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Late acceptance hill climbing algorithm for solving patient admission scheduling problem

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ABSTRACT

This article tackles a patient admission scheduling using Late Acceptance Hill Climbing Algorithm (LAHC). The LAHC algorithm is among the newly proposed metaheuristic-based algorithm which belongs to the one-point solution technique. Patient admission scheduling is a complex combinatorial optimization problem which have been proven to belongs to class of NP-hard problem in almost all its variations. This problem is concerns with assigning a set of patients arriving for medical services in the hospital to a set of rooms, timeslots and beds subject to satisfying a set of predefined constraints. The proposed adaptation of LAHC to the patient admission scheduling named LAHC-based PAS comes in two stages: the first stage involves generating of initial feasible solution using the room oriented-based approach (ROP), while the second stage utilizes three neighbourhood structures which are embedded within the component of LAHC-based PAS to further enhances the initial solution generated at the initial stage. The proposed LAHC method is evaluated using the standard benchmark dataset. The experimental results shows that the proposed method is an effective technique for tackling the PAS problem. It is observed that the method outperform many of the existing techniques when compared with the state-of-the-arts.

1. Introduction

In recent time, with the alarming rate of the world population, there is needs for the immediate and efficient automated system in order to improve the performance of health service institution such as hospitals and clinics. However, due to unavailability of health resources such as manpower, hospital utilities, medical equipment etc., the effectiveness of these institutions are hindered across the globe. Satisfying the need of patients by the admission unit has made patient admission scheduling (PAS) problem as one of the challenging problem faced by numerous medical establishments. Practically, the operations of the PAS could be thought as a scheduling a certain number of patients to a set of limited resources such as rooms, beds, specialism and timeslots subject to a predefined set of constraints. The common constraints in a PAS problem could be classified into: hard and soft constraints. Note that, it is mandatory for the hard constraints to be satisfied in order to generates a *feasible* PAS solution while the satisfactions of the soft constraints in a feasible PAS solution is not essential but their violations should be reduced as much as possible. The key objective of the PAS is to produce a high-quality solution which satisfies the hard constraints (feasible solution), while its quality is determined by the number of the soft constraints satisfaction. Due to the rugged search space and highly constraints nature of the PAS, producing feasible PAS solution that satisfies all the soft constraints is almost impossible [1]. Furthermore, different formulations of the PAS have been proposed from the literature. Bilgin et al. [2] originally proposes the most popular PAS formulation which has been utilized extensively to test the performance of the different algorithmic techniques. Other formulations that worked on specific hospital cases can be found in [3–5]. Owing to the NP-hard and complexity nature of the PAS formulation under consideration, solving this formulation requires large amount of resources and time [1]. Thus, these limitations led to proposition of different approaches by the workers in the domain automated timetabling and operations research.

The successes recorded in the utilization of metaheuristics-based approaches to tackle difficult combinatorial optimization problems have been increasing tremendously over the last few decades. These successes have motivated the researchers in the domain to tailored numerous metaheuristic-based approaches for such problems of high dimensionality. Typically, two classification of metaheuristic-based approaches are multi-point and one-point solution approaches. The multi-point solution techniques begins with a set of points (i.e., solutions) and explores different re-

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gions of the solution search space simultaneously until the stop criterion is achieved. The major drawback of this approaches is that the search focus more exploration rather than exploitation of the already-visited regions. Few examples of the multi-point solution techniques that have been recently adapted, modified and hybridized to tackle complex combinatorial problems of high dimensionality can be found in [6–10]. Conversely, one-point-solution methods starts with a single solution and exploits it until a local optimal solution is reached. The main shortcoming of this method is its inability to escape the problems local optima. Some examples of one-point solution techniques that are utilized to tackle the numerous complex problems of this are [11–14].

The algorithmic techniques that are newly introduced by the researchers to optimize the PAS as a category of the problem of high dimensionality are exact-based methods, meta-heuristics, hyper-heuristics and hybrid-based methods. The methods employed under the exact-based are column generation algorithm [15,16] and integer programming algorithm [3]. The techniques utilized successfully under the one-point solution algorithm are simulated annealing (SA) [3,17], great deluge (GD) [18] while those employed using the multi-point solution algorithm include genetic algorithms (GA) [4,5], and Biogeography-based optimization algorithm [19]. Other methods such as hyper-heuristic technique are also utilized [2,20] and hybrid technique [21]. It is worthy of notice that none of the existing techniques have been able to obtained optimal solutions for the instances of the formulation under consideration and thus research in this direction is still open for further investigations. The main motivation of this paper is to propose a one-point solution technique with integration of simple and effective neighbourhood structures for optimizing the results of PAS problem.

Among the recently proposed one-point solution algorithms that have shown the capability of producing good results is the Late Acceptance Hill Climbing (LAHC), an easy but powerful stochastic search technique that is based on the idea of delays the comparison by comparing the new candidate solution with the one generated several iterations before, namely is proposed by Burke and Bykov in [22]. The LAHC algorithm does not employ external cooling scheduling like other metaheuristic techniques such as Simulated Annealing (SA), Threshold Accepting (TA) and Great Deluge Algorithm (GD). This strategy makes the LAHC to have better or similar performance to other single point techniques. Due to the robustness and effectiveness of the LAHC, it has been successfully adapted, modified, hybridized and parallelized to solve many complex optimization problems like examination timetabling problem [22], lock scheduling problem [23], traveling purchase problem [24], Liner shipping fleet repositioning problem [25], balancing two side assembly lines with multiple constraints [26], reassignment problem in Google Machine [27] and so on. It is noteworthy that no studies have adopted the utilization of the LAHC algorithm for solving the PAS problem. Therefore, this paper proposes an adaptation of the LAHC algorithm (i.e., LAHC-based PAS) to tackle the PAS problem. The proposed technique is evaluated using a standard benchmark dataset proposed by Bilgin et al. in [2], which consist of 13 real-world problem instances. Note that six popularly utilized instances from this dataset are employed in the evaluation of the proposed algorithm. Experimental results proved that the performance of the proposed method is better than some of the state-of-the-art methods that worked on the same dataset. The contribution of the study is in two folds which include (i) the proposition of room oriented approach to generate an initial feasible solution. (ii) provide the timetabling community with a LAHC template that combines both flexibility and effectiveness for solving the PAS problem.

The organization of this paper is as follows: Section 2 provides the background descriptions and formulations of the PAS. An overview of the LAHC is presented in Section 3, and Section 4 describes the proposed adaptation of LAHC to the PAS. Presentation of the experimental analysis, discussions of the results and comparison is given in Section 5. Section 6 provides the conclusion and future research directions.

2. Patient admission scheduling problems

2.1. Problem descriptions

The description of the PAS requires the basic inputs like patients, rooms, wards and timeslots, where the patients are associated with elements such as treatment demands (nursing and medical equipment), age group, gender, room preference, admission date and the duration of stay. The attributes of the room are medical equipment, number of beds and the location of the bed in the ward. In accordance with characteristics of ward and the equipment in the rooms, a ward determines the natures of the treatment that can be offered. While the timeslots represents a length of stay of the patients. A unit of patient-stay is given by scheduling a patient to a bed located in a room during one timeslot (night). Similarly, the set of timeslots (nights) represents the planning horizon for this problem and lastly, the admission durations of patients are known in advance with a fixed length of the stay. The formulation of the PAS problem considered in this research consists of five hard constraints (i.e., $H_1 - H_5$ as shown in Table 1) that must be satisfied in order to achieve feasible solution and six soft constraints (i.e., $S_1 - S_6$ see Table 1). The basic objective of the PAS is to minimize the violations of the soft constraints in a feasible solution

2.2. Problem formulations

The PAS is the problem of assigning a set of n patients $\mathfrak{P} = \{p_1, p_2, \ldots, p_n\}$ to a set of m beds $\mathfrak{B} = \{b_1, b_2, \ldots, b_m\}$ in a set of k rooms $\mathfrak{R} = \{r_1, r_2, \ldots, r_k\}$ each with a specific capacity and features and a set of j timeslot $\mathfrak{T} = \{t_1, t_2, \ldots, t_j\}$ subject to satisfying a set of constraint. Table 2 shows the symbols for the formulation of the PAS problem. The PAS solution is represented by the vector $\boldsymbol{x} = (x_1, x_2, \ldots, x_N)$ of patients, where the value of x_i is a map of bed b_m in a room r_k and timeslot t_k for patient i:

2.2.1. Definitions

The following are the formal definitions of both hard and soft constraints in PAS:

Definition 1. The position i is feasible for patient x_i to be assigned to the solution $\boldsymbol{x}$ if and only if the following conditions are met:

- The first hard constraint of this formulation can be described as:

$$\forall b \in \mathfrak{B}, \forall t \in \mathfrak{T}, \sum_{p \in \mathfrak{P}} \varrho_{p,b,t} \leq 1$$

- The first, second, third and fourth hard constraints can be given as:

$$\forall b \in \mathfrak{B}, \forall t \in PS_p, \sum_{b \in \mathfrak{B}} \varrho_{p,r,t} = 1$$

- The fifth hard constraint can be defined as:

$$\forall t \in \mathfrak{T}, \sum_{p \in \mathfrak{P}} \sum_{r \in \mathfrak{R}} X_{p,r,t} \leq C_r$$

Definition 2: Soft constraints mathematical formulation.

- The description of the total gender penalties (GP) is given as:

$$GP = \sum_{r \in R} \sum_{t \in \mathfrak{T}} min(f_{r,t}, m_{r,t})$$