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Using Discrete Event Simulation Approach to Reduce Waiting Times in Computed Tomography Radiology Department

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***Abstract*—**The purpose of this study was to reduce patient waiting times, improve system throughput and improve resources utilization in radiology department. A discrete event simulation model was developed using Arena simulation software to investigate different alternatives to improve the overall system delivery based on adding resource scenarios due to the linkage between patient waiting times and resource availability. The study revealed that there is no addition investment need to procure additional scanner but hospital management deploy managerial tactics to enhance machine utilization and reduce the long waiting time in the department.

***Keywords*—**Arena, Computed Tomography (CT), Discrete event simulation, Healthcare modeling, Radiology department, Waiting time.

I. Introduction

THE healthcare sector in Saudi Arabia has been grown very fast in recent decades due to the high priority and attention given by the government into this sector. The government invested larger amounts of money in this sector in order to improve the health services in terms of quality and quantity. Therefore; health services in Saudi Arabia have been substantially increased and improved due to the generous investment in this sector [1]. The quality of health services can be measured by the productivity, waiting times, efficiency, patient satisfaction and stressed medical staff [2]. Despite of the high attention into this sector, the public healthcare sector in Saudi Arabia undergoes many challenges due to increase in high demand for health services that attributed to the population growth rate. According to governmental statistical reports, the annual population growth rate for 2007 to 2013 was 2.7% per year [3]. This increase in demand for health services requires new policies and strategies to be adopted by the Ministry of Health (MOH) in Saudi Arabia to face the demand challenges from hospitals such as services in emergency departments, outpatients departments (OPD), laboratories, radiology departments, …etc.

Radiology departments at hospitals are experiencing increasing rates of patients demand and hence suffering from inability to accommodate these high rates of demand. Therefore; the increased demand for radiology department services will lead to a considerable increase in the patients waiting times and subsequently will negatively affect the patients' satisfaction for the provided services. Thus; improving the radiology department performance to reduce the patient waiting times, increase throughput and improve patient satisfaction is the overall target to achieve.

Improvement of healthcare systems such as radiology departments has to be judge on the bases of quantitative figures for the impact of suggested scenarios of amendment. In recent years, simulation showed to be an efficient decision making tool that have been applied to solve healthcare problems in USA, UK and other countries. Discrete event simulation proved to be an effective studying tool that has been widely applied in healthcare organization and proved considerable success in assessing of the inefficiency of the existing systems, probe the relationship between system variables, study the impact of possible changes and evaluate the suggested alternatives for improvement [4].

Several discrete event simulation studies have been carried out to study and evaluate the patients waiting times at radiology department. O'Kane [5] applied simulation to model a diagnostic radiology department and Klafehn [6] used simulation approach to study the points that effect in patient flows through a radiology department. Thereafter; Coffin et al. [7] conducted a simulation study to investigate waiting time and staff allocation in order to improve patient flow in X–ray facility. Reference [8] used discrete event simulation to investigate six different scenarios for staff and physical resources variation at the radiology department in Jackson Memorial Hospital (JMH) in Dade County, Florida, USA to define the impact of these variations on patient flow and utilization of the operating rooms and department staff. The study specified the appropriate cost – effective labor level for each process and determined further revisions to improve process and service efficiencies.

An attempt is made within this paper to apply discrete event simulation approach to the radiology department within a regional hospital in the southern part of the Kingdom of Saudi Arabia. The hospital is a 574 bedded, nonprofit, teaching, government run hospital located in the southern region of Saudi Arabia. The radiology department at this hospital is considered to be one of the busiest departments and more than 23000 patients visit this department every year. One of the major aims of hospital management for the radiology department is to reduce the patient waiting time and increase the productivity in order to improve the quality of services in this department. Therefore; to achieve this goal, a discrete event simulation model has been constructed for the existing system and proposed alternatives to test the impact of

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additional resources on the patients waiting times and determine the optimum number of required resources in the radiology department.

II. Fundamentals of Discrete Event Simulation in Healthcare System

Discrete event simulation (DES) is defined as a form of computer based modeling of systems operations as it evolve over time where the state variables changes only at a separated set of points in time [9]–[11]. DES was originally developed in 1960s in industrial engineering and operations research to help in the analysis and improvement of industrial and business systems and since then; DES became a common and an efficient decision making tool in healthcare organization for the analysis and optimization of patient flow, planning and determining the optimal required healthcare resources (staff and equipments) to increase throughput, improve patient flow, increase patient satisfaction and reduce healthcare delivery expenses. DES was applied in different disciplines of sciences and healthcare was one of these disciplines.

Discrete event simulation has been widely applied in healthcare applications and it has increased over the last 40 years [12]. The application of DES was mainly in the analysis of healthcare systems for the purpose of reducing waiting times, increasing productivity and improving the delivered services of healthcare organizations. Discrete event simulation has been applied in different healthcare facilities like **hospitals** [13]–[21], **emergency departments** [22]–[33], **special units** [34]–[37], **intensive care units** [38]–[42], **surgical procedures** [43]–[53], **demographic health provision** [54]–[57], **outpatient clinics** [58]–[65], and **facilities allocated in the health care supply chain** [66]–[68].

Discrete even simulation has an important advantage in allowing designers (model builders) to build very high complex models for healthcare organizations and enabling modelers in answering "what if" question to test different alternatives and scenarios at no cost. Deciding on the success or failure of a DES study depends on a set of standard steps that can be followed by a model builder. References [9], [10], and [69] summarized the most common steps necessary for a successful classical DES study. The basic steps include problem formulation, overall plan of study, model conceptualization, data collection, model translation, verification, validation, experimental design, production run and analysis using the computer model, documentation, and implementation. It is noted that problem formulation, data collection, and model translation are key steps for a successful simulation study. Therefore; failure to conduct a successful DES study in healthcare organization will result in lives losses. Hence; a constructed tutorials for conducting a DES study in healthcare organization was provided by Mahachek [70].

III. Methodology

A. Data Collection

Data collection is one of the most important, difficult, and challenging tasks that faces a model builder in any simulation and modeling study [9]. The accuracy of results and conclusions in simulation studies depends on a robust and high quality of the collected input data. The famous principle "garbage – in garbage – out" or (GIGO) is a basic concept in computer science which is pertinent to data collection in discrete event simulation. Poor quality or inaccurate collected data will result with a misleading modeling output data even though the model is valid and representing the system in a correct way.

In this study, an actual data was collected over 12 months period by the research team and from the radiology department past records. Also, interviews with the radiology department staff were conducted to gain a deep understanding of the department processes. The data were collected for the computed tomography (CT) section in the radiology department. Data were collected for equipment and staff capacity, arrival times, processing times and waiting times for the CT section of the radiology department. Processing time data collection required the observation of the system over the entire workday by recording the patient arrival and departure times. The required time for a patient to undress and dress their cloths was incorporated into the operation processing time. In addition to that, the waiting times for patients in the radiology department were calculated as the time interval from the moment patients scheduled to receive the imaging procedure to the time they were collected by imaging staff. The CT radiology department operates for one shift (8:00 am – 4:00 pm) per day and there was a one hour break scheduled between 12:00 pm – 1:00 pm. Also, there are three resources (scanning machines) in this department.

The collected data showed that the patients arrival rate at the radiology department is according to Poisson statistical distribution with a mean value of $\lambda = 0.08883$ and units in days and the processing time is according to the Triangular statistical distribution (14.4125, 20, 89.508) with units in minutes. Fig. 1 shows the arrival pattern while Fig. 2 shows the probability density function that best fits these data. From Fig. 1, it is clear that there is a high variability in the demand (number of patients per day) in the CT radiology department.

Staff in the radiology department work only for five days per week (Sunday till Thursday) and there is a technician on call for urgent cases on Fridays and Saturdays therefore, only urgent cases can be handled on these two days and can be processed at the same time.

B. Simulation Model

Simulation is considered to be as one of the most powerful tool used for analysis, planning and decision making for design and operation of complex system. Therefore; a simulation model for the existing system at the radiology department was developed for the purpose of understanding the system behavior and investigate various suggested

scenarios and strategies for the processes in this department without disruption to staff and patients. The impact of changing the number of resources in the radiology department will be investigated. Also, the model is used to understand the complex interactions between the various factors that control the operations in the radiology department. Arena simulation software was used for developing the model and analyzing the results. The arrival patients in the model join a single FIFO queue discipline in the waiting room. Once the patient done with the imaging process, he or she will be discharged from the department.

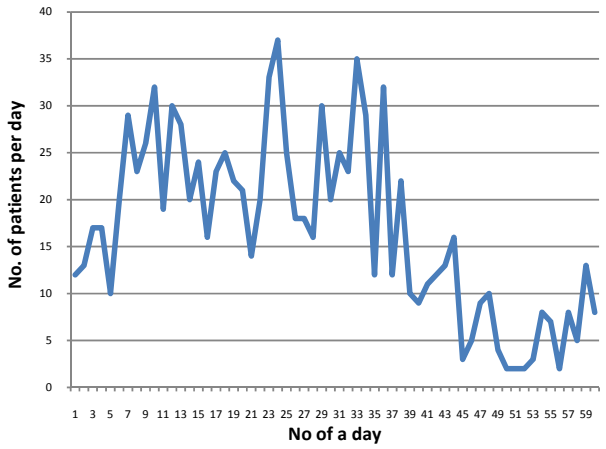

Fig. 1 Patients arrival pattern per day

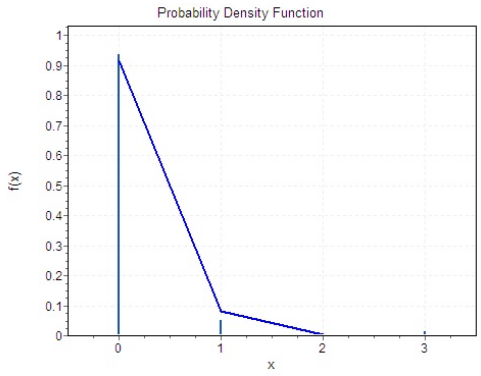

Fig. 2 Poisson probability density function for arrival rate at CT department

The simulation model was carried out for a period of 12 months and the study was repeated for 100 replications. The results of the 100 runs were averaged by Arena simulation software. In addition to that, a warm up period of 30 days was used in the model because it starts from an empty status.

IV. Results and Discussion

As mentioned earlier, the main target of this study was to reduce the long waiting time (14 days) in the CT radiology department as claimed by the management and shown on their reports. Interviewing the department staff about patients scheduling and machine failure or breakdown revealed that appointments were scheduled on an hourly bases during the working day and machine breakdown are not common but rare and the machines are well serviced and maintained.

In this study, all alternatives and scenarios are investigated and "what if" questions were tested. Table I shows the simulation results as an average time values. Simulation results showed that it is unpractical to use one resource because the waiting time will be too long. Unfortunately, the simulation results for average waiting time, average total time and average waiting number in queues by running three CT scanners was significantly less than the numbers and times claimed by the department staff and management. Also, the impact of adding one more CT scanner to increase the total number to four was investigated but it did not improve the situation substantially (did not reducing the waiting time). Hence, if the three CT scanning machines well utilized, then all patients should get scanned in the same day with zero day waiting time and the waiting time before get scanned will be 31 minutes. Therefore, it is suggested that:

1) Schedule appointments on the bases of 20 – 30 minutes during the working day.
2) Management should investigate the reasons behind the long waiting time in the CT.
3) Department management should keep a control on their employees and train them well.

TABLE I
Simulation Results under Different Scenarios

No. of resources	Average waiting number (patients)	Average Waiting Time (min)	Average Total Time (min)
2	2.38	100.58	141.79
3	0.75	30.9584	72.1897

Department management claims that there is a delay in preparing scanning reports which it took between 5–7 days to be ready and handy, therefore; it is suggested that the hospital hire one additional specialist or subcontract with other hospitals to speed the reports preparing process.

V. Conclusion

These papers demonstrated how simulation can be used to study, investigate and understand complex systems such as a radiology department. This study demonstrated how Arena simulation software can be helpful in better understanding the system under study and support decision making process. Also, simulation can stimulate the hospital management to conduct an investigation on quantitative and qualitative bases for any flows in the system operations. It is shown that three CT scanners are enough if they well utilized and there is no need for any addition CT scanning machines but the long waiting time before the patients can approach the radiology department can be attributed to managerial issues. In addition to that, simulation allows analysts to investigate all alternatives and scenarios without any disruption to the actual system.

The limitations of this study can be highlighted as (1) the data quality affect the simulations results as explained in the

data collection section, and (2) the data provided from the radiology department records needed a long time for filtration which affect the sample size.

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