Automatic Nurse Allocation based on a Population Algorithm for Home Health Care

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Abstract: The provision of home health care services is becoming an important research area, mainly because in Portugal the population is aging and it is necessary to perform home services. Home care visits are organized taking into account the medical treatments and general support that elder/sick people need at home. This health service can be provided by nurses teams from Health Units, requiring some logistics for this purpose. Usually, the visits are manually planned and without computational support. The main goal of this work is to carry out the automatic nurse's allocation of home care visits, of one Bragança Health Unit, in order to minimize the nurse's workload balancing, spent time in all home care visits and, consequently, reduce the costs involved. The developed methodologies were codified in MatLab Software and the problems were efficiently solved, obtaining several nurse's allocation solutions of home care visits for the presented case study. All the solutions found by particle swarm optimization have a significant improvement and reduction in the total time, in the nurse workload balancing, as well as the patients waiting time.

1 INTRODUCTION

According to the World Health Organization the ageing people and dependency rate care of older people in Europe, namely in Portugal, is increasing. The number of people who needs home care services, consequently, is growing over the years. The National Health System has to deal with more and more demanding scenarios in what concerns home care.

This scenario — to provide home care services — is not only advantageous to elder/sick people but also to the National Health System since it is economically advantageous to keep people at home instead of providing them with a hospital bed (Nickel et al., 2012; Rest and Hirsch, 2015).

The home-based care provided by public or private entities has been the subject of recent research mainly in the operations research area with particular attention on route's optimization and on the staff teams composition that provide this kind of services (Nickel et al., 2012; Benzarti et al., 2013; Bertels and Fahle, 2006; Rasmussen et al., 2012). According to studies already carried out, the utilization of optimization strategies contributes to improve the Home Health Care services (Liu et al., 2013a; Sahin and Matta, 2015).

The Portuguese public health system consists in two types of units: Hospitals and Health Units. The Health Units are closer to the population since they follow up their patients continuously and the home care services are performed by health professionals teams (usually nurses) of these Units. In this context, Health Units have to perform the schedule and the best allocation of the nurses' teams inside and outside of the Health Units.

The schedule of the home care visits provided by the Health Units teams depends on the patients, nurses profiles and resources to perform the home care. This represents a complex problem being its main goal to minimize the time needed, provided by the best allocation in the nurses team, allowing also workload balancing between them to perform all the home care visits (considering the travel and treatment patient time) and return to the Health Unit.

The rest of the paper is organized as follows: Section 2 given a brief description of the literature review involved in Home Health Care and its applica-

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tions. Section 3 overviews the problem definition and formulation for nurses allocation, and Section 3 describes the general real data collection implemented in the case study. Section 4 presents the population algorithm applied and coded to support the problem optimization. Section 5 will present and discuss the results obtained, with a special focus on the approach obtained and its comparison with what is currently performed. Finally, Section 5 rounds up the paper with the conclusions and future work.

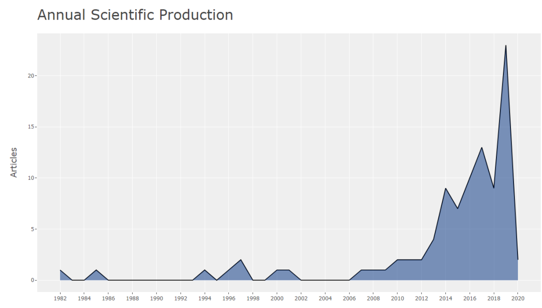

Figure 1: Annual Scientific Production related to Home Health Care and its applications.

2 Literature Review

Many countries, such as Portugal, faces a growing elderly population, which increases the pressure on institutions and professionals to provide social and medical care in the most cost-effective way.

In this sense, a small literature review was carried out to determine the state of the art involved in keywords such as ”Home Health Care”, ”Allocation”, ”Optimization” and ”Scheduling”. The same search was performed on the Scopus database which enabled the results of 94 documents from different sources such as journals, books and conference proceedings. With the bibliographic database collected, it was organized to enable the use of the Bibliometrix package using the Biblioshiny interface (Aria and Cuccurullo, 2017). It is important to refer to that, today bibliometrix is more than just a statistical tool, which includes all the main bibliometric methods of analysis, but we use it especially for science mapping and networks and not for measuring science, scientists, or scientific productivity. In this purpose, it was used the shiny interface for bibliometrix, called biblioshiny. It supports in easy use of the main features of bibliometrix, like for example, data importing and conversion to data frame collection, data filtering, analytics and plots for three different level metrics (sources, authors, documents) and analysis of three structures of knowledge (conceptual structure, intellectual structure, social structure). In this sense, after analyzing the dataset and obtaining the main information among them, it should be noted that the annual scientific production in the field of applications and Home Health Care study has grown exponentially in the last 5 years (as illustrated in the Figure 1), which reveals the extreme importance of studies and works that enhance the optimization of health logistics, such as primary care services and their decision support in this scientific environment.

In another analysis, more related to the scientific mapping and its conceptual structure, it was also possible to collect the networks of conceptual words, which makes it possible to discover links and concepts through co-occurrences of terms. The conceptual framework is often used to understand the topics covered by scholars (called the research front) and identify which are the most important and most recent questions. Thus, the co-word analysis through correspondence analysis was collected, according to the dendrogram topic, which enables the iconic representation that organizes the particular links. This analysis employs a quantitative method that leads to groupings and their ascending hierarchical ordering (similar to the branches of a tree). The analysis and representation obtained can be verified in Figure 2.

In the conceptual structure obtained by the dendrogram in Figure 2, it is possible to highlight at the outset the two large clusters that group the co-word analysis of the literature review performed. The weights vary depending on a specific co-word or its grouping, however it was possible to create connections already existing in the literature, with the work developed here. With a blue rectangle, you can focus on the terms nursing, home care services, workload balancing and decision making. In a smaller rectangle, scheduling algorithms and swarm optimization using particle swarm optimization (PSO) are referred to. Thus, it is easy to identify the importance of the literature involved, its health context and how the solution will be obtained in terms of an automatic nurse allocation system in a Health Unit. Moreover, it is expected to enhance the growth of this co-words in the future.

With this literature review, we sought to understand the domains that influence Home health care, such as its continuity of care and consistency, the staff involved, their competence and of course, the quality of this increasingly common practice, especially in regions of the interior of Portugal. This thematic and with optimized and practical bibliometrix feature, also made it possible to identify some of the most prominent papers, revealing themselves as top

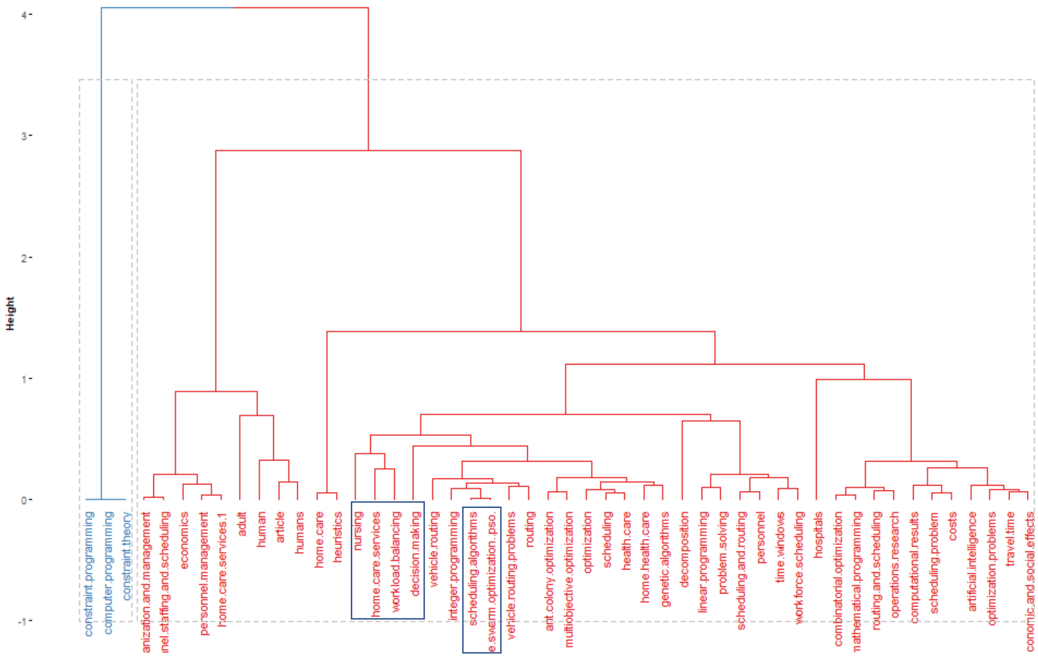

Figure 2: Dendrogram on the Conceptual Structure about the literature involved.

manuscripts per citations. From the results obtained and analyzed, there is a steady growth in applications and studies of the home health care problem, where it is possible to highlight from the research carried out some highlighted works such as routing reviews and scheduling of home health care (Fikar and Hirsch, 2017), multi-objective optimization in Home care (Braekers et al., 2016), assignment and allocation (Cappanera and Scutellà, 2014), heuristics and meta-heuristics (Liu et al., 2013b; Hiermann et al., 2015), among others applied to this domain, revealing its extensive applicability.

3 Problem Definition

Health Centers have nurses devoted partially to the task of providing health care at home patients, who live at any location in the area under supervision of the Health Center. For a given day, a Health Care Center on the and needs to provide the schedule of all nurses team to perform the tasks inside and outside of the Health Care Center, but on the other hand may need the schedules of the available cars.

In this paper, it is studied the problem to schedule the tasks outside the Health Care Center, particularly, to find the home care visits schedule for a given day, in order to minimize the travel time to perform all visits since these are planned manually and take a long time. Then, the main objective of this study is to perform automatic planning of home care visits by a nurses team and also produce a cars schedule of a Health Care Center of Bragança (HUB), Bragança, Portugal, aiming to minimize all the time spent by the nurses and cars to perform all home care visits.

This optimization problems, related and given by the HUB, is formulated and solved as follows.

3.1 General Assumptions for the allocation to Perform

It was assumed for the general problems the next assumptions:

A.1 Patients who live in the area of HUB can have different profiles.

A.2 A patient profile is assumed to be known *a priori* and does not change during the home care visit.

A.3 The number and average duration of the treatments that characterize a patient profile are known and are the same among the patients who have the same profile (defined and given by HUB).

A.4 The number of patients who need home care services and assigned to a working day is known in advance and does not change during that day.

A.5 Human resources that perform home care visits is known in advance.

A.6 All the patients assigned to a working day are covered which means that all the patients admitted to the home care visits have to be assigned to a set of nurses or cars.

A.7 The locations of all patients.

A.8 The time matrix of travel between all the localities is also known in advance.

A.9 All the travels begin and end up in the HUB.

A.10 It was considered 15 minutes for the trip, in the same city, to visit different patients.

3.2 Problem Formulation for Nurses Allocation

Taking into account all the above assumptions for a working day, consider the following general parameters for the formulation of nurses' schedules:

- N is the total number of nurses assigned for home care visits.
- P is the total number of patients that need some treatments at their homes.
- L is the total number of different patients' locations.
- The list of the treatments that each nurse can perform.

Consider the variable $(p;n) = (p_1,...,p_P;n_1,...,n_P)$, where the patient p_i will be visited by the nurse n_i, for $i = 1,...,P$, and $p \in \{1,\cdots,P\}^P$ and $n \in \{1,\cdots,N\}^P$.

Then, for a given $(p;n)$ it is possible to define the nurse schedule and also the total time needed by each nurse to finish her work. So, consider the objective function $tt(p;n)$, $n = 1,..,N$ defined as

$$f(p;n) = \max_{n=1,...,N} tt(p;n) \qquad (1)$$

which represents the time spent by the nurses to perform all treatments, including the returning journey to the HUB.

Then the constrained integer optimization problem will be defined as

$$\begin{array}{ll} \min & f(p;n) \\ \text{s.}t. & 1 \le p_i \le P,\ i \in \{1,...,P\}, p_i\text{integer} \\ & 1 \le n_j \le N,\ j \in \{1,...,P\}, n_j\text{integer} \end{array} \qquad (2)$$

where all the patients need to be treated $\cup_{i=1}^{P} p_i = \{1,...,P\}$ and the nurse n_i needs to perform all the treatments of the patients p_i, for $i = 1,...,P$.

4 General Real Data

It is intended to apply the developed problems formulations to a real problem of the HUB. The data provided by the HUB concern the day April 18, 2016. The data used were available by the Healthcare Center of Bragança (chosen by the institution and simulated a normal working day in the center), that is, simulated for nurses allocation.

The home care services provided by the assigned nurses to this job can be classified into five different treatments (or home care visits). The treatments are thus divided according to their diversity. Thus, Treatmente 1 (T.1) refers to curative care with an average time of 30 minutes, while Treatment 2 (T.2) refers to Surveillance and Rehabilitation, with an average duration of 60 minutes. Treatment 3 (T.3) is Curative and Surveillance care averaging 75 minutes, while Treatment 4 (T.4) is only Surveillance care and has an average care of around 60 minutes. Finally, treatment 5 (T.5) concerns more general health care such as support and monitoring and has an average of 60 minutes as well.

On April 18, there were thirty one patients who needed home care visits by HUB.

The thirty one patients are from twelve different locations of the Bragança region, that belong to the action area of the HUB.

In Table 1, the locations are represented by the corresponding abbreviation. From hereafter it will be used only these abbreviations. In third column it is shown the related number of patients who need health care. The major part of the patients (18) are from Bragança city while 13 patients are from rural localities around Bragança.

Table 1: Short name of the locations and total number of patients in each locality.

Localities	Abbreviations	Number of Patients
Bragança	Bg	18
Parada	Pa	2
Rebordainhos	Re	1
Carrazedo	Car	1
Espinhosela	Esp	1
Rebordãos	R	1
Salsas	Sal	1
Serapicos	Se	1
Outeiro	Ou	1
Meixedo	M	1
Bragada	Bda	1
Milhão	Mil	2

Each patient, required specific medical assistance — one or more different treatments, from the 5 treatments that the nurses can performed. On the other hand, the time required to travel between two locations is shown in Table 2. It was assigned 15 min to travel between two different places, in the same location.

Based on all the presented general data, the objective is to obtain the nurses allocation in a specific schedule, in order to minimize the total time needed by each nurse to provide all the treatments to all the patients and return to the Health Unit.

4.1 Specific Data for Nurses' Allocation

In addition to all the data presented previously, more specific information is needed to produce nurses' schedules. Thus, it is necessary to know, how many nurses exist for the study day and what treatments each one performs (nurses are allocated in different types of treatments, information obtained by the HUB).

The HUB has twelve nurses designated to perform home care visits during the day in study. Table 3 shows the allocation of the five treatments by each nurse as well as the average time treatment required.

With the data presented in the Table 3 and with the general information presented previously, it is possible to apply them in computational contexts in an attempt to obtain nurses' allocation.

5 Population Algorithm

A global optimization method were used to solve the nonlinear optimization problem defined previously: Particle Swarm Optimization (PSO) method. This method are population-based method and a brief summary of him follows.

5.1 Particle Swarm Optimization - PSO

The Particle Swarm Optimization (PSO) was developed by Kennedy and Eberhart (Kennedy, 2010) and it is based on natural social intelligent behaviors.

The PSO method applied in this work is summarized by the following algorithm.

PSO is a computational method that optimizes a given problem by iteratively measuring the quality of the various solutions. This method consists in optimizing an objective function through the exchange of information between individuals (particles) of a population (swarm). The PSO idea is to perform a set of operations and move each particle to promising regions in the search space. The PSO method also works with a population of solutions and stops when the stop criteria is met (Poli et al., 2007; Imran et al., 2013).

Algorithm 1 : Particle Swarm Optimization Algorithm

Generates a randomly population of individuals, $\mathcal{P}^0$, with dimension N_{pop}.
Set the values of w, c_1, r_1. Define c_2, r_2 random numbers in $[0,1]$. Set $v_i = 1$, for $i = 1, ..., N_{pop}$, and $k = 0$.
while stopping criterion is not met **do**
  Set $k = k + 1$.
  Update the value of $xbest_i$ for the individual with index i, for $i = 1, ..., N_{pop}$.
  Update the value of $gbest$ for all population $\mathcal{P}^j$, for $j = 1, ..., k$.
  Update the individual velocity according to:

$$v_i^{k+1} = wv_i^k + c_1 r_1 (xbest_i - x_i^k) + \lfloor c_2 r_2 \rceil (gbest - x_i^k).$$

  Update the individual position according to: $x_i^{k+1} = x_i^k + v_i^{k+1}$.
  If necessary, adapt x_i^{k+1} to a feasible schedule.

At each iteration the velocity of each individual is adjusted. The velocity calculation is based on the best position found by the neighborhood of the individual, the best position found by the particle itself - *xbest* and the best position found by the whole population, taking into account all individual - *gbest* or the best position overall (Bratton and Kennedy, 2007).

During the iterative process if x_i^{k+1} is not a feasible solution, the coordinate that is not feasible will be projected to the feasible region (Alves et al., 2017).

The iterative procedure terminates after a maximum number of iterations or after a maximum number of function evaluations.

6 Results and Discussion

The main objective is to produce the best allocation for the existing problem in Health Units: nurses' schedules for home care visits.

The present study was carried out at the Health Care Center of Bragança, on a date provided by the Health Center, April 18, 2016. The daily route carried out on April 18 was made manually, that is, without any mathematical model or subject to computational mechanisms. It was provided by the Health Unit schedules manually produced to date in the study.

The nurses' schedules were collected, presenting the schedule made available by the Health Care Center on April 18 for the twelve nurses that performed the home care visits in that day.

Analyzing the scheduling carried out by the Health Care Center, it is possible to conclude that all nurses have different work schedules. The number of patients that each nurse visits change from 1 (Nurse 8) to 7 (Nurse 3) and it is Nurse 3 who has the highest time to provide the home care visits. The time needed

Table 2: Data about travel times between different locations (in minutes).

	Bg	Pa	Re	Car	Esp	R	Sal	Se	Ou	M	Bda	Mil
Bg	15	28	25	26	20	14	23	31	23	20	22	24
Pa	28	15	27	39	37	25	25	23	27	40	26	36
Re	25	27	15	33	34	22	12	20	32	37	14	33
Car	26	39	33	15	24	23	34	42	38	39	33	39
Esp	20	37	34	24	15	24	32	40	33	18	31	34
R	14	25	22	23	24	15	20	28	26	27	19	27
Sal	23	25	12	34	32	20	15	8	30	34	9	31
Se	31	23	20	42	40	28	8	15	38	42	17	39
Ou	23	27	32	38	33	26	30	38	15	29	30	14
M	20	40	37	39	18	27	34	42	29	15	34	31
Bda	22	26	14	33	31	19	9	17	30	34	15	31
Mil	24	36	33	39	34	27	31	39	14	31	31	15

Table 3: Treatments performed by the nurses.

	T.1 (30 min)	T.2 (60 min)	T.3 (75 min)	T.4 (60 min)	T.5 (60 min)
Nurse 1	X			X	
Nurse 2	X	X		X	
Nurse 3	X			X	
Nurse 4	X		X	X	
Nurse 5	X			X	
Nurse 6	X			X	X
Nurse 7	X		X	X	
Nurse 8	X			X	
Nurse 9	X			X	
Nurse 10	X			X	
Nurse 11	X			X	
Nurse 12	X			X	

to each nurse to perform the health treatment is represented in the Table 4.

Table 4: Time needed to perform home care visits by each nurse

Nurses	**Time (minutes)**
1	221
2	260
3	**369**
4	212
5	86
6	90
7	241
8	70
9	194
10	90
11	240
12	183

On this working day, the total time needed on home visits ended after 369 minutes.

Therefore, and as mentioned above the HUB presents a not very consistent schedule, with nurses to perform many home care visits and others who perform only one, ending with the travel times do not have an equal each other.

One more time, and as mentioned above the HUB presents a not very consistent schedule, with a balancing workload without much balance.

The idea is to optimize this process of home care visit, and to produce for the day in question (April 18, 2018), the nurses' best allocation

In an attempt to plan the schedules automatically, one computational algorithms was used — PSO. The numerical results were obtained using an Intel(R) Core(TM) i7 CPU 2.2GHz with 6.0 GB of RAM and using the MatLab software. The fix variable for both methods were $N_{pop} = 30$, $w = 1$ and $c_1 = r_1 = 2$.

6.1 Results and Discussion for the nurses' allocation

Since the method used are stochastic method, each implementation was tested with 100 executions in order to evaluate the results obtained and compare them with the ones obtained from the Health Care Center. Both methods used the same stop criteria, limit the number of function evaluation to 5000 or after 1000 iterations.

PSO had 100% of successful rate since they found a feasible solution in all runs. The Figure 3 depicts one obtained solution using PSO.

Regarding the identification of patients and treatments, P(1) - T.1 represents Patient 1 who needs Treatment 1. For example, the schedule of the Nurse 1, tat have a effort per day of 4h, will be: moves from the HUB to the village of Parada (Bg - Pa) to execute the home care visit of Patient 2, that requires the Treatment 1 (P(2) - T.1). After this, the nurse returns to the point of origin, the Health Care Center (Pa - Bg). For this nurse, the time spent in this home care visit was 86 minutes.

From Figure 3 it is possible to see that the min-

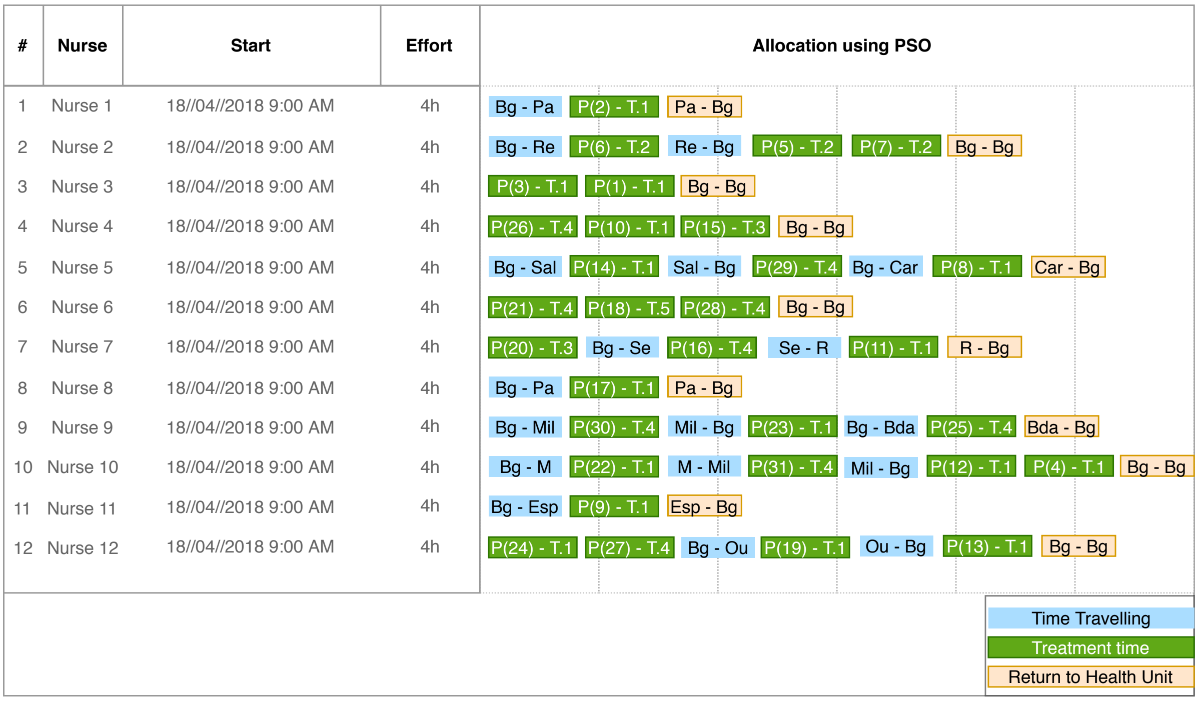

Figure 3: Automatic Nurse Allocation for HUB Scheduling.

imum time needed to the last nurse perform all the visits and return to the Health Care Center was 260 minutes. The solution obtained have a significant time reduction (109 minutes) when compared to the HUB manual planning, which was 369 minutes.

Table 5 presents the summary of PSO, such as: the best solution obtained in all runs (f^*_{min}), the solution average (f^*_{avg}), the number of different optimal solutions found (Nx) and, finally, the average time to solve the optimization problem (Time$_{avg}$) in seconds.

Table 5: Results obtained by GA and PSO methods.

	f^*_{min}	f^*_{avg}	Nx	**Time$_{avg}$ (s)**
PSO	260	307	3	98

Analyzing the numerical results presented in the previous table, it is possible to verify that the minimum total time found by PSO is 260 minutes, the average of the solutions and the number of optimal solutions. Finally, the average time to solve the problem, that means that PSO finds the problem solution faster. In PSO, it was obtained more than one optimal solution, so the method find different nurses allocation with the same minimum (260 minutes). This allows that the Health Care Center can choose one of those nurses' schedules. To show (in an easy and fast way) the time spent by each nurse, using PSO allocation, and compare it with the related time obtained manually by the HUB, Table 6 list for each nurse (first row), the time needed to finish the home care visits done manually (second row) and the time spent obtained with PSO (third row).

Table 6: Total time spent by each nurse in home care visits.

	Time needed in each allocation	
Nurses	HUB	PSO
1	221	86
2	260	**260**
3	**369**	105
4	212	225
5	86	218
6	90	240
7	241	253
8	70	86
9	194	242
10	90	255
11	240	70
12	183	241

From the above table it is possible to state that with PSO algorithm, the maximum time spent by the nurses never exceeded 260 minutes. In turn, the maximum time spent by the nurses in HUB scheduling is 369 minutes (greater than both computational solutions). On the other hand, an automatic allocation is achieved that allows a better workload balancing, favoring not only the work of nurses but also limiting the waiting time of patients.

7 CONCLUSIONS AND FUTURE WORK

Since, in HUB, home care visits are planned manually and without computational support, this implies that the solution obtained may not be the best one. In this way, and in an attempt to optimize the logistic process, specially in the nurses allocation, it is necessary to use strategies to minimize the maximum time spent by each nurse on home care schedule, without, however, worsening the quality of the provided services and, always, looking for the best schedules organization. Optimization can be used very advantageously in the context of Health Care Centers scheduling for home care aged people visits.

The allocation problem of nurses in the HUB was efficiently solved using the PSO method. Moreover, the optimal solution was found quite fast and that in addition to the verified optimization, providing a better nurses workload balancing. This approach represents a gain for all the involved people, health professionals and patients.

For future work, it is possible to reformulate the problem and take into account a multi-objective approach to minimize not only the maximum time for each nurse, but also minimize the total kms performed and needed by each car, and also minimizing the total cost involved, thus providing strategic, tactical and operational decision-making support.

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