Artificial Intelligence in Medicine xxx (2018) xxx–xxx

Contents lists available at ScienceDirect

Artificial Intelligence in Medicine

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

Approximate dynamic programming approaches for appointment scheduling with patient preferences

Xin Li [a], Jin Wang [b,*], Richard Y.K. Fung [b]

[a] Research Center for Modeling and Optimization of Complex Management Systems, College of Management, Shenzhen University, 3688 Nanhai Road, Shenzhen, Guangdong, China
[b] Department of Systems Engineering and Engineering Management, City University of Hong Kong, 83 Tat Chee Ave, Kowloon, Hong Kong

ARTICLE INFO

Article history:
Received 3 April 2017
Received in revised form
12 September 2017
Accepted 6 February 2018

Keywords:
Appointment scheduling
Health service
Dynamic programming
Markov processes

ABSTRACT

During the appointment booking process in out-patient departments, the level of patient satisfaction can be affected by whether or not their preferences can be met, including the choice of physicians and preferred time slot. In addition, because the appointments are sequential, considering future possible requests is also necessary for a successful appointment system. This paper proposes a Markov decision process model for optimizing the scheduling of sequential appointments with patient preferences. In contrast to existing models, the evaluation of a booking decision in this model focuses on the extent to which preferences are satisfied. Characteristics of the model are analysed to develop a system for formulating booking policies. Based on these characteristics, two types of approximate dynamic programming algorithms are developed to avoid the curse of dimensionality. Experimental results suggest directions for further fine-tuning of the model, as well as improving the efficiency of the two proposed algorithms.

1. Introduction

It is difficult to improve patient satisfaction, because current health care are facing increasing pressure from various demands. [16] indicate that patient satisfaction is influenced not only by the perceived quality of medical services but also by their appointment booking experiences. An effective appointment system cannot only increase the utilization of the health care system but also improve the level of patient satisfaction if patients' preferences are given appropriate consideration. This paper mainly focuses on sequential appointment scheduling in out-patient departments (OPDs) in hospitals in China. The objective is to maximize the total satisfactions of all patients who seek to make appointments. The health care situation in China differs from that in the West because of the imbalance between supply and demand. The China Statistical Yearbook (2011) shows that there are only 2.74 practicing physicians per 1000 persons in urban areas. Conversely, patients in the West often have their own primary care provider (PCP) [6], who is also aware of their preference. However, patients in China do not have PCPs, which results in different reasons of preference. Generally, there are two types of preference: *time-dominated preference* and *physician-dominated preference* [15]. If patients are very busy in their work or with other matters, they probably pay attention to when they can see a doctor, which is an example of time-dominated patients. Such patients do not care which physician will serve them. By contrast, physician-dominated patients care only about which physician will treat them, rather than when they can see a physician. In practice, there are two main reasons why they prefer a particular physician. First, patients who are return visitors tend to see their previous physicians. Second, a particular physician at a hospital or clinic may be renowned. Some patients believe that such physicians provide more effective treatments than other doctors. Specially, we say a patient has *strong preferences*, if they have both time and physician preferences, whereas patients with *weak preferences* care neither time nor physicians.

A Markov decision process model is formulated to tackle the sequential appointment scheduling process. The objective is to maximize the expected satisfaction level during the booking periods. For convenience, the term "revenue" is used in some statements in this paper, which means the patient satisfaction level. Characteristics of the model are proposed, including policy, marginal revenue, and bounds. To avoid the curse of dimensionality during computation, two approximate algorithms are proposed, namely a simulation-based algorithm and an aggregation algorithm. By generating sample paths on the base of the arrival distribution of calls, the simulation-based algorithm can avoid looping all states, which saves considerable computational resources. After certain number of iterations, the value of states converges to approach a true value, as shown by our experiments. The aggregation algorithm combines several states, which reduces

* Corresponding author.
E-mail address: wangjin.devin@my.cityu.edu.hk (J. Wang).

https://doi.org/10.1016/j.artmed.2018.02.001
0933-3657/

the number of states considerably. Different aggregation levels lead to different results and computation times, both of which cannot be optimal simultaneously. Therefore, schedulers should seek to balance these considerations.

The reminder of this paper is organized as follows. Section 2 gives a review of literature. Section 3 proposes a MDP model. In Section 4, we present some characteristics of the model. Section 5 develops approximate algorithms for computing value functions. In Section 6, numerical studies are performed. Section 7 presents concluding remarks along with some possible future work.

2. Literature review

Appointment scheduling allows patients to book medical services booking efficiently and in a timely manner. It has become a widely researched topic in recent years. [3,5] show a broad review of this research area. [5] point out that patient preferences will be a key part of the next generation of appointment scheduling systems. [1] review optimization approaches for the appointment scheduling in out-patient appointment systems.

Research on patient preferences and choices in health care was preceded by studies on customer choices in revenue management. [14] provide an exact and relatively general analysis of revenue management in the context of customer preferences. In the model, some candidate choices are provided to customers. The decision that customers make depends on the choices available to them. With the assumption that the purchase probability increases with the number of choices, they propose an optimal policy with an elegant form consisting of an ordered family of efficient subsets. [17] consider the airline revenue management problem with customer choice within a group of flights between a common origin and destination. [4] discuss an airline revenue management problem with discrete customer choice behavior, and preference orders are proposed to describe the customers' choice list. If a customer's preferred option is not available, (s)he moves to the next choice on the list with some probabilities. A post optimization heuristic is used to refine the allocation. [13] review some methods of modeling customer behavior in revenue management and auctions. However, [5] indicate that there are two types of differences between marketing and health care industries. First, choices made by patients are affected by various factors, such as the provider and availability of appointment times. Second, adjusting the price of health care services is usually not a feasible method for controlling patient choices.

Few papers focus on patient preferences during appointment scheduling, e.g. [6,16,11]. [6] are the first to explicitly model patient preferences. To some extent, their model is a significant advancement in appointment scheduling research for health care services. Patient choices in that paper include his/her preferred physician and time slot. Patients are divided into two categories, namely regular patients who call more than one day in advance, and same-day patients who arrive at the start of the workday. The patient choice of a particular workday is modeled as a Markov decision process (MDP). Patients can switch their choice if the preferred time slot or physician is not available. Both single-physician and multi-physician systems are simulated, and the results signify that there is an appointment threshold for each appointment request, and this threshold depends on the total number of booked slots in the clinic. Although the patient loyalty is investigated, the relationship between no-show rates and patients preference is not discussed in-depth. Based on [6,16] develop an adaptive appointment system that can dynamically learn and update patient preferences. The patients who want to book a block have an acceptable set, in which the scheduler should choose a block to appoint the patient. The authors claim that adaptive systems will be the direction for designing the next generation of appointment systems. [15] consider patient preferences and choices in the appointment scheduling problem. This paper differs from the literature, since patients are categorized in different ways. In [15], patients are categorized according to which slots they prefer, whereas patient preferences here are divided into two types as noted in Section 1.

Another crucial point on scheduling in the health care industry pertains to patient taxonomy. [9] classify patients on the basis of their arrival probabilities at different times. [6] discuss the problem of how to provide some candidates to patients by dividing patients according to choice probabilities when they have different candidates to choose from. [8] addresses the optimal choices of appointment windows in the event of a no-show. A study by [7] describes how no-show phenomena affect appointment scheduling in clinics. In that study, patients are on the basis of no-show rates. However, the taxonomy in the present paper is based on patient preferences.

In summary, this paper differs from existing publications in several areas. First, in the present paper, the performance of the appointment system is evaluated according to the degree to which patient preferences can be satisfied during a given booking period, rather than the economic income that can be derived from each appointment. Second, revenue in past papers mainly consider whether patient-physician pairs are matched. However, in the present paper, whether a time slot request is satisfied also affects revenue. Third, in our model, there is a new taxonomy; specifically, patients are categorized according to their preferences.

3. Model formulation

In this section, we introduce the process of model formulation. Booking process and preference categories are introduced as the background of the model. The revenue function is developed to calculate the revenue of an appointment decision. Finally, a MDP model is formulated.

3.1. Booking process and preference categories

The model formulation is based on the booking process in a typical clinic. Patients can make appointments through placing telephone calls. The booking process is shown in Fig. 1. While making an appointment, patients must provide their preferences, including which physician they want to see (physician preference) and which time slot is convenient for them to attend (time preference). Considering patient preferences and the current system state, the scheduler makes an appointment decision. Finally, the call is terminated.

To model the booking process, the call-in periods (booking horizon) are partitioned into T time intervals [7]. Each interval is sufficiently small so that there is no more than one call within the given period. For a particular workday schedule, the calls come within the booking horizon. In contrast to existing papers that divide patients on the base of their arrival probabilities [9], choice probabilities [6], or no-show rates [7], in our model, patients are categorized on the base of their preferences. Generally, the condi-

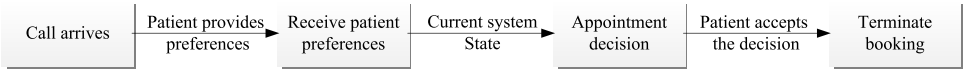

Fig. 1. Booking process.

Please cite this article in press as: Li X, et al. Approximate dynamic programming approaches for appointment scheduling with patient preferences. Artif Intell Med (2018), https://doi.org/10.1016/j.artmed.2018.02.001