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USING SIMULATION TO EXAMINE APPOINTMENT OVERBOOKING SCHEMES FOR A MEDICAL IMAGING CENTER

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ABSTRACT

In this paper, we present an appointment scheduling problem faced by a medical imaging center in a major hospital in Macau. We developed an empirically calibrated simulation model to represent the appointment and medical diagnosis procedure as a multi-server queuing network with multiple patient classes. Four appointment overbooking schemes are proposed to compensate for patient no-shows and unpunctuality. The focus of this study is to integrate overbooking schemes with existing appointment rules to improve the operational efficiency of the center. Simulation results show that our proposed overbooking schemes significantly enhance the performance of the center. Compared with the current practice, the best performing overbooking scheme reduces the overtime by 58.32% and the idle time by 23.65%, increases the number of patients served by 15.9%, while still ensuring that patient waiting times remain acceptable.

1 INTRODUCTION

Patients' no-show behavior and its negative impact on medical practice have been documented in many studies. A 12% no-show rate is reported at general practices and outpatient clinics in the United Kingdom (Sharp and Hamilton 2001). Dreiher et al. (2008) report a 30% proportion of non-attendance in an outpatient obstetrics and gynecology clinic. Defife et al. (2010) report a 21% no-show rate in psychotherapy appointments. All of these facts indicate that patient no-shows are prevalent in different healthcare units all over the world.

Our research is motivated by an appointment scheduling problem in a medical imaging center of one of the major hospitals in Macau. Due to the increasing patient demand for medical diagnostic services, our project team was asked by the hospital administrators to improve the efficiency of the medical imaging center. In addition to anticipating the increasing patient demand, the center has also been suffering from patient no-shows and unpunctuality, and is looking for solutions to reduce the idle time of valuable resources and staff overtime.

In this study, an empirically calibrated simulation model is developed to represent the appointment and medical diagnosis procedure of the imaging center. Four appointment overbooking schemes are proposed and tested to examine their effectiveness for reducing the adverse impact of no-shows and unpunctuality on the efficiency of the center. We notice that naïve overbooking schemes can result in overcrowding, increased staff overtime and prolonged waiting times (Kim and Giachetti 2006). Therefore, our study aims to provide solutions by integrating overbooking schemes into prevailing appointment rules propounded in the existing literature. Specifically, we propose effective ways to assign the overbooked patients to different time slots so that the resulting appointment schedule can effectively reduce the expected idle time and at the same time avoid overtime.

2 RELATED LITERATURE

In many healthcare delivery systems, operations are driven by the appointment schedules, which determine the incoming flow of patients to expensive medical resources. The quality of appointment schedules can directly affect the effectiveness and efficiency of healthcare systems and is of primary interest for researchers and practitioners.

There has been extensive research on appointment scheduling in healthcare. Detailed reviews of the literature can be found in Cayirli and Veral (2003) and in Gupta and Denton (2008). In most practical cases, finding an optimal schedule is analytically intractable, and, thus, most of the studies in the literature use search algorithms, simulation-based techniques, and/or heuristics to obtain near-optimal solutions.

In this section, we review the salient and relevant literature to our research. First we summarize the existing literature about appointment rules and then we discuss overbooking policies.

2.1 Appointment Rules

Appointment rules determine the basic template of an Appointment System (AS) by specifying the number of patients scheduled to each appointment slot (i.e. block size) and the length of appointment intervals (Cayirli, Veral, and Rosen 2006). Klassen and Yoogalingam (2014) show that a combination of variable-length intervals and block scheduling are better at mitigating the effects of patient unpunctuality

The best performing appointment rules reported in the healthcare literature include: 1. the individual-block/fixed-interval rule (**IBFI),** used as a benchmark usually, which assigns patients individually to intervals of the same length equal to the mean service time of patients; 2. **OFFSET** rule (Ho and Lau 1992), where the initial patients are scheduled earlier and the rest are scheduled later than their appointment times by IBFI; 3. **DOME** rule (Wang 1997; Robinson and Chen 2003; Denton and Gupata 2003; Hassin and Mendel 2008; Cayirli, Yang, and Quek 2012), where appointment intervals are shorter at the beginning and the end of the day and longer in the middle of the day; 4. **2BEG** rule (Bailey 1952, Ho and Lau 1992, Klassen and Rohleder 1996), which adopts a IBFI rule but assigns two patients at the beginning of the session; 5. the multi-block/fixed-interval rule (**MBFI**) (Soriano 1966; Cox, Birchall, and Wong 1985), which assigns two patients to one time slot, where the length of each time slot is twice the mean service time. The **2BGDM** and **MBDM** rules are variations of **2BEG** and **MBFI** with non-fixed appointment intervals that follow a "dome" pattern.

In the literature discussed above, although patient no-shows are considered as an important environmental factor to test the performances of different appointment rules, overbooking schemes are not incorporated in development of these rules.

2.2 Overbooking

Patient no-show is reported as one of the most disruptive factors to healthcare delivery systems and can create inefficiencies. One way to mitigate the negative impact of no-shows is the practice of overbooking.

LaGanga and Lawrence (2007) examine the problem of no-show and propose appointment overbooking as one means of reducing the negative impact of no-shows. Using numerical experiments, they show that patient access and provider productivity are significantly improved with overbooking, but that overbooking causes increases in both patient wait times and provider overtime. Muthuraman, and Lawley (2008) develop an appointment scheduling policy for outpatient clinics. The appointment schedule is constructed for a single service period that is partitioned into time slots of equal length. Each calling patient has a no-show probability and overbooking is used to compensate for patient no-shows. Chakraborty, Muthuraman, and Lawley (2010) develop a sequential clinical scheduling policy for a clinic with general service time distributions and patient no-shows. The performance of the policy is compared with the appointment rules IBFI, 2BEG, OFFSET, DOME, 2BGDM, MBFI, and MBDM, which we discussed in Section 2.1. Zeng et al. (2010) study a clinical scheduling model with overbooking for a set of heterogeneous patients and prove that, unlike the overbooking model for homogeneous patients, the model for heterogeneous patients is not multimodular. With the assumption that the service times are deterministic and the feature that the show-up rates vary according to the appointment time slot, LaGanga and Lawrence (2012) develop an analytic appointment scheduling model which allows overbooking, and show that appropriate scheduling in health care clinics can significantly improve patient experience and provider productivity.

Their computational experiments demonstrate a number of important patterns regarding appointment overbooking, such as “frontloaded” suggested by Bailey (1952)，“double-booking” suggested by Welch and Bailey (1952), and “wave ” patterns suggested by Baum (2001). They also point out that it is not possible to draw general conclusions regarding how overbooked schedules should be constructed-the circumstances of each clinic need to be carefully studied and evaluated to obtain the best possible clinic appointment scheduling policy. The recent work by Zacharias and Pinedo (2014) about appointment overbooking also found “frontloaded” and “wave ” patterns in the majority of optimal schedules.

Our study focuses on incorporating overbooking schemes into appointment rules to provide an effective way to compensate for patient no-shows and unpunctuality. To our best knowledge, the integration of overbooking patterns addressed in Section 2.2 and the existing appointment rules reviewed in Section 2.1 has not been discussed in the literature yet. In this work, we adopt a simulation approach, which has been shown to be an appropriate and popular tool to evaluate appointment rules and overbooking schemes (e.g., Guo et al. 2004; Wijewickrama and Takakuwa 2008; Yeon et al. 2010), to examine the effectiveness of various schemes.

3 DATA COLLECTION AND MODEL DESCRITION

3.1 Data Collection

We collected data related to the appointments for ultrasound imaging services of the center from January 2015 to March 2015, including the dates and times that patients called to make appointments, their appointment dates and times, the number of medical diagnostic tests scheduled for each patient, their arrival times at the center (if showed up), the start times and end times of medical diagnostic tests, and patient departure times.

3.2 Description of daily operations

There are 2 ultrasound facilities in the center. For each ultrasound facility, there are 27 time slots available per working day from 9 am to 6 pm. Each time slot is of 20 minutes, which is the total of the average examination time and the average setup time for one medical diagnostic test. The center serves all the patients who show up on the day. The extra time spent by the staff to serve patients after the office hours, i.e., after 6pm, is regarded as overtime.

For a regular working day, there are around 20 to 30 appointment requests for ultrasound diagnostic services. After making an appointment, most patients will arrive at the medical imaging center for an ultrasound examination prior to their scheduled appointment times, but some will be late or even not show up. The appointment times and the actual arrival times of the patients were recorded and their differences are used to model the patient unpunctuality, which will be described in Section 3.3. In addition to the ordinary patient no-shows, there is another cause for the waste of resources in our motivating example, which occurs when patients do not fast as instructed. If patients do not fast as instructed, they simply cannot proceed to examination, which causes resource idle time and reduces the utilizations of the valuable resources further.

With the data collected, we estimated the probability distributions and parameters used in our simulation, as shown in Table 1 and Table 2. In our study, we assume that all of the parameters in Table 2 are fixed during the day.

Table 1: Arrival pattern of appointment requests.

Hour of the Day	Arrival Rate	Distribution
9:00	4.26	Exponential
10:00	4.02	Exponential
11:00	3.32	Exponential
12:00	3.00	Exponential
13:00	1.02	Exponential
14:00	2.52	Exponential
15:00	3.08	Exponential
16:00	3.00	Exponential
17:00	0.00	Exponential

Table 2: Summary statistics from empirical data.

Parameter	Mean (μ)	Standard Deviation (σ)	Distribution
Examination time (min.) per test	12.70	8.09	0.5 + 87· BETA(2.3,12.7)
Setup time for ultrasound imaging (min.)	6.40	5.17	-0.5 + LOGN(7.01,6.43)
No-show probability	0.176	-	-
No-fasting probability	0.361	-	-
Probability of 1 diagnostic test	0.639	-	-
Probability of 2 diagnostic tests	0.157	-	-
Probability of 3 diagnostic tests	0.135	-	-
Probability of 4 diagnostic tests	0.043	-	-
Probability of 5 diagnostic tests	0.023	-	-
Probability of 6 diagnostic tests	0.003	-	-
Lateness time	- 4.58	17.10	-60 + 120· BETA(6.48,7.61)

3.3 Simulation model

A 25-day session was used to simulate the actual procedure of the ultrasound imaging diagnostic examinations in this center over a typical one-month period. Since our simulation starts with an empty appointment list, we used a warm-up period to exclude the first few days, which generally had a low resource utilization, from our reported statistics. The warm-up period was 5 days, since the number of patients served every day stabilizes from day 4 in the simulation. This allows us to build up an adequately long appointment list. Ten independent replications are used to obtain an estimate of the key performance indicators (KPIs) that resulted from the appointment overbooking schemes. In other words, we gathered simulation statistics of 200 independent days and 4,875 patients examined from 10 replications, where each replication started with an empty medical imaging center.

In our simulation model, each arrival of an entity corresponds to a request for ultrasound imaging services. The collected data shows that the interarrival times of requests for ultrasound imaging services follow exponential distributions, and the arrival rates vary from one hour to next. The arrival rates are shown in Table 1.

Upon the patient's request, the model will suggest the earliest available time slot in the current schedule for him, where the scheduled time slot should be sufficiently long to conduct all the examinations required. Then the patient decides whether to accept this proposed time slot, based on his own personal schedule. If the patient accepts, the appointment is made and the number of patients that can be assigned to that time slot will then decrease by one. No appointment can be made for subsequent patients when this number drops to zero. If the patient rejects, then the model will suggest the next earliest available time slot in the current schedule for him. This process is repeated until the patient can be assigned to a time slot.

Once the appointment is made, the patient may eventually show up or not, according to the empirical no-show probability. If the patient shows up, the actual arrival time is obtained by the scheduled appointment time plus the lateness time generated from its probability distribution. If the lateness time is negative, this means that the patient arrives prior to his or her scheduled appointment time. After reporting to the registration staff, the patient waits in the queue until the ultrasound facility is available. The patients in queue are called for medical diagnostic tests on a first-come-first-served basis. With some probability the patient may have more than one diagnostic test (see Table 2), with the result that the service times will be correspondingly longer. When called for diagnostic test, if the patient is found out to not have fasted as required, he or she has to cancel the examination, make a new appointment at the registration desk, and come back for examination on another day. This is unfavorable to the medical imaging center because the valuable resource may become idle. Figure 2 shows the flow of our simulation model.

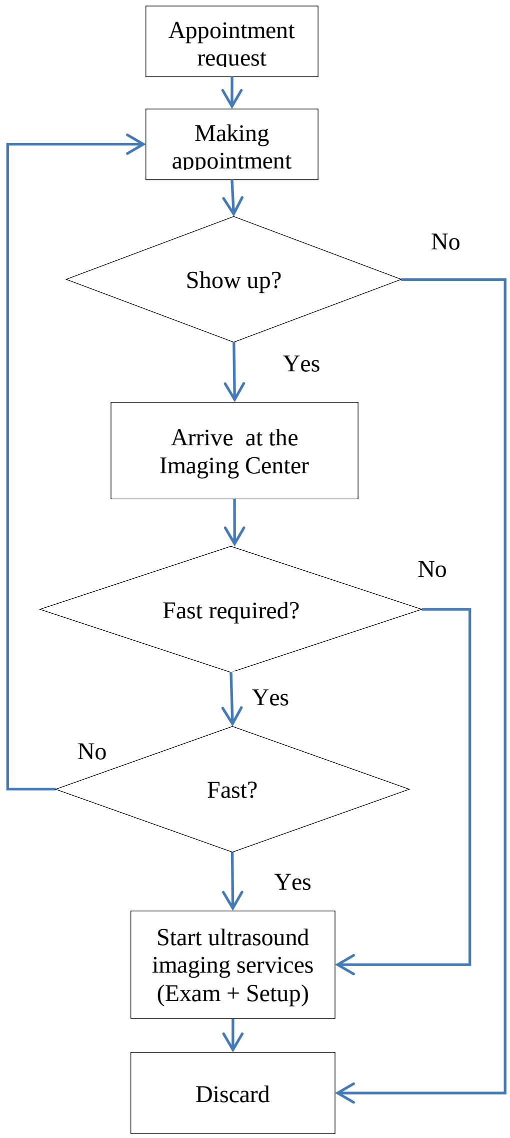

Figure 2: Model Framework.

4 ANALYZING THE IMPACT OF DIFFERENT OVERBOOKING SCHEMES

The purpose of this study is to incorporate overbooking schemes into appointment rules to reduce the adverse effect of patient no-shows and unpunctuality. The objective is to minimize the resource idle time and overtime, and the patient waiting time.

We propose four different appointment overbooking schemes: 1. η-IBFI , 2. η-Dome, 3. η-2BEG-Revised, and 4. η-2BGDM, where η denotes the overbooking rate, i.e., the percentage of overbooked time slots. In our study, we set η = no-show probability + no-fasting probability, which is the proportion of the actual unattended time slots of those scheduled.

4.1 Baseline

The baseline appointment scheduling procedure is IBFI with no overbooking, representing the current practice of the medical imaging center. IBFI stands for individual-block/fixed-interval rule (Cayirli, Veral and Rosen, 2006), which calls patients individually at time intervals of equal length of μ, the mean service time. For ultrasound imaging diagnostic tests, the mean service time is the sum of the average setup time and the average examination time.

4.2 η-IBFI

A maximum of η percent is allowed for overbooking. Patients are individually assigned to time periods of equal length of μ^*, where

$$\mu^* = \mu / (1 + \eta) . \tag{1}$$

4.3 η-Dome

Similar to η-IBFI, η-Dome policy allows a maximum overbooking rate of η percent. The dome pattern is used to determine the start time for each time slot, based on the mean service time μ, the standard deviation σ of the service time, the total number of time slots, and parameters β_i ($\beta_1 = 0.12$, $\beta_2 = 0.05$, $\beta_3 = 0.01$) and k_i ($k_1 = 10$, $k_2 = 35$) (Cayirli, Veral and Rosen, 2006). The parameter values of β_i and k_i are chosen to form a dome pattern in the appointment schedule during the pilot study. Then patients are individually assigned to these time slots.

4.4 η-2BEG-Revised

Similar to the previous two schemes, η-2BEG-Revised policy allows a maximum overbooking rate of η percent. Then the "frontloaded", "double-booking", and "wave " patterns are used to determine which time slots will be overbooked, i.e., more than one patients are assigned to those time slots which allow overbooking. Basically, the regular working hours (9 am to 6 pm) will be partitioned into even and separated sessions. Two patients will be assigned to the every first time slot in each session, and the rest of the time slots allows only one patient scheduled each.

4.5 η-2BGDM

This appointment overbooking scheme integrates the η-2BEG-Revised with the dome pattern. Instead of using fixed time interval, the dome pattern is used to determine the start time of each time slot. The parameter values of the dome pattern we used are β_i ($\beta_1 = 0.15$, $\beta_2 = 0.3$, $\beta_3 = 0.1$) and k_i ($k_1 = 10$, $k_2 = 20$). The parameter values of β_i and k_i are also chosen to form a dome pattern in the appointment schedule during the pilot study.

Table 3 lists the total number of time slots, the start time of each time slot, and the number of patients assigned for each time slot resulted from the above five appointment schemes.

Table 3: The start time and the number of patients assigned for each time slot resulting from appointment schemes IBIF, η-IBFI , η-Dome, η-2BEG-Revised, and η-2BGDM.

Time Slot	**IBFI-No overbooking**		**η-IBFI**		**η-Dome**		**η-2BEG-Revised**		**η-2BGDM**	
	Start Time	No. of Patients	Start Time	No. of Patients	Start Time	No. of Patients	Start Time	No. of Patients	Start Time	No. of Patients
1	9:00	1	9:00	1	9:00	1	9:00	2	9:00	2
2	9:20	1	9:13	1	9:00	1	9:20	1	9:04	1
3	9:40	1	9:26	1	9:15	1	9:40	2	9:26	2
4	10:00	1	9:39	1	9:29	1	10:00	1	9:48	1
5	10:20	1	9:52	1	9:44	1	10:20	2	10:10	2
6	10:40	1	10:05	1	9:58	1	10:40	1	10:32	1
7	11:00	1	10:18	1	10:13	1	11:00	2	10:54	2
8	11:20	1	10:31	1	10:27	1	11:20	1	11:16	1
9	11:40	1	10:44	1	10:42	1	11:40	2	11:38	2
10	12:00	1	10:57	1	10:57	1	12:00	1	12:00	1
11	12:20	1	11:10	1	11:10	1	12:20	2	12:31	2
12	12:40	1	11:23	1	11:24	1	12:40	1	12:50	1
13	13:00	1	11:36	1	11:37	1	13:00	2	13:09	2
14	13:20	1	11:49	1	11:51	1	13:20	1	13:27	1
15	13:40	1	12:02	1	12:05	1	13:40	2	13:46	2
16	14:00	1	12:15	1	12:18	1	14:00	1	14:05	1
17	14:20	1	12:28	1	12:32	1	14:20	2	14:23	2
18	14:40	1	12:41	1	12:46	1	14:40	1	14:42	1
19	15:00	1	12:54	1	12:59	1	15:00	2	15:01	2
20	15:20	1	13:07	1	13:13	1	15:20	1	15:20	1
21	15:40	1	13:20	1	13:27	1	15:40	2	15:38	2
22	16:00	1	13:33	1	13:40	1	16:00	1	15:57	1
23	16:20	1	13:46	1	13:54	1	16:20	2	16:16	2
24	16:40	1	13:59	1	14:08	1	16:40	1	16:34	1
25	17:00	1	14:12	1	14:21	1	17:00	2	16:53	2
26	17:20	1	14:25	1	14:35	1	17:20	1	17:12	1
27	17:40	1	14:38	1	14:49	1	17:40	2	17:30	2
28	-	-	14:51	1	15:02	1	-	-	-	-
29	-	-	15:04	1	15:16	1	-	-	-	-
30	-	-	15:17	1	15:30	1	-	-	-	-
31	-	-	15:30	1	15:43	1	-	-	-	-
32	-	-	15:43	1	15:57	1	-	-	-	-
33	-	-	15:56	1	16:10	1	-	-	-	-
34	-	-	16:09	1	16:24	1	-	-	-	-
35	-	-	16:22	1	16:22	1	-	-	-	-
36	-	-	16:35	1	16:34	1	-	-	-	-
37	-	-	16:48	1	16:47	1	-	-	-	-
38	-	-	17:01	1	17:00	1	-	-	-	-
39	-	-	17:14	1	17:13	1	-	-	-	-
40	-	-	17:27	1	17:26	1	-	-	-	-
41	-	-	17:40	1	17:39	1	-	-	-	-

5 SIMULATION RESULTS

To validate the simulation model, we compare the simulated results and the actual data to examine if they are consistent. Table 4 shows the Actual data v.s. Simulated results. The simulated data in each category are quite close to the actual data. We also presented the model logic to a doctor of the center and he believed that the model is accurate enough to represent the actual appointment and medical diagnosis procedure.

Table 4: Actual data v.s. Simulated results.

	Number of Patients Served / day	% of unattended time slots
Actual data	15.10	53.67%
Simulated results	15.36	54.19%

We now present the results for the idle time, the overtime, the average patient waiting time, and the number of patients served from 10 simulation replications. We use one-factor ANOVA to analyze the differences, which is summarized in Figure 2. The resulting pairwise Tukey test results are reported in Table 5.

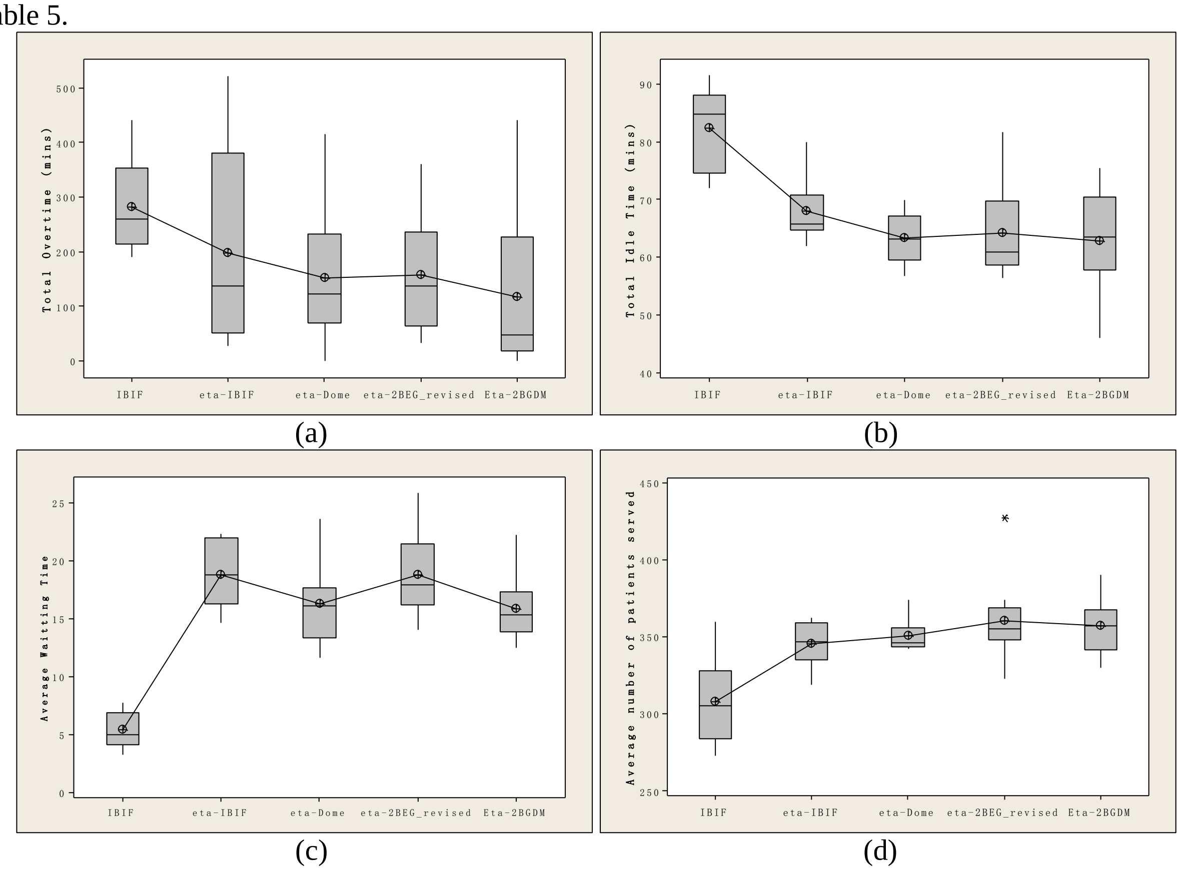

Figure 2: One-factor ANOVA Analysis.

The boxplots in Figure 2 show the that performances of the four overbooking schemes and the current practice (IBFI) are significantly different. First of all, the experiments demonstrate that the appointment schedules with overbooking, i.e., η-IBFI, η-Dome, η-2BEG-Revised, and η-2BGDM, substantially increased the productivity of the imaging center. In addition, η-Dome, η-2BEG-Revised, and η-2BGDM reduced the idle time and the overtime of the technicians, while the average patient waiting time increased. Different overbooking schemes make different levels of impact on patient waiting time. Among all of the

4 overbooking schemes, η-2BGDM gives to the minimum increase in the average patient waiting time. As the best performing overbooking scheme, η-2BGDM reduces the overtime by 58.32% and the idle time by 23.65%, increases the number of patients served by 15.9% , and keeps the average waiting time around 15.9 minutes, which is acceptable to the hospital administration.

Table 5: Connecting letters reports from mean comparison of the idle time, the overtime, the average patient waiting time, and the number of patients served resulted from appointment rules under the study. Two appointment rules are statistically different for a given performance measure if they do not share a common letter.

Appointment rules	Overtime (Mins)			Idle Time (Mins)			Average Patient Waiting Time (Mins)				The number of patients served		
			Average			Average				Average			Average
Baseline-IBFI	A		282	A		82.4	A			5.4	A		308
η-IBFI	A	B	198		B	68.1		B		18.8		B	346
η-Dome		B	151		B	63.4			C	16.3		B	351
η-2BEG-Revised		B	157		B	64.2		B		18.9		B	360
η-2BGDM		B	118		B	62.9			C	15.9		B	357

There are two major insights obtained from the experimentation results above.

1. Overbooking may not necessarily lead to increased overtime. It also depends on other elements of appointment schedules, such as the number of patients overbooked and the length of time interval of each time slot.
2. The way of assigning overbooked patients to appointment time slots does have a significant impact on the operational efficiency. As we observe, the negative impact of overbooking on the patient waiting time has been significantly mitigated by η-2BGDM.

6 CONCLUSIONS

Our study was motivated by a realistic and challenging situation facing by a medical imaging center in a major hospital in Macau, which has been suffering from patient no-shows and unpunctuality. Four appointment overbooking schemes are proposed to provide an effective way to compensate for the patient no-shows and unpunctuality, and maintain the balance between the idle time and the overtime of valuable resources. We developed an empirically calibrated simulation model to imitate the appointment and medical diagnosis procedure. Experimentation results show that compared with the current practice, the proposed overbooking schemes can significantly improve the overall operational efficiency of the center, in terms of KPIs such as idle time and over time of staff, productivity, and patient waiting time.

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