A Home Care Scheduling Model For Human Resources

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ABSTRACT

Home Care service is recognized to be one of the major solutions to contain costs in health care. However delivering this service is not an easy task because of the large number of actors that participate in the process, of the variety of clinical and organizational decisions, and last but not less important, of the difficulty of synchronizing human and material resources at patient's home. In this paper we propose a linear integer scheduling model developed to support human resource short term planning in home care. In particular, the model deals with the problem of deciding (a) which human resource should be used and (b) when to execute the service during the planning horizon, in order to satisfy the care plan for each patient served by the Home Care providers. The scheduling model has been tested on different real data sets collected from two Italian Home Care providers. The weekly plans generated by the proposed model have been compared with the real ones. The main result is a significant benefit, in terms of the increase in service quality and in efficiency, obtained by using operations research techniques in the home care short term planning.

Keywords: scheduling, home care, short term planning, linear programming.

1. INTRODUCTION

Home Care (HC), defined as "*medical and paramedical services delivered to patients at home*" [1], is a service generally provided to elderly and terminal patients with the aim of maintaining or improving their life conditions. However HC services may be applied to other patients categories such as children, post-surgery patients, people hit by cerebral ictus, etc. The main benefit of the Home Care is the significant decrease in the hospitalization rate that leads to costs reduction in the whole health system [2,3].

The HC service first requires the definition of care plans on the basis of the patients needs, then the execution of these plans paying attention to coordination and management of human resources (i.e. nurses, doctors, physiotherapists, social assistants, volunteers) and materials (i.e. drugs, equipment, devices, etc). The service is generally defined and delivered by taking into account the satisfaction level of patients, the service cost and the resource constraints [4]. The activities of defining and delivering the care plan are executed by the multi-evaluation unit and the service provider respectively, not necessarily in the same structure [5]. In this paper, HC providers dealing with care plan execution are considered.

Material and resource planning for HC providers is a core activity because of the peculiarity of the home care service, i.e. the care is delivered at patient's home with all the necessary resources. Unfortunately, planning in HC is made difficult by several practical reasons:

- the service involves patients whose clinical and social conditions may change quickly;
- the large number of procedures and protocols to be followed decreases the flexibility of providers' organization;
- patients may be spread in a wide area.
- the synchronization of resources is relevant to provide the service in an effective and efficient way because service cannot be stored;
- the respect of the time tables required in the care plans may be particularly important for the patient safety;
- providers do not have adequate skills to optimally plan materials and resources because of the lack of an engineering culture in the staff.

HC planning is run on different levels, regarding long, medium and short period [4]. In particular, the goal of the *short term planning* in HC is to determine the weekly visit plan for each operator and each material resource, in order to respect the patient's care plan in an efficient way.

In this context, the development of a short term planning support tool for HC providers can be considered a useful tool to support decision making. This is therefore the aim of this work, that focuses on the development of a human resource short term planning tool.

This paper is divided into three parts: the service environment is presented in Section 2, the mathematical description of the developed model in Section 3 and the application of the scheduling model to two different real cases in Section 4. Conclusions and further developments are then stated in the last section.

2. SERVICE DESCRIPTION

Every patient in HC service has to be treated respecting his care plan, which includes, among others, the number, the type and the sequence of visits that the patient should receive. To provide this service, a HC structure has to coordinate its resources, especially the human ones as the service is human intensive. In most cases, the HC structure provides a weekly visit plan for all its operators, pointing out which patient each operator has to assist, what kind of visit he/she has to execute and possibly when, specifying the day and the hour. Experienced nurse coordinators are usually responsible for this short term planning process.

Human resource short term planning can be hierarchically divided into four phases. First of all, nurse coordinators have to assign the care of every patient to an operator, considering his workload, the particular skills that the operator should have in order to satisfy the patient's needs and the travel distance of the operator for reaching the patient's home. The assignment patient-operator can be revised periodically depending on the specific needs. Some HC providers often consider as a quality objective the concept of *continuity of care*, for which the assigned operator becomes the reference figure for the patient during the whole duration of the care plan. The assignments during the patient care should be therefore changed as less as possible; this is also the case considered in this work. The second phase of the planning process is to define the days in which each operator should visit the assigned patients during the week. The third phase is to set the visits time in every day of the week for each operator; the last phase is the management of unpredictable events that may occur during the week.

During planning decisions, coordinators have to take into account many factors that can influence the quality service level and the internal efficiency of the organization. Continuity of care is one of the most important quality factors to be considered during the planning process.

In order to avoid a low level of patient satisfaction, planners have to keep under control also the number of *outsourced visits*: they could ask the family, or more generally the caregiver[1], to execute some simple care activities on the patient. The outsourcing of the service to the caregiver must be avoided and it may derive only from the impossibility of the HC structure to execute the care activities.

The respect of the *preferential days* can also allow nurse coordinators to reach a better service quality: according to the frequency of visits defined in the patient's care plan, nurse coordinators define the plan of the visits during the working week that is preferred by the patient (e.g. if a patient has to be visited 3 times a week, Monday, Wednesday and Friday may be the preferential days).

The provider efficiency can be improved by planners respecting the *geographic coherence*, that is avoiding to assign a visit to an operator who comes from a geographic area different from that of the patient.

Furthermore, nurse coordinators try to balance the workload among operators, considering also the presence of a particular pathology that may affect them: the *burn out syndrome*. For each operator a *burn out level* can be defined for synthesizing the stress level caused by the interaction with the patient and his family; it is an illness that impacts on the mood of the operator affecting his working standards. The nurse coordinators have to take into account the burn out level thanks to the personal acquaintance with their colleagues.

[1] A person who lives with the patient and can contribute to the execution of care plan activities; he/she has to be trained in these activities by nurses [5].

3. MODEL DESCRIPTION

Few works about short term planning of human resources in HC can be found in scientific literature. Bertels and Fahle [6] presented a model to solve the assignment and scheduling problems at the same time, comparing different mathematical solutions of this problem; Eveborn et al. [7] dealt only with scheduling, considering the care continuity as a constraint and using a repeated matching method; Begur et al. [8] developed optimization models for scheduling through Integer Mixed Programming and, above all, for routing by comparing some heuristic procedures.

The solution presented in this paper allows to adapt technical methods used in industry to the HC service. A hierarchic structure, composed by assignment and scheduling models and similar to the one used in the industrial planning, is proposed. The mathematical models are developed by using integer linear programming techniques.

Routing problem, i.e. deciding the best routes for operators considering the real travel distances, and the dispatching problem, i.e. the fourth phase in the proposed hierarchical approach for the HC short term planning, are not tackled in this work.

3.1 Assumptions and notations

Assumptions at the base of the two models as well as the notation used in the scheduling model are described below.

Indexes

Indexes used in the models' expressions are defined as:

Patient i: $1 \ldots N$ with N number of patients.

Operator j: $1 \ldots M$ with M number of operators.

Week w: $1 \ldots W$ with W number of considered weeks.

Day d: $1 \ldots D$ with D number of working days in a week.

Hour h: $1 \ldots H$ with H number of time windows in a day.

General assumptions

- The care plan has a finite horizon of two weeks ($W=2$).
- Discrete time is assumed.
- Only one reference operator can be assigned to one patient. This assignment parameter is expressed as r_{ij} and assumes the following values: 1 if operator j is the reference one for patient i; 0 otherwise.
- Temporary re-assignment of patients to other non reference operators is considered in the scheduling model.
- Only one visit in one day can be executed on the same patient.
- Visits have a deterministic and constant duration T.

- Travel times are included in the visit duration *T*.
- Constrained visits are considered[2] and expressed as v_{iwdh}, which assumes the following values: *1* if patient *i* needs a constrained visit during week *w*, on day *d*, hour *h*; *0* otherwise.
- The possibility of outsourcing visits to patient's caregiver is considered. According to caregiver's skills, the parameter f_{iwd} is defined with the following values assumed: *1* if it is possible to outsource to the caregiver the visit to patient *i* on week *w*, on day *d*; *0* otherwise.
- Preferential days of visits are considered in the parameter g_{id}, which assumes values: *1* if day *d* is a preferential day for patient *i*; *0* otherwise.
- Unforeseen events, such as operators' sudden unavailability or changes in patient's conditions, are not considered.

Operators' availability
- Operators can have full-time or part-time contracts; this can be expressed through the parameter c_{jdh}, which assumes the following values: *1* if operator *j* is available by contract during day *d*, hour *h*; *0* otherwise.
- Operator's availability, not depending by contract, is considered. An operator can be unavailable because of holidays, meetings, training courses or long illness. It is expressed as a_{jwdh} and assumes values: *1* if the operator *j* is available during week *w* on day *d*, hour *h*; *0* otherwise.

Service quality and efficiency assumptions
- Coherence between operator's skills and patient needs. Operators skills are expressed as s_{jk} assuming the following values: *1* if operator *j* has the skill *k*; *0* otherwise. Patients' needs are expressed with n_{ik} and assume the following values: *1* if patient *i* requires care *k*; *0* otherwise.
- Coherence between operator and patient geographic areas. This is expressed as l_{ij} and assumes the following values: *1* if patient *i* and operator *j* belong to the same geographic area; *0* otherwise.
- The impact of a patient on the burn out level of the operator assigned to him is considered. Parameter q_i is the impact of patient *i* on operators' burn out; b_j is the burn out level measurement of operator *j* at the moment in which schedule starts. Parameter m_j is the maximum burn out threshold operator *j* can tolerate.

Decision variables
- The variable x_{ijwdh} indicates a visit to patient *i* assigned to the operator *j* at a determined period, and it assumes the following values: *1* if the visit is carried out by the operator *j* to patient *i* during week *w*, day *d* at hour *h*; *0* otherwise.
- The variable y_{iwdh} expresses the decision to outsource or not the visit and it assumes the following values: *1* if the visit to patient *i* during week *w*, day *d*, hour *h* is outsourced to caregiver; *0* otherwise.

3.2 Assignment model

The assignment model runs when one or more new patients enter the system in a rolling approach. Its output is the assignment of each patient to a reference operator. The goal of this model is to balance the operator's workload in the following weeks.
The assignment problem can be compared to the workload balance problem found in the industrial planning. Traditional techniques and models can be used to solve the assignment problem [9]. For this reason, this model is not presented in detail in this paper, but only two characteristics are pointed out.
In order to avoid infeasibilities during the assignment, it can occur that a reference operator has to be assigned to a patient living in a different geographic area. For this reason, a penalty *Cg* was introduced in the objective function to minimize these events.
The peculiarity of the assignment model is in the consideration of the constraint concerning the respect of the operator's *burn out* level. At the moment, the burn out level that each operator can tolerate and the contribution of each patient on the operator's burn out are not easy to be determined. In fact it is not possible to find in literature standard scales that can link a burn out score for a patient (considering clinical and social conditions) with the burn out level of a specific operator. Scales used in this work are therefore based on professionals' assumptions.
The output of the assignment model represents an input of the scheduling problem.

3.3 Scheduling model

The scheduling model has the goal to develop the weekly plan (i.e. day and time) of visits for each operator, taking as input the output of the assignment model (the link patient-reference operator). The main objectives that can be pursued during the HC scheduling process are:
1. To minimize the number of visits outsourced to the patient's caregiver.
2. To minimize the number of visits carried out by non reference operators who belong to the same geographic area of the patient.
3. To minimize the number of visits carried out by a non reference operator who comes from a geographic area different from that of the patient.
4. To minimize the number of visits carried out during non preferential days.
5. To concentrate visits in the first part of the day to enable operators to focus on administrative activities after the therapeutic ones. This objective has an impact on the service efficiency because

[2] A constrained visit has to be executed in a fixed time (day and hour) as the patient needs a particular therapy.

operators generally execute during the day both the activities, but respecting priorities of their work.

Objective function:
All the objectives previously described are included in the multi-objective function. Penalties have been assigned to the events that have a negative impact either on the patient satisfaction level or on the structure's efficiency. The penalties have to be chosen according to each specific structure strategy. The objective function is expressed as:

$$\min \sum_{i=1}^{N}\sum_{j=1}^{M}\sum_{w=1}^{W}\sum_{d=1}^{D}\sum_{h=1}^{H} x_{ijwdh}\cdot\left[h+(1-r_{ij})\cdot Cs+(1-r_{ij})\cdot(1-l_{ij})\cdot Cg+(1-g_{id})\cdot Cp\right]+ \sum_{i=1}^{N}\sum_{w=1}^{W}\sum_{d=1}^{D}\sum_{h=1}^{H} y_{iwdh}\cdot Cd \qquad (1)$$

where h, Cs, Cg, Cp and Cd are penalties associated to each objective. Parameter h is the penalty associated to the objective of concentrating visits in the first part of the day; its value corresponds to the time windows index. Cs is the penalty for visits carried out by non reference operator due to a temporary re-assignment; Cg is assigned for the violation of the geographic coherence due to a temporary re-assignment; and Cp for visits carried out during a non preferential day; Cd is added if an outsourced visit occurs. Generally, Cd assumes the largest value.
The value definition of these penalties can be difficult, because they have to translate in an unbiased and quantitative way some quality objectives subjectively defined by the HC structure's management. For this reason, a sensitivity analysis should be executed in order to evaluate the impact of penalty variations on the weekly scheduled plan. First numerical results show that the weekly scheduled plan may be sensitive to the chosen penalty values depending on the particular situation of resource capacity and patient requests. For this reason, the use of a decision tool, as for example the Analytic Hierarchy Process [10], is suggested in order to estimate the values of these penalties.

Model constraints:
Three main sets of constraints about service level, respect of operators' contracts and coherence of the model are defined.

Discrete time period constraints
In each time window at maximum *(time window/T)* visits can be scheduled. It is expressed as:

$$\sum_{i=1}^{N} x_{ijwdh} \leq \frac{timewindow}{T} \qquad \forall j, w, d, h \qquad (2)$$

Constraints to respect the operator's contract conditions

- The operator can visit patients only in the time periods of his/her contract:
$$c_{jdh} \geq x_{ijwdh} \qquad \forall i, j, w, d, h \qquad (3)$$
- The operator can visit patients only in the time periods in which he/she is available:
$$a_{jwdh} \geq x_{ijwdh} \qquad \forall i, j, w, d, h \qquad (4)$$

Constraints to guarantee the quality of the service

- All visits must be planned:
$$\sum_{j=1}^{M}\sum_{d=1}^{D}\sum_{h=1}^{H} x_{ijwdh} + \sum_{d=1}^{D}\sum_{h=1}^{H} y_{iwdh} = e_{iw} \qquad \forall i, w \qquad (5)$$
Where e_{iw} is the number of visits to be executed during the week w, according to the care plan of patient i.
- Maximum one visit to each patient can be executed every day:
$$\sum_{h=1}^{H}\left(\sum_{j=1}^{M} x_{ijwdh} + y_{iwdh}\right) \leq 1 \qquad \forall i, w, d \qquad (6)$$
- Constrained visits must be respected:
$$\sum_{j=1}^{M} x_{ijwdh} + y_{iwdh} \geq v_{iwdh} \qquad \forall i, w, d, h \qquad (7)$$
- The operator's skills must answer to the patient's needs:
$$s_{jk}\cdot x_{ijwdh} \geq n_{ik}\cdot x_{ijwdh} \qquad \forall i, j, w, d, h, k \qquad (8)$$
- A visit can be outsourced only if the caregiver has the required skills:
$$\sum_{h=1}^{H} y_{iwdh} \leq f_{iwd} \qquad \forall i, w, d \qquad (9)$$
- Burn out threshold for every operator has to be respected:
$$b_j + \sum_{i=1}^{N}\sum_{w=1}^{W}\sum_{d=1}^{D}\sum_{h=1}^{H} x_{ijwgh}\cdot q_i \leq m_j \qquad \forall j \qquad (10)$$

From the results obtained by the scheduling model, factors considered by the nurse coordinators during the planning (see Section 2) can be used as *quality indicators* of the service of a HC provider. A mathematical description of these indicators is provided in Table 1.

Service level	
Care Continuity (CC)	$\dfrac{\sum_{i=1}^{N}\sum_{j=1}^{M}\sum_{w=1}^{W}\sum_{d=1}^{D}\sum_{h=1}^{H}(x_{ijwdh}\cdot r_{ij})}{\sum_{i=1}^{N}\sum_{j=1}^{M}\sum_{w=1}^{W}\sum_{d=1}^{D}\sum_{h=1}^{H} x_{ijwdh}}\cdot 100$
Outsourced Visits (OV)	$\dfrac{\sum_{i=1}^{N}\sum_{w=1}^{W}\sum_{d=1}^{D}\sum_{h=1}^{H} y_{iwdh}}{\sum_{i=1}^{N}\sum_{w=1}^{W}\sum_{d=1}^{D}\sum_{h=1}^{H} y_{iwdh} + \sum_{i=1}^{N}\sum_{j=1}^{M}\sum_{w=1}^{W}\sum_{d=1}^{D}\sum_{h=1}^{H} x_{ijwdh}}\cdot 100$
Preferential Days (PD)	$\dfrac{\sum_{i=1}^{N}\sum_{j=1}^{M}\sum_{w=1}^{W}\sum_{d=1}^{D}\sum_{h=1}^{H}(x_{ijwdh}\cdot g_{id})}{\sum_{i=1}^{N}\sum_{j=1}^{M}\sum_{w=1}^{W}\sum_{d=1}^{D}\sum_{h=1}^{H} x_{ijwdh}}\cdot 100$
Efficiency	
Geographic Coherence (GC)	$\dfrac{\sum_{i=1}^{N}\sum_{j=1}^{M}\sum_{w=1}^{W}\sum_{d=1}^{D}\sum_{h=1}^{H}(x_{ijwdh}\cdot l_{ij})}{\sum_{i=1}^{N}\sum_{j=1}^{M}\sum_{w=1}^{W}\sum_{d=1}^{D}\sum_{h=1}^{H} x_{ijwdh}}\cdot 100$

Table 1. Mathematical description of the performance indicators.

4. SCHEDULING MODEL TESTING

4.1 Data samples

The described scheduling model was tested involving two HC Italian providers. These providers supplied historical data about a specific past week visits plan; these data included information about the assignments patient-reference operator and the visits plan for each operator established by the nurse coordinator without any tool supporting the decisions. Starting from the assignments patient-reference operator decided by the real providers, only the scheduling model was tested by comparing the real plan defined by each provider with the one generated by the proposed model.
Characteristics of sample data provided by the two HC structures involved are reported in Table 2.

	Provider A	Provider B
Number of patients (*N*)	382	87
Number of operators (*M*)	25	6
Number of geographic areas	3	1
Number of skills/needs	2	2
Number of working days (*D*)	5	7
Time window	60 min	90 min
Visit duration (*T*)	30 min	30 or 45 min

Table 2. Characteristics of sample data.

The two types of skills defined by provider A refer to the ability to carry out or not palliative cares.
For provider B, there are two kinds of operators: the first one can executes a visit in 30 min, the second one, instead, carries out a visit in 45 min. In order to consider this peculiarity, the discrete time period constraint (2) was modified in the scheduling model applied to provider B.
Experiments were carried out using the LINGO 8.0 solver on a two-processor Intel-Xeon CPU 2.80 GHz, 2.00 GB of RAM.

4.2 Provider A

The week taken into account was particularly critic for the organization as it was characterized by a high rate of operators' unavailability: two operators were unavailable for the whole week due to illnesses and other operators were unavailable for few days during the week, implying a total number of 20 days of unavailability. Data regarding the burn out level and the constrained visits were not available.
In the analyzed scenarios operators have three kinds of contracts: full time (58%), part time at 75% (29%) and part time at 50% (13%).
The average number of patients cared by one operator is 14.3 with a standard deviation of 7.5. This large value of standard deviation is due to the presence of back-up operators to which a very low number of patients is assigned; they are used to react to unforeseen events.
Figure 1 describes the distribution of the care plans, in terms of weekly frequency of visits required. Most of patients require just one visit a week for extemporary cares.

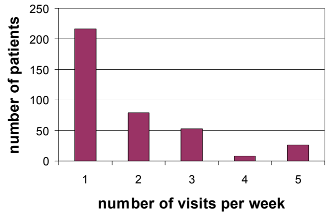

Figure 1. Care plan distribution for provider A.

The penalty values defined by the structure's managers and assigned in the objective function are 100, 50, 40 and 10 for *Cd*, *Cg*, *Cp* and *Cs* respectively. The coefficient for the outsourced visits has the highest value as it has a strong impact on the service quality; the geographic coherence is also important because of the distance among the different areas in the territory in which provider A supplies its service.
The solution was found in around 3 hours. The model results seem to be quite positive. A significant improvement in the performance indicators, except for the percentage of outsourced visits (null in both plans) can be observed in Table 3.

Indicators	Real Plan	Model Plan	Δ
CC	81%	93.6%	12.6 %
OV	0%	0%	-
PD	83.6%	99.2%	15.6%
GC	83.9%	92.1%	8.2%

Table 3. Performance indicators calculated from the model results for provider A.

It can be noticed that often the respect of preferential days, described as an important objective, was not taken into account by provider A because of the complexity of the problem. The gain regarding the geographic area is due to the centralized planning for the three areas of the model, while in the real case Provider A uses to plan them in a decentralized way.

4.3 Provider B

In the week under consideration, all the operators were available for the visits, except for one operator who had a busy afternoon due to a meeting.
Provider B provided information regarding the impact level on the burn out, the tolerated burn out level and the specific skills for each operator. Patients are divided into two classes of impact on burn out, with value 1 and 3 respectively.
There are three types of contracts for operators, ranging from 20 to 56 hours/week.
The average number of patients cared by one operator is 14.2 with a standard deviation of 4.6.
Figure 2 describes the distribution of the care plans, in terms of weekly frequency of visits required. Many patients have to receive one, two and three visits/week.

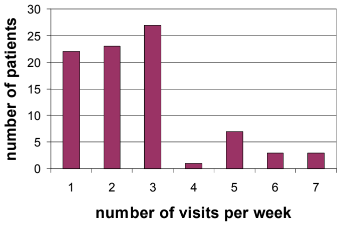

Figure 2. Care plan distribution for provider B.

The penalty values indicated by the structure's managers and assigned in the objective function are 100, 30, 40 and 20 for *Cd*, *Cg*, *Cp* and *Cs* respectively. Also in this case, the most important objective is the minimization of the number of outsourced visits. The respect of preferential days is considered very important, thus denoting provider B pays high attention on the service quality.

The solution was found in around 10 minutes. The plan defined by the scheduling model is similar to the one developed by the HC structure. The performance indicators related to both plans are very high also because of the high available rate of the operators during the week and of the presence of just one geographic area. The values of the obtained performance indicators are presented in Table 4.

Indicators	Real plan	Model plan	Δ
CC	96.7%	97.2%	0.5%
OV	0%	0%	-
PD	86.1%	93.7%	7.6%

Table 4. Performance indicators calculated from the model results for provider B.

The improvement is smaller than that obtained for provider A, probably because of the lower number of patients and operators contained in the sample. Moreover, the percentage of available operators during the considered week was greater than that of provider A, thus the problem complexity was quite affordable in reality.

5. CONCLUSION

The resource short term planning process in a HC provider requires the respect of a large number of constraints and objectives, regarding both the efficiency of the system and the quality of the care. This is true in particular for the human resource short term planning. For this reason, a mathematical support tool for HC providers was developed. The solution is hierarchical, composed of two models of linear programming: the first one regards the assignment of the patients entering the system to a reference operator, the second one is a scheduling model, whose output is the weekly plan for each operator. A set of performance indicators was defined in order to compare the results of the scheduling model with the real plans provided by two HC providers during the testing phase. The obtained results show a good improvement in the performance of both the structures involved in the testing phase of algorithm.

Many advantages can be obtained using this model during the planning. First of all, the quality of the service and, consequently, the patient's satisfaction can be improved. Moreover, nurse coordinators could be just responsible for overseeing the process and managing unpredictable events. A third advantage can benefit providers that operate in different districts: they could execute only one central planning, in order to employ human resources on the territory in a more efficient way than the local sub optimum planning.

Improvements for this model could be obtained considering standard evaluation scales for the burn out problem and executing a sensitivity analysis on the penalty values. Moreover, a quantitative evaluation on advantages in considering or not the continuity of care is an ongoing work. Future developments could concern the creation of a model for the short term planning of materials in HC providers, parallel to the human resources models here presented.

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