An Ant Colony Optimization Approach for Efficient Admission Scheduling of Elective Inpatients

Ying Lin
and Jun Zhang (Corresponding Author)
Department of Computer Science, Sun Yat-sen University
Key Laboratory of Digital Life, Ministry of Education
Key Laboratory of Software Technology, Education Dept. of Guangdong Province, P.R. China
junzhang@ieee.org

ABSTRACT
This paper proposes an ant colony optimization (ACO) approach to offer online decision support for making admission plans of inpatients. The approach considers patients' severity degrees and urgency levels, aiming to find an admission plan that offers treatment in time to as many patients as possible. At each decision point, the ACO approach builds a construction graph, with each vertices denoting one possible admission time for a patient in wait. Artificial ants walk on the construction graph to construct feasible admission plans by selecting vertices under guides of pheromones and heuristic information. The resulting plans are evaluated from both terms of the total admission rate and the severity degrees of admitted patients. The weights of the two components can be determined according to the preferences of hospital administrators. When implementing the admission plan, only the admissions that are scheduled before the next decision point are actually executed. The rest of the admission plan is used as guides for optimizing the implemented admissions. Simulations based on actual data show that the ACO approach outperforms two classical admission policies and improve the hospital performance in the long run.

Categories and Subject Descriptors
I.2.8 [**Artificial Intelligence**]: Problem Solving, Control Methods, and Search – *heuristic methods*, *scheduling.*

General Terms
Algorithms, Experimentation, Management

Keywords
Hospital management, admission scheduling, ant colony optimization (ACO)

1. INTRODUCTION
With the social progress, people's desires for healthy living have become stronger. Health care systems including hospitals are faced with the urgent demand of improving working efficiency and service quality. In order to fulfill the demand, management issues such as resource capacity planning [1], nurse roster organizing [2], and patient activity scheduling [3] must be better addressed. Scheduling admissions of patients to hospital care units is one of the management issues that significantly influence the overall performance of a hospital. This paper studies the admission scheduling problem (ASP) and presents a new method to offer online decision support to generate admission plans.

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2. PROBLEM DEFINITION
Suppose at time t, a set $W(t)$ of patients are waiting for admission to a care unit with B beds. In the care unit, a set $I(t)$ ($|I(t)|\le B$) of patients are now receiving treatment and a subset $O(t+1)\subseteq I(t)$ of patients are known to be discharged at the time $t+1$. Then the ASP can be regarded as finding an optimal admission plan that specifies the admission times for all patients in $W(t)$. Only the admission scheduled at time $t+1$ will be implemented. Other admission decisions serve as guides when determining the actually implemented admission. At the following time $t+1$, $t+2$, …, similar ASPs with updated information of patients and medical resources will be solved.

Now we detail the formulation to the ASP at time t. Suppose the care unit is specialized for the treatment of a set of D diseases. Each disease $d\in D$ corresponds to μ_d severity degrees. The subset of patients in $W(t)$ with disease d is denoted as $W_d(t)$. Suppose a patient is treated for one disease at a time. For each patient $i\in W(t)\cup I(t)$, the care unit keeps a record containing his/her disease identifier $d_i\in D$, severity degree s_i, estimate of length of stay (LOS) l_i, arrival time ar_i, and maximum waiting time w_i. The patient stops waiting and leaves the care unit if admission is not permitted until ar_i+w_i. If patient i is admitted, the admission time ad_i and the discharged time dis_i are also included in the record.

With the above premises, define an admission plan $\mathbf{X}$ as

$$\mathbf{X}=[X_{i_1},X_{i_2},\ldots,X_{i_{|W(t)|}}]^T, \quad (1)$$

$$X_{i_k}=[x_{i_k,1},x_{i_k,2},\ldots,x_{i_k,m}], \quad (2)$$

where $x_{i_k,j}\in\{0,1\}$ is a value indicating whether patient $i_k\in W(t)$ is admitted at time $t+j$ and $t+m$ is the last day when at least one patient is still waiting. The ASP can thus be stated as finding an admission plan $\mathbf{X}$ that strikes a balance between the following two conflicting objectives:

$$\max\ Z_1=\frac{1}{D}\sum_{d\in D}\psi_d \ \text{ and } \max\ Z_2=\frac{1}{|W(t)|}\sum_{i\in W(t)}\sum_{j=1}^{m}x_{ij}, \quad (3)$$

where ψ_d is termed the normalized sum of severity degrees of admitted patients with disease $d\in D$ and b_{t+j} is the number of available beds at time $t+j$. The plan $\mathbf{X}$ must also satisfy the three constraints: 1) each patient can be admitted at most once; 2) a patient will not be admitted after his/her latest admission time; 3) the number of patients staying in the care unit is no more than B.

3. THE PROPOSED ACO APPROACH

3.1 The Objective Function

The two objectives defined in Section II are aggregated as the objective function, i.e.,

$$f = \omega_1 \cdot \exp(-Z_1) + \omega_2 \cdot \exp(-Z_2). \quad (4)$$

where ω_1 and ω_2 are two weights given by hospital administrators to Z_1 and Z_2, respectively.

3.2 Ants' Solution Construction Behavior

When faced with an admission problem at time t, the ACO approach builds a construction graph in the view of an irregular matrix with $|W(t)|$ rows. The number of vertices on row k is the number of days during which the patient $i_k \in W(t)$ is still waiting. A vertex located at (k,j) represents an admission decision that patient i_k is to be admitted at time $t+j$.

When deciding patients to be admitted at time $t+j$, the ant first composes a candidate list CL_j of unscheduled patient. If $CL_j=\varnothing$, all the patients in $W(t)$ have either been scheduled or left. In that case, the ant finishes building a solution. If $CL_j\neq\varnothing$, admission decisions are taken on the principle that the care unit admits as many patients as possible. If $|CL_i|$ is no larger than the number of currently available beds b_{t+j}, the ant schedules the admission of all patients in CL_j at time $t+j$. If $|CL_j|$ is larger than b_{t+j}, the ant first selects b_{t+j} patients from CL_j to be admitted at time $t+j$ and then moves on to schedule admission at time $t+j+1$.

When taking admission decisions (selecting vertices in the construction graph), ants are biased towards decisions with larger products of pheromones and heuristic values. The heuristic value for the decision to admit patient i_k at time $t+j$ is defined as the reverse of the normalized difference between the latest admission time and the schedule time. Pheromones are attached to each admission decision to record its historical desirability. The rules of state transition and pheromone updating in the proposed approach are similar with those in the ant colony system [4].

3.3 A Summary to the ACO Approach

An overall description to the proposed ACO approach is given below:

Step 1) Initialization: Besides the control parameters, the construction graph as well as pheromones and heuristic values on each vertex are initialized. All elements in the solution $\mathbf{X}(a)$ of ant a are set to zero, $a=1,2,\ldots,M$ and M is the number of ants.

Step 2) Solution Construction: Each ant a builds a solution. The local pheromone update rule is implemented after each ant makes an admission decision.

Step 3) Global Pheromone Updating: After all the ant finish building solutions, the global pheromone update rule is applied.

Step 4) Termination Check: Return to Step 2) for a new iteration if the termination criterion is not satisfied. Otherwise, terminate and return the best-so-far solution as the resulting admission plan.

4. SIMULATIONS

The effectiveness and efficiency of the proposed ACO approach are evaluated by simulation based on real data from a hospital. Figures 1 and 2 show the simulation results in comparison with the first-come-first-serve (FCFS) admission policy and the SWALIS policy in [5] on cases with two and four types of diseases, respectively.

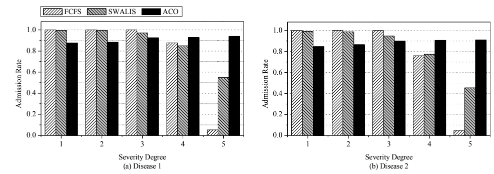

Figure 1. Comparisons in terms of the admission rates of patients with different severity degrees on a case with |*D*|=2.

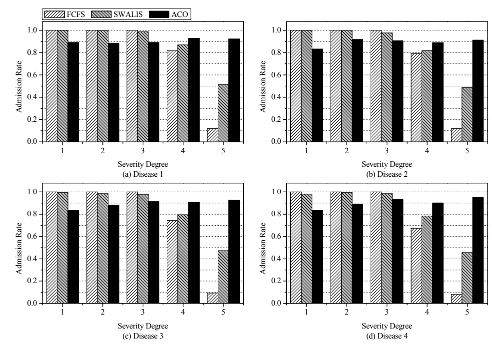

Figure 2. Comparisons in terms of the admission rates of patients with different severity degrees on a case with |*D*|=4.

5. CONCLUSION

This paper presents an ACO approach for the ASP problem. Instead of simply selecting to-be-admitted patients from the waiting list, the approach plans the admission times of all the waiting patients. Only part of the resulting admission plan, i.e., the admissions scheduled at the next time, will actually be implemented. The rest of the admission plan serves as guides to decide the implemented admissions. Simulation results show the advantage of the proposed approach in comparison with the FCFS and WALIS admission policies.

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