Solving a Home Health Care Routing Problem through Iterated Local Search: the real case of Ferrara

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Abstract. *The Home Health Care Routing Problem (HHCP) consists on the following: given a set of medical services requested by a set of patients and given set of the available nurses that can perform the service, the problem consists on assigning the patients to the nurses and creating routes to visit them, with the objective of minimizing costs and maximizing service quality. In this paper the problem is first described, then an algorithm based on Iterated Local Search (ILS) is developed and applied on a set of instances based on a real situation localized in the city of Ferrara, Italy. Results are the presented and compared to results obtained in previous work.*

1 Introduction

Home Health Care (HHC) service consists of assistance provided by medical staff, such as nurses, physical therapists and home care aides, to people with special needs, for example old adults, chronically ills or disabled people.
The main reasons for the development of HHC service are basically two: the service quality and the cost. The quality of life perceived by patients who stays home is higher than if they stay at the hospital. And for other side, a patient in a hospital has a high cost to the community, so the main benefit of the Home Health Care service is the significant decrease in the hospitalization rate that leads to a cost reduction in the whole health system. This is particularly relevant if the patient needs service only a few minutes a day, a common case for a high number of patients.
During the last decade the Health Care service industries experienced significant growth in many European countries due to the governmental pressure to reduce healthcare costs, the demographic changes and the development of new services and technologies. To take into account these challenges, Health Care decision problems have to be solved for Home Care Services by rigorous methodologies involving Operations Research and Computer Science techniques. For a relevant survey in the applications of Operations Research to Health Care see Rais and Viana (2011). Recent works in Home Care can be founded in Fikar and Hirsch (2015) and Fikar et al. (2016).
Planning nowadays is still mostly done by hand, usually by experienced nurses. But the fast growing of requests makes this procedure more complex and difficult. It can be observed that Home Health Care is an optimization problem with many constraints often depending on specific cases and with the objective of finding a feasible solution while minimizing costs and maximizing the service quality. A good solution to Home

Health Care Problem (HHCP) has to satisfy all the requests with the constraints of available human resources and working time limit, and at the same time has to obtain some goals such as the minimization of costs, the maximization of loyalty between nurse and patient and the balance of workload between nurses. In the present work, we used a weighted function on both objectives and also output all non-dominated solutions.
In this work we propose an Iterated Local Search (ILS) algorithm to solve the HHCP, with a particular application of this service in the city of Ferrara, Italy. The case in Ferrara has already been used as real case study for the HHCP in Cattafi et al. (2012) and in Boccafoli (2012). The main contribution of this work is to take a multiobjective approach to the problem, not only minimize costs but also maximize loyalty among nurses and patients; as well design a simple and equal efficient algorithm to solve the problem.

2 Description of the Home Health Care Problem

The goal of this work is to model and solve the Home Health Care Problem focusing in nurse scheduling and in particular observing the case in the city of Ferrara, Italy.
Home Care service is generally activated by the doctor assisting a patient and therapies are decided with nurses.
From a mathematical point of view what we have is a set R of weekly requests and a planning horizon H of one week divided in days h, from Monday to Sunday. Each request must be performed on a specific patient p who is linked with a specific address. We also know the distance $d_{pp'}$ between two different patients, expressed in time, and the time needed to go from hospital to a specific patient, and to return from this patient to hospital. A request consists in a service s needed from a specific patient. One patient may need more than one service and each service has a given requested frequency during a week. So every patient has to be treated respecting his/her care plan, which includes the number, the type and the sequence of visits that he or she should receive. So for each request of service the frequency f_s, i.e. the number of times the service must be performed during week is given. We have to observe that for each service a minimum number of days e_s must pass between two repetitions of it. The duration a_s, i.e. the estimated time to perform a service s, is also given. Another aspect that must be considered is that each patient has a different set of available days on which a nurse can visit him/her, so a request can be performed on a specific day only if the patient is available on this day.
Services are provided by a set of nurses, each nurse works 5 days a week and he/she has the same fixed working time a day, that we consider of 8 hours, each additional minute is considered as extra work. Every day each nurse starts from the hospital, travels by car from one patient's home to the next and finally returns to the hospital.
As Ferrara is a medium-size town (about 150.000 inhabitants), the considered area is rather large and its population ageing. Although most of the population is concentrated in town, a number of elderly people live in the countryside. For these reasons the service is characterized at the same time by high variance of duration and significant geographical dispersion of the requests. HHC structure provides a weekly visit plan for all its operators. Each nurse has to know the patients to be visited, the type of service to per-

form and the order and the day of the visit.
It is crucial to deliver the service in a cost effective manner while not deteriorating service quality, so we have two different objectives: minimize service total costs and maximize service quality. The costs are related with normal and extra hours of the nurses, where extra hours are paid more and should be avoided. So a good solution should achieve the minimization of the travel times over the service times. On the other side, the service quality is measured in terms of loyalty. The loyalty is related to the relation between patient and nurse, a patient feels more comfortable if the same operator visits him or her. For this reason we have to minimize the number of different nurses who visit one patient.

3 Solving HHCP using Iterated Local Search

The HHCP problem can been seen as a generalization of the well-know Vehicle Routing Problem and therefore it is an NP-hard. The planning process Home Health Care requires to satisfy a large number of constraints related with the medical characteristics nurses conditions, and objectives, regarding both the efficiency of the system and the quality of the care. In addition we have to consider that in each planning period a new set of patients has to be considered. Boccafoli (2012) proposed exact methods that could only solve small instances, and also *Adaptive Large Neighborhood Search* based metaheuristics to solve the problem.
Due the large-scale and complexity of the real problem, the best way to approach to this problem is by using Metaheuristics approaches. In this work a metaheuristic based on Iterated Local Search to solve the HHCP is proposed. The Iterated Local Search (Lourenço et. al (2003, 2010) is a simply but efficient method to solve difficult and complex optimization problems, like the one treated in this paper. Due to its flexibility ILS seems to be a good choice to be adapted to different problem and also to be extended in order to be applied on stochastic and multiobjective problems.

To design an ILS to solve a specific problem four components must be defined:

- *GenerateInitialSolution*
- *LocalSearch*
- *Perturbation*
- *AcceptanceCriterion*

In the following all the components of the developed ILS method are described.

3.1 Initial Solution

Before starting with the initial solution algorithm we have to introduce some elements that must be generated.

- CostMatrix : matrix of costs between two different requests r and r'. Each element in the matrix expresses the cost to go from patient p to patient p' performing respectively services s and s', so $c_{rr'}$ is equal to the distance $d_{pp'}$ plus the time needed to perform service s', $a_{s'}$. Note than both distances and costs are expressed in time. In this matrix is included the time to go to a patient from the hospital and to come back to it considering $a_0 = 0$.
- Priority Matrix : matrix of N_r rows and 7 columns. For each request a vector of seven elements is created. $priority_r^h$ is equal to:
  - 0 if requested service s is not available on day h;
  - 1 if requested service s is available on day h but it is not urgent, i.e. h is not the last day during which service s can be performed;
  - 2 if requested service s has $f_s = 1$ and h is the last day during which it can be performed or if service s has $f_s > 1$ and h is the last day during which it can be performed considering that it must be repeated f_s times with e_s days between each repetition.

The initial solution method is based on the Clarke and Wright algorithm, a procedure designed for the Vehicle Routing Problem. The algorithm is based on the concept of savings. Given two routes we can evaluate how much we can save by *merging* these two, i.e. joining them. The propose initial solution's algorithm is a modified version of the original one. In fact we add the condition that two paths can be *merged* only if the total cost of the new paths is less than the maximum working time.
The algorithm for the initial solution is presented below. The algorithm works in a sim-

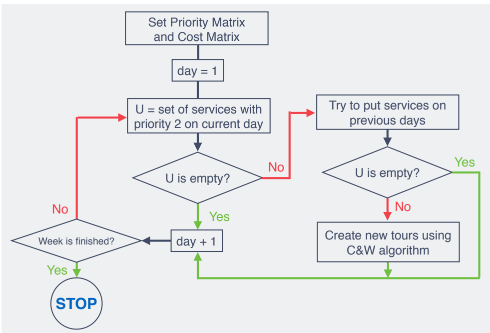

Fig. 1: Initial Solution algorithm for HHCP

ple and fast way to find a feasible initial solution. It starts evaluating the cost matrix and

the priority matrix as explained before. Then for each day *h* a subset of services *U* with priority 2 on that day is found. If the set is empty we go on to the next day, otherwise, if we are not on Monday, we try to put the services in *U* in the previous days.
This part evaluates, for each service in *U*, if there is a previous available day in which we can perform this service; if we find a day we try to put the service in one of the paths of this day prefering a path where other services of the same patients are perfomed or where it costs less performing the considered service, avoiding extra working time, otherwise if the number of paths is less than the number of available nurse, a new path is generated.
After this operation (or if we are on Monday), if the set *U* is not already empty it means that the algorithm has not been able to put all the services in the set on previous days because the nurses are all already full. To optimize the distribution of these services in tours, we can use a modified Clarke and Wright algorithm, obtaining a set of optimized paths with costs lower than 8 hours. The decision of applying the modified Clarke and Wright algorithm only on a small subset of services is due to minimize the needed computational times. A problem that we can have is to find a number of paths that is greater than the number of available nurses on this days, this can happen especially on Saturday or Sunday when the number of nurses is low. In this case we have to split some paths on the others, to make it faster and to have lower costs we split the shortest paths.
Times needed to find the initial solutions are very low: less than 0:10 seconds for each instance.

3.2 Local Search

In this section we present the *Local Search* method that uses a combination of different move operators. All the used operators can be summarized in one: the operator *move*. This operator consists in taking a service from a given tour on a given day and put it in another tour in the position where it costs less. The difference between operators is the criterion used to select from which nurse, from which day or from which tour we are going to take the service to be moved, or which service we choose, and to which nurse and which tour we move it.
All operators can move a service only if constraints about available days and days to wait between two repetitions of the same service are satisfied.
Four different operators are used:

- **M1: from an overloaded nurse to an underloaded one**.
  This operator is chosen in order to minimize the maximum average of working time between all nurses. We select the nurse with higher average of working time and we move one service from this nurse to another one with a lower average of working time.

- **M2: from a nurse with less services of patients p to another one with a lot of services of him/her.**
  This *move* is chosen in order to maximize the loyalty, i.e. to have for each patient the lowest number of different nurses visiting him. In this case the service to be

moved is chosen in a different way: we evaluate for a patient *p* how many nurses visit him during the week and how many services each nurse does to this patient. We order the nurses considering the number of services each nurse does to patient *p* and we try to move all the services of the nurse with lower number of services, of the considered patient, to the ones with higher. In this case the services to be moved are fixed but we still have to choose to which nurse and to which tour move them. In the same way as before we start with the nurse with highest number of services and we evaluate for each tour and position which is the best place where to put the observed service and we move it only if the cost of the resulting tour is less than the maximum working time. If no place is found we try to move the service to the following nurse in the order and so on.

– **M3: from an overloaded nurse to an underloaded one serving the same patient.** This *move* is chosen in order to maximize the loyalty without penalize the costs. It works in the same way as M2 but this time nurses are ordered observing the average of working time during the week.
– **M4: from the longest tour to another one.** We have to remember that sometimes the initial solution generates an extra work *w* that must be avoided to not have high costs. With the operator M4 we try to reduce this extra work time, because sometimes the operator M1 is not sufficient. This operator works in a very easy way taking a service from the tour that exceed more the maximum working time and putting it in another tour. Obviously both the service and the position where to put it are chosen with the goal of minimizing the cost and not exceeding the maximum working time.

In the Local Search method, the move (neighborhood) is chosen in order to be fast and to find a solution that is a compromise between the different objective functions we have to consider. The algorithm works starting from the initial solution and trying to improve it. At the beginning it checks if the extra work time is bigger than 0, if yes operator **M4** is used. Then it tries to make the maximum average of working time between all nurses lower with a maximum of 50 *move*, i.e. it uses operator **M1** until there are not more improvement or the maximum number of iteration is achieved. Then it uses functions operator **M2** and operator **M3** for each patient. The algorithm stops when for two consecutive iterations we obtain the same results or if the number of iterations is bigger than 15.

3.3 Perturbation

The perturbation is based on a random destroy-construct approach using a Geometric distribution function.
After several tests we decide to make the perturbation removing all the services of a set of patients and inserting them again in the order they have been removed. Of course we have to choose a criterion for selecting patients and for deciding where to put the services again in the tours.

After running the *Local Search* and selecting the best solution found so far, we have for each nurse on which day and in which tour a patient has to be visited. Observing that the loyalty is the most critical part of the objective function the idea is to sort all patients on increasing loyalty and then took the 20% of them, the index of the removed patients are chosen according to a Geometric distribution. In this way patients with lowest loyalty have an higher probability to be taken. Then all the services of these patients are removed from the tours and reinserted in the places where they cost less.
Of course, removing and reinserting services, we have to consider the availability of the services, the frequency and the waiting time between two repetitions.

3.4 Algorithm: ILS for HHCP

Connecting all the sub parts explained in the previous sections we can now formulate the final algorithm to apply ILS method to HHCP.
The selected stopping criterion is a maximum running time that is set at $TimeLimit = 1500s$.
For the Acceptance Criterion all the solutions found after the perturbations are always accepted so we do not put the part for the acceptance criterion in our algorithm. The reason under this choice is to have a strong diversification that can be useful in anticipation of considering the HHCP as a multiobjective problem introducing in the algorithm the concept of Pareto frontier.

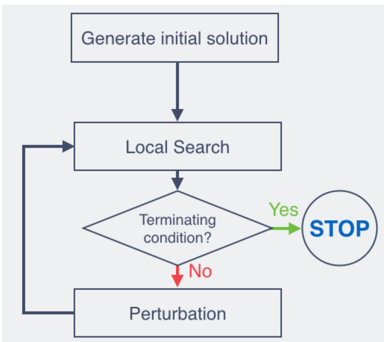

Fig. 2: ILS algorithm for HHCP

4 Application to a real case: results

To test the algorithm, we have considered real data make available by the ASL of Ferrara, Italy. This data represents the historical of requests R during February 2010, i.e. a period of four weeks.The total number of nurses available in that period were 13 and each of them can work 5 days per week. The number of available nurses from Monday to Friday is 12, it becomes 4 on Saturday and 1 on Sunday.
In Figure 3, we can see the number of requests for each day and each considered week. As we can see, the number of requests during the weekend is lower than during the weekdays.
A list of type of services with their duration is also given. There are 42 different types of service can be performed, a treatment lasts from 5 to 60 minutes, depending on its specific characteristics. In Figure 4, the number of services that need a specific duration are shown.

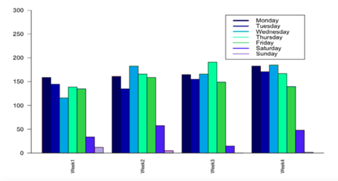

Fig. 3: Histograms of the number of requests for each day of the week from real data

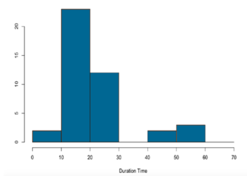

Fig. 4: Number of services that need a certain ammount of time

From these real data 60 instances were generated in Boccafoli (2012). These instances are generated starting from the historical data.
For each request the type of service, the patient who needs this service, the requested frequency f_s and the expectation days e_s between two repetitions of the services are specified. One patient may need more than one service during the week and each patient has a different given availabile days on which his/her request can be performed.
The average number of patiens and requests between instances are respectively:

- Patiens: 228.4;
- Requests: 778.9.

From these values we can conclude that the mean number of request for each patient during the week is 3,4.
The applied algorithm consists in about 900 Python lines and it is ran on a laptot with the following characteristic: 2GB of RAM and processing speeds of 1067 MHz.
For each instance the time limit is set at 25 minutes.

The results found applying the ILS algorithm on instances, first after using the *InitialSolution* algorithm, then after using the ILS method, are now presented. It can be observed the improvement of results before and after using the metaheuristic, considering costs, expressed in time, loyalty, in terms of total sum of different nurses visiting the same patient, and the total objective function that is the sum between costs and loyalty. The shown values are the average of results obtained on each instance.
The results obtained by ILS can be also compared to previous results found in Boccafoli (2012) applying *Adaptive Large Neighborhood Search* algorithm on the same instances and with the same time limit. As it can be noticed in Figure 6 the average value of the objective function obtained after applying the Iterated Local Search algorithm are more or less the same than the one obtained using the ALNS, even this is a weighted function. With respect to the cost function, ILS obtains better results than the ALNS. For the loyalty objective function, the situation is different, but we are already working in a better ILS that deals with the multiobjective model directly without taking into account the weighted sum of objective functions.

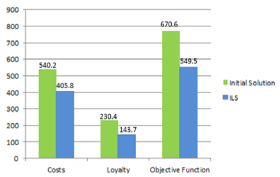

Fig. 5: Comparison Initial Solution and ILS

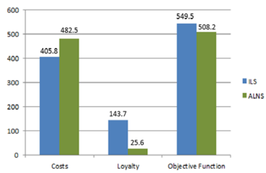

Fig. 6: Comparison ILS and ALNS

5 Conclusion

The HHCP is a realistic complex problem with a significant amount of constraints that have to be considered and the main objective functions are the minimization of costs and the maximization of service quality in terms of loyalty between nurse and patient. The problem is NP-hard, as it is a generalization of the Vehicele Routing Problem. We propose an Iterated Local Search based metaheuristics, that seems to be a good choice as it is a simple but efficient method to solve complex optimization problems.
The developed algorithm is applied to solve HHCP using 60 different instances generated by previous work from historical data and solutions are compared to solutions obtained using ALNS algorithm on the same instances. The idea of using ILS algorithm to solve the HHCP seems interesting as obtained results are good. This method also has the advantage to be simpler to generalized to a multiobjective problem not only considering the nurse loyalty but also optimizing the balance of workload between nurses.
Another issue that it will be relevant to explore is the introduction of stochasticity, on services and travel time. As ILS is simple and flexible algorithm it can be adapted on both these different development of the problem.

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