Expert Systems with Applications 39 (2012) 385–394

Contents lists available at ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

Using Constraint Satisfaction Problem approach to solve human resource allocation problems in cooperative health services

Cicero Ferreira Fernandes Costa Filho [a,*], Dayse Aparecida Rivera Rocha [b], Marly Guimarães Fernandes Costa [a], Wagner Coelho de Albuquerque Pereira [c]

[a] *Centro de Tecnologia Eletrônica e da Informação, Universidade Federal do Amazonas, Av. General Rodrigo Otávio Jordão Ramos, 3000, Aleixo, Campus Universitário – Setor Norte, Pavilhão Ceteli, CEP: 69077-000, Manaus, AM, Brazil*

[b] *Fundação Centro de Análise, Pesquisa e Inovação Tecnológica – FUCAPI, Av. Danilo Areosa, 381, Distrito Industrial, Manaus, AM, Brazil*

[c] *Programa de Engenharia Biomédica, COPPE/UFRJ, Caixa Postal 68510, CEP 21941-972 Rio de Janeiro, RJ, Brazil*

ARTICLE INFO

Keywords:
Human resource allocation
Cooperative services
Heuristics
Constraint Satisfaction Problem
Backtracking search algorithm

ABSTRACT

In developing countries, the increasing utilization of health services, due to a great life expectancy, is followed by a reduction in incomes from the public health system and from private insurance companies, to the payment of medical procedures. Beyond this scenery, it is mandatory an effective hospital cost control though the utilization of planning tools.

This work is intended to contribute to the reduction of hospital costs, proposing a new tool for planning human resources utilization in hospital plants. Specifically, it is proposed a new tool for human resources allocation in health units. The solution to the allocation problem uses the CSP technique (Constraint Satisfaction Problem) associated with the backtracking search algorithm. With the objective of enhancing the backtracking search algorithm performance a new heuristics is proposed. Through some simulations the performance of the proposed heuristics is compared to the other heuristics previously published in literature: remaining minimum values, forward checking and grade heuristics.

Another important contribution of this work is the mathematical modeling of the constraints, that could be unary, multiple, numeric and implicit constraints. In the results it is presented a case study of a human resource allocation in a cooperative health service.

Based on the results, it is proposed that for a real allocation problems solution, the best approach is to combine the remaining minimum values heuristics with the grade heuristics, to select the best unit allocation to be filled, and then use the proposed heuristic to select the best physician to the chosen unit allocation. This association shows a satisfactory result for the human resource allocation problem of the case study, with an algorithm convergence time of 46.7 min with no backtracks. The same problem when manually resolved took about more than 50 h.

1. Introduction

The infrastructure involved in providing medical services is complex and expensive, and encompasses both human resources and equipments; therefore, it needs an adequate resource management to attain profitable results. As stated by Spyropoulos (2000), a hospital infrastructure is composed of:

(a) Human resources: physicians, nurses, administrative personal, technicians for equipment maintenance, etc.
(b) Intensive therapy units, with an expensive infrastructure.
(c) Surgery room, with dedicated equipments for several procedures.
(d) Specialized laboratories: X-rays, ultrasound, tomography, magnetic resonance, etc.
(e) Auxiliary infrastructure: ambulance for emergency transfer, patient's rooms, pharmacy, restaurant, etc.

In recent decades many tools with the aim of providing efficient management of this infrastructure have been proposed.

Oddi and Cesta (2000) considered that managers of medico-hospital facilities are facing two general problems when allocating resources to activities: (1) to find an agreement between several and contrasting requirements; (2) to manage dynamic and uncertain situations when constraints suddenly change over time due to medical needs. This paper describes the results of a research aimed at applying constraint-based scheduling techniques to the

* Corresponding author.
E-mail address: cicero.costa@uol.com.br (C.F.F. Costa Filho).

0957-4174/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.eswa.2011.07.027

management of medical resources. A mixed-initiative problem-solving approach is adopted in which a user and a decision support system interact to incrementally achieve a satisfactory solution to the problem of allocating resources to medical activities. The authors claim two main contributions of the paper. The first one concerns the domain modeling. The medical problem is represented as a Constraint Satisfaction Problem (CSP) (Tsang, 1996), hence described as a set of variables and a set of constraints on the values of the variables. A solution to the problem is a variable assignment which is compatible with all the constraints. Two main objects are represented in this schema: medical protocols and resources. The constraints are classified as relaxable or non-relaxable. The solution represents an agreement between different and contrasting goals by reducing the total amount of violations of non-relaxable constraints. A second contribution is the introduction of a new solution algorithm, in which two types of algorithm are integrated: a greedy procedure to create an initial solution and a local search method to improve the initial solution with respect to the amount of violations contained in it. The local method used is tabu-search.

Valouxis and Housos (2003) presented a detailed model and an efficient solution methodology for the monthly work shift and rest assignment of hospital nursing personnel. A model that satisfies the rules of a typical hospital environment based both on published research data and on local hospital requirements is designed. A hybrid methodology that utilizes the strengths of operational research and artificial intelligence was used for the solution of the problem. In particular, an approximate integer linear programming (ILP) model is firstly solved and its solution is further improved using local search techniques, as tabu-search strategy.

Other papers that address the problem of nurse allocation were published by Weil, Heus, François, and Poujane (1995), Oughalime, Ismail, and Yeun (2008), Tsai and Li (2009) and Dowsland (1998). The nurse area presents special characteristics that allow the use of automatic human resource allocation systems:

(a) There is a great number of actors that perform the same task in the hospital and, therefore, can be changed one by another without any impairment.
(b) There are some restrictions for allocation timing, due to profession regulation and hospital requirements.

Concerning physicians, nevertheless, the first of these conditions is not observed. The number of physicians in each specialty is significantly lower than the number of nurses. This fact implies that the effort needed to accomplish an automatic physician allocation is lower than the one needed to accomplish an automatic nurse allocation. In some Brazilian metropolis, otherwise, a special situation concerning physicians' services brings this condition into focus. The physician services are provided through medical cooperatives. Nowadays, in the city of Manaus (State of Amazonas, Brazil), for example, there are about two thousand cooperated physicians. These cooperatives (gathering pediatricians or anesthesiologists or obstetricians, etc), which comprehend between fifty and two hundred physicians, provide services to about twenty public hospitals, including emergency units, pediatric units, etc. Depending on the cooperative, the service is provided on time periods of 8, 12 or 24 h. In some units it is needed more than one physician/specialty in one time period. The cooperatives schedules are made in a monthly period. In this scenario, as with the nurse professionals, the first condition previously reported is satisfied. A manually solution to this allocation is a hard task, that demands a large time. In the present paper it is proposed an automatic solution to this allocation problem.

Frequently, two models are used to obtain an automatic solution to human resource allocation problem. In the first one the allocation is viewed as an optimization problem. A state concept is defined for the problem and is created a cost function that attributes a value for each state. Each of these states is a complete attribution to the problem: each vacancy of the schedule is filled with one cooperated physician. The cost function building considers the constraints established to the problem. Each constraint represents a term in the cost function, multiplied by a weight factor. So, the cost function is a linear combination of weighted constraints, as shown in Eq. (1).

$$c = k_1 r_1 + k_2 r_2 + \cdots k_n r_n \tag{1}$$

where r_i is the number of times a constraint is violated in a state of the problem; k_i the weight factor of the constraint. The more important is the constraint, the higher is the weight factor. The optimization method tries to find a state where Eq. (1) is a minimum value. The exploration of the state space can be done using one of the following methods: tabu-search, hill climbing, genetic algorithm, simulated annealing or any other local method. The search process consists of generating new states from old states, obeying defined rules in each one of these methods.

The second model uses an artificial intelligence technique, entitled Constraint Satisfaction Problem – CSP. Differently from the first method that begins with a complete attribution, CSP initiates with an empty attribution: no physicians addressed to any vacancy in the schedule. The attributions of physicians to vacancies are incremental, one each time. Each attribution is confirmed only if no constraint violation is verified. When this is not possible, the technique goes back to the last attribution and searches other possibilities to the new attribution. The use of the CSP technique is associated with problem modeling and choice of a search algorithm.

In the modeling stage are defined the variables, their domains and the problem constraints. One contribution of this paper is the mathematical modeling of the problem constraints that can be unary, multiple, numeric and implicit ones. Besides the theoretic work, it was developed a computational tool that enables the technique implementation. The main characteristic of this tool is the flexibility in constraint programming, allowing search solutions for different problems of similar nature. Moreover, it is possible the free insertion of the following information: duration of a period (8 12 or 24 h), duration of the schedule (one month, one week, etc), name of the health unit and number of physicians needed in each health unit/period, name of physicians involved in the allocation problem and number of periods of each physician. All this information is registered in the first block of Fig. 1.

In this paper, to solve the allocation problem, we use the CSP approach associated with the backtracking search algorithm (Russel & Norvig, 2004). This algorithm encompasses a depth search, which, in its turn, is time-consuming, because it explores all the state space looking for a solution. Using heuristics associated with a depth search algorithm can speed up the solution search. Another intended contribution of this paper is the proposal of a new heuristics to the backtracking search algorithm, entitled *domain verification heuristics*. Its performance is compared with

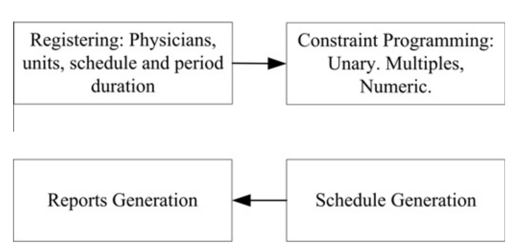

Fig. 1. Block diagram of the developed tool.