Simulation study of management issues of a dental clinic

Kamel K. Al-Anzi [a] and Hussam M. Ramadan [b]
[a] *Network Development & Maintenance Dept., Saudi Telecom, Riyadh 11343, Saudi Arabia*
Email: kanzi@stc.com.sa
[b] *Information Systems Dept., College of Computer & Information Sciences,*
P. O. Box 51178, King Saud University, Riyadh 11543, Saudi Arabia
Email: hussam@ccis.ksu.edu.sa

This paper describes a simulation study of a dental clinic system that attempts to help management in decision-making. A major local dental clinic system that suffered from several inefficiencies is analyzed and field data is collected and summarized. Based on the collected information, a conceptual model of the system is constructed. A computer simulation model is built based on the ARENA simulation environment. After model verification and validation, the different potential management alternatives are used to formulate a plan for simulation experiments. Finally, experimental results are obtained and analyzed to draw conclusions for the clinic system management.

يقدم هذا البحث دراسة محاكاة لنظام عيادات أسنان لمحاولة مساعدة الإدارة في اتخاذ القرار. وقد تم تحليل نظام عيادات أسنان محلي كبير لكنه يعاني من عدة مشاكل تتعلق بالكفاءة الإدارية. وتم جمع بيانات ميدانية وتلخيصها. وبناء على ما تم جمعه من معلومات ، فقد تم بناء نموذج تصوري أعقبه بناء برنامج محاكاة باستخدام بيئة المحاكاة أرينا. وبعد التحقق من صحة وصلاحية النموذج، تم إعداد خطة لإجراء اختبارات المحاكاة أخذاً في الاعتبار البدائل الإدارية الممكنة. وفي النهاية، تم استخراج وتحليل نتائج المحاكاة من أجل الوصول لخلاصة حول كيفية إدارة نظام العيادات.

Keywords: Simulation, Health services, Queuing, ARENA

1. Introduction

Simulation is an important decision-support tool. A simulation model represents the real-system's behavior as a computer-based model that enables the decision maker to change the system input variables that can affect the system measures of performance. Based on the experimental results, the decision maker can formulate a decision that may lead to better performance of the real system. Simulation has many advantages for the decision maker. For example, new policies can be tested without distributing the real system. It also compresses time to get performance results faster, and can provide good insight into the system's complex behavior and interactions. A simulation model consists of a set of variables that store a number of system states and events. An event is any timed occurrence that might change the system state variables [1]. In addition, a simulation model usually includes entities (dynamic objects that affect the system performance and state), entity attributes, resources, queues, and a simulation clock.

Many modeling methodologies exist, each of which is suitable in certain problem situations. Among these are: declarative models, functional models, constraint models, and spatial models [2]. Prior to using any of these methodologies, a *conceptual model* of the system has to be built. The conceptual model is developed at an early stage of the simulation project in order to provide basic knowledge about the system in both static and dynamic aspects. It emphasizes objects and their relationships, whereas declarative or functional models usually describe dynamic behavior. Declarative models are based on sequences of states and events that occur over time. They are formed by states and state transitions, where transitions from one state to another occur due to external and/or internal inputs. Functional models are used to model problems that involve objects that are connected with each other in a directional way, or problems that involve flow of materials through the system. One important type of functional models is queuing models, such as the model described in this paper.

Information systems play a critical role in providing health services efficiently. Different types of information systems are used to support work in health services. For example, decision support systems are designed to assist in decision-making and in evaluating potential alternatives.

Several successful projects exist worldwide have used simulation as a decision-support aid in health-service organizations. For example, the department of industrial engineering at the University of Central Florida and a trauma center in a teaching hospital worked together to improve hospital processes [3]. The hospital's Emergency Room (ER) was receiving around 75000 patients per year and 2% of the whole patient population would leave the hospital before they are treated. A team collaborated in the project to improve the ER operations. The objectives were to reduce the patient waiting time, decrease the number of patients that leave without treatment, and increase patient satisfaction. The team members decided to use simulation to achieve their goals. They noticed that 26 patients came daily and spent 90 minutes in the fast-track beds, which opened from 11 AM to 11 PM. This indicated that they were under-utilized. The team members conducted "what if analyses" using the simulation model. They found that transferring 25% of adult patients to fast-track beds would result in 30% reduction in adult triage time and reduction in the number of patients leaving the hospital from 3 patients to 0.5 per day.

In another project, the operation research division analysts of the Department of Health in the United Kingdom faced a problem of long patients waiting time in outpatient clinics [4]. To reach a solution, they developed a special simulation package called CLINSIM that was based on queuing models. This package was a visual simulation environment that modeled patient flow in outpatient clinics. Typically, patients arrive to the out-patient clinics, check-in with the receptionist, perform pre-consultation tests, wait to see the doctor, receive the consultation, check-out and book another appointment (if needed), and leave the place. Patient movement is controlled in the model by three rules provided by CLINSIM. These are: *appointment scheduling rules* (where patients are scheduled for appointments with doctors), *queue discipline rules* (that identify the number of queues to be used and the specification of each queue), and *operating practice rules* (that define how a patient is selected to be seen by a doctor). CLINSIM has helped in reducing patients waiting time in outpatient clinics. The Department of Health has tested the package in 20 different clinics all over the UK and the tests showed excellent results.

This paper describes a simulation study of a dental clinic system in Riyadh, Saudi Arabia. A major local dental clinic system that suffered from several inefficiencies is studied and simulation results are reported in an attempt to help managers in the decision-making process. The rest of this paper is organized as follows. Section 2 provides a brief overview of the studied dental clinic system. Section 3 describes the data collection process performed on site. Section 4 presents the system's conceptual model. Section 5 discusses model verification and validation. Section 6 discusses the experimental results. Finally, section 7 provides conclusions and recommendations.

2. System description

The Saudi Arabian National Guard Health Affairs (NGHA) general administration was established in 1994 with a mission to provide the National Guard personnel and their eligible dependents with the highest quality primary and secondary health care services, while ensuring efficiency and proper utilization of available resources. It runs four medical compounds located throughout the Kingdom of Saudi Arabia. These are located in Riyadh, Jeddah, Dammam, and Ihsa [6]. Furthermore, primary health care services are provided by NGHA in twenty-eight other locations in the Central and Eastern provinces.

This paper is concerned with King Abdulaziz Housing dental clinic located in Riyadh. The dental clinic is an outpatient non-profit clinic owned by the National Guard. It covers all types of tooth treatments, including extraction (adult and pediatric), oral hygiene, permanent crown, temporary crown, consultation, permanent restoration, temporary restoration, denture, general treatment, emergency treatment, and tooth adjustment [6]. There are nine dentist offices, each of which is equipped with a small X-ray machine, dentist seat, and other dentist tools. In addition there are two receptionists, two rest areas for dentists (male/female), and two waiting areas for patients (male/female). Work hours are from 8:00 AM to 6:00 PM, including two break times: a lunch break from 12:00 PM to 1:00 PM and *Asar* prayer break time from 3:00 PM to 4:00 PM, Saturday through Wednesday.

Patients book appointments for the next day by calling one of two telephone numbers. The operator books about 108 patients (12 patients per dentist) every day. The steps of processing regular patients are as follow:

1. A patient arrives at the reception and hands in his/her medical card.
2. The receptionist checks if the patient has an appointment.
3. If the patient has an appointment and did not have any X-ray before and the central X-ray machine is busy, the patient is asked to wait in the proper waiting area, otherwise an X-ray is performed for the patient.
4. If the dentist is not busy, the patient enters the dentist's office; otherwise the patient has to wait in the proper waiting area.
5. The dentist examines the patient and performs the proper procedure.
6. When the treatment is finished, the patient leaves the clinic.

A special type of patient is called *walk-in patient*. A patient is a walk-in patient only if he has a swelling. Walk-in patients do not need a medical record nor do they need an X-ray in order to be seen by a dentist. Because walk-in patients have high treatment priority than regular patients, they stay for shorter times than regular patients in the clinic. Fig. 1 below illustrates patient flow in the King Abdulaziz Medical City dental clinic.

The dental clinic management was not satisfied with the long waiting time of the patients in the clinic. We suggested using simulation to model the system and support management in taking the right decision to solve the problem. The project consisted of the following tasks: identifying the performance measures, determining controllable and uncontrollable variables, collecting data, building the simulation model, validating and verifying the model, designing simulation experiments, reporting output results, and recommending solutions.

In this paper, we focus on several performance measures including the average waiting time of the regular patient in the clinic (Tw), the average waiting time of the Emergency (ER) patient in the clinic (Twer), the number of regular patients served per day (Np), and number of ER patients served per day (Nper). Input variables could be controllable or uncontrollable. In addition they may be quantitative or qualitative (i.e. policy or condition). Controllable variables are those that can be changed in the model while uncontrollable variables are those that are fixed. Controllable variables include: the number of central X-ray machines (NX), the number of dentist offices (ND) and the policy of patient assignment to dentist offices (i.e. fixed or variable assignment). If the policy is fixed, it means the patient has to be seen by a certain dentist, and if it is variable it means the patient can be seen by any available dentist. Uncontrollable variables include the number of receptionists (NR), the number of small X-ray machines in each dentist office (NSX), the number of waiting areas (NWA), working hours (TW), and the number of treatment kinds (CT). Treatment kinds include adult extraction, pediatric extraction, temporary restoration, permanent restoration, teeth adjustment, oral hygiene, general treatment, temporary crown, permanent crown, denture, consultation, and emergency treatment table 1 below shows the current values for both the controllable variables and the uncontrollable variables.

3. Data collection

A data collection team was formed to conduct this stage of the project. Meetings were held with the dental clinic manager, dentists and receptionists in order to clearly define what types of data need to be collected.

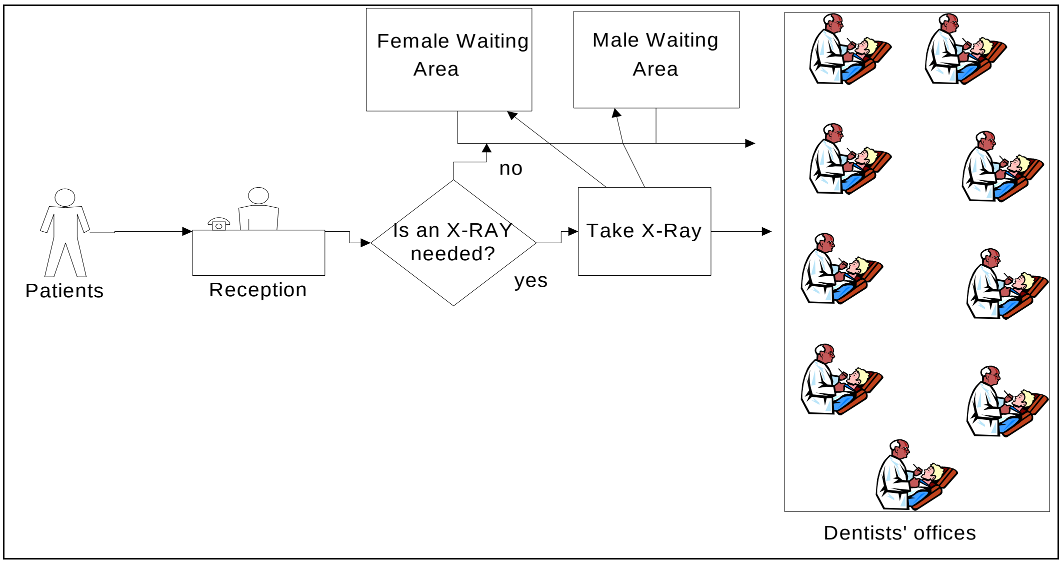

Fig.1. Patient flow in the dental clinic.

Table 1
Controllable variable and uncontrollable variable values

Variable	NX	ND	Assignment policy	NR	NSX (per dentist's office)	NWA	TW (Hrs)	CT
Value	1	9	Fixed	2	1	2	10	12

Three input data types were agreed on: patients arrival times, patients entrance times into the dentist's office, and patients discharge times. The system was observed in action and data were collected randomly at different times of the day for a period of one month. The team was distributed among three locations during data collection. The first person stood in the reception area and recorded patients arrival times, the second person stood on the way to the dentists offices and recorded entrance times to the offices, and the third person stood at the exit to record the patients discharge times. The average service time for each kind of treatment and percentage of each daily treatment kind are shown in table 2.

4. Conceptual model

The purpose of the conceptual model is to give a good insight and understanding of the system in order to develop a simulation model that will accurately represent the real system. Our model consists of *entities* that move through the system according to some logic and a set of *resources* that provide service for entities. Two types of entities in our model exist. These are *patient* and *ER_patient.* Furthermore, resources are: two *receptions*, one *X-ray machine*, and nine *dentists.*

Fig. 2 above shows that there are three main processes: *preparation of patient file, performing X-ray*, and *treatment.* Furthermore, there are two waiting processes performed by patients: waiting for X-ray and waiting for treatment. When a resource is busy, an entity has to wait in a queue. The entities *(patient* and *ER-patient*) follow the paths shown in fig. 2.

5. Model verification and validation

For implementation, we used the modeling framework provided by the ARENA® Research edition simulation environment to develop the

Table 2
Average service time and percentage for each treatment kind

Treatment	Average service time (Min)	Daily percentage (%)
Adult extraction	40	8
Pediatric extraction	45	9
Temporary restoration	35	15
Permanent restoration	40	26
Tooth Adjustment	42	4
Oral Hygiene	35	11
General treatment	30	14
Temporary crown	35	3
Permanent crown	40	7
Denture	45	1
Consultation	30	2
	Total	100%
Emergency treatment	20	9

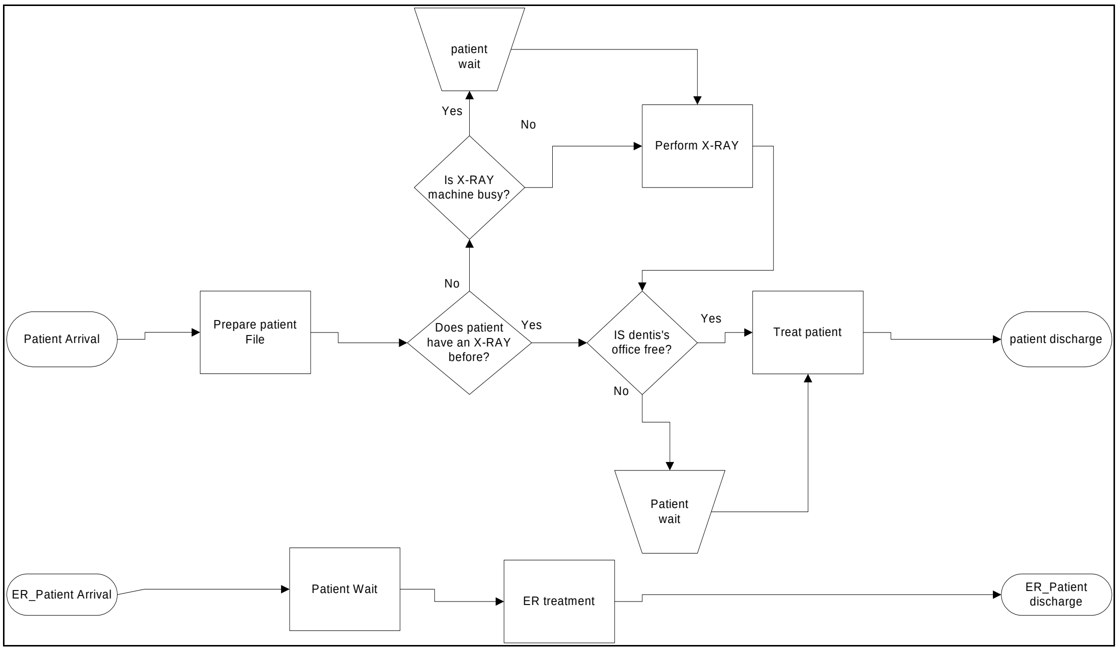

Fig. 2. Dental clinic flowchart.

simulation model [7]. ARENA is a complete simulation environment developed by Rockwell software. ARENA was chosen between several simulation environment because of its flexibility, ease of use, integrity with databases and spreadsheets, and drawing capabilities [8]. Verification and validation of a simulation model are of great importance. Since decisions are made on the basis of simulation results, the validity of these results should be subject to question and investigation. The purpose of model verification is to assure that the conceptual model is reflected accurately in the implemented ARENA model. The technique used for verification is the common sense technique [1]. The common sense technique is based on:

1. Checking the model animation by someone other than the developer such as the clinic manager or dentists.
2. Examining the flow diagram of the system.
3. Checking where output is resample mat through calculating current contents and total count statistics.

Validation is the process of comparing the model and its behavior to the real system and its behavior. The comparison of the model to reality is carried out by a variety of tests, which can be either subjective or objective. Two techniques were used to validate our model [1]:

1. *Validation of model assumptions:* Model assumptions fall into two classes: structural assumptions and data assumptions. Structural assumptions involve questions of how the system operates. Data assumptions involve characteristics of system parameter data. In our model, the structural assumptions include the patient to dentist assignment policy and the kinds of regular patient treatments covered by the dental clinic. These structural assumptions were validated by the direct observation of the real system and the operational simulation model. Data assumptions include the assumed characteristics of data quantities like the average service times per receptionist, the average treatment time for each treatment kind, the average time for taking an X-ray, and the average ER patient treatment time. These data assumptions were validated by collecting data on the real system for a period of time (about one month) at random times and calculating the average values for these data. The data were analyzed using the ARENA Input Analyzer tool to produce the closest probability distribution and statistics representing the collected data. Finally, these same distributions and statistics were used to represent these data quantities in the simulation model.

2. *Validation of input-output transformations*: This technique is based on comparing the output of the model to the real system output using the same input data set. If they approximately match, it means that the model represents the real system; otherwise the model should be revised. We simulated one selected scenario of the dental clinic system and compared the real system with the model based on some performance measures. The results of this performance comparison can be found in table 3. It can be seen that percentage difference values are sufficiently small to conclude that the model is a good-enough representation of reality.

6. Simulation results

Our target here is to calculate the average patient waiting time for regular patients in the dental clinic (Tw) and try to minimize it. This will be done by simulating different alternative combinations of controllable variables, and analyzing the simulation system responses to find the most suitable among those combinations. Additional performance measures such as the average waiting time for ER patients (Twer), the number of regular patients served per day (Np), and the number of ER patients served per day (Nper), will also be computed by the simulation.

Recall that we have one qualitative input; that is the policy of patient assignment to dentist offices. We also have two quantitative input variables: the number of central X-ray machines (NX), and the number of dentist offices (ND) .The simulation experimental design plan will include a total of two cases under each of the two patient assignment policies as follows:

- *Policy 1: Fixed patient assignment to dentist offices:*

1.1 Fixed NX, variable ND.
1.2 Variable NX, fixed ND.

- *Policy 2: Variable patient assignment to dentist offices:*

2.1 Fixed NX, variable ND.
2.2 Variable NX, fixed ND.

The fixed patient assignment policy amounts to assigning each patient to a specific dentist office. Each dentist is responsible

Table 3
Comparison of the real and simulated system performance measures

	Tw	Twer	Np	Nper
Real system	147 min	22.21 min	50 patients	11 patients
Simulation model	154.43 min	23.33 min	53 patients	11 patients
Percentage difference	5%	5%	6%	0%

for the treatment of his/her patients only. On the other hand, the variable patient assignment policy amounts to assigning each patient to the first available dentist office. The simulation model was executed for several runs. Table 4 shows the resulting average values for the dental clinic system performance measures under the current fixed patient assignment policy. Table 5 gives a sample of the performance measures after applying the variable assignment policy for different numbers of dentist offices, while fixing the number of X-ray machines to 1 machine. Simulating the model for R=17 runs and for the above-mentioned alternatives, we have obtained the performance measure graphs shown in Fig. 3 through 8.

Fig. 3 shows the effect of increasing the number of dentist offices under the fixed and variable patient assignment policies while fixing the number of X-ray machines on the average waiting time of regular patients. We can see that the variable assignment policy curve moves down faster than the fixed assignment policy curve with increasing number of dentist offices. We may also see that for all the used values of the number of dentist offices, the variable assignment policy results in a lower average patient waiting time than the fixed assignment policy. Fig. 4 shows the effect of increasing the number of dentist offices under the fixed and variable policies while fixing the number of X-ray machines on the average waiting time of ER patients. Since the dentists are better utilized under the variable assignment policy, it can be seen that the average waiting time for ER patients tends to be higher in this case because ER patients are more likely to wait longer to receive service, since they are more likely to arrive to the clinic at a time when all dentists are busy. It can also be seen that increasing the number of dentist offices under both policies will not result in a significant change in the average waiting time of ER patients.

Table 4
Performance measure values for the current (fixed) dental clinic system

Performance measure	Tw	Twer	Np	Nper
Average value	150.35 min	21.79 min	86 patient	11 patient

Table 5
Sample performance measures under the variable assignment policy

Number of dentist offices	Tw	Twer	Np	Nper
9	132.57	24.02	92	11
11	94.24	21.55	96	11
15	70.73	19	105	11

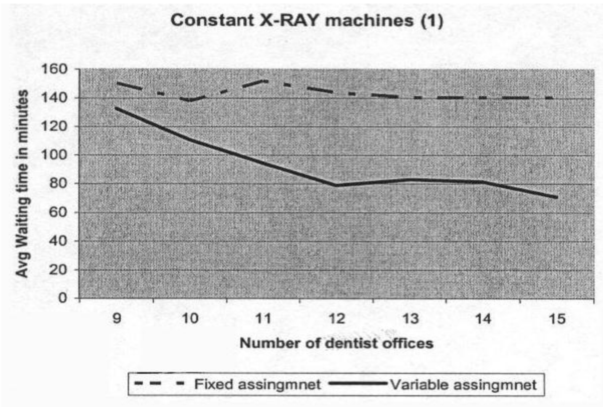

Fig. 3. Effect of increasing the number of dentist offices on regular patient average waiting time.

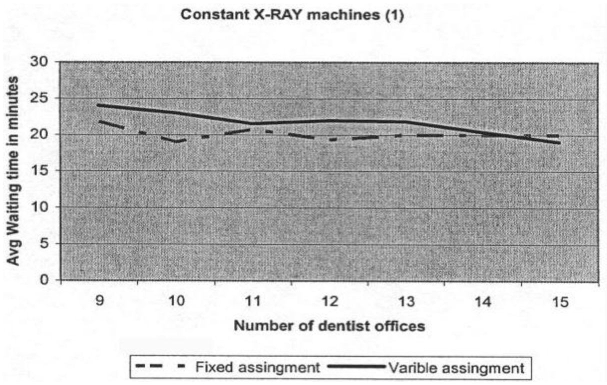

Fig. 4. Effect of increasing the number of dentist offices on ER patient average waiting time.

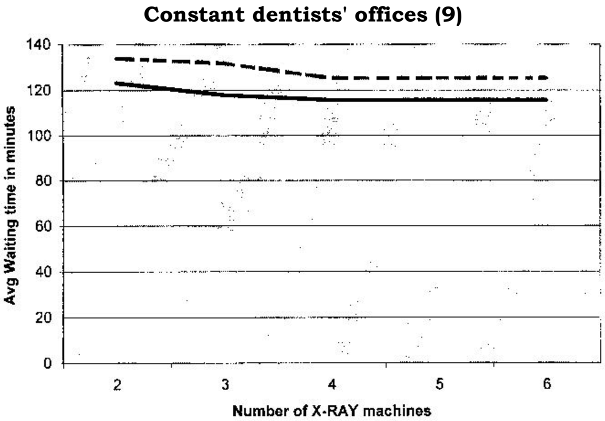

Fig. 5. Effect of increasing the number of X-ray machines on regular patient average waiting time.

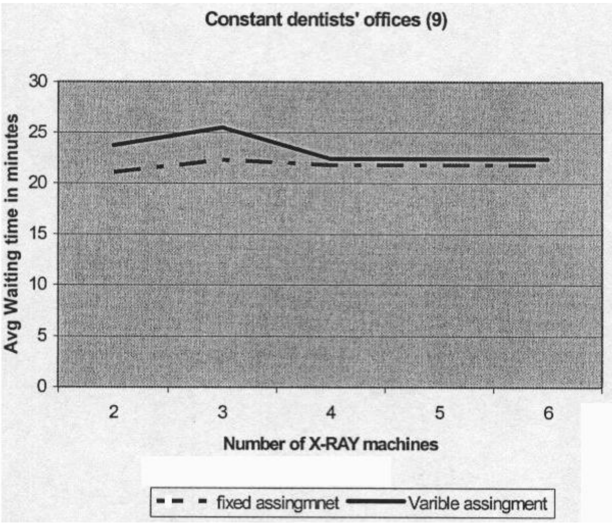

Fig. 6. Effect of increasing the number of X-ray machines on ER patient average waiting time.

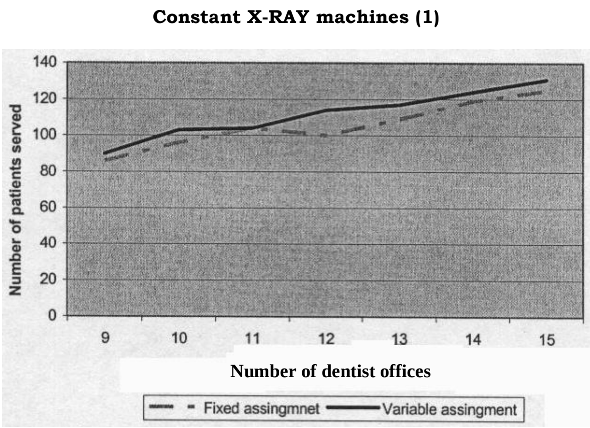

Fig. 7. Effect of increasing the number of X-ray machines on the number of regular patients served.

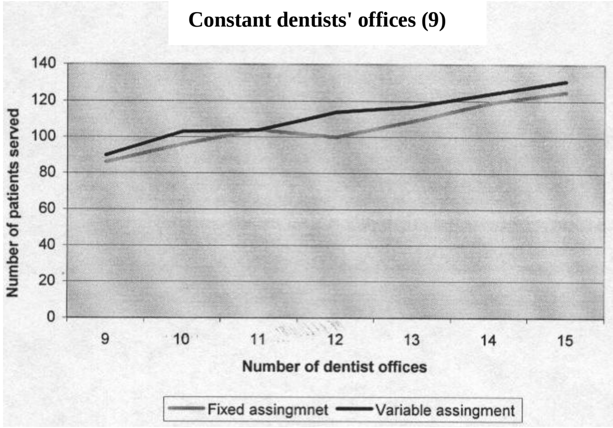

Fig. 8. Effect of increasing the number of dentists' offices on the number of regular patients served.

Fig. 5 illustrates the effect of adding new X-ray machines to the dental clinic while leaving the number of dentist offices constant, for both the fixed and variable patient assignment policies, on the average waiting time of regular patients. It can be seen that adding additional X-ray machines under either policy will reduce the average waiting time of regular patient by a very small amount. This means that central X-ray machines do not represent a system bottleneck and, therefore, acquiring new X-ray machines will not be helpful in improving the system performance as measured by the average waiting time of regular patients. Fig. 6 illustrate the effect of adding new X-ray machines to the dental clinic while leaving the number of dentist offices constant, for both the fixed and variable patient assignment policies, on the average waiting time of ER patients. Again, we can see that adding additional X-ray machines under either policy will insignificantly reduce the average waiting time of ER patients.

Fig. 7 shows the effect of adding new dentist offices on the number of regular patients served for both the fixed and variable patient assignment policies. It is clear that adding new dentist offices under the variable policy will result in a larger number of served regular patients than adding additional dentist offices under the fixed assignment policy. It may also be seen that the increase in the number of served patients with increasing number of dentist offices is almost linear under both policies. Fig. 8 shows the effect of adding new X-ray machines on the number of regular patients served for both the fixed and variable patient assignment policies. It is clear that adding more X-ray machines under the variable assignment policy will result in a larger number of served regular patients than adding more X-ray machines under the fixed assignment policy. This means that adding more X-ray machines is only helpful to the system performance in terms of increasing the number of served patients per day. It may also be seen that the increase in the number of served patients with increasing number of X-ray machines is almost linear under both policies.

7. Conclusion

A simulation study of a dental clinic system in Riyadh, Saudi Arabia, was conducted in an attempt to aid the decision-making process and help improve efficiency and resource utilization. A major local dental clinic system that suffered from several inefficiencies was studied and simulated. Reported simulation output results have shown the following:

1. Patients waiting time was long because of the lack of dentist offices and the implementation of a fixed patient assignment policy rather than a variable one.
2. Adding more X-ray machines under any patient assignment policy has a minor effect on the average patient waiting time, but was seen to increase the average number of patients served per day.

Therefore, it is recommend to adopt a variable patient assignment policy and to add (if possible) more dentist offices up to the saturation point. This will result in a significant decrease in the average waiting time of regular patients and will increase the number of served regular patients. It is also recommended to slightly increase the number of X-ray machines (e.g. one more machine) for the sake of improving the system performance in terms of the average number of patients served per day, although this increase is not likely to reflect on the average patient waiting time.

References

[1] J. Banks, J. S. Carson II, and B. L. Nelson, Discrete-Event System Simulation, Prentice-Hall, Upper Saddle River, New Jersey (1996).

[2] P. A. Fishwick, Simulation Model Design and Execution, Prentice-Hall, Englewood Cliffs, New Jersey (1995).

[3] F.F. Basesler and J. A. Sepulveda, Working with Healthcare Practitioners to Improve Hospital Operations with Simulation, Rockwell Software Press, PA (2001).

[4] J. Kuljis, R.J. Paul, and C. Chen, Visualization and Simulation: Two Sides of the Same Coin?, SCS SIMULATION, 77 (3-4), pp. 141-152 (2001).

[5] L. Moreno, R.M. Aguilar, C.A. Martin, J.D. Pineiro, J.I. Estcrez, J.F. Signt, and J.L. Sanchez, Patient-Centered Simulation to Aid Decision-Making in Hospital Management, SCS SIMULATION, Vol. 74 (5), pp. 290-304 (2000).

[6] Saudi Arabian National Guard, NGHA Highlights, National Guard Health Affairs Press, Riyadh, Saudi Arabia (2002).

[7] W.D. Kelton, R.P. Sadowski, and D.A. Sadowski, Simulation with ARENA, McGraw-Hill, Boston (2002).

[8] V. Bapat, and N. Swets, The ARENA Product Family: Enterprise Modeling Solutions, Proc. the 2000 Winter Simulation Conference, Orlando, FL, pp. 163-169 (2000).

Received March 6, 2004
Accepted March 7, 2005