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Original Article

Application of queuing theory and simulation to reduce waiting time in dental hospitals

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Abstract

Background: Patient waiting time is an important factor in the management of the health sector. This study aimed to develop a suitable queuing theory and simulation technique to optimize dental hospital management.

Methods: A descriptive-analytical study was performed in a dental hospital in Tehran, Iran. A sample of 3364 patients referred to the hospital was selected to calculate the patient flow and queuing system performance. After an initial data assessment, the dental hospital queuing system performance indicators were calculated for two shifts. The queuing system of the current situation was modeled using ARENA software, and two scenarios were examined.

Results: The average number of patients waiting in the queuing system was 38 and 17 in the morning and evening, respectively. The average time patients spend waiting in the system was 110 and 49 minutes in the morning and evening, respectively. The two scenarios, based on the simulated queuing network model, showed that in the first scenario, by using two nurses (one male and one female) as triage clerks for filing requests, one clerk for managing financial records, and one information desk secretary, the average queue length and waiting time were reduced to 0.02 patients and 4 minutes, respectively. In the second scenario, by using two nurses (one male and one female) as triage clerks for filing requests and two secretaries (one male and one female) for financial record management and registration, the average queue length and the waiting time in triage were reduced to 0.03 people and 5 minutes, respectively.

Conclusion: Based on the results, using queuing theory and simulation techniques can improve the queuing status of health centers without any changes in the number of staff and only by implementing a suitable rearrangement in staff duties, establishing parallel service lines in busy service-providing centers, and using nurses able to multitask.

Keywords: Queuing theory, Simulation, Dental hospitals

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Introduction

Changes, such as inflation and the fast rate of information updates in healthcare, have increased the complexity of healthcare processes, and competition among healthcare service-providing institutions has changed the viewpoint of experts on the healthcare delivery system. Due to limited facilities and human resources, hospital managers try to provide the highest quality services for patients through optimization of the current resources, increasing the satisfaction of patients and the profit generated by the center.[1,2]

There are different quality assurance indicators in sections of field hospitals، the main indicator being patient waiting time.[3] Many people choose private hospitals to receive high-quality services and avoid the crowds and long waiting times in public health centers.[4,5]

The long waiting time in healthcare centers can lead to an increase in the severity of diseases and result in socio-economic costs. A great portion of dental treatments is provided on an emergency and outpatient basis. Patient waiting time is one of the important factors that must be managed and organized in health care centers. Patient satisfaction directly correlates with shorter waiting time, and it is also considered one of the quality assessment indicators of outpatient services.[6]

Queues are formed when the number of patients

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arriving is more than the number of patients receiving services.[7] Long waiting time affects the efficiency of the hospital and can cause dissatisfaction amongst patients. Some studies have shown a strong correlation between patients' overall satisfaction and their satisfaction with provided dental services.[7]

Queuing theory and simulation techniques are mathematical-based methods that can be utilized to assess the length of waiting queues, the average time of waiting in a queue, the maximum components in a queue, and the average waiting time in the whole system.[8,9]

Queuing theory is an analytic assessment of waiting in a queue as a comprehensive and scientific tool in the management of services.[7] Queuing theory has been widely used in some healthcare fields like emergency care centers, organ transfer waiting lists, and pharmaceutical services. Less attention has been given to queuing theory and its application in dental practice management.[10]

Simulation is a reliable tool for assessing and analyzing the current system to make the necessary corrections to implement a new system. Simulation is a method that provides information obtained from a structural model based on the observation of workflow pivoting in the current state and other related variables.[7]

Due to the increased development and complexity of health systems there has recently been outstanding advances in the application of simulation software for analyzing complicated systems.[9]

The main reason for utilizing research tools is to assess hospital function, activity, and optimal application of physical facilities, technology, and human resources. Two of the most practical scientific tools in this field are queue theory and simulation techniques; queue theory is a mathematical viewpoint based on which analysis of waiting queues can be performed. The current study aimed to assess the queuing system of Baqiyatallah Dental Hospital, analyze the current status, and offer suggestions to improve its function through queue theory and simulation techniques.

The objective of this study was to investigate the queuing network in a military dental hospital to model its queuing system by simulation and develop essential strategies for improving service quality after reviewing the suggested scenarios.

Methods

This was a practical descriptive cross-sectional study. The survey protocol was reviewed and approved by the Ethics Committee at the Research Center for Prevention of Oral and Dental Diseases, Baqiyatallah University of Medical Sciences (Ethics No: IR. BMSU. REC.1399.134). The population of interest consisted of all patients referred to Baqiyatallah Dental Hospital in the morning and afternoon working shifts in one month. To ensure that the sampling represented the society, patients were chosen randomly. Sample size estimation was based on data from a previous study[11] considering a confidence interval of 95% and time-variance of 5.12 minutes with a maximum error of 1 minute for patients in each day, $n = (1.96 \times 5.12/1)^2 = 100.70$.

With the consideration of probable loss of samples, information on arrival and exit, and different lines in different service sections of the dental hospital in two working shifts overall 3364 patients were recorded. Interview and observation were the two tools for obtaining data in this study.

Firstly, open interviews in regular and consecutive sessions were conducted to find out about the overall mechanism of the services provided, available facilities and quantity of dental units in each section, and information on the number of dentists and assistants working in the dental hospital. The automated appointment system in Baqiyatallah Dental Hospital was used to collect the required data, including the number of patients, their arrivals and exits, and the length of each service provided.

After the data on the current status of queuing in the dental hospital were recorded and variables of interest were determined based on a statistical analysis of queuing theory, using the data and simulation, the queuing network in the dental hospital was modeled, and different case scenarios were examined.

Simulation models suggest effective, evidence-based approaches to choice-making by using a virtual representation to investigate the impact of procedure changes and 'what if' scenarios, using which the approach that delivers the best results can be found.

A simulation model was planned using ARENA to predict changes in patient waiting time and queue waiting length resulting from changes in the system. Two scenarios were examined considering the present arrangement of staff, two men and two women operating simultaneously to record medical documents and payment information and give information to patients.

Scenario 1: two nurses (one man and one woman) for filing documents, one secretary to record payment information, and one secretary at the information desk

Scenario 2: two nurses (one man and one woman) for filing documents and two secretaries (one man and one woman) for entering payment records and giving information to patients.

Data analysis

Information about the time of patients' arrival to the dental hospital, the time needed to reach each dental section, the time needed to finish the dental procedures, and finally, the time the patient left the hospital were recorded in two working shifts of morning and afternoon, taking into account each provided dental service, in the dental hospital queuing system. All these data were analyzed using SPSS 22. Information obtained through

previous steps, consisting of the average number of patients in each section, the average number of patients in the waiting queue, the average patient waiting time in each section, and the average patient waiting time in the queue, were used to analyze parameters of queuing theory in the current queuing system of the dental hospital. After that, the dental hospital queuing network and different scenarios based on results from the analysis of queuing theory were designed. All the data were entered into ARENA simulation software, and the two scenarios were assessed based on changes in queuing system parameters, such as changes in the number of personnel and patients.

Results

The number of patients in different sections of the dental hospital, i.e., the patients waiting in queues to receive dental services, was 3364 throughout the study period. Figure 1 shows the flow of patients through Baqiyatallah Dental Hospital.

Based on Table 1, the longest waiting and dental service time in the clinic of Baqiyatallah Dental Hospital were 41.93 and 36.25 minutes, respectively (Figure 2).

The average number of patients waiting in queue in one month and patients waiting in each queue are shown in Table 2. The most patients were in the clinic queue (0.37 patients/min), and the fewest patients were in the cash desk queue (0.02 patients/min). Also, the longest waiting time belonged to the clinic queue (41.9 minutes), and the shortest waiting time was related to the cash desk (1.9 minutes) (Table 2).

As seen in Table 3, the assessment results of queue theory parameters in the current hospital system for the morning working shift shows that there were 38.02 patients on average in queues, which means that in the morning working shift hours, waiting queues were 38 people long per unit of time, which reveals the crowdedness of the dental hospital in morning hours. In the afternoon working shifts, on average 17 patients waited in queues to receive dental services, 21 people fewer than the average number of patients waiting in queues in the morning.

Table 1. Patient waiting time and time spent in each section of Baqiatallah Dental Hospital

Sections	Time spent in each section per patient				Waiting time per patient			
	Average time (min)	Standard deviation (min)	Average minimum time (min)	Average maximum time (min)	Average time (min)	Standard deviation (min)	Average minimum time (min)	Average maximum time (min)
Consultation	12.06	0.01	4.18	20.51	14.14	0.03	3.23	51.8
Diagnosis	6.52	0.02	3.48	9.55	29.29	0.04	15.98	49.08
Emergency	30.06	0.12	18.84	40.3	38.36	8.07	21.24	109.23
Cash desk	1.9	0.01	1.98	3	9/1	0	0.93	3.1
Information	3.53	0	1.4	4.43	3.48	0.03	1.12	6.01
Clinic	36.25	0.04	14.91	55.1	41.93	0.02	25.87	109.19
Radiology clinic	5.4	0.02	1.4	9.5	13.1	0.06	2.6	38.66
Reception	4	0.01	2.96	5.01	8.47	3.25	2.3	13.1
Secretary	4.02	0	2.99	5.01	5.3	0.01	3.1	8.1
Triage	3.43	0	2.47	5.48	9.03	1.8	5.8	10

Table 2. Each patient's waiting time and number of patients waiting in queue in different sections of Baqiatallah Dental Hospital in a time period of 1 minute

Sections	Number of patients waiting in queue in a time period of 1 minute				Each patient's waiting time in queue in a time period of 1 minute			
	Average number of patients (person)	Standard deviation (person)	Average minimum number of patients (person)	Average maximum number of patients (person)	Average time (min)	Standard deviation (min)	Average minimum time (min)	Average maximum time (min)
Consultation	0.12	0	0	0.3	14.14	0.03	3.23	51.8
Diagnosis	0.26	0	0.01	0.4	29.29	0.04	15.98	49.08
Emergency	0.34	0.02	0..9	2	38.36	8.07	21.24	109.23
Cash desk	0.02	0	0.01	0.02	1.9	0	0.93	3.1
Information	0.03	0	0.01	0.05	3.48	0.03	1.12	6.01
Clinic	0.37	0	0.3	0.4	41.93	0.02	28.87	109.19
Radiology clinic	0.11	0.01	0.01	0.2	13.1	0.06	2.6	38.66
Reception	0.07	0	0.05	1	8.47	3.25	2.3	13.1
Secretary	0.05	0	0.02	1	5.3	0.01	3.1	8.1
Triage	0.08	0	0.05	1	9.03	1.8	5.8	10

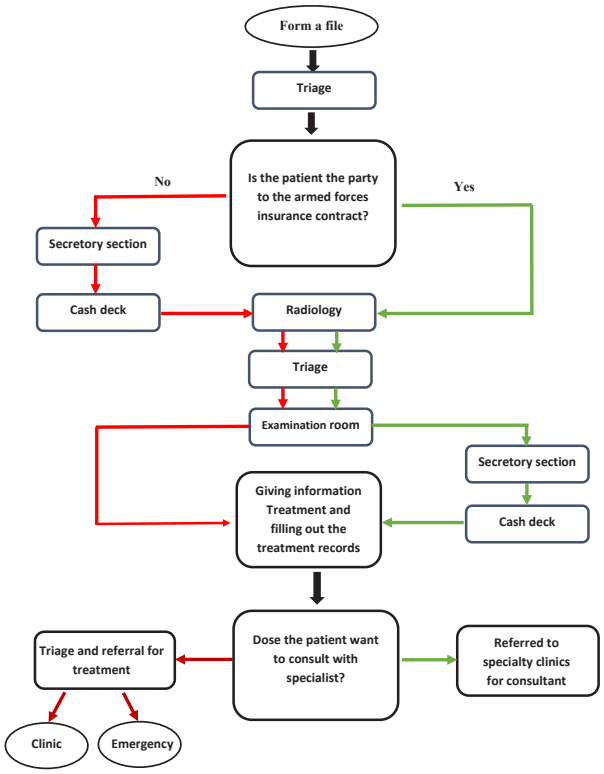

Figure 1. Flow of patients in Baqiyatallah Dental Hospital.

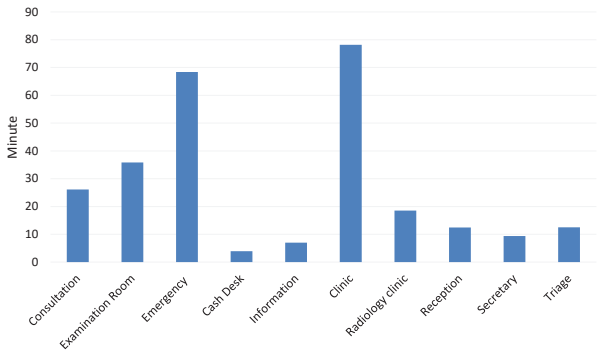

Figure 2. Average time required for each patient in different sections of Baqiatallah Dental Hospital.

Patients attending dental hospitals in the morning waited about 110 minutes to receive dental services (from arrival until they left the hospital). This indicator decreased to 49 minutes during afternoon working hours.

According to the modelling results, if the current queuing system of Baqiyatallah Dental Hospital at the triage section (2 men and 2 women operating simultaneously to record medical documents, enter payment records, and give information to patients), were changed to two nurses (one man and one woman) for filing requests, one secretary to record payment information, and one secretary at the information desk (Scenario 1), the waiting time would decrease to 55% of the present waiting time and the number of patients waiting in queue would decrease from 0.08 to 0.02. Modeling the second scenario, i.e. two nurses (one man and one woman) for filing requests and two secretaries (one man and one woman) for entering payment records and giving information to the patients, would decrease patients' waiting time in the triage queue to 42.5% of the present waiting time and the number of patients waiting in queue to 0.03 (Table 4).

Discussion

One efficient approach for studying complex systems is through computer simulation. One important aspect of providing a simulation model is demonstrating the operation of a healthcare facility by taking precise present system information and providing a basis for improving the system processes. In this paper, we used a simulation model to reduce the patent waiting time without any changes in the number of staff in Baqiyatallah University Dental Hospital.

The current study showed that the number of patients waiting for morning and afternoon appointments was 38 and 17 people per time unit, respectively, and waiting times were also calculated based on those results. In contrast, in a study by Adeleke et al, which used queuing theory in an outpatient hospital with an arrival rate of 0.1 and a service rate of 0.12, the average number of patients in a queue was 4.5 people, and the average number of patients in the whole system was 5.4 people. They reported that the average waiting time in a queue was 43 minutes and the average time each patient spent waiting in a queue and receiving treatment was 51 minutes. In the end, they found that the probability of queuing on arrival

Table 3. Number of patients waiting in queue and the time required to receive dental services

Appointment	Number of patients waiting in all queues per time unit	Average time required for each patient to receive dental services
Morning	38	110
Afternoon	17	49

was 0.84.[12]

Results obtained from a simulation model of the current status of the queuing system at Baqiyatallah dental hospital revealed that most of the time spent by patients was in the clinic, which means each patient waited for 41 minutes in the waiting queue and spent 36 minutes to receive dental services in this section, however in Huarng and Lee's study using simulation in outpatient queues, 50% of patient waiting time was spent at the cash desk, which is different from the current study.[13]

In the current study, in case an increase in the service capacity were attempted by adding workforce to the clinic section, the service utilization rate in the whole healthcare providing system would decrease. Similarly, in another study on the effect of increasing the number of practitioners on cost, time, and services, the service-providing capacity decreased, confirming the current study results. In that study, with the increase in the number of physicians from 10 to 11, the service capacity index decreased from 86.6% to 78.8%, and with the increase in number of physicians to 12, 13 and 14, the service utilization rates dropped to 72.2%, 66.7%, and 61.9%, respectively. On the other hand, with a decrease in the service utilization rates due to the increase in physician numbers, waiting time in queues and throughout the whole system was reduced.[14]

The approach to improve the queuing system of Baqiyatallah Dental Hospital in the current study was to use the available resources but to change the queuing patterns, such as the arrangement of staff in the triage section; therefore, simulation was used after assessment of the current status with queuing theory. In the study by Huarng and Lee, the results revealed that there are two main methods for addressing queuing problems: changing the arrival process and changing the service process. Service processes were assessed and corrected in the current study, which makes it similar to Huarng and Lee's study from this point of view.[13]

In a study by Alpaslan et al, who reduced patient waiting time by simulations, assessed five scenarios, and increased medical residents from one to three, if only one physician in the dermatology ward took care of the cases related to general medicine and general surgery and the others only took care of dermatology-related cases, the average patient waiting time in the studied department and in the queues could be reduced from 40 to 12–13 minutes and from 28.45 to 0.4–1.5 minutes, respectively.[15]

In a study on using queuing theory the number of patients leaving the center without receiving any services could be reduced by increasing the working efficacy of the emergency ward staff of a hospital without any increase in hours of service and only by rearrangement of human resources.[16] In a study by Bahadori et al[9] on using queuing theory to optimize hospital pharmacy performance, decreasing personnel number at the prescription reception station from two to one did not change queue characteristics. Increasing the prescription-filling personnel from one to two reduced the queue's average length to ten people and the average waiting time to 18 minutes and 14 seconds.[14] On the other hand, simulation results showed that in the evening, by reducing personnel in the prescription delivery counter from two to one had minimal effect on queue characteristics. An increase in prescription filling personnel could reduce the average queue length by five people and the average waiting time by 8 minutes and 44 seconds.[9] Therefore, the results of that study confirm the results of the current study.

In the current study, by analyzing both working shifts of Baqiyatallah Dental Hospital, it was revealed that the queuing pattern was single-layered, multistage, and multi-service. After the analysis of changes in the arrangement of nurses providing services, the pattern changed to a parallel service-providing mechanism. A study on the application of queuing theory to patient satisfaction at a hospital by Ameh et al, yielded different results; however, with the use of queuing theory and by changing queuing patterns from multi-line, single service to multi-line, single service they showed that waiting line could be reduced to 67%.[17] In a study by Obamiro, it was concluded that to reduce the overall patient waiting time, some services should be provided simultaneously in a way that the overall waiting time for those outpatients who were in need of more than one healthcare service could be reduced.[18] From that point of view, the results of their study confirm the result of the current study.

In a study by Alpasan et al on the reduction of waiting time using simulation, it was indicated that with an increase in nurses from one to three, average patient waiting time in the queue would be reduced from 28.45 to 0.4–1.5 minutes, which is in line with the current study results.[15]

The potential limitations in this study are mainly

Table 4. Comparison of triage queuing parameter changes in Scenarios 1 and 2 with the present state

Parameters	Scenario 1	Scenario 2	Present state	Changes
Average queue length (number of patients)	0.02	0.03	0.08	Rearrangement of triage staff composition decreases the queue length
Average time each patient waits in the triage section	4.15	5.19	9.03	Rearrangement of triage staff composition decreases waiting time

related to the high number of sections in a dental hospital, making the thorough assessment of all sections difficult, so this study has assessed the intended scenarios only in the triage section, as the main part of the dental hospital.

A correct and careful analysis of the queuing characteristics of patients in the other parts of the hospital could be achieved by using queuing theory, and the costs and personnel surplus could be reduced by exploring different scenarios using simulation techniques without making perceivable changes in the queuing characteristics of the other service delivery stages.

Conclusion

In general, it could be concluded that with the application of statistical analysis and queuing theory, we can achieve a good understanding of queuing problems in dental hospitals. Using a simulation model without making any changes in the number of staff, the queuing status of the dental hospital can be improved in busy service-providing centers by implementing a suitable rearrangement in the staff, establishing parallel service lines, and using multitasking nurses.

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Conflict of Interests

The authors declared no conflict of interest.

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