: Input parameters for the base scenario

### 6.3.1 Minimization of HHC costs under demand satisfaction constraint

This design of experiment is related to model (A). Base scenario input parameters and performance indicators are listed in Table 12. Three sets of experiments are proposed through the variation of three parameters:

1. Cost of outsourced processes ( $c_{ip}$ ): this experiment intends to help understand the impact of the cost of outsourced processes versus internal processes (ratio  $c_{ip}/b_{ip}$ ). This experiment is interesting to determine the best policy health authorities should encourage through state refunds.
2. Availability of external resources ( $l_{jr}$ ): this experiment allows to understand the impact of territory characteristic such as freelance resource availability of the economic stability of the center.
3. Salary ( $a_r$ ): this experiment allows to adjust the salary of resources depending on the environment. This design of experiment is useful for HHC managers who wants to adjust their expenses to remain competitive on their local territory.

Results of this experiment are presented in Table 13 with performance indicators related to the amount of outsourced processes for the considered demand, and in Table 14 with the usage of freelance resources.

Regarding the variation the cost of outsourced processes ( $c_{ip}$ ), demand assignment distribution is stable at around 50% for internal and outsourced, as shown in Table 13. Relevant changes in results are obtained with a 10,000 factor between outsourced and internal costs. It means that hiring freelance resources for HHC is always a good solution and allows a more flexible management of the HHC center, even if its cost is higher. Lowest treatment costs (Table 14) are achieved when outsourced and internal process have similar values.

The second group of experiments (availability of external resources  $l_{jr}$  is useful to adjust HHC center activity. The ratio internal/outsourced is sensible to that change for a certain interval. Medicine distribution activity is the most stable unless in the last scenario. Table 14 shows a decrease in the number of freelance resources used, as well as a decrease in the ratio of external costs.

Finally, model sensitivity has been tested with a variation of resources salaries ( $a_r$ ). As expected, more resources are employed when the cost is lower, inducing a higher ratio of internally managed processes. On an other hand, freelance resources usage is highly reduced. In the light of these results, a manager of HHC center should adjust the salary depending on the availability of freelance resources in the territory where it is implanted.

### 6.3.2 Maximization of coverage under fixed budget

This set of tests is related to model (B). Experiments are based on budget variation to evaluate the sensitivity of the solution considering a change in the budget. As base scenario, we propose a relaxation of budget constraint ( $W = \infty$ ). Results are presented in Table 15 and Table 16.

Covering reduction accordingly to budget decrease is the first major impact. If we compare the last scenario ( $W = 25$  M€) with the base scenario, maximum covering is reached but the last scenario has better results considering unused capacity and treatment cost. Such analysis show the limitations of our method which is based on mono-objective optimization. Multi-objective optimization is a good alternative to solve this problem and will be considered for future works.

Using this approach, a HHC center manager is able to determine the best budget  $W$  to maximize employed resources occupation and control the demand assignment. Freelance resources are used as an adjustment factor which allows flexibility in HHC center management. In this

	Value	Unused capacity	Management		% internal management				
			Internal	Outsourcing	$I_0$	$I_1$	$I_2$	$I_3$	$I_4$
$c_{ip}$	$b_{ip}$	6.3 %	46.7 %	53.3 %	100 %	15 %	57.5 %	15 %	45.8 %
	$b_{ip} \times 100$	7.05 %	46.8 %	53.2 %	100 %	17.5 %	54.2 %	25.8 %	36.7 %
	$b_{ip} \times 1,000$	4.66 %	50.3 %	49.7 %	100 %	19.2 %	54.2 %	42.5 %	35.8 %
	$b_{ip} \times 10,000$	4.36 %	68.2 %	31.8 %	100 %	50.8 %	58.3 %	96.7 %	35.0 %
$l_{rj}$	[0,10]	9.14 %	33.5 %	66.5 %	100 %	11.7 %	20.0 %	14.2 %	21.7 %
	[0,2]	11.03 %	36.8 %	63.2 %	100 %	11.7 %	31.7 %	15.0 %	25.8 %
	[0,1]	8.42 %	42.5 %	57.5 %	100 %	11.7 %	42.5 %	20.8 %	37.5 %
	[0,0.667]	4.66 %	50.3 %	49.7 %	100 %	19.2 %	54.2 %	42.5 %	35.8 %
$a_r$	$a_r \times 0.01$	3.30 %	94.5 %	5.5 %	100 %	100 %	100 %	100 %	70.0 %
	$a_r \times 0.03$	3.76 %	79.4 %	20.6 %	100 %	93.3 %	72.5 %	100 %	30.8 %
	$a_r \times 0.05$	3.15 %	70.3 %	29.7 %	100 %	75.8 %	45.8 %	100 %	29.2 %
	$a_r \times 0.08$	3.35 %	63.8 %	36.2 %	100 %	60.0 %	32.5 %	100 %	25.8 %
	$a_r \times 0.1$	2.92 %	60.0 %	40.0 %	100 %	47.5 %	30 %	95.8 %	24.2 %
	$a_r$	9.14 %	34.5 %	65.5 %	100 %	11.7 %	20 %	14.2 %	21.7 %

Table 13: Parameter variation impact on management

	Value	Ratio of freelance	Freelance resources usage					Budget allocation		Treatment cost (€)
			$R_0$	$R_1$	$R_2$	$R_3$	$R_4$	Outsourced	Internal	
$c_{ip}$	$b_{ip}$	26.5%	8.75	4.68	4.63	2.95	3.95	0.01%	99.99%	338 023
	$b_{ip} \times 100$	28.1%	9.88	4.47	4.81	3.27	3.97	1.28%	98.72%	343 473
	$b_{ip} \times 1,000$	27.2%	9.90	3.96	4.60	3.31	3.84	9.40%	90.60%	379 628
	$b_{ip} \times 10,000$	21.5%	9.30	1.68	3.43	3.11	2.76	16.54%	83.46%	531 296
$l_{jr}$	[0,10]	2.8%	17.54	6.36	6.53	4.41	4.68	17.01%	82.99%	302 230
	[0,2]	12.6%	14.85	5.83	6.07	4.12	4.60	15.61%	84.39%	322 495
	[0,1]	22.2%	12.79	5.32	5.34	3.55	4.24	13.08%	86.92%	356 635
	[0,0.667]	27.2%	9.90	3.96	4.60	3.31	3.84	9.39%	90.61%	379 983
$a_r$	$a_r \times 0.01$	0.1 %	0.97	0.00	1.13	1.24	0.88	0.27 %	99.73 %	152 535
	$a_r \times 0.03$	0.6 %	8.14	1.21	3.17	3.00	1.96	1.77 %	98.23 %	163 883
	$a_r \times 0.05$	0.9 %	13.29	2.22	3.94	3.50	2.41	3.37 %	96.63 %	173 393
	$a_r \times 0.08$	1.0 %	15.72	2.69	4.44	3.85	2.86	4.34 %	95.66 %	185 937
	$a_r \times 0.1$	1.1 %	16.03	3.02	4.68	3.98	3.17	5.61 %	94.39 %	193 682
	$a_r$	1.4 %	17.54	6.36	6.53	4.41	4.68	11.52 %	88.48 %	446 245

Table 14: Parameter variation impact on freelance resources usage

example, a 10 M€ budget is enough to assign more than 80 % of the demand for a treatment cost of 200 K€. Increasing the budget is not worthy considering the associated expenses (more than 300 K€).

$W$	Unused capacity	Demand assignment (coverage)			% internal management				
		Internal	Outsourced	Total	$I_0$	$I_1$	$I_2$	$I_3$	$I_4$
$\infty$	30.65 %	68 %	32 %	100 %	100 %	59.2 %	57.5 %	60.0 %	64.2 %
1,000,000	4.60 %	8 %	10 %	18 %	18.3 %	0.8 %	3.3 %	14.2 %	3.3 %
2,500,000	3.68 %	11 %	19 %	30 %	30.0 %	1.7 %	3.3 %	14.2 %	4.2 %
5,000,000	1.39 %	18 %	39 %	57 %	56.7 %	2.5 %	6.7 %	17.5 %	5.8 %
7,500,000	1.86 %	22 %	48 %	69 %	69.2 %	4.2 %	7.5 %	19.2 %	8.3 %
10,000,000	0.95 %	28 %	57 %	84 %	84.2 %	9.2 %	10.0 %	21.7 %	13.3 %
25,000,000	0.09 %	34 %	67 %	100 %	100 %	11.7 %	20.0 %	14.2 %	21.7 %

Table 15: Budget variation impact on management

$W$	Freelance resources usage					Budget allocation		Treatment cost (€)
	$R_0$	$R_1$	$R_2$	$R_3$	$R_4$	Outsourced	Internal	
$\infty$	8.9	3.1	3.0	2.0	2.1	3.34 %	96.66 %	740 589
1,000,000	2.8	0.7	0.9	0.7	0.7	24.98 %	75.03 %	88 743
2,500,000	5.4	1.6	1.8	1.3	1.3	31.33 %	68.67 %	110 184
5,000,000	10.4	3.3	3.7	2.7	2.7	30.52 %	69.49 %	146 099
7,500,000	13.2	4.3	4.7	3.3	3.4	27.46 %	72.54 %	168 157
10,000,000	15.7	5.2	5.6	3.9	3.9	23.61 %	76.39 %	197 756
25,000,000	17.5	6.4	6.5	4.4	4.7	17.01 %	82.99 %	302 230

Table 16: Budget variation impact on freelance resources usage

## 7 Conclusions and perspectives

In this paper we proposed a comprehensive methodology for the design and the management of a home health-care network taking into account medical demand evolution in a territory and a complex cost structure adapted to our problem. The first optimization model provides a strategic location plan for home health-care centers across a territory, demand assignment and resource sizing. The model is solved for a single and multi-period time horizon. The second optimization model provides a tactical management plan for the crucial activities of each HHC center by deciding if certain activities should be outsourced or not. Both models have been tested on a realistic case study using real data from the Loire department (France). Various scenarios have been tested to study the behavior of the models. Results are also realistic and relevant for stakeholders (health authorities and HHC centers managers), inducing that the methodology can be applied for real size case studies. Stability factors have also been introduced to take into account social constraints related to working conditions of health-care practitioners.

Choosing the location of HHC centers across a territory has a high impact on resource sizing, demand assignment and pathologies to be treated. Thus the economic viability of a HHC center is strongly correlated to its localization in the network with regards to other health-care hubs such as hospitals. Taking into account the economic fragility of HHC centers in developed countries, decision aid tools and methodologies are crucial to optimize the operations of a home health-care network. Collaboration between HHC centers is also important to optimize the global performance of the network: the global assignment of the demand in a territory is more efficient than the local optimization of a center.

This paper provides a comprehensive toolbox for both HHC centers managers and regional health agencies to better organize the deployment of home health care across a territory taking



into account its characteristics (freelance health resources availability, demand dynamic, traveling distances). The strategic plan allows an efficient coverage of a territory to satisfy the demand under while minimizing costs. To ensure the economic stability of HHC, design of experiments are provided, allowing a fine tuning of centers management through adjustment of salaries and the determination of a ratio of outsourced activities.

For future works, we need to extend the case studies of the proposed models to include different territory configurations, including special characteristics such as map topology (inducing long traveling distances for certain zones). In order to better fit the varying demand over the time horizon, it is also possible to improve both strategic and tactical optimization models by including random variables. Stochastic optimization using scenarios may lead to more accurate solutions. Finally, we intend to provide a performance evaluation of the proposed organization using discrete-event simulation in order to capture the complex processes related to the visit of practitioners at home.

## Appendices

Auxiliary data used as input for the models are presented in this section. Estimation of the demand in zones is presented in Table 17. Distance matrix between main zones is presented in Table 18. Resource requirements for palliative care and pain management are presented in Table 19: we suppose that the duration for a visit to a patient for palliative care (resp. pain management) is 5 hours (resp. 3 hours). Minimal amount of resources required to get the authorization for certain type of care is presented in Table 20. Resource capacity, distance assignment ratio and fixed costs are presented in Table 21. For the management optimization problem, resource requirements ( $\tau_{rpi}$ ) have been recalculated to get significant behavior. These parameters are presented in Table 22. Table 23 presents costs of all processes for each pathology.

$j$	$\delta_{j0}$	$\delta_{j1}$	$j$	$\delta_{j0}$	$\delta_{j1}$	$j$	$\delta_{j0}$	$\delta_{j1}$	$j$	$\delta_{j0}$	$\delta_{j1}$
<b>1</b>	48	25	<b>16</b>	2	1	<b>31</b>	3	1	<b>46</b>	5	3
<b>2</b>	3	2	<b>17</b>	14	7	<b>32</b>	3	2	<b>47</b>	10	5
<b>3</b>	1	1	<b>18</b>	9	4	<b>33</b>	9	5	<b>48</b>	13	7
<b>4</b>	5	2	<b>19</b>	11	6	<b>34</b>	4	2	<b>49</b>	8	4
<b>5</b>	7	4	<b>20</b>	4	2	<b>35</b>	5	2	<b>50</b>	2	1
<b>6</b>	6	3	<b>21</b>	2	1	<b>36</b>	4	2	<b>51</b>	25	13
<b>7</b>	13	7	<b>22</b>	15	7	<b>37</b>	172	88	<b>52</b>	1	0
<b>8</b>	3	2	<b>23</b>	1	1	<b>38</b>	8	4	<b>53</b>	2	1
<b>9</b>	2	1	<b>24</b>	4	2	<b>39</b>	3	2	<b>54</b>	1	0
<b>10</b>	7	3	<b>25</b>	6	3	<b>40</b>	3	1	<b>55</b>	4	2
<b>11</b>	7	3	<b>26</b>	9	5	<b>41</b>	4	2	<b>56</b>	5	3
<b>12</b>	10	5	<b>27</b>	5	3	<b>42</b>	6	3	<b>57</b>	5	2
<b>13</b>	1	1	<b>28</b>	5	2	<b>43</b>	4	2	<b>58</b>	2	1
<b>14</b>	13	7	<b>29</b>	6	3	<b>44</b>	6	3	<b>59</b>	2	1
<b>15</b>	2	1	<b>30</b>	36	18	<b>45</b>	8	4			

Table 17: Demand distribution according to population count ( $\delta_{jp}$ )

## Acknowledgments

The authors are grateful to anonymous reviewers for their useful comments about the article.

	<b>1</b>	<b>14</b>	<b>22</b>	<b>30</b>	<b>37</b>	<b>51</b>
<b>1</b>	0	59	40	67	63	56
<b>14</b>		0	32	27	23	31
<b>22</b>			0	41	38	30
<b>30</b>				0	21	43
<b>37</b>					0	42
<b>51</b>						0

Table 18: Distance matrix

$P$	$\tau_{p0}$	$\tau_{p1}$	$\tau_{p2}$	$\tau_{p3}$	$\tau_{p4}$
$P_0$	2h	1.2h	0.8h	0.6h	0.4h
$P_1$	1.2h	0.6h	0.6h	0.4h	0.2h

Table 19: Resource required depending on pathologies  $\tau_{pr}$

$P$	$\eta_{p0}$	$\eta_{p1}$	$\eta_{p2}$	$\eta_{p3}$	$\eta_{p4}$
$P_0$	1	1	0	0	0
$P_1$	1	0	0	1	0

Table 20: Minimal resource amount required for authorization ( $\eta_{pr}$ )

	$r_0$	$r_1$	$r_2$	$r_3$	$r_4$
$q_r$	175h	190h	150h	175h	150h
$\xi_r$	0.05	0.05	0	0	0
$a_r$	70 010	52 674	87 689	58 675	58 675

Table 21: Resource capacity ( $q_r$ ), distance assignment ratio ( $\xi_r$ ) and fixed costs ( $a_r$ )

	$P_0$					$P_1$				
	$R_0$	$R_1$	$R_2$	$R_3$	$R_4$	$R_0$	$R_1$	$R_2$	$R_3$	$R_4$
$i_0$	0	0.4	0.2	0.1	0	0	0.2	0.2	0.1	0.1
$i_1$	0	0	0.1	0.1	0.2	0	0	0	0	0.1
$i_2$	1.8	0.4	0.2	0.1	0	1	0.2	0.1	0.1	0
$i_3$	0	0.4	0.1	0	0	0	0.2	0.1	0	0.1
$i_4$	0.2	0	0.2	0.3	0.2	0.2	0	0.2	0.2	0.1
$\sum_i \tau_{rpi}$	2h	1.2h	0.8h	0.6h	0.4h	1.2h	0.6h	0.6h	0.4h	0.2h

Table 22: Resource requirements ( $\tau_{pri}$ )

	<b>Process</b>	<b>Label</b>	$P_0$	$P_1$
$I_0$	Coordination	Diagnosis, medical and social care coordination	36.9	32.1
$I_1$	Distribution	Logistics (for the patient, medical, and global management)	52.9	46.8
$I_2$	Consultation	NA	23	23
$I_3$	Care	Actors (home and transportation) + Workload at patient home	170.3	275.9
$I_4$	Waste disposal	Continuity of care	6.1	7.7

Table 23: Internal variable costs for each process and each pathology ( $b_{ip}$ )

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