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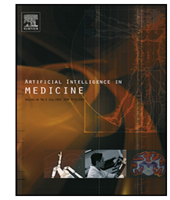

Adaptive dynamic programming algorithms for sequential appointment scheduling with patient preferences

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A B S T R A C T

Objectives: A well-developed appointment system can help increase the utilization of medical facilities in an outpatient department. This paper outlines the development of an appointment system that can make an outpatient department work more efficiently and improve patient satisfaction level.

Methods: A Markov decision process model is proposed to schedule sequential appointments with the consideration of patient preferences in order to maximize the patient satisfaction level. Adaptive dynamic programming algorithms are developed to avoid the curse of dimensionality. These algorithms can dynamically capture patient preferences, update the value of being a state, and thus improve the appointment decisions.

Results: Experiments were conducted to investigate the performance of the algorithms. The convergence behaviors under different settings, including the number of iterations needed for convergence and the accuracy of results, were examined. Bias-adjusted Kalman filter step-sizes were found to lead to the best convergence behavior, which stabilized within 5000 iterations. As for the effects of exploration and exploitation, it resulted in the best convergence behavior when the probability of taking a myopically optimal action equaled 0.9. The performance of value function approximation algorithm was greatly affected by the combination of basis functions. Under different combinations, errors varied from 2.7% to 8.3%. More preferences resulted in faster convergence, but required longer computation time.

Conclusions: System parameters are adaptively updated as bookings are confirmed. The proposed appointment scheduling system could certainly contribute to better patient satisfaction level during the booking periods.

1. Introduction

Healthcare systems are facing increasing pressure to satisfy diverse demands especially in an aging society. According to statistics from Ministry of Health of China, the number of visits to health institutions in 2012 approached 6.9 billion, representing a 9.7(2013) [1] showed that there were only 3.19 practicing physicians per 1000 persons in the urban areas. Therefore, demands for healthcare resources far outstrips their supply. Owing to ineffective healthcare systems, the complaints received by institutions are escalating. Hence, it is essential that healthcare resources and medical quality have to be significantly improved as early as possible. In 2009, the Ministry of Health in mainland China started requiring hospitals to install appointment systems. Currently, because of great demand, a patient wanting to see a specialist (a senior physician) has to make an appointment in advance.

A good appointment system can increase utilization of facilities, cut waiting time for patients, and in turn improve patients' satisfaction level. Besides, patients' satisfaction is influenced not only by the perceived quality of medical services but also by their appointment booking experience [2]. However, there are a lot of variables in the patients' arrival and service process, making scheduling of outpatient appointments more complicated. Many papers focus on different aspects, such as no-show [3,4], interruption [5], cancellation [6], traditional and open-access policies [7], and patient priority [8]. These papers contribute greatly for their respective areas. However, patient preference is still a relatively new attribute in the scheduling problem in healthcare industry. Fortunately, the problems of preference and choice in marketing have been widely studied in the past, giving great inspirations to healthcare. Van Ryzin [9] provides an exact and general analysis of the revenue management issues subject to customer preference. In the model, some available choices are provided to allow

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customers to select. With the assumption that purchase probability increases with the number of choices made available, they arrive at an optimal policy involving an elegant form of an ordered family of "efficient" subsets. Zhang and Cooper [10] consider airline revenue management problems with customer choice within a group of flights serving a common route. Chen and Homem-de-Mello [11] discuss an airline revenue management problem with discrete customer choice behavior, and preference orders are proposed to describe customers' choice list. If a preferred option is not available, the customer moves to the next choice on the list subject to certain probabilities, and a post-optimization heuristic is used to refine the allocation process. Shen and Su [12] review methods of modeling customer behavior in revenue management and auction. These papers definitely give researchers a great deal of inspirations to study the problem of patient preferences.

Patient preference is first modeled explicitly by Gupta and Wang [2]. To some extent, the approach constitutes significant progress in research on appointment scheduling. Patient choices in this paper include preferred physicians and time slots. Patients are divided into two categories: regular patients who call more than one day in advance, and same-day patients who arrive at the start of a workday. The patient choice of a particular workday is modeled as a Markov decision process (MDP). Patients are allowed to switch their choice if their preferred time slot or physician is not available. Both single physician and multi-physician scenarios are simulated. Based on this work, Wang and Gupta [13] further develop an adaptive appointment system, which dynamically learns and updates patients' preferences. The patients seeking to book a block have an acceptable set, from which scheduler offers a block to them. The work described in this paper differs from their previous one since appointments are scheduled in an outpatient department more than just resources allocation. Qu and Shi [14] model the performance of open access scheduling with patient choice. Vermeulen et al. [15] consider both patient preference and the urgency of the cases.

However, most available literature considers appointment systems in the western world which are relatively well-developed. However, very little work has been done concerning situations relevant to mainland China. This paper mainly focuses on sequential appointment scheduling in outpatient departments (OPDs) in hospitals in China. The appointment systems in OPD also have different characteristics because of differences in the approaches used in China and the West. Gupta and Denton [16] summarize three different healthcare scenarios: primary care clinics, specialty care clinics and hospitals. In the West, most people go to a neighborhood clinic in ordinary consultations. If necessary, they are referred to a hospital for follow-up actions. Neighborhood clinics greatly relieve the pressure on the hospitals. However, in China, most people prefer to go directly to a hospital because they trust hospitals more. As a result, hospitals become heavily crowded, especially the more "famous" ones. OPD in China is similar to some extent to primary care clinics in the West. However, there are some distinct differences. For instance, in China, most OPD physicians also work in inpatient departments and the distribution can vary daily based on the planned schedule. Also, in Western primary care clinics, patients usually have a designated physician, the primary care provider, to take care of the majority of the medical needs of a given individual. However, in China, people believe that it is better to go to a well-known hospital specializing in a given type of medical needs. In most Western cases, the primary care clinic is close to the patient's home whereas, in China, patients do not mind going to a hospital far away from home, if it is well-known. Therefore, along with the availability of the resources needed, patient preference in China can vary with the reputation of the hospital or, even, of a certain physician.

Taking the special healthcare environment into account, this paper mainly focuses on the appointment scheduling for specialists in OPD. The main contributions of this paper are as follows:

- A new revenue function is formulated to evaluate patient satisfaction level, disregarding the financial income.
- Based on a new evaluation method, a MDP model is developed to model the sequential appointment process.
- Adaptive dynamic programming algorithms are proposed to dynamically capture patient preferences, and thus update the value functions timely.

2. Model formulation

2.1. Booking process

The model tries to emulate the booking processes in an outpatient department of a typical hospital in China specializing in the treatment to cardiovascular diseases. The outpatient department is composed of seven sub-departments each with several physicians. Patients can make their choices according to the availability of physicians and the schedule on the website. The booking process is illustrated in Fig. 1. During online booking exercises, patients indicate their preferences, including the preferred physician(physician preference) and the convenient time(time preference). It is common for a patient to have more than one choice. Denote R as a preference set and p_R as the probability that a patient with a preference set R calls for an appointment in a call-in period. Let Ω be a set that includes all possible preference sets and p_0 the probability that there is no appointment request during the call-in period. $\sum_{R\subseteq\Omega} p_R$ is considered as the probability that there is a call (no matter what preferences (s)he holds) in a call-in period. There is $\sum_{R\subseteq\Omega} p_R + p_0 = 1$, indicating that the probability that there are more than one call in a call-in period is zero. Considering patient preferences and the current system state, the scheduler confirms an appointment decision, i.e., assigns or refuses the request. Since no emergency patients are considered in the proposed model, a non-assignment policy is permitted provided that the penalty of a non-assigned patient is smaller than the expected revenue upon completion of the time slot in question. If the request is refused, a penalty l_1 is imposed on the hospital. Upon receiving an offer, the patient can choose to accept or decline it. Whenever a patient declines an offer, the hospital suffers a revenue penalty of l_2 because the appointment decision dissatisfies the patient (normally, $l_1 \geq l_2$). Finally, the booking process is terminated. If all slots in a shift have been fully scheduled, the booking system for the given shift is closed. Hospital statistics have indicated that, owing to the high demand for specialist service and reputation of the hospital in question, the rate of a patient declining an appointment decision is low.

Each call-in period (the booking horizon) is divided into T time intervals [4]. Each interval is small enough so that there is no more than one call within the given time period. For a given workday schedule, calls come within the booking horizon. Different from literature where patients are divided according to on their arrival probabilities [17], choice probabilities [2], or no-show rates [4], patients in our model are categorized according to their preferences.

2.2. The states and the action set

In the proposed appointment system, there are M physicians whose working shifts in a day are divided into N time slots. It is assumed that the length of all the time slots are equal [17], all patients should arrive punctually without no-shows, each time slot