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Computational Science and Its Applications – ICCSA 2017

17th International Conference
Trieste, Italy, July 3–6, 2017
Proceedings, Part III

3 Part III

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Lecture Notes in Computer Science 10406

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Preface

These multiple volumes (LNCS volumes 10404, 10405, 10406, 10407, 10408, and 10409) consist of the peer-reviewed papers from the 2017 International Conference on Computational Science and Its Applications (ICCSA 2017) held in Trieste, Italy, during July 3–6, 2017.

ICCSA 2017 was a successful event in the ICCSA conference series, previously held in Beijing, China (2016), Banff, Canada (2015), Guimarães, Portugal (2014), Ho Chi Minh City, Vietnam (2013), Salvador, Brazil (2012), Santander, Spain (2011), Fukuoka, Japan (2010), Suwon, South Korea (2009), Perugia, Italy (2008), Kuala Lumpur, Malaysia (2007), Glasgow, UK (2006), Singapore (2005), Assisi, Italy (2004), Montreal, Canada (2003), (as ICCS) Amsterdam, The Netherlands (2002), and San Francisco, USA (2001).

Computational science is a main pillar of most present research as well as industrial and commercial activities and plays a unique role in exploiting ICT innovative technologies. The ICCSA conference series have been providing a venue to researchers and industry practitioners to discuss new ideas, to share complex problems and their solutions, and to shape new trends in computational science.

Apart from the general tracks, ICCSA 2017 also include 43 international workshops, in various areas of computational sciences, ranging from computational science technologies to specific areas of computational sciences, such as computer graphics and virtual reality. Furthermore, this year ICCSA 2017 hosted the XIV International Workshop on Quantum Reactive Scattering. The program also features three keynote speeches and four tutorials.

The success of the ICCSA conference series in general, and ICCSA 2017 in particular, is due to the support of many people: authors, presenters, participants, keynote speakers, session chairs, Organizing Committee members, student volunteers, Program Committee members, international Advisory Committee members, international liaison chairs, and various people in other roles. We would like to thank them all.

We would also like to thank Springer for their continuous support in publishing the ICCSA conference proceedings.

July 2017

Giuseppe Borruso
Osvaldo Gervasi
Bernady O. Apduhan

Welcome to Trieste

We were honored and happy to have organized this extraordinary edition of the conference, with so many interesting contributions and participants coming from more than 46 countries around the world!

Trieste is a medium-size Italian city lying on the north-eastern border between Italy and Slovenia. It has a population of nearly 200,000 inhabitants and faces the Adriatic Sea, surrounded by the Karst plateau.

It is quite an atypical Italian city, with its history being very much influenced by belonging for several centuries to the Austro-Hungarian empire and having been through several foreign occupations in history: by French, Venetians, and the Allied Forces after the Second World War. Such events left several footprints on the structure of the city, on its buildings, as well as on culture and society!

During its history, Trieste hosted people coming from different countries and regions, making it a cosmopolitan and open city. This was also helped by the presence of a commercial port that made it an important trade center from the 18th century on. Trieste is known today as a ‘City of Science’ or, more proudly, presenting itself as the ‘City of Knowledge’, thanks to the presence of several universities and research centers, all of them working at an international level, as well as of cultural institutions and traditions. The city has a high presence of researchers, more than 35 per 1,000 employed people, much higher than the European average of 6 employed researchers per 1,000 people.

The University of Trieste, the origin of such a system of scientific institutions, dates back to 1924, although its roots go back to the end of the 19th century under the Austro-Hungarian Empire. The university today employs nearly 1,500 teaching, research, technical, and administrative staff with a population of more than 16,000 students.

The university currently has 10 departments: Economics, Business, Mathematical, and Statistical Sciences; Engineering and Architecture; Humanities; Legal, Language, Interpreting, and Translation Studies; Mathematics and Geosciences; Medicine, Surgery, and Health Sciences; Life Sciences; Pharmaceutical and Chemical Sciences; Physics; Political and Social Sciences.

We trust the participants enjoyed the cultural and scientific offerings of Trieste and will keep a special memory of the event.

Giuseppe Borruso

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ICCSA 2017 was organized by the University of Trieste (Italy), University of Perugia (Italy), Monash University (Australia), Kyushu Sangyo University (Japan), University of Basilicata (Italy), and University of Minho, (Portugal).

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Contents – Part III

Optimal Schedule of Home Care Visits for a Health Care Center

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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 ageing. 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 nurse teams from Health Care Centers. Usually, the visits are manually planned and without computer support. The main goal of this work is to carry out the automatic schedule of home care visits, of one Portuguese Health Care Center, in order to minimize the time spent in all home care visits and, consequently, reduce the costs involved. The developed algorithms were coded in MatLab Software and the problem was efficiently solved, obtaining several schedule solutions of home care visits for the presented data. Solutions found by genetic and particle swarm algorithms lead to significant time reductions for both nurse teams and patients.

Keywords: Genetic Algorithm · Particle Swarm Optimization · Health care services · Optimization · Scheduling

1 Introduction

Advances in health care, declining fertility rates and longer life expectancy have led to an increasing number of elderly people in European society, namely, in Portuguese society. Consequently, the number of people who needs home care services is growing over the years. 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 [11,15].

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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 [2,3,11,14].

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

The schedule of the home care visits provided by the Health Care Centers teams depends on the patients and nurses profiles. This represents a complex problem being its main goal to minimize the time needed, by the nurses team, to perform all the home care visits and return to the Health Care Center. The schedule of the home care visits provided by the Health Care Centers can be seen as a vehicle routing problem with specific conditions [10].

The paper is organized as follows: first, it is given a description of the real problem and its mathematical formulation; then it is presented a summary of the genetic algorithm method (GA) and the particle swarm optimization method (PSO) since they were the selected methods to solve the problem. After, numerical results are presented and a comparison is made between the different algorithms used. Finally, some conclusions and future work ideas are given.

2 Problem Description

For a given day, a Health Care Center need to provide the schedule of all nurses team to perform the tasks inside and outside of the Health Care Center. 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. Then, the main objective of this study is to perform automatic planning of home care visits by a nurses team of a Health Care Center of Bragança (HUB), Bragança, Portugal, aiming to minimize all the time spent by the nurses to perform all home care visits.

This optimization problem, related with the HUB, is formulated and solved as follows.

2.1 Assumptions

In the developed model it was assumed, without loss of generality, that:

- 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.

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 (nurses) that perform home care visits have different profiles, this means that not all the nurses perform all the treatments.
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.
A.7 The number of nurses assigned to a working day is known in advance.
A.8 The time of travel between all the localities is also known in advance.
A.9 All the travels begin and end up in the HUB.

2.2 Mathematical Formulation

Taking into account all the above assumptions for a working day, consider the following general and fixed variables:

- 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.

Another mathematical entities are needed to obtain the final formulation, such as:

- The list of all different treatments and the time needed to perform each treatment.
- The list of the treatments that each nurse can perform.
- The time matrix that presents the time needed to travel between all the different locations.
- The list representing the patient treatment needs.
- The locations of all patients.

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

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

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

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

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 patient p_i, for $i = 1, ..., P$.

2.3 Real Data

It is intended to apply the developed mathematical model to a real problem of the HUB. The data provided by the HUB concern the day April 18, 2016, [1]. The home care services provided by the assigned nurses to this job can be classified into five different treatments (or home care visits) presented in Table 1.

The HUB has twelve nurses designated to perform home care visits during the day in study. Table 2 shows the allocation of the five treatments by each nurse as well as the average time treatment required.

Table 1. Characterization of the different treatments provided by the nurses.

Treatment	Description	Characterization
T.1	Curative	Treatments, for example, pressure ulcer, venous ulcer, surgical wounds, traumatic wounds, ligaments, remove suture material, burns, evaluation and dressing of wound dressings
T.2	Surveillance and Rehabilitation	Evaluation, implementation and patient monitoring
T.3	Curative and Surveillance	Wound treatment, watch over bandage, frequency and tension monitoring, teach and instruct the patient of the complications and pathologies
T.4	Surveillance	Assess risk of falls, self-care, patient behaviors and still the providers knowledge. Monitor, height, tension and heart rate. Patients dietary and medical regimen
T.5	General	Evaluate, support and teach about mourning

Table 2. 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	

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

Each patient, represented in the first column of Table 3 by P(·), required specific medical assistance — one or more different treatments, from the 5 treatments that the nurses can perform.

Table 3. Summary of which kind of treatments each patient needs.

	T.1	T.2	T.3	T.4	T.5
P(1)	X				
P(2)	X				
P(3)	X				
P(4)	X				
P(5)		X			
P(6)		X			
P(7)		X			
P(8)	X				
P(9)	X				
P(10)	X				
P(11)	X				
P(12)	X				
P(13)	X				
P(14)	X				
P(15)			X		
P(16)				X	
P(17)	X				
P(18)					X
P(19)	X				
P(20)			X		
P(21)				X	
P(22)	X				
P(23)	X				
P(24)	X				
P(25)				X	
P(26)				X	
P(27)				X	
P(28)				X	
P(29)				X	
P(30)				X	
P(31)				X	

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

In Table 4, 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.

The time required to travel between two locations is shown in Table 5. It was assigned 15 min to travel between two different places, in the same location.

Table 4. 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

Table 5. 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

Based on all the presented data, the objective is to obtain the nurses 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 Center.

To solve the minimization problem presented in (2), two different optimization methods were used: Genetic Algorithm and Particle Swarm Optimization method.

3 Optimization Methods

Two global optimization methods were used to solve the nonlinear optimization problem defined in (2): Genetic Algorithm and Particle Swarm Optimization method. Both methods are population-based methods and a brief summary of them follows.

3.1 Genetic Algorithm - GA

The Genetic Algorithm (GA) was proposed by Holland [6] and it is based on the theory of the species evolution.

GA is a stochastic method, whose mechanism is based on simplifications of evolutionary processes observed in nature, namely selection, mutation and crossover [5,7,9,13]. As opposed to many other optimization methods, genetic algorithm works with a population of solutions instead of one single solution. In GA, the solutions are combined to generate new ones until a satisfactory solution is obtained, i.e. until the stop criteria is met.

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

Algorithm 1. Genetic Algorithm

1: Generates a randomly population of individuals, $\mathcal{P}^0$, with dimension N_{pop}. Set $k = 0$.
2: **while** stopping criterion is not met **do**
3: Set $k = k + 1$.
4: $\mathcal{P}' =$ Apply crossover procedure in population $\mathcal{P}^k$.
5: $\mathcal{P}'' =$ Apply mutation procedure in population $\mathcal{P}^k$.
6: $\mathcal{P}^{k+1} = NP$ best individuals of $\{\mathcal{P}^k \cup \mathcal{P}' \cup \mathcal{P}''\}$.

The initial population, $\mathcal{P}^0$ consists of N_{pop} individuals, where each one represents a feasible schedule (all constraints are satisfied).

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

3.2 Particle Swarm Optimization - PSO

The Particle Swarm Optimization (PSO) was developed by Kennedy and Eberhart [8] and it is based on natural social intelligent behaviors.

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 Particle Swarm Optimization method also works with a population of solutions and stops when the stop criteria is met [12,16].

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 [4].

The particle swarm optimization method applied in this work is summarized by the following algorithm.

Algorithm 2. Particle Swarm Optimization Algorithm

1: Generates a randomly population of individuals, $\mathcal{P}^0$, with dimension N_{pop}.
2: 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 $k = 0$.
3: **while** stopping criterion is not met **do**
4: Set $k = k + 1$.
5: Update the value of $xbest_i$ for the individual with index i, for $i = 1, ..., N_{pop}$.
6: Update the value of $gbest$ for all population $\mathcal{P}^j$, for $j = 1, ..., k$.
7: Update the individual velocity according to:

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

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

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.

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

4 Results and Discussion

The main objective is to produce the nurses' schedules for the home care visits of the Health Care Center of Bragança for April 18, 2016.

The daily route carried out on April 18 by the Health Care Center of Bragança was made manually, that is, without any mathematical model or subject to computational mechanisms.

The nurses' schedules were collected [1]. Figure 1 presents 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.

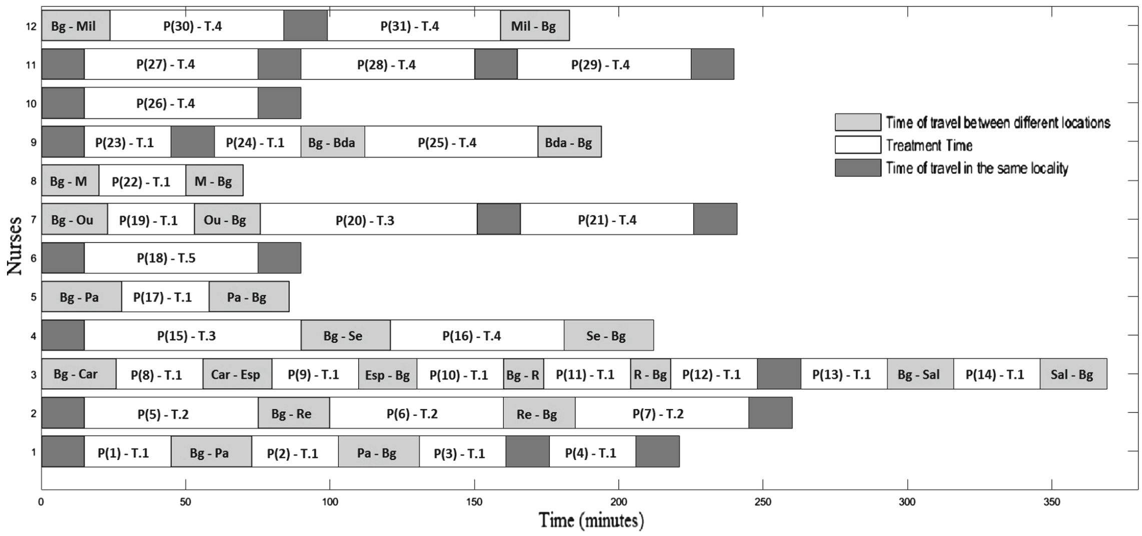

Fig. 1. Schedule carried out by the Health Care Center (manually)

The time needed to each nurse to perform the health treatment is represented by no color. The light gray color show the time of travel between different locations. The assigned 15 min ride between to different houses in the same city is represented by the dark gray color.

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 8 will be: moves from the HUB to the village of Meixedo (Bg - M) to execute the home care visit of Patient 22, that requires the Treatment 1 (P(22) - T.1). After this, the nurse returns to the point of origin, the Health Care Center (M - Bg). For this nurse, the time spent in this home care visit was 70 min.

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.

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

In an attempt to plan the nurses' schedule automatically two computational algorithms were used — GA and 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 $c_1 = r_1 = 2$.

Since the methods used are stochastic methods, 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.

Both methods had 100% of successful rate since they found a feasible solution in all runs.

Table 6 presents the summary of both methods, 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 6. Results obtained by GA and PSO methods.

	f^*_{min}	f^*_{avg}	Nx	Time$_{avg}$ (s)
GA	260	305	5	191
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 both algorithms is the same (260 min), the average of the solutions found is slightly higher in the PSO, and the number of optimal solutions found is higher in GA. Finally, the average time to solve the problem is better in the PSO, that means that PSO finds the problem solution faster than GA.

In both methods, it was obtained more than one optimal solution (three by the PSO and five by the GA), so the methods find different nurses schedules with the same minimum (260 min). This allows that the Health Care Center can choose one of those nurses' schedules.

Figure 2 depicts one obtained solution using GA.

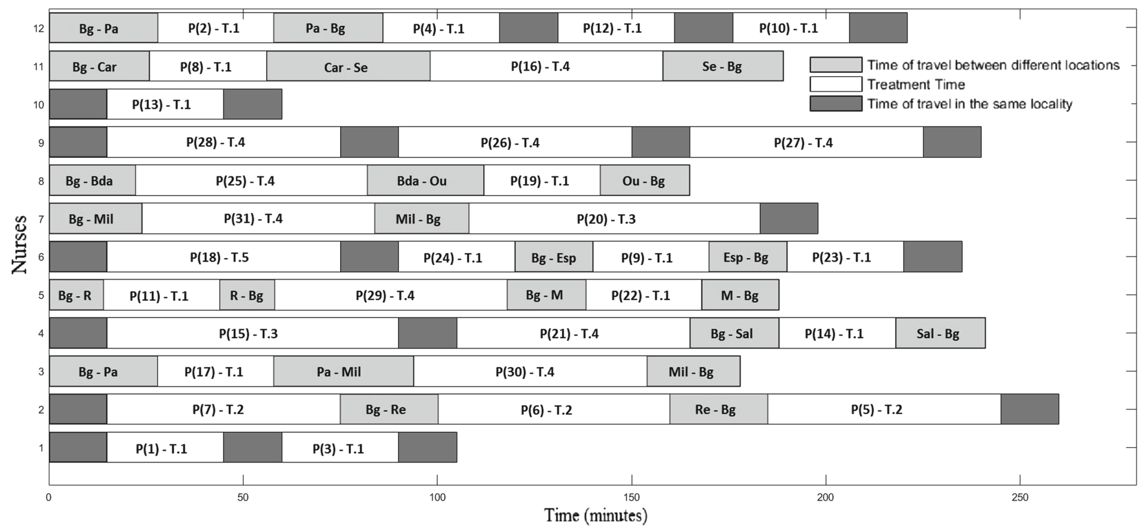

Fig. 2. Optimal nurses' schedules using GA

Analyzing Fig. 2 it is possible to see that the minimum time needed to the last nurse perform all the visits and return to the Health Care Center is 260 min. This value is less than the related value in the manual schedule (369 min). Only two nurses have more than 3 patients — Nurse 6 and Nurse 12. This means that the nurses' schedule produced by the algorithm are more balanced in comparison with the Health Care Center schedule (Fig. 1).

Analyzing Fig. 2, is possible to conclude that all real restrictions are met, accordingly to the data from the Health Care Center.

The next figure, Fig. 3, depicts one obtained solution using PSO algorithm.

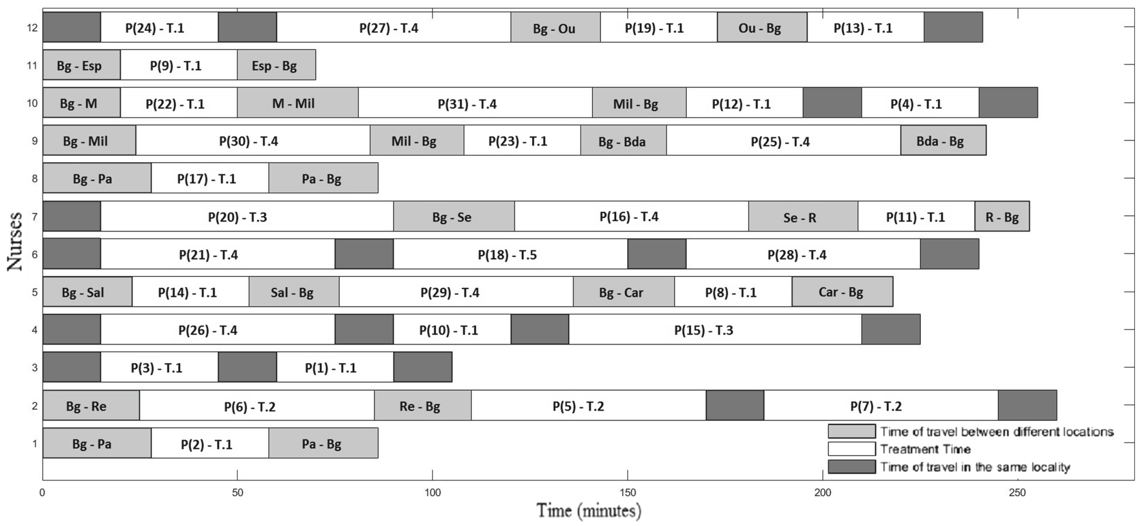

Fig. 3. Optimal nurses' schedules using PSO

From Fig. 3 it is possible to see that the minimum time needed to the last nurse perform all the visits and return to the Health Care Center was 260 min (the same value as the one obtained with GA). Both solutions obtained by both methods have a significant time reduction (109 min) when compared to the HUB manual planning, which was 369 min. However, the GA schedule is more homogeneous than the PSO schedule.

To show (in an easy and fast way) the time spent by each nurse, using both methods, and compare it with the related time obtained manually by the HUB, Table 7 list for each nurse (first row), the time needed to finish the home care visits done manually (second row), the time spent obtained using GA (third row) and the time spent obtained with PSO (fourth row).

Table 7. Total time spent by each nurse in home care visits.

	Nurses											
	1	2	3	4	5	6	7	8	9	10	11	12
HUB	221	260	369	212	86	90	241	70	194	90	240	183
GA	105	260	178	241	188	235	198	165	240	60	189	221
PSO	86	260	105	225	218	240	253	86	242	255	70	241

From the above table it is possible to state that with both algorithms, the maximum time spent by the nurses never exceeded 260 min. In turn, the maximum time spent by the nurses in HUB scheduling is 369 min (greater than both computational solutions).

4.1 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 process, it is necessary to use strategies to minimize the maximum time spent by each nurse on home care routes, 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 scheduling problem of nurses in the HUB was efficiently solved using the GA and PSO methods. Moreover, the optimal solution was found quite fast. 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 the number of vehicles available in the Health Care Center and use multi-objective approach to minimize not only the maximum time for each nurse, but also the total time spent by all nurses.

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