Appointment Rule of CT Department under Emergency Random Demand: Based on Numerical Calculation

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Abstract. This work considers on the impact of different appointment rules on the expected direct waiting cost of patients, the service provider's expected idle cost and overtime cost under the random demand of emergency patients. We compute these costs by modeling and numerical calculation on MATLAB. Numerical examples show that allocating the reserved slots in the middle of the session could dramatically decrease the direct waiting cost of patients. For idle cost and overtime cost of service provider, reserving the slots in the end of the session performs best. Allocated the reserved slots in the end of the session performs well on the expected total cost.

Introduction

Appointment scheduling is an efficiency lever to manage the capacity of the CT department [1, 2, 3]. The appointment rule includes the length of each time slot and the number of patients in each slot. Ho and Lau studied the appointment rules to minimize the total idle cost of doctor and patient by numerical simulation [4]. Kolisch and Sickinger compared three decision rules with three appointment rules under three parameter sets by numerical calculation [5]. Luo et.al considered the problem of prolonging patient waiting time and overtime of CT departments under the situation of unpunctually patients [6].

The emergency demand in CT department of A hospital is huge, about 20%-30% of the total demand. So the emergency random demands should be considered. They are given non-preemptive priority [7, 8]. Emergency cutting in line will cause the waiting time of regular patient. Each service session is equally divided into several slots. Each patient occupies one slot [9, 10]. Regular patient should make appointment in advance and arrive according to the appointment time. The decision variables of appointment scheduling are the number of the reserved slots which are unscheduled for regular patient and the position of these slots. The arrival of emergency patient is described by a sequence of independent non-identically distributed Bernoulli variables. According to the emergency arrival pattern in a hospital, the service session is divided into three parts: the front part (F), the middle part (M) and the back part (B). The reserved slots are allocated at the end of each part. Reserving some slots could achieve balance between the expected waiting time of regular patients, the service provider's expected idling time and overtime working.

The reserved slots could be used for both the delayed regular patients caused by emergency interruption and emergency patient, if there is any. The expected waiting time of regular patient and the idling time of service provider should be calculated in three steps since the reserved slots could be distributed in each part. The overtime is calculated at last since the overtime working occurs only after regular hour. Three steps of calculation are:

(1) The front part: The expected waiting time is $E(W^F)$. The expected idling time is $E(I^F)$.

(2) The middle part is divided into two cases.

(a) If there is no delayed regular patient from the front part, then the expected waiting time is $E(W_1^M)$ and the expected idling time is $E(I_1^M)$.

(b) If there are delayed regular patients from the front part, then the expected waiting time is $E(W_2^M)$ and the expected idling time is $E(I_2^M)$.

(3) The back part is divided into four cases.

(a) If there is no delayed regular patient from the front part and no delayed regular patient from middle part, then the expected waiting time is $E(W_{11}^B)$, the expected idling time is $E(I_{11}^B)$ and the expected overtime is $E(O_{11})$.

(b) If there are delayed regular patients from the front part but no delayed regular patient from middle part, then the expected waiting time is $E(W_{12}^B)$, the expected idling time is $E(I_{12}^B)$ and the expected overtime is $E(O_{12})$.

(c) If there is no delayed regular patient from the front part but some delayed regular patients from middle part, then the expected waiting time is $E(W_{21}^B)$, the expected idling time is $E(I_{21}^B)$ and the expected overtime is $E(O_{21})$.

(d) If there are delayed regular patients from the front part and delayed regular patients from middle part, then the expected waiting time is $E(W_{22}^B)$, the expected idling time is $E(I_{22}^B)$ and the expected overtime is $E(O_{22})$.

The total expected waiting time is $E(W)= E(W^F)+ E(W_1^M)+ E(W_{11}^B)+ E(W_{12}^B)+ E(W_{21}^B)+ E(W_{22}^B)$. The total expected idling time is $E(I)= E(I^F)+ E(I_1^M)+ E(I_2^M)+ E(I_{11}^B)+ E(I_{12}^B)+ E(I_{21}^B)+ E(I_{22}^B)$. The total expected overtime is $E(O) =E(O_{11}) + E(O_{12}) +E(O_{21}) + E(O_{22})$.

Numerical Analysis

We take one month for example to show the impact of the appointment rule on three expected time. For other months, the calculation could be done at the same way. There are 4 hours and 42 slots in one service session in a hospital. The average emergency demand in given in Table 1, (p_i is the probability of emergency arrival in each slot). All the calculation is conducted by MATLAB. The results could be given by nested operation. The calculation results are given in Fig. 1. AMF represents the reservation slots are allocated at the end of the front part of Morning session in Fig. 1. We can give some concludes from Fig. 1.

Table 1 The average demand of emergency patients

Morning (AM)		Afternoon (PM)	
time span (slot)	p_i	time span (slot)	p_i
8:00-9:00（1-10）	0.132	14:00-15:00（1-10）	0.190
9:00-11:00（11-32）	0.321	15:00-17:00（11-32）	0.265
11:00-12:00（33-40）	0.320	17:00-18:00（33-42）	0.203

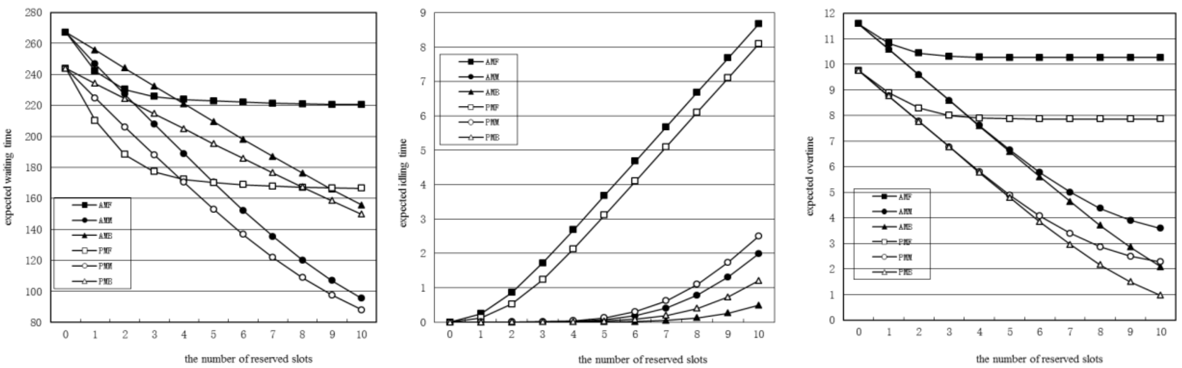

Figure 1. The expected waiting time, idling time and overtime

Expected Waiting Time of Regular Patient. The waiting time decreases as the number of reserved slots increasing, no matter at which part the slots are allocated and in which service session (Morning session and Afternoon session). The best policy is reserving the slots at the end of middle part, namely before the 33th slot if the number of reserved slots is larger than 4. The reason for this is that the reserved slots at the middle part effectively reduce the backlog of regular patient caused by emergency cutting in line.

Expected Idling Time of Service Provider. The idling time increases as the number of reserved slots increasing, no matter at which part the slots are allocated and in which service session. The best policy is reserving the slots at the end of back part, namely at the end of the service session. The reason for this is that there is no idling at the front and middle part.

Expected Overtime of Service Provider. The overtime decreases as the number of reserved slots increasing, no matter at which part the slots are allocated and in which service session. The best policy is reserving the slots at the end of back part, namely at the end of the service session. The reason for this is that there is no idling at the front and middle part. The total number of patient (regular and emergency) who have been served is the larger. And we can see that there is litter difference in idling time and overtime if the number of reserved slots is less than 5, compared allocated the slots in the middle part and the back part.

In what follows, we want to show the impact of the two decision variables on the expected total cost. The unit waiting cost of one patient is w. The unit idling cost and overtime cost of service provider is i and o, respectively. So the total cost is $E=w\cdot E(W)+i\cdot E(I)+o\cdot E(O)$. It is very difficult to obtain accurate estimates for all the parameters. To compensate for the unreliability of some of the cost data as well as to represent a spectrum of possible actual operating situations across hospitals, some experimental investigations should be done under a fairly broad range of values. All monetary units are CNY (￥). The 11 experiments are listed below. E1: (w, i, o)=(10,500,500); E2: (w, i, o)=(15,500,500); E3: (w, i, o)=(5,500,500); E4: (w, i, o)=(10,400,500); E5: (w, i, o)=(10,300,500); E6: (w, i, o)=(10,500,400); E7: (w, i, o)=(10,500,300); E8: (w, i, o)=(10,400,400); E9: (w, i, o)=(10,300,300); E10: (w, i, o)=(15,400,400); E11: (w, i, o)=(5,400,400). In each experiment, we list the best number of reserved slots on total cost for allocating these slots in the front, middle and back part, respectively. The cost of the best number of reserved slots is also listed in Table 2, (the second number of each table cell).

Table 2 The calculation results of expected total cost

NO.	Moring session (AM)			Afternoon session (PM)		
	front	middle	back	front	middle	back
E1	2，7947.81	9，3668.60	10，2841.44	2，6291.73	8，3064.67	10，2583.56
E2	2，9098.85	9，4202.99	10，3619.59	2，7233.42	9，3576.88	10，3332.48
E3	1，6744.68	9，3134.22	10，2063.30	2，5350.03	8，2520.59	10，1834.64
E4	2，7862.34	9，3537.72	10，2792.03	2，6238.89	9，2915.72	10，2462.99
E5	2，7776.87	10，3341.14	10，2742.61	3，6140.33	9，2742.38	10，2342.42
E6	1，6873.10	9，3279.52	10，2633.83	2，5462.89	8，2779.02	10，2486.99
E7	1，5790.62	9，2890.44	10，2426.21	2，4634.06	8，2493.36	10，2390.42
E8	2，6818.67	9，3148.64	10，2584.41	2，5410.06	9，2666.38	10，2366.42
E9	2，5689.52	10，2625.99	10，2327.38	2，4528.39	9，2243.69	10，2149.27
E10	2，7969.71	10，3660.52	10，3362.56	3，6350.05	9，3154.19	10，3115.34
E11	1，5637.92	9，2614.25	10，1806.27	2，4468.36	8，2125.29	10，1617.50

We could conclude from the calculation results in Table 2, that the best reservation policy is stable although the three unit cost fluctuate in a broad range. The worst policy on the total cost is allocating the slots at the end of front part. Both of reserving the slots at the end of middle part and back part could effectively decrease the total cost.

Conclusion

In this paper, we consider the impact of two decision variables (the quantity of the reserved slots and the position of these slots) on the expected waiting time of regular patients, the service provider's expected idle time and overtime. These times are calculated by mathematical model on MATLAB. Numerical calculations show that allocating the reserved slots in the middle of the service session could dramatically decrease the waiting time of regular patients. Allocating the free slots in the end of the session performs best on idle time and overtime of service provider. Allocating the free slots in the middle of the session could effectively reduce the expected total cost.

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References

[1] Gupta D, Denton B. Appointment scheduling in healthcare: Challenges and opportunities, IIE Transactions, 40(2008) 800-819.

[2] Du S, Xie J, Liu Z. Progress and prospects in an emergency hot topic: Healthcare operations management. Journal of Management Sciences in China, 16(2013)1-19.

[3] Hall R. Handbook of healthcare system scheduling. Springer Science+ Business Media, LLC.2012.

[4] Ho C, Lau H. Minimizing total cost in scheduling outpatient appointments. Management Science, 1992 38(1992)1750-1762.

[5] Kolisch R, Sickinger S. Providing radiology health care services to stochastic demand of different customer classes. OR Spectrum, 30(2008)375-395.

[6] Luo L, Shen X, Yan, Chen X, Guo H. Simulation and optimization in CT examination appointment considering the situation of unpunctually patients. Industrial Engineering and Management, 20(2015)77-84.

[7] Luo J., Kulkarni V., Ziya S. Appointment scheduling under patient no-shows and service interruptions. Manufacturing & Service Operations Management, 2012, 14:670-684.

[8] Zhou J, Li J. An M/E k/1 queues with emergency non-preemptive priority of a diagnostic resource. Operational Research (2015) (in press).

[9] Dobson G., Hasija S., Pinker E. Reserving capacity for urgent patients in primary care. Production and Operations Management, 2011, 20:456-473.

[10] Schütz H.J., Kolisch R. Capacity allocation for demand of different customer-product combinations with cancellations, no-shows, and overbooking when there is a sequential delivery of service. Annals of Operations Research, 2013, 206:401-423.