Sigma J Eng Nat Sci, Vol. 41, No. 2, pp. 423−432, April, 2023

Sigma Journal of Engineering and Natural Sciences
Web page info: https://sigma.yildiz.edu.tr
DOI: 10.14744/sigma.2023.00045

Research Article

Estimation of the utilization rates of the resources of a dental clinic by simulation

Abdulkadir ATALAN[1,*], Abdulkadir KESKIN[2]

[1]*Gaziantep Islam, Science and Technology University, Department of Industrial Eng., Gaziantep, Turkey*
[2]*Istanbul Medeniyet University, Department of Quantitative Methods, Istanbul, Turkey*

ARTICLE INFO

Article history
Received: 07 September 2021
Revised: 28 December 2021
Accepted: 21 January 2022

Keywords:
Dental Clinic; Discrete Event Simulation; Utilization Rates; Length of Stay; Waiting Time

ABSTRACT

This study aimed to calculate the resource utilization rates, patient length of stay, and patient waiting times of a small-scale dental clinic using the discrete-event simulation (DES) technique. Dentists, orthodontists, assistants, clerks, beds, triage areas were considered dental clinical resources in this study. In contrast to the traditional doctor-patient contact calculation of healthcare resource efficiencies, clinical resource efficiencies were calculated using the DES technique. Since the patient's arrival both with and without an appointment, the patient arrival times were calculated with a uniform distribution. According to actual data, 100 patients were treated per day on average, while the number of patients treated by the dentists and orthodontists was simulated as 105 in the simulation model. The utilization rate of the dentists, orthodontists, assistants, and clerks were computed as 65.5%, 77.5%, 35.5%, and 45%, respectively. The beds reserved for dentists, the beds for orthodontists, the triage locations used by assistants, and the registry office where clerks work have a utilization rate of 68.25%, 89.5%, 31.0%, and 99.0%, respectively. The time a patient must spend in the clinic for treatment was calculated a maximum of 155.51 minutes and a minimum of 41.68 minutes. A patient waits an average of 15.45 minutes to complete the dental treatment in this clinic. Patients wait 15.81 minutes for an available staff member and 15.1 minutes for an available location to receive dental treatment. We presented this study as the best example for the dental clinics to provide results that should be obtained in a short time and at a low cost.

Cite this article as: Atalan A, Keskin A. Estimation of the utilization rates of the resources of a dental clinic by simulation. Sigma J Eng Nat Sci 2023;41(2):423−432.

***Corresponding author.**
*E-mail address: abdulkadiratalan@gmail.com;
abdulkadir.atalan@gibtu.edu.tr; abdulkadir.keskin@medeniyet.edu.tr

This paper was recommended for publication in revised form by Regional Editor Sania Qureshi

Published by Yıldız Technical University Press, İstanbul, Turkey

INTRODUCTION

DES is a statistical-based computer model developed to simulate the movements, behaviours, and interactions of entities in real systems with complex and dynamic structures [1]. The most important purpose of this model is to make changes that are very difficult to make in practice, in a short time, and at a low cost. Thus, comprehensive results are obtained and compared by testing options that require different strategies in a simulation model [2]. DES models enable the prediction of the results that will occur in the system when too much randomness experienced in a system is associated with each other. DES models are designed to simulate real systems, helping to improve and develop the real system and achieve desired results [3]. The developed simulation models are verified by a statistical comparison of the real system results with the simulation results [4].

DES models are also used to determine the productivity or utilization rates, working capacities, and idle rates of assets in systems with complex and dynamic structures [5,6]. Although it is superficial to calculate the efficiency of resources, especially in systems with the human factor, there is a discrepancy between the results obtained and the actual results [1]. Statistical results of the assets in the system are obtained by the DES models designed by using the historical and current data of real systems [7]. Thus, DES models should be preferred in terms of determining work efficiency in mobile systems. Researchers have helped solve many problems by using the DES method in complex and dynamic structures [8]. In this study, the efficiency of the resources and the time of the resources were determined using the DES method in the field of health, which has a dynamic structure. For this reason, we have taken into account the literature review of the study, studies in the field of healthcare.

DES models applied in the healthcare field are generally aimed at minimizing patient waiting times [9–12]. It has been determined that patients who have to wait for a long time in the emergency department of a hospital in Quebec province reduce the waiting time by providing more responsibility to the nurses with the DES method [13]. In another study, strategies were developed using the DES method to significantly reduce the waiting time by analyzing the patient flow in the emergency departments [14]. It has been observed that patient waiting times and patient stay times are reduced by simulating scenarios in the DES model by creating two types of scenarios in emergency service units with a large number of patients [1]. The DES method was applied to identify bottlenecks that cause patient waiting times by analyzing the radiotherapy planning process in the London Regional Cancer Program. By making changes in the number of health resources, patient waiting times were reduced by 6.65% with this study [15]. Hasan et al. developed a DES model to statistically analyze the average waiting time of patients for intensive care beds [16].

The simulation models measure how the system is affected as a result of changes in the number of resources in the designed systems [17]. The results to be obtained as a result of the changes made in the numbers of health resources take a long time. However, getting these results with DES models requires both low cost and a short time. The use of the DES method is preferred by researchers for optimum results to be obtained by making resource planning for a health department [18]. In a study, the number of patients treated, the patient waiting time, and the efficiency rates of patient resources were calculated using the DES method as a result of the changes made in the number of health resources without adding externally to the system [11,19]. By managing the resources of an Internal Medicine outpatient clinic, patient waiting times, lengths of stay, and system performances were examined through the DES model [4]. The changes in the number of nurse resources were analyzed through the DES model to improve the system in order to increase the number of patients treated in an on-campus clinic at Mississippi State University [10].

The aim of this study is to calculate the efficiency rate of the clinic without changing the number of health resources belonging to a dental clinic and to determine the times related to the patients. Additionally, the patient flow system of the dental clinic is discussed in this study to identify the bottlenecks that cause incoming patient congestion [20]. Although the DES method is frequently used in the field of health, it has been applied by very few researchers in dental clinics. Mohammed et al. created a DES model to reduce the waiting time of patients for dental treatment and to increase the efficiency of existing health resources [21]. Although the DES method is frequently used in the field of health, it has been applied by very few researchers in dental clinics. Mohammed et al. created a DES model to reduce the waiting time of patients for dental treatment and to increase the efficiency of existing health resources [22]. Czech et al. created a DES model of a dental clinic and confirmed that reducing patient waiting time and increasing the number of patients treated were achieved at zero incremental cost [23]. In the present study, we emphasize that the DES model was developed to validate the efficiency of a dental clinic's resources and determine wait times, not to increase the number of patients treated or reduce patient waiting times.

This study consists of four main parts. The first part includes a literature review of studies that are directly or indirectly related to the study. Information about the methodology of the study is discussed in the second part of the study. The simulation outputs of the DES model developed for the present study are discussed in the third part. The information that the DES method should be applied in dental clinics and that helps determine the utilization of the resources in dental clinics is given in the last part of the study.

METHODOLOGY

Data of Study

A discrete event simulation model was developed for a dental clinic, and the efficiency ratios of the resources of the clinic, the LOS (length of stay), and waiting time were considered in this study. DES models are widely used in dynamic structures to obtain statistical results in situations that do not act according to a certain rule. Although dental clinics work with an appointment system, according to the data used for this study, 32.91% of the patients come to the clinic without an appointment (Such patients are defined as first-visit patients). The rate of patients who visited again was calculated as 67.09% (with an appointment- creating several sessions for those whose dental treatment is not completed).

The clinic operates between 08:00-19:00. Six physicians, including four regular dentists and two orthodontists, work in the clinic. Other health resources are employed as two assistants and two clerks. The clinic has six beds and two triage (dental x-ray) locations. In this clinic, which has these health resources, the daily patient capacity and the number of patients treated were given in **Table 1**. In the clinic, an appointment is given to a firs-visit patient every 45 minutes by orthodontists and every 60 minutes by dentists, regardless of the duration of the treatment. An orthodontist treats up to 15 first-visit patients in a day. The same orthodontist treats up to 22 re-visit patients in one day. Likewise, for normal dental treatments, a dentist treats 11 patients (first-visit) or 15 patients (re-visit) per day. Considering the number of doctors, the number of first-visit patients treated and the number of re-visit patients are calculated as 74 and 104, respectively. Usually, no physician can fill their appointment system. According to the data collected for the simulation model, the number of first-visit patients treated by orthodontists and dentists was calculated as 30 and 49, respectively and the number of re-visit patients treated by orthodontists and dentists was calculated as 8 and 18, respectively.

There is an irregular patient arrival situation in this dental clinic as the daily appointment time does not fill. Therefore, patient arrival times for the simulation model were calculated according to distribution rather than an appointment system. The number of patients admitted in one-hour intervals was shown in **Figure 1**.

DES Model of the Study

The computer program Flexsim Healthcare version 21.00 was used for the DES model. This program is 3D and works with icons pull-and-drop system. One of the biggest reasons why this program is preferred is that it is easy for patients to follow their milestones step by step in patient flows. The simulation model was created according to the layout of the clinic. The screenshots of the 3D simulation model were shown in **Figure 2**.

Table 1. Number of patient arrivals daily with (re-visit patient) or without (first-visit patient) an appointment

Status	Expected Situation				Actual Situation	
Resources/Numbers	First-visit[1]		Re-visit (No triage)[2]		First Visit	Re-visit
	Time	Patients	Time	Patients	Patients	Patients
Orthodontist/2	45	15/ (30)	30	22/ (44)	30 by 2 Orthondists	8 by 2 Orthondists
Dentists /4	60	11/ (44)	45	15 / (60)	49 by 2 dentists	18 by 2 dentists
Total		(74)		(104)	79	26

[1]only valid for no-appointment-patient capacity (first visit), [2]only valid for appointment-patient capacity (re-visit)

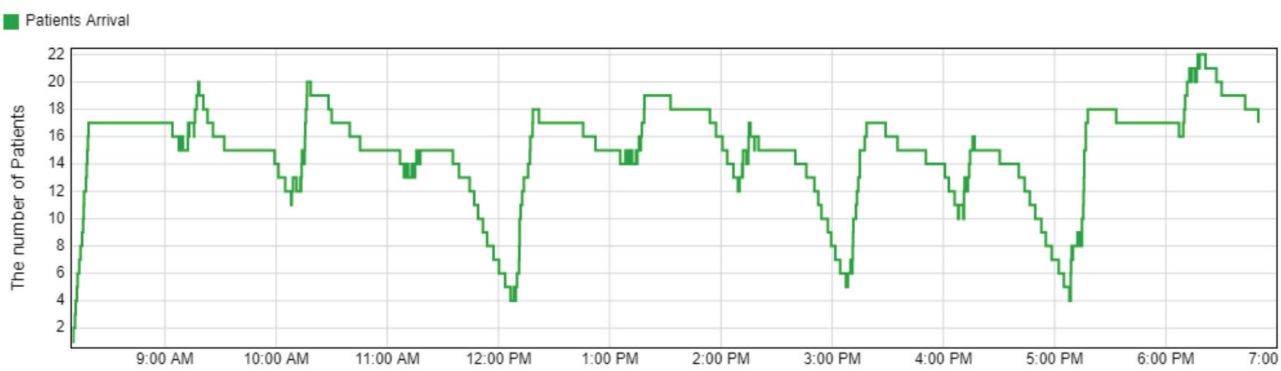


Figure 1. The number of patient arrivals by hour.

Figure 2. 3D Simulation model screenshot of dental clinic.

The operating principle of the simulation model is based on the patient flow chart. Patients come to the clinic for two types. First, normal dentists are visited for treatments such as tooth extraction, tooth filling, root canal. The second type of patients come to orthodontists for treatments such as placement of braces, removal of braces, chek up, etc. 34.0-36.0% of patients visit orthodontists, while 64.0-66.0% of patients who come to the clinic visit regular dentists. The patient flow chart of the dental clinic was shown in **Figure 3** in detail. The term WR in the patient flow chart is defined as the waiting room (this room is the area where patients have to wait until the start of the events during the treatment in the simulation model). The terms WR1...WR7 are expressions that indicate which stage the patients are waiting for. For example, all patients who come to the dental clinic are expressed as WR1 to define the time they wait until the registration desk or the registration staff is available before the registration process.

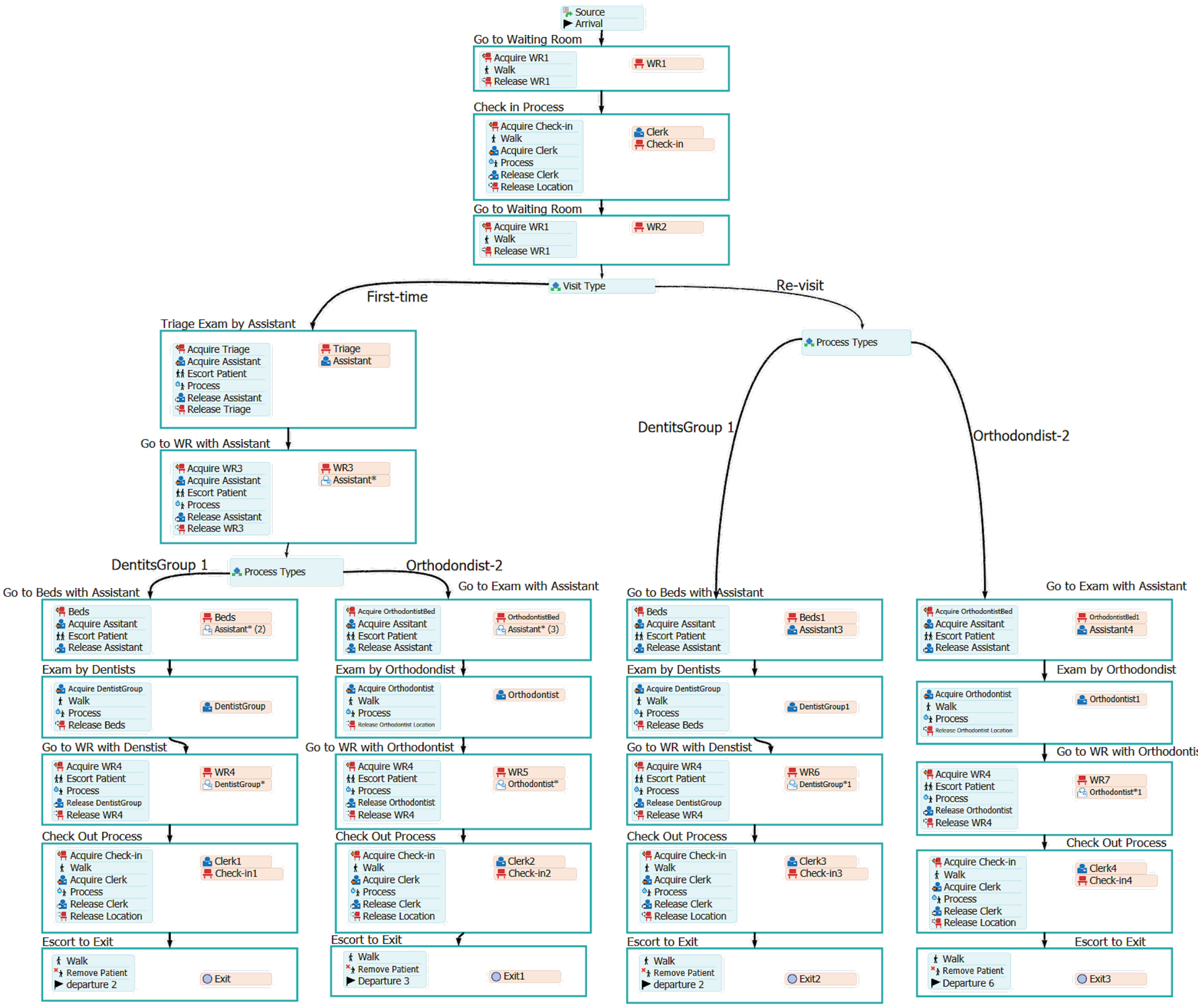
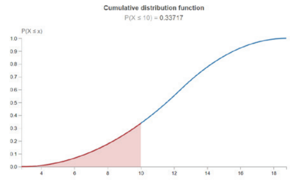
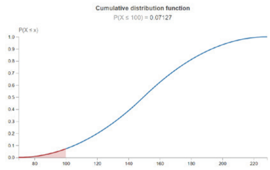
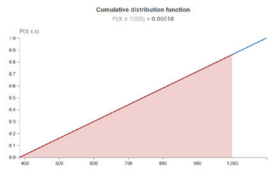
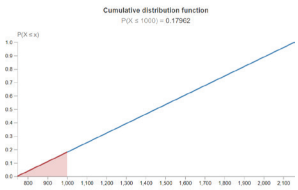
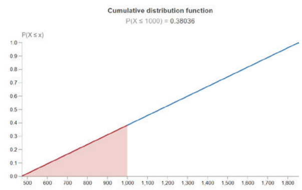
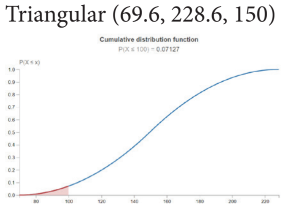


Figure 3. 2D simulation model showing a patient flowchart.

Input parameters of the DES model

In the patient flow diagram, each patient passes through different processes. Distributed times were used for each process, not an exact time. The main reason for this is that each patient has a different treatment process. If a patient visits the clinic for the first time, the patient sees four processes in total. The patient first logs in and registers, then the assistants help the patient with the triage process. Triage is performed for those who come to the clinic for the first time. After triage, the assistants decide by which doctor the patient will be examined. If the patient is to be examined by a regular dentist, the patient is referred to one of the four available dentists. If an orthodontist treats the patient, the patient is referred to one of the two orthodontists. The patient, whose treatment process is over, leaves the clinic by exiting by the officers. The IDs, definitions, and distributions of the process were provided in **Table 2**.

Table 2. The IDs, definitions and distributions of the process

Process ID	Process Name	Definitions	Process Time
0.0	Arrival	- time of patient's arrival to the clinic	triangular (169.2, 1126.8, 722.4) 
1.0	Check-in by clerks	- Sharing the arrival information of the patients in cooperation with the assistants - Check-in - fee payment - Setting an appointment time	Triangular (69.6, 228.6, 150) 
2.0	Triage by Assistants	- X-ray - collaborating with dentists for the next process - type of treatment decision - Dentists' selection decision	Uniform (386.4, 1099.74) 
3.1	Exam by Dentists	- collaborating with assistants to deal with dental problems - tooth extraction - dental filling - root canal - tooth stone cleaning - tooth decay and plaque removal - prosthesis, concealer and whitening application - etc.	Uniform (746.52, 2157.72) 
3.2	Exam by Orthodontists	- collaborating with assistants to deal with dental problems - designing and creating dental moulds - Denture procedures, - braces procedures, - excessive biting, - procedures required for tooth gap or crowding situations, - other orthodontic procedures,	Uniform (473.64, 1857.48) 
4.0	Check-out by clerks	- Sharing the arrival information of the patients in cooperation with the assistants - check-out - fee payment - Setting an appointment time	Triangular (69.6, 228.6, 150) 

*Patient arrival times and the durations of the other processes were calculated in seconds.

There are some limitations of the DES model. The patient arrivals were provided in a distributed manner, not according to the appointment system in the simulation model. For this reason, the simulation works with the principle of first-come, first-serve treatment (FCFS). In simulation models, it generally works on the principle of first-come, first-out (FIFO). However, in the DES model we developed, the exit time of the patient who first entered the system is not precise because the processes have dispersed times. The processes required for treatment were calculated according to a distributed time, not for each treatment type. At the end of each process, the patient is directed to the waiting room. Otherwise, the patient will wait where the resources involved in the process are available to start the following process. In such a case, the next patient becomes unable to continue their processes. As a result, the correct operation of the simulation is prevented. In standard clinics, each dentist has his room. However, in the DES model, rooms are preferred to be used jointly. The dentist cannot treat the patient who is treated at the orthodontist. The available personnel, not the same personnel, have been assigned in order to prevent backlogs in all processes. Another limit is the preference of a dentist who is available for the subsequent treatment of the patients. Thus, the patient waiting time was reduced to a minimum. Rest time was not added to the DES model because clinical resources do not have a specific resting time. Instead, rest times were taken into account as the times when resources were idle to treat patients. The results of the simulation were calculated according to the number of patients leaving the system, not the number of patients entering the system.

RESULTS OF THE STUDY

In terms of DES use, researchers mainly were preferred hospitals, but very few researchers until now used the DES method in a limited way for dental clinics [21–24]. In this study, very detailed data were obtained by using the DES method. We obtained data on the efficiency rates of the health resources of the clinic, patient waiting, and length of stay in the system by creating a 3D simulation model of a dental clinic. The developed 3D simulation model was run for 11 hours (8:00 am-7:00 pm) per day.

The data expressed in **Figure 4** were defined as two types. The data obtained by running the simulation and the data in the real situation were compared. The numbers of patients treated daily in terms of locations are given in **Figure 4**. According to this figure, the number of patients treated in the triage area should not be included in the total number. This is because the patient undergoing triage treatment is already examined by either a regular dentist or orthodontist.

It is very difficult to determine the efficiency ratios of resources in systems with dynamic structures. Utilization rates of the resources in a system are traditionally manner calculated with the following formula [25]:

$$\rho = \frac{\lambda}{s * \mu} \tag{1}$$

where ρ represents the utilization rates of the resource. λ and μ signify the arrival rate and process time, respectively. The number of servers (resource) is denoted by the symbol s. The utilization rates based on the simulation model are calculated by considering the time each resource spends

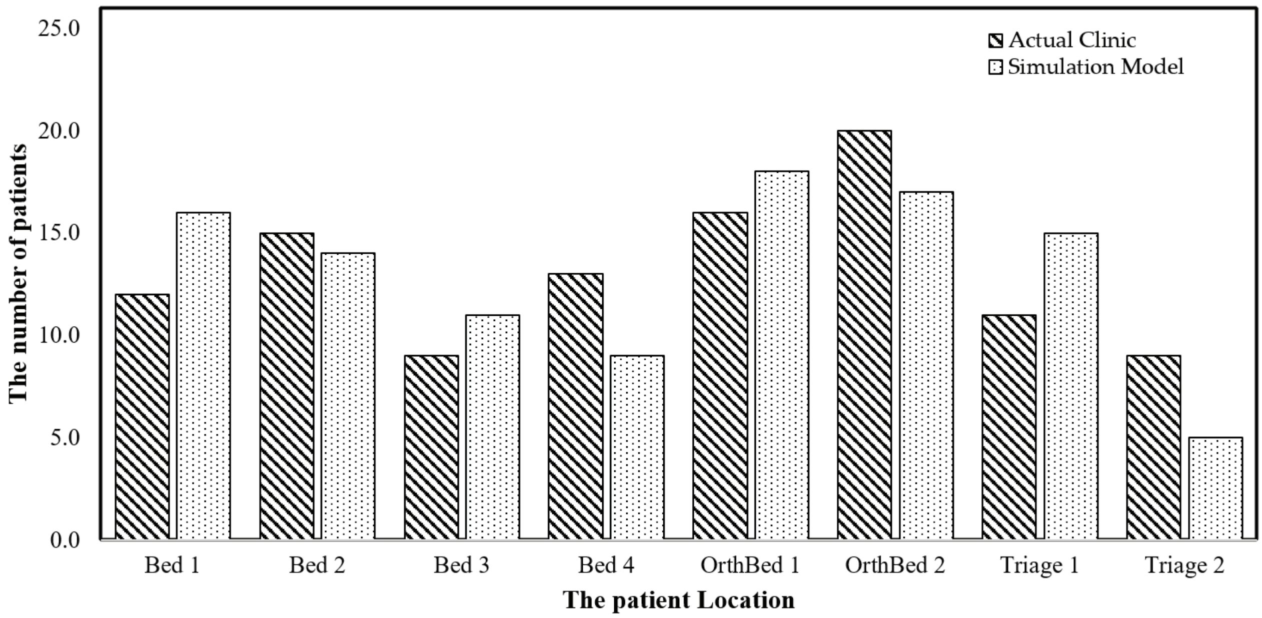


Figure 4. The numbers of patients treated daily in terms of locations.

with each input. In contrast, the traditional utilization rates consider the relationship between the resource and the output. The resource costs, treatment cost, and variable and fixed costs were ignored in Eq (1). For this reason, simulation utilization rates are calculated lower than conventionally calculated utilization rates. There are two reasons for the low efficiency of resources in the simulation model. The reason for this is that the entities in the simulation act as a robot. However, people meet their needs such as resting, eating and drinking, and toilet in real life. Therefore, the human factor should be taken into account when comparing these rates. In the other case, in the simulation, a resource starts to form its efficiency rate only from the moment it starts an event. It does not take into account the idle time between events. The utilization rates of resources based on the DES model and the traditional manner were compared in **Figure 5**.

The results obtained in the DES model according to the utilization rates of the dental clinic were given in **Table 3** and **Table 4**. The utilization rates of the dental clinic's resources were obtained hourly by running a simulation model in the computer environment. According to **Table 3**, dentists, orthodontists, assistants, and clerks have a working utilization of 65.5%, 77.5%, 35.5%, and 45%, respectively.

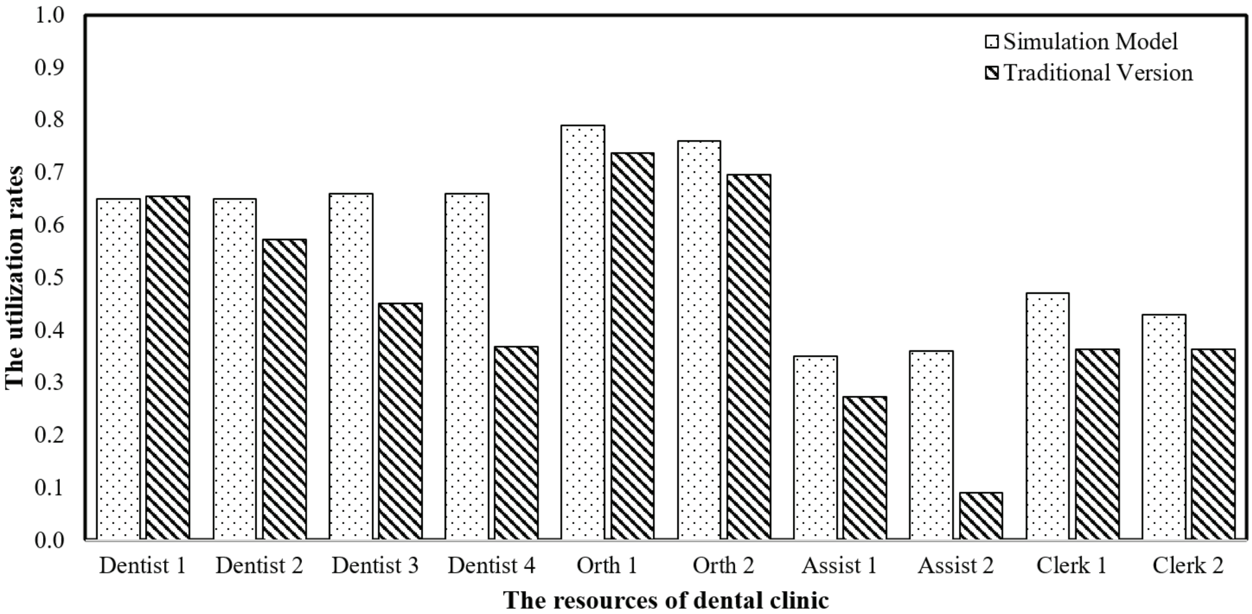


Figure 5. The utilization rates of resources based on the DES model and traditional manner.

Table 3. The utilization rates of human resources during working hours

Time	Dentist 1	Dentist 2	Dentist 3	Dentist 4	Orth 1	Orth 2	Assist 1	Assist 2	Clerk 1	Clerk 2
08:00-09:00	0.69	0.54	0.48	0.37	0.65	0.59	0.46	0.21	0.41	0.04
09:00-10:00	0.46	0.74	0.60	0.70	0.86	0.83	0.05	0.40	0.47	0.49
10:00-11:00	0.35	0.38	0.55	0.38	0.80	0.93	0.46	0.35	0.47	0.49
11:00-12:00	0.88	0.99	0.78	0.96	0.86	0.85	0.31	0.56	0.49	0.46
12:00-13:00	0.64	0.10	0.57	0.64	0.79	0.74	0.55	0.37	0.47	0.49
13:00-14:00	0.86	0.85	0.80	0.86	0.99	0.99	0.49	0.40	0.49	0.46
14:00-15:00	0.72	0.84	0.75	0.52	0.98	0.92	0.23	0.32	0.47	0.48
15:00-16:00	0.30	0.65	0.31	0.49	0.75	0.58	0.76	0.47	0.49	0.47
16:00-17:00	0.88	0.80	0.87	0.86	0.91	0.99	0.08	0.10	0.46	0.46
17:00-18:00	0.69	0.51	0.67	0.62	0.33	0.27	0.27	0.33	0.50	0.46
18:00-19:00	0.64	0.73	0.89	0.88	0.82	0.71	0.17	0.45	0.48	0.48
Average	0.65	0.65	0.66	0.66	0.79	0.76	0.35	0.36	0.47	0.43
Maximum	0.88	0.99	0.89	0.96	0.99	0.99	0.76	0.56	0.50	0.49
Minimum	0.30	0.10	0.31	0.38	0.33	0.27	0.08	0.10	0.46	0.43

According to **Table 4**, the beds reserved for dentists, the beds for orthodontists, the triage locations used by assistants and the registry office where clerks work have a working utilization of 68.25%, 89.5%, 31.0%, and 99.0%, respectively.

According to the box chart, it is observed that the data are generally distributed between the third quarter (100.30 min) and the minimum value (41.68 min). According to the data of 105 patients with LOS value, the standard deviation was calculated as 23.28. The skewness trends of the data are positive (0.58), and the LOS values approach the minimum value. Only two patient's LOS values were out of order and were calculated as 155.51 and 141.69 minutes, respectively. There was a 30-minute time difference between this patient and the patient with the third-highest LOS value (119.07 min). 54.28% (57 patients) of the treated patients were below the mean LOS value, while 20% (21 patients) of the treated patients fell between the mean and Q3 values. The LOS value

Table 4. The utilization rates of locations resources during working hours

Time	Bed 1	Bed 2	Bed 3	Bed 4	Bed 5*	Bed 6*	Triage 1	Triage 2	Registration
08:00-09:00	0.70	0.54	0.49	0.37	0.80	0.76	0.38	0.18	0.91
09:00-10:00	0.64	0.57	0.65	0.66	0.99	0.84	0.36	0.00	1.00
10:00-11:00	0.79	0.55	0.35	0.16	1.00	1.00	0.51	0.24	1.00
11:00-12:00	1.00	0.76	0.88	1.00	0.92	1.00	0.35	0.43	1.00
12:00-13:00	0.86	0.58	0.46	0.15	1.00	0.97	0.51	0.36	1.00
13:00-14:00	1.00	1.00	1.00	1.00	1.00	1.00	0.59	0.20	1.00
14:00-15:00	0.94	0.67	0.54	0.75	1.00	0.97	0.18	0.26	1.00
15:00-16:00	0.76	0.53	0.44	0.04	0.90	0.92	0.76	0.41	1.00
16:00-17:00	0.98	0.80	0.77	0.90	0.96	1.00	0.06	0.00	1.00
17:00-18:00	0.87	0.64	0.50	0.51	0.43	0.51	0.52	0.00	1.00
18:00-19:00	0.91	0.99	0.59	0.73	0.83	0.92	0.38	0.13	1.00
Average	0.86	0.69	0.61	0.57	0.89	0.90	0.42	0.20	0.99
Maximum	1.00	1.00	1.00	1.00	1.00	1.00	0.76	0.43	1.00
Minimum	0.64	0.53	0.35	0.04	0.43	0.51	0.06	0.00	0.91

*These beds are only reserved for orthodontists during working hours.

Another result obtained in the DES model is the average time that patients should spend in the clinic. This period is called the length of stay (LOS) [1,11]. The LOS value of the patients is calculated with the following formula:

$$LOS = time_{asistants}^{check-in} + time_{asistants} + \{time_{dentists} \text{ or } time_{dentists}\} + time_{clerks}^{check\ out} + time_{wait}^{personnel} + time_{wait}^{locations} \quad (2)$$

There are six different time types in the LOS value. Two of these times are related to waiting time (time expected for available personnel or location). The statistical information about the time a patient should spend for dental treatment is shown in **Figure 6** as a box pilot. The maximum, third quartile, median (second quartile), first quartile, and minimum values of the data obtained in the simulation model and the distribution of the data are shown with a box-plot. In addition, this plot was used to display skewness, frequency, symmetry, and outliers, which are other statistical data. The time a patient must spend in the clinic for treatment was a maximum of 155.51 minutes and a minimum of 41.68 minutes. In the DES model, which included 105 patients, the mean LOS value of a patient was calculated as 80.67 minutes. The biggest reason for a patient to wait for such a long time is the bottlenecks caused by healthcare resources in the DES model and the inability to allow other processes between successive processes in the patient flow diagram.

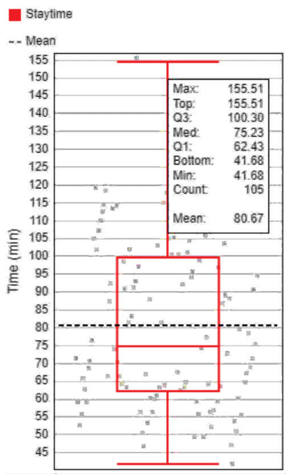


Figure 6. Time spent (length of stay) by patients in the dental clinic.

of 24.76% (27 patients) of the treated patients is between Q3 and the patient with the second maximum LOS value.

The average time a patient spends with dentists was calculated at 24.69 minutes. The patient spends 21.48 minutes in contact with orthodontists, and the average time that the patient spends with the assistants for the triage procedure was computed 13.20 minutes. The other time type for the LOS value is patient waiting times. A patient waits an average of 15.45 minutes to complete the dental treatment in this clinic. Patients wait 15.81 minutes for an available staff member and 15.1 minutes for an available location to receive dental treatment. The patients wait for the available location for 23.7% of the beds, 74.10% for the beds reserved for orthodontists' treatments, and 2.2 % for the availability of the triage area for the triage process. A large proportion of the time patients wait for available staff is caused by assistants.

CONCLUSIONS, RECOMMENDATIONS, AND FUTURE DIRECTIONS

The aim of this study is to calculate the efficiency of the resources of a dental clinic using the DES technique, as well as to calculate the patient treatment and waiting times. The importance of the simulation technique has been revealed by comparing the obtained results with the actual results. A long time and a high cost are inevitably needed to get the results of the changes made on a system in the real world. However, the results are obtained at a low cost and in a short time by imitating a system in a computer environment. We presented this study as the best example to provide results that need to be obtained in a short time and at a low cost [26]. Considering that mathematical models or statistical analyses are insufficient, especially in a dynamic structure system, it is inevitable to use the DES method in these structures.

Although this method is widely used in the field of healthcare with a dynamic structure, few researchers have used it in dental clinics. However, we observed that the researchers using this method could not obtain detailed data and approached it superficially. In this study, detailed results, mainly statistical data, were obtained with the DES model created within the framework of accurate data. For this reason, we fully believe that this study will be the most important resource for studies that are considered to apply the DES method in dental clinics. The most important recommendation for future studies is to examine the effect of changes in sources not included in this study on the results.

In this study, besides calculating the efficiency ratio of the resources of a dental clinic, the time that a patient should spend in the clinic was calculated. In future studies, a detailed DES model should be created to increase the efficiency of the resources of a dental clinic as well as to reduce patient waiting times. Researchers should aim to calculate the optimum scenario for the clinic by creating many scenarios. In particular, the optimum number of sources should be calculated by integrating the Full Factorial Design of Experiment method, which takes into account all combinations of clinical source numbers, with the DES method.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

New data were created with the DES model in this study. The published publication includes all graphics collected or developed during the study.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

REFERENCES

[1] Atalan A, Donmez C. Employment of emergency advanced Nurses of Turkey: A discrete-event simulation application. Processes 2019;7:48. [CrossRef]

[2] Zhang X. Application of discrete event simulation in health care: a systematic review. BMC Health Serv Res 2018;18:687. [CrossRef]

[3] Kampa A, Gołda G, Paprocka I. Discrete Event Simulation Method as a Tool for Improvement of Manufacturing Systems. Computers 2017;6:10. [CrossRef]

[4] Norouzzadeh S, Riebling N, Carter L, Conigliaro J, Doerfler ME. Simulation modeling to optimize healthcare delivery in an outpatient clinic. 2015 Winter Simul. Conf., IEEE; 2015, p. 1355−1366. [CrossRef]

[5] Kelton WD. Simulation with Arena. 4th ed. Boston: Mass: WCB/McGraw-Hill; 2004.

[6] Günal MM, Pidd M. Discrete event simulation for performance modelling in health care: a review of the literature. J Simul 2010;4:42−51. [CrossRef]

[7] Altiok T, Melamed B. Simulation Modeling and Analysis with Arena. 1st ed. Cambridge, Massachutes: Academic Press; 2007. [CrossRef]

[8] Atalan A. A cost analysis with the discrete-event simulation application in nurse and doctor employment management. J Nurs Manag 2022;30:733−741. [CrossRef]

[9] Lim ME, Worster A, Goeree R, Tarride JÉ. Simulating an emergency department: The importance of modeling the interactions between physicians and delegates in a discrete event simulation. BMC Med Inform Decis Mak 2013;59:13. [CrossRef]

[10] Dayarathna VL, Mismesh H, Nagahisarchoghaei M, Alhumoud A. A discrete event simulation (DES) based approach to maximize the patient throughput in outpatient clinic. Eng Sci Technol J 2020;1:1−11. [CrossRef]

[11] Atalan A, Dönmez CC. Optimizing experimental simulation design for the emergency departments. Brazilian J Oper Prod Manag 2020;17:1−13. [CrossRef]

[12] Shahabi A, Raissi S, Khalili-Damghani K, Rafei M. Designing a resilient skip-stop schedule in rapid rail transit using a simulation-based optimization methodology. Oper Res 2019;21:1691-1721. [CrossRef]

[13] Baril C, Gascon V, Vadeboncoeur D. Discrete-event simulation and design of experiments to study ambulatory patient waiting time in an emergency department. J Oper Res Soc 2019;70:2019−2038. [CrossRef]

[14] Nuñez-Perez N, Ortíz-Barrios M, McClean S, Salas-Navarro K, Jimenez-Delgado G, Castillo-Zea A. Discrete-event simulation to reduce waiting time in accident and emergency departments: A case study in a district general clinic. ubiquitous comput. Ambient Intell 2017, p. 352−63. [CrossRef]

[15] Babashov V, Aivas I, Begen MA, Cao JQ, Rodrigues G, D'Souza D, et al. Reducing patient waiting times for radiation therapy and ımproving the treatment planning process: a discrete-event simulation model (radiation treatment planning). Clin Oncol 2017;29:385−391. [CrossRef]

[16] Hasan I, Bahalkeh E, Yih Y. Evaluating intensive care unit admission and discharge policies using a discrete event simulation model. Simulation 2020;96:501−18. [CrossRef]

[17] Hamrock E, Paige K, Parks J, Scheulen J, Levin S. Discrete event simulation for healthcare organizations: A tool for decision making. J Healthc Manag 2013;58:110−124. [CrossRef]

[18] Zeinali F, Mahootchi M, Sepehri MM. Resource planning in the emergency departments: A simulation-based metamodeling approach. Simul Model Pract Theory 2015;53:123−138. [CrossRef]

[19] Ahmed MA, Alkhamis TM. Simulation optimization for an emergency department healthcare unit in Kuwait. Eur J Oper Res 2009;198:936−942. [CrossRef]

[20] Connelly LG, Bair AE. Discrete event simulation of emergency department activity: A platform for system-level operations research. Acad Emerg Med 2004;11:1177-1185. [CrossRef]

[21] Mohammed MA, Mohsin SK, Mohammed SJ. The effectiveness of using discrete event simulation to optimize the quality of service of outpatient in Iraq: A case study. Iraqi J Ind Res 2021;8:40−49. [CrossRef]

[22] Chang W-J, Chang Y-H. Design of a patient-centered appointment scheduling with artificial neural network and discrete event simulation. J Serv Sci Manag 2018;11:71−82. [CrossRef]

[23] Czech M, Witkowski M, Williams EJ. Simulation Improves Patient Flow And Productivity At A Dental Clinic. ECMS 2007 Proc. Ed. by I. Zelinka, Z. Oplatkova, A. Orsoni, ECMS; 2007, p. 25−29. [CrossRef]

[24] Kiley DP, Haley S, Saylor B, Saylor BL. The value of evidence-based computer simulation of oral health outcomes for management analysis of the Alaska Dental Health Aide Program. Institute of Social and Economic Research, University of Alaska Anchorage; 2008.

[25] Green L. Queueing Analysis in Healthcare. Patient Flow Reducing Delay Healthc. Deliv., 2006, p. 281−307. [CrossRef]

[26] Dönmez NFK, Atalan A, Dönmez CÇ. Desirability Optimization models to create the global Healthcare Competitiveness Index. Arab J Sci Eng 2020;45:7065−7076. [CrossRef]