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SIGICAM: A New Software to Improve the Patient Care Supported by a Constraint-Based Model

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Abstract

Health facilities are care centers that receive patients with different requirements. The management of patients falls to the clinical staff trained for this activity. However, given the demands of the population, the task of managing beds is sometimes too complicated when carried out manually. In this work, we propose the design and implementation of a technological platform that provides an improved optimization approach. It manages the patient-bed allocation efficiently, by considering hospital resources given the number of units and patient diagnosis. This tool was deployed in hospitals of the Atacama regional health service in Chile, boosting the work of the clinical staff of the health facility.

Keywords:

Beds, Health Facilities, Health Resources

Introduction

Recently, health facilities are approaching digitalization as a process of improvement to boost their services. They highlight this approach as a critical factor for the management of health resources and an increase in the efficiency of the clinical services. Informatics services such as Electronic Medical Record [1], traceability in clinical documents [2], medical examinations [3], among others, have taken health to the next level in order to enhance the quality of patient care.

When we focus our efforts on improving patient care, we inevitably entrust ourselves with the task of offering the best available resource [4]. Here, we must define what tasks should performed by the clinical staff and also, we allocate resources to the patient. This decision is not trivial. For instance, what is the ideal bed for a patient? When answering this question, it is necessary to know patient requirements and both features and characteristics of available beds. For instance, patients may need complex clinical tests, specialized care, mandatory isolation, and more. Also, it is essential to be able to classify beds by aspects like age, gender, critical levels, and others.

In the current literature, the patient bed assignment problem has been studied as a particular case of the scheduling problem [5,6]. It corresponds to a typical and recurrent task in hospitals or medical centers. It consists of finding an assignment of available beds for patients with critical medical assistance [7]. Studies have resolved this problem by using a structured mathematical model [8, 9]. Other works have used an efficient approximate algorithm to solve a linear programming model that uses soft and hard constraints but does not include critical medical information [10].

In this work, we propose software supported by a new mathematical approach that improves the patient care process just in time when a bed is required. Our software works from emergency control to the hospitalization of the patient. In this process, the mathematical model uses features of patients for finding the best available beds. It generates a list of potenial beds, and the user decides which bed will be best for the patient.

The software has been deployed in the health services of the Atacama, a region of Chile. During its use, we have detected that the patient care process has improved due to users (nurses) having total visibility of available beds and the assignment process is more efficient.

The remainder of this paper is organized as follows, first we detail the problem statement. Second, we present the proposed software. Finally, the conclusions of this work are detailed.

Problem statement

People demand more and better services, this is a fact. In many situations, these demands trigger a collapse in public health services, especially in hospitals and medical centers [11]. People arrive at hospitals, those who require admission need to be assigned a bed, and at this moment, they become in patients of the health service. According to their needs, each patient presents variables such as age, risk, gender, if they require isolation (or not), among others [12]. Furthermore, beds are a scarce resource that should be optimized, but this is not always the case. In Chile, this process is directed by a national policy. Therefore, we must respect it. Ministry of Health defines the protocol for receiving patient requirements for bed availability. The detail of this protocol is shown in Figure 1.

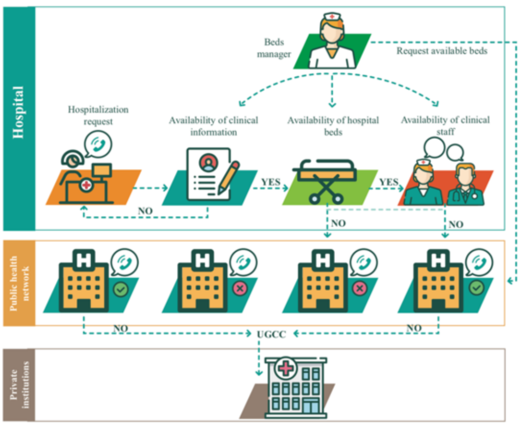

Figure 1– Request protocol for bed availability.

There beds are not always available, and those that are vacated must be treated correctly to satisfy the needs of patients. In order to accomplish that, it is necessary to know the properties of each bed to ensure efficient assignment. The properties of beds are the type (basic, critical), classification (neonatal, pediatrics, adult, older people, etc.), gender, type of insulation, among others. All these properties must be considered when assigning a patient to the best available bed. However, what would happen if the only available bed is an adult type and a teen needs it? Current optimization models and mixed linear methods determine that it is not possible to assign it [13].

To address this problem, we developed new software, boosted by a new binary model bed assignment problem, that minimizes the inter-movement of patients, and also considers constraints. There is exsisting work that takes a similar approach [14].

Search process

When we designed the software, we defines a search process based on two-stages, as shown in Figure 2, and Figure 3.

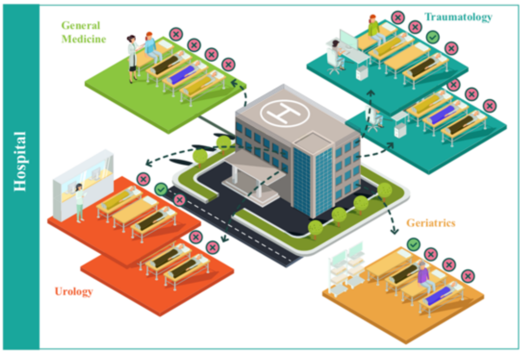

Figure 2– Internal Search Process (hospital).

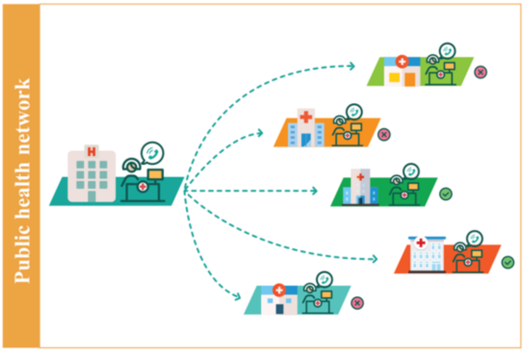

Figure 3– External Search Process (public health network).

The first stage allows us to find the best bed into the hospital that belongs to the regional health service. If it is not possible to find this match, the next stage begins. We take the best available beds and we perform the assignment patient-bed searching in all public assistance network. We designed this process in order to initially reduce the search space, and to use potential solutions that exhibit good performance from the beginning.

For the software to work correctly, we need to control the following aspects:

- The configuration of hospitals and units (set of rooms) is known and this set does not change during the decision period.
- Needs of patients will not change during the decision period. For example, if a patient needs isolation, their critical level is maintained during the phase of bed search.
- Beds remain unavailable while in use by patients, until discharge.

Decision variables

To initiate the model, we describe the binary decision variables: bed (*b*). This variable is used to determinate if a bed is available or it is assigned to a patient: 1 if the bed *b* of a specific type and it belongs to a particular room is assigned to a patient, 0 otherwise. In our case, all beds belong to a specified room, and they are defined by a type.

Regional health service have several hospitals, and each hospital is characterized according to its complexity. If a hospital has intensive care units (ICU) or it has critical patient units (CPU), we can say that this hospital is defined as complex. Not every hospital is designated as complex because of limited resources/equipment. Complex hospitals and normal hospitals, both have basic beds available to assign. However, only complex hospitals have *critical* beds.

Additionally, we use $f_r = 1$ and $m_r = 1$ if at least one woman and one man, respectively, is in room r, 0 otherwise. This value is computed after to search for an availability bed. Finally, we define $y_{pl} = 1$ if patient p is consistent with age policy l, 0 otherwise.

Constraints

Next, we present the following constraints that we should cover but could be violated. It is important to mention that hospitals, units, and rooms, have non-variable capacity during the resolution process.

- c_1: **Assignment**. Each patient is assigned to only one bed, and only one bed is assigned to a patient.
- c_2: **Risk and dependence**. It indicates the severity of the patient and it is classified into 3 categories:
  - *Maximum risk* is assumed for the patient. A critical bed must be assigned to the patient. In case that there is not one available critical bed, a normal bed will be equipped as a critical bed.
  - *Medium risk* is assumed for the patient. A critical bed will be found but if there is not, a normal bed will be assigned.
  - *Minimum risk* is assumed for the patient. A normal bed will be assigned to the patient.

  This constraint is extremely relevant, however, due to the shortage of critical beds, there is a high possibility that even being a critical patient the assigned bed will not be the critical type. Therefore, this constraint can be violated. Complexity hospitals can transform a normal bed into a critical bed.
- *c_3*: **Isolation**. In the health systems, contagious diseases develop that in some cases can be more serious than the disease originated abroad. This constraint may not be satisfied because hospitals follow internal protocols to modify a room using

special equipment. This process allows the patient to be "isolated" in a room with other persons.

- c_4: **Unit policies**. Each hospital offers a set of units that it groups a set of rooms. A patient-derived to a unit should be assigned to one bed of a room of this unit. However, if it is not possible finding one bed in a specified room, by default, he/she will be assigned to one bed into a general room.
- c_5: **Gender policies**. If a patient declares belonging to the male gender or the female gender, the assigned bed must belong to a room with this characteristic. This constraint may not be satisfied because it is possible to modify a room as in the isolation restriction.
- c_6: **Age polities**. This constraint considers the choice of the hospitalization area. Since the beds are heterogeneous according to the age range, it is possible to determine 4 types: neonatology, pediatrics, adult, elderly. If there is no available beds with the desired age feature, an adult bed will be assigned to the patient. A preliminary study conducted to there are more adult beds than any other type. Therefore, we can conclude that this constraint may not be covered.
- c_7: **Distance**. If a patient requires one bed and no beds are available at the current hosptial, it is necessary to transfer the patient to the nearest hospital. Nevertheless, the nearest hospital may not be the best alternative according to patient requirements. In this case, it is necessary for finding the best bed in another hospital that may not be the closest. This case can be violated.

Resolution

To give an efficient response to the model, we perform this model by using an approximate algorithm. This technique is known as bat algorithm.

Bat algorithm was proposed Xin-She Xang [15, 16] and it is inspired by eco-localization behavior (biosonar) that belong microbats. Rules that led this algorithm are:

1. All bats use echolocation to perceive the distance they have to objects or obstacles. They can differentiate between food, prey, or obstacles in their way.
2. Bats randomly fly, with velocity v_i position x_i. When they are looking for a prey they adjust their frequency f_i by changing their wavelength and volume A_o. Bats can adjust their frequency and adjust the pulse emission radius$r \in [0,1]$.
3. The volume varies from a positive value A_0 to a minimum value A_{min}.

The bat algorithm proposes the change of position using three equations:

1. Calculate the frequency of the bat.

$$f_i = f_{min} + (f_{max} - f_{min})\beta \quad (1)$$

2. Calculate the speed of the bat considering the frequency as input data.

$$v_i^d(t+1) = v_i^d(t) + (x_i^d(t) - \hat{x}^d)f_i \quad (2)$$

3. Calculate the new position of the bat.

$$x_i^d(t+1) = x_i^d(t) + v_i^d(t+1) \quad (3)$$

Updating position can alter the binary domain of the problem. However, the algorithm proposes an adaptation to the domain by using the sigmoid function and a probabilistic selection. Algorithm 1 describes the procedure to find a solution.

Algorithm 1: Bat algorithm

Input: Parameters of the problem
Output: List of available bed.

for all bat x_i, $(\forall_i = \{1,\dots,n\})$ **do**
  for all dimension d, $(\forall_d = \{1,\dots,m\})$ **do**
    $x_i^d \leftarrow Random\{0,1\}$
  end for
  $A_i \leftarrow Random[0,1]$
  $r_i \leftarrow Random[0,1]$
  $fit_i \leftarrow cost\_function(x_i)$
end
$globalfit \leftarrow +\infty$
while $t < T$ **hacer**
  for all bat b_i, $(\forall_i = \{1,\dots,n\})$ **do**
    $rand \leftarrow Random[0,1]$
    if $rand < A_i$ **the**
      $A_i \leftarrow \alpha A_i$
      $r_i \leftarrow r_i^{t=0}(1 - e^{-\gamma t})$
    end
  end
  $\{minfit, minindex\} \leftarrow min(fit)$
  if $minfit < globalfit$ **then**
    $globalfit \leftarrow minfit$
    $\hat{x}^d \leftarrow x_{minindex}^d$
  end
  for all bat b_i, $(\forall_i = \{1,\dots,n\})$ **do**
    $\beta \leftarrow Random[0,1]$
    $rand \leftarrow Random[0,1]$
    if $rand < r_i$ **then**
      For all dimension d, $(\forall_d = \{1,\dots,m\})$ **do**
        $x_i^d \leftarrow \varepsilon\bar{A}$
        $rand \leftarrow Random[0,1]$
        if $rand < \frac{1}{1+e^{-x}}$ **then**
          $x_i^d \leftarrow 1$
        else
          $x_i^d \leftarrow 0$
        end
      end
    fin si
    $rand \leftarrow Random[0,1]$
    if $rand < A_i$ **y si** $fit_i < globfit$ **then**
      $f_i \leftarrow f_{min} + (f_{max} - f_{min})\beta$
      for all dimension d, $(\forall_d = \{1,\dots,m\})$ **do**
        $v_i^d \leftarrow v_i^d + (x_i^d - \hat{x}^d)f_i$
        $x_i^d \leftarrow x_i^d + v_i^d$
        $rand \leftarrow Random[0,1]$
        if $rand < \frac{1}{1+e^{-x}}$ **then**
          $x_i^d \leftarrow 1$
        else
          $x_i^d \leftarrow 0$
        end
      end
    end
  end
  $t \leftarrow t + 1$
end
retornar $\hat{x}$

To find an optimal solution, it is usually necessary to combine the exploitation and exploration processes. In this context, the variability of the solutions is given by the adjustment of the volume A and the radius r, as shown in equations (4) and (5).

$$A_i\,(t+1) = \alpha A_i\,(t) \quad (4)$$

$$r_i\,(t+1) = r_i(t=0)[1-e^{-\gamma t}] \quad (5)$$

Software

Finally, the implemented software has successfully been deployed in Government Regional Health Services. The user can access in http://www.sigicam.cl. Primary functions are described as follows:

- Each user logins to the application by using a specific account. After login, the software alerts the user if patients have been waiting more 12 hours for an available bed. At this moment, the users can see a "waiting list" (highlighted in red).

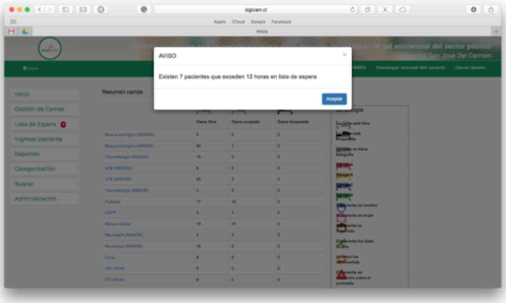

Figure 4– After login.

- From the "waiting list", the user can assign a specific bed using a list of beds deployed in the "floor map".

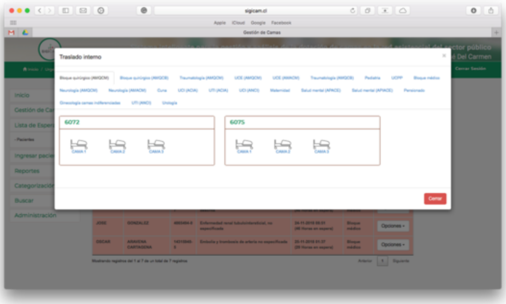

Figure 5– Assign manually a bed.

- When a patient is registered in the platform, the users can decide if it is the application itself who assign the best available bed or not. The system shows a list of best beds according to features or conditions of the patient. Here, the optimization model works to help users quickly find a bed. This list is rated.

The software provides additional functions, such as internal movements, external movements (government hospitals or private health facilities), daily monitoring and update of risk-dependence, statistical information, reports, among others.

Finally. we can say that our software supports the nurse's work, which in turn directly impacts the quality of patient care. Furthermore, the platform highlights bed occupation rates by the hospitals and shows how efficiently the beds are being used. This information includes the stay times of each patient and, above all, the waiting times that each patient suffers when there are no available beds.

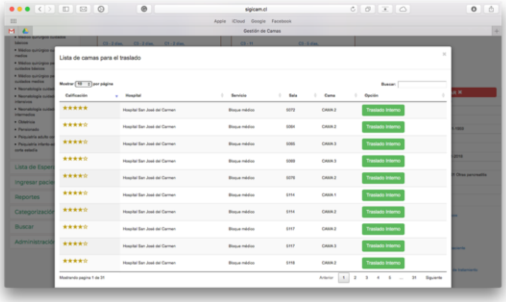

Figure 6–Semi-automatic assignment of beds.

Conclusion

In this work, we present new software to improve the patient care supported by a constraint-based model. The software can find the best available bed for patients and it alerts when one of them waits for more than 12 hours. For that, we design a constraint-based model using hard and soft constraints according to the needs of patients. Using those constraints, we implement the bat algorithm to optimize bed selection.

SIGICAM is a web-based implementation that coverages the resolution of the model on-demand for expert users. This software includes the comunication between the optimization approach and the functional features of the software.

As future work, we plan to develop a self-adaptive approach to the bat algorithm in order to improve the quality of the reached solutions. This self-adaptive approach will be based on the principle of the autonomous search, following the work conducted by Soto et. al. [17].

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