Approximate dynamic programming approaches for appointment scheduling with patient preferences

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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.

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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

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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 ser-
vices 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 cus-
tomer behavior in revenue management and auctions. However,
[5] indicate that there are two types of differences between mar-
keting 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, 6,16,11,6] are the first to explicitly model patient
preferences. To some extent, their model is a significant advance-
ment 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 sys-
tem 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 design-
ing 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 prob-
lem of how to provide some candidates to patients by dividing
patients according to choice probabilities when they have differ-
ent 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 pre-
ference). 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.](https://doi.org/10.1016/j.artmed.2018.02.001)

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