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Evaluation of provided services at MRI department in a public hospital using discrete event simulation technique: A case study

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Abstract: The main purpose of this study is to improve on the performance of a specific healthcare department in order to meet the major administrative expectation. These expectations include better serving the patients in that department in a seamless and most economical manner. This need opened the door for a full review of an existing system. In this research a radiology department in a public hospital has been selected. The quality of service, patients' medical needs, and the cost of service are the main criteria used to develop a simulation model in this study. This study uses Discrete Event Simulation as a main management tool. Collected and gathered data related to the processing time and arrival time over a period of one years are used in this study. A model was created using Arena modeling package. The model main results exhibited that the resources in the selected radiology division were exhausted. These results provided the needed tools for the management team to make managerial decisions resulting in enhancing the quality of the provided services by improving the imaging services in the radiology department. This improvement

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PUBLIC INTEREST STATEMENT

Discrete event simulation (DES) is proven to be an efficient evaluation and assessment management tool. DES can be utilized in testing and investigating different proposals or alternatives without any disruption to the existing systems. DES requires building a model in one of the simulation software packages such as Arena similar to what have been done in this study. A model was constructed on Arena simulation software to imitate a case in the MRI radiology department of a given hospital, where different scenarios were investigated. The model outcomes, in conjunction with trade-off analysis, equipped the hospital management staff with a vital tool to make an efficient administrative decision resulting in improving the quality of the scanning services. Incorporating the results of this study in the radiology department of the given hospital will reduce the patients' waiting time and increase the patients' satisfaction.

lead to reducing the patients' waiting time and at the same time improved the quality of medical provided services. The major contribution of this article is related to investigating the operation effectiveness of MRI radiology division within a healthcare system by utilizing the Arena Simulation Software. This study utilizes an optimization technique to provide the higher management team the needed tools to make efficient decisions.

Subjects: Operations Management; Flexible Manufacturing Systems; Integrated Manufacturing Systems

Keywords: discrete event simulation; waiting time; radiology department; healthcare modeling; performance evaluation

1. Introduction

Usually patients experience the side effects of chronic diseases, which need to be explored through X-ray radiography, Magnetic Resonance Imaging (MRI), Computed Tomography (CT) scan and Ultrasound. In this case prompt medical treatment becomes necessary. The radiology office gives basic medical imaging services to settle on essential choices by a medical specialist for the analysis and prescriptions. The deferral in getting such services postpones the urgently needed medical treatment. Patients crowding at radiology division are considered part of the system used in the radiology office. Hence, the executed assessment of the radiology division is considered a basic requirement in evaluating the use of equipment and the patients' waiting time. In such circumstance, the simulation becomes a key part in the assessment execution and decision-making process.

Simulation in hospital services has aided medical practitioners and administrators in creating value added services in hospitals. MRI technique is one of the well-known imaging types widely used in the medical applications for creating high quality and detailed images of the body tissues and organs within the body of the patients. Lately, MRI has been widely utilized to treat patients of special medical cases such as abnormalities of the joints, abnormalities of the spinal cord and brain, cysts, injuries, tumors, and others. MRI Radiology scanning machines are considered to be an essential part of any radiology department. Hospitals and most physicians rely on this type of scanning machines as an essential tool for the diagnosis of different disease and abnormal medical conditions. Therefore, medical practitioners routinely request this type of imaging technique for the diagnosis of different diseases which, in turn, burdens the radiology department and overcrowds it with long line of patients.

Increasing rates of demand for healthcare services and crowding at radiology departments are the major problems that face governments and public healthcare providers (Bataineh, Al-Aomar, & Abu-Shakra, 2010; Sanmartin et al., 2000). In particular, radiology departments at governmental and public hospitals in Saudi Arabia struggling with the same issue of expanding rates of interest for scanning processes which requires an intervention to accommodate this high rate of demand for healthcare services. Higher rates of demand for imaging services continues to escalate resulting in prolonged patients waiting time, and consequently negatively affecting patients' loyalty and customer satisfaction. The lengthy waiting times at radiology department create a necessity for enhancing workflow management within the radiology department settings to provide high-quality services. Consequently, enhancing the efficiency of the radiology office execution to lessen waiting times, increase throughput and improve patients' fulfillment become the desired target to be accomplished.

Suggested change in radiology divisions of social insurance associations must be bolstered with verifications and quantitative proof. As of late, modeling and simulation results that showed to be a viable choice bolster apparatus which lead to unraveling medical services issues in numerous nations. Discrete event simulation (DES) is thought to be an efficient analyzing tool that has been generally applied in medical services organizations. It has shown its impressive accomplishment in evaluating the wastefulness of the present system, focusing at the connection between the factors impacting the system, scanning impact of likely changes and surveying the proposed choices for improvement (Jun, Jacobson, & Swisher, 1999).

An endeavor is made in the current research to apply DES method to the scanning room in the division of radiology inside a public and nonprofit hospital situated in the southwestern part of the Kingdom of Saudi Arabia (KSA). The imaging office at this healthcare facility experiences a high rate of demand for consistent imaging operations. One of the significant goals of the hospital administration pertaining to the imaging room is to lessen patient holding up time and improve the efficiency increment with a specific end goal to enhance the nature of services in that department. Consequently, to accomplish this objective, a DES model is set up to study the impact of extra assets in the principal and to recommend system that deals with the patient holding up times. The model optimizes the ideal number of required assets in the imaging room that best serves the patients

2. Application of DES in medical service organizations

DES is characterized as a type of PC-based demonstrating of systems processes as it develops after some time where the factors vary just at an isolated arrangement of focuses in time (Banks, Carson, Nelson, & Nicol, 2004; Kelton, Sadowski, & Zupick, 2014; Law & Kelton, 2000). DES was initially created in the 1960s in operations research and modern designing to aid in the investigation and advancement of industrial and business systems and from that point forward, the DES turned into a common and a productive basic leadership instrument in healthcare organizations. This process leads to detailed examination and determination of proposed optimum solution pertaining to the flow of patients which is related to planning and quantifying the desired resources (staff and equipment) in order to raise throughput, boost the flow of patients, improve customer satisfaction and lower costs of delivered healthcare services. DES was utilized as a part of various territories of learning and medical service facilities were one of these areas.

DES modelling has been generally connected with medical service implementations and it has expanded in the course of the latest 40 years (Jacobson, Hall, & Swisher, 2006). The utilization of simulation and modelling was primarily on the examination of medical service systems with the end goal of diminishing waiting times, expanding profitability and enhancing the conveyed administrations of medical services associations. DES simulation and modelling have been connected with various social insurance offices. Many researchers utilized discrete even simulation to investigate various issues in outpatient clinics. Huarng and Lee (2003) developed a simulation model and they were able to reduce the doctors' work load and patients' waiting time by studying different scenarios of variations in the service units, staffing policies and appointment system in out—patient clinics. Harper and Gamlin (Harper & Gamlin, 2003) identified different critical factors which affect the crowding and waiting times in ENT outpatients clinic and Dodds (2005) identified and quantified the problems in the vascular—surgery outpatient clinics by testing several proposals. Wijewickrama (2006) and Rohleder and Klassen (2002) explored the bottlenecks problems in outpatient clinics by evaluating different appointment list rules. Rohleder, Bischak, and Baskin (2007) investigated the waiting time reduction in clinics by redesigning the patients' service centers. Everett (2002) constructed a simulation model as an operational tool for providing a managerial decision support in the patients' scheduling procedure and for comparing the efficiency of different alternate policies in the elective surgery in hospitals. Harper and Shahani (2002) applied DES in the planning and management of bed capacities in hospitals within a settings of variability, uncertainty and lack of resources. El-Darzi, Vasilakis, Chaussalet, and Millard (1998) and Hoot et al. (2008) utilized DES in forecasting the average length of stay and future crowding in geriatric hospitals and emergency departments respectively. Joshi and Rys (2011) applied DES using Arena 10.0 software to probe the different arrival patterns and time duration of disaster victims' impact on emergency department ability to handle this sudden surge in demand. Chu, Lin, and Lam (2003) developed a simulation model that used for the prediction or evaluation of lift performance of the new designed or existing hospitals. Wijewickrama (2004) used a DES simulation model to build on Arena to determine the optimum number of parking lots in hospitals.

DES has a front line of allowing the creator to make a complex model for service analysis and performance assessment. The creator may apply in different service associations, such as medical service facilities, and empower designers to investigate diverse strategies and situations in a given time with no extra cost. Modeling procedure may yield futile if standard methodology is not trailed by a modeler. Law and Kelton (2000) and Banks et al. (2004) prescribed the standard strides for successful modeling through DES study. The recommended standard strides incorporate a plan of the issue, general review plan, model conceptualization, collection of data, model interpretation, check, approval, trial outline, creation run and examination utilizing the PC model, documentation, and execution. The key strides of a fruitful simulation contemplate incorporating detailing of the issue, collection of data, and model interpretation. Hence, It is of most extreme significance to conduct simulation study with awesome alert and care, falling flat which will bring about a loss of valuable lives. The modeler may take after standard instructional exercise provided by Mahachek (1992) for conducting a DES study in a healthcare setup.

3. Methodology

The radiology room under study is part of a non-profit, public hospital run by the Ministry of Health in Saudi Arabia. The hospital is in a city situated in the southwestern part of the nation with a populace of around 2.4 million.

3.1. Simulation model

Modeling is regarded to be a standout amongst the most generally utilized tools for decision-making, studying and investigating various operations of complex systems where a high inconstancy is intrinsic in the arrival rate and processing time (Shannon, 1998). Therefore a simulation model is created for the radiology space to comprehend the conduct of the radiology system, investigate the different possible alternatives and strategies, reply “What-If” question to improve the patient stream in this division, decrease patients waiting time and so clients’ fulfillment increment. In this way, a DES model was built for the investigation of patients’ flow through the scanning rooms in the division. Figure 1 displays the MRI radiology department process logic.

Arena modeling package is utilized for model construction and output analysis of various proposed strategies and alternatives. In this model, all the arrived patients to the radiology division join a single line in the waiting room where the patients seen in order of their entry as indicated by priority category.

Since the simulation model starts running from an empty state, the warm-up period is defined as the time it takes to reach the steady-state behavior. Law and Kelton (2000) presented several

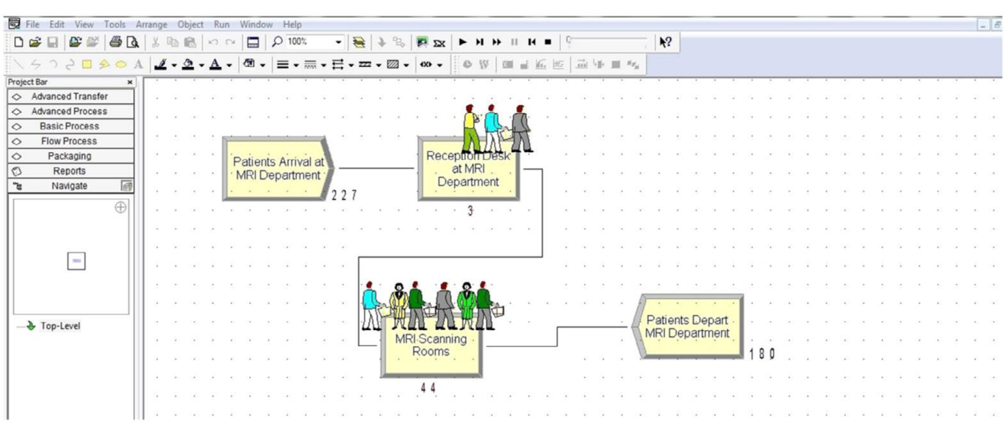


Figure 1. MRI radiology department process logic.

methods for defining the warm-up period. Therefore and based on all of the previous studies, the warm-up period of the present constructed model was specified as 15 days due the imposed limitation related to the initiation of the simulation model starting from an empty status. Likewise, Thesen and Travis (1992) stated that the longer the simulation model running time the more accurate the results will be. This will also build more confidence in the model outcomes. Also, Thesen and Travis recommended that running times be as large as possible in order to ensure at least 1,000 events. Therefore, the current simulation model was kept running for 260 days with 100 replications and the outcomes were averaged by Arena simulation software.

3.2. Data collection

A standout amongst the most troublesome, challenging and vital obligations in any simulation and modeling study is gathering the required data for the sake of building the models (Banks et al., 2004). The collected data determine the accuracy of model's results and conclusion. Therefore, the high quality of a collected data combined with an accurate model and thorough interpretation and analysis will result in accurate results, conclusions, and better guided recommendations.

In this study, a group of five students was divided into three teams and each team consists of two students as indicated by arranged schedule. The three teams observed the imaging procedure at the radiology room and gathered genuine data for the processing time more than four-month duration by measuring the time it takes to get past the entire procedure. The primary data related to the processing time were collected by observing the system during the working hours and registering the arrival and departure time of patients.

The teams could acquire the patients' waiting times from the radiology office past records. The patients' waiting times are evaluated as the elapsed time between the date of demand and the date of appointment. The past records of the radiology office at the hospital show that the minimum, average and maximum patients waiting times were 0, 59, and 289 days respectively. Additionally, it is noticed that 64.92% of patients waited for over 6 days, 39.94% of patients waited for over 30 days and just 6% of patients scanned at the same time. This gives an unmistakable confirmation that the quality of the provided services in the MRI radiology room is negative and requires improvement as shown in Table 1. The confirmation is based on a benchmark technique against some industrialized countries such as United States, Canada, and Japan. The Ontario Association of Radiologists reported that Ontario Ministry of Health reduced the waiting time at MRI from 12–18 months in 2004 to less than 30 days for outpatient as of October 2015 by increasing the number of MRI diagnostic imaging devices (Emery et al., 2009; Ontario Association of Radiologists, n.d.). Canada, United States and Japan have 4.6, 19.5, and 35.3 MRI diagnostic devices per million population respectively (Emery et al., 2009; Stein, 2005) while in the case under study, it lags far behind these countries with a rate of 0.81 MRI unit per million population. Therefore, the figures give clear proof about patients' prolonged holding up time in radiology division. The patients sent to the radiology office could have a major issue that requires brisk findings, treatment or surgical intercession. In this manner, delayed treatment could prompt to undesirable outcomes notwithstanding the serious excruciating feeling.

Table 1. A statistical analysis of patients waiting time in the MRI radiology department

Patients waiting time until being scanned in the radiology department	Percentage
Zero days waiting time	6
More than 6 days	64.92
More than 14 days	53.22
More than 30 days	39.94
More than 60 days	7.08
More than 75 days	3.66
More than 90 days	2.31
More than 120 days	1.35

The required data for the inter-arrival times was recovered from the radiology division database for the review time frame from 1 January 2014, till 31 December 2014. Likewise, meetings with the division workers were directed to pick up a profound comprehension of the division operations. Through interviews, the group could obtain more data about the quantity of scanning machines in the radiology room and staff capacity.

The gathered data exhibited that entry rate of patients at radiology room is as indicated by Gamma distribution while the patients' processing time is as per the Weibull distribution. The arrival pattern at the MRI radiology department is represented in Figure 2 for easy understanding. A conclusion of high fluctuation in the patients' request for imaging operations can easily be drawn from this figure.

Moreover, patients in the radiology room are booked for the scanning procedure at regular intervals and the radiology office database uncovered that the patients' minimum, average, and maximum waiting times are zero, 59, and 289 days respectively. These figures show that the patients' services in the radiology room are not overseen adequately.

The radiology room works for one shift per day from 8:00 am in the morning till 3:00 pm in the evening and for five days per week, Sunday until Thursday. All through this working day, there is a break period planned from 12:30 pm to 1:30 pm. The administration of the radiology division entirely demanded not to change the break time frame and the greater part of the specialists ought to get their break at the same time. Notwithstanding that, there is a specialist accessible and available to come back to work for critical cases at weekends and in night shifts for dire cases to be prepared in the meantime. Thus, just weekdays were considered in this model with just a single scanning machine accessible in the radiology division.

3.3. Model building

Various suppositions were made in the process of model building:

(1) Only weekdays were considered in the model.

(2) Patients' arrival rate and processing times are according to statistical probability density functions that fit the collected data.

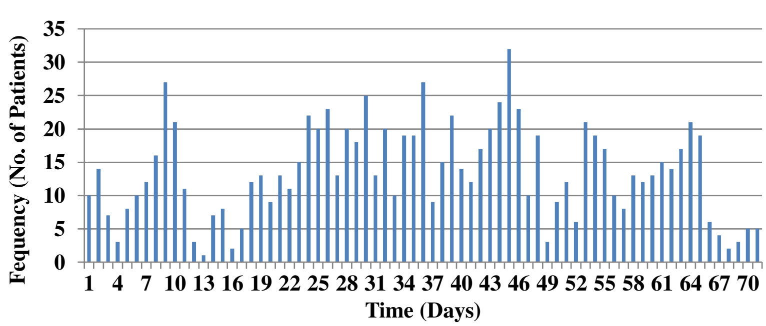
(3) The system was simulated for the period from 8:00 am till 3:00 pm.

(4) All radiology division staff is thought to be indistinguishable and completely qualified resources.

(5) Patients delay for the strolling separation between the waiting region and scanning area was consolidated in the imaging processing time.

(6) The non-included esteem time that squandered in dressing and undressing of patients' fabrics was considered as part of the processing time.

Figure 2. Sample of patients' arrival pattern at radiology room per day.



3.4. Model verification
The simulation model is a simplified representation of a genuine system under review. Along these lines, it is from time to time that the model would be a genuine representation and catch the majority of the attributes of the genuine system because of varieties between the system conduct and the measurable conveyances that fit the arrival rate and processing times and in the varieties between staff qualities and capacities. In this way, it is once in a while that the models will dependably predict precisely the execution of the system (Altiok & Melamed, 2007). Therefore, the prime target of model developers is to construct a right model.

Model confirmation is characterized as the way toward verifying that conceptual description and specifications were implemented effectively and precisely during building the model (Kleijnen, 1995) with the end goal of developing a powerful, exact and solid model. In this study, the basic dynamic animation provided by Arena simulation software is empowered for the accuracy assurance of model development. Hence, watching the model animation simplified the verification process of model coherent operations in the radiology room which guaranteed the presence of all scanning resources and processes in the model and affirmed duplication of the genuine system.

3.5. Model validation
Validation is known as the technique for determining whether the developed model is a genuine true representation of the current existing system (Law & Kelton, 2000). The simulation model is an approximation of the real systems, therefore, complete validation is impossible. Banks et al. (2004) and Kelton et al. (2014) provided a framework for models validation of existing systems. They proposed comparing the results from created model to the results from the real system using the past data. In this study, the run-length period is kept much larger than the warm-up period. Several researchers suggested that the ratio of the run-length period to the warm-up period should be greater than 10 (Kelton et al., 2014). Several researchers concluded that more simulation replicates leads to better outcomes and more robust model (Mould & Upton, 2012). Based on that, the model was kept running for 100 replications and the outcomes resulted from this model were contrasted with genuine gathered data utilizing the principles of the confidence interval.

4. Simulation results
Utilizing Arena simulation software, a model was constructed and simulated to investigate the greater part of the proposed options and situations and to test "What-If" question in order to accomplish the objective of patients waiting time reduction. The present circumstance with one scanning machine in the radiology room was examined and was found that this state is unreasonable to use because of the long waiting time that will be experienced with this situation. From that point onward, the accompanying situations and methodologies were investigated utilizing the simulation model:

Methodology 1: Two scanning machines are proposed with one hour break from 12:30–1:30 pm and patients are scheduled every 30 min.

Methodology 2: Three scanning machines are proposed with one hour break from 12:30–1:30 pm and patients are scheduled every 30 min.

Methodology 3: Four scanning machines are proposed with one hour break from 12:30–1:30 pm and patients are scheduled every 30 min.

5. Discussion
Table 2 shows the consequences of the considered and researched systems, which demonstrate patients' average waiting time, total time (system time), minimum and maximum waiting time for three distinct strategies or alternatives.

Table 2. The output yield of various proposed procedures for waiting time reduction

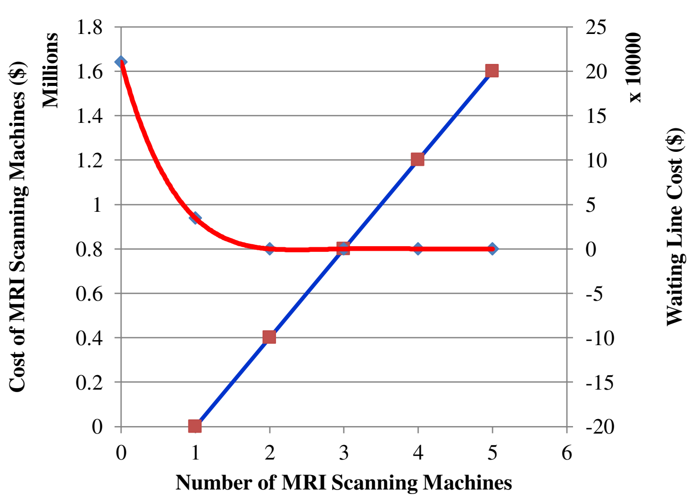
Strategy	No. of machines in system	Break	Average waiting time (min)	Average total time in the system (min)	Minimum waiting time (min)	Maximum waiting time (min)
Strategy 1	2	60 min break	95	127	0	781
Strategy 2	3	60 min break	28	58	0	407
Strategy 3	4	60 min break	6	37	0	42

It is evident from the table that alternatives 1, 2 and 3 brought about a noteworthy change in waiting and total times duration contrasted with the current existing circumstance. Through the utilization of options 2 and 3, all arrived patients can be scanned around the same time and the waiting time will be dropped to zero days while in option 1, a few patients need to wait for one day keeping in mind the end goal to be scanned in the following day. Comparing options 2 and 3 delineates that there is a distinction of 22 min in average waiting time. However, elective 2 is supported over option 3 because of the way that option 2 has to bring down the beginning and working expense. Also, the average holding up time which can be controlled through the suitable planning process is satisfactory. Moreover, option 2 is supported over option 1 because of the reality that option 2 will provide more adaptability in case of the breakdown of one the scanning machines.

Quality improvement of the provided services in the MRI radiology division requires a generous decrease in patients waiting times. This reduction requires an interest in extra scanning machines, procuring new radiology professionals, and employing or subcontract another radiology expert. Along these lines, there is a need to decide on the ideal number of extra imaging machines in the perspective of aggregate cost and waiting time decrease. Figure 3 represents the connection between the servers capacity vs. patients' waiting line cost trade-off. It is coherent and evident that expanding the quantity of MRI scanning machines will decrease the patients' waiting line cost and increase the cost of the provided services as far as extra scanning machines and professionals. Henceforth, it is apparent that the ideal number of MRI scanning machines as far as cost is concern, is three machines. This requires two extra scanning machines, making the total number of the MRI scanning machines is three. Accordingly, elective 2 is the adequate one in order to enhance the quality of provided services and to lower the cost. The extra two MRI scanning machines will empower the department to scan all arrived patients around the same time, resulting in enhancing the administrative system, upgrading clients' fulfillment, lessening the required time for findings and treatment, and decreasing the patients experiencing serious agony.

However, a trade-off analysis of providing health care services, with great quality and higher customer satisfaction, against cost reduction and longer waiting time will come about with option 2 as

Figure 3. Capacity of servers against waiting time trade-off.



the best alternative over other alternates. The circumstance could be inadequate with option 1 in case if the machine breaks down or fails. In this situation, just a single machine will work and the waiting time will be increased excessively. The likelihood of this expected undesired result of failure can be reduced with a scheduled preventive maintenance during off hours. In this case, it is prescribed to include two more MRI scanning machines. The division requires procuring three more radiology experts in addition to the specialist working in the office keeping in mind the end goal to get the optimum use of the scanning machines.

6. Limitations

Disregarding the capacity of simulation and modeling the vital bits of knowledge into the jamming issue in the healthcare systems need to be considered. These issues have certain restrictions which impact their focal points.

The restrictions of this study may be summarized as; the quality of the data influencing the modeling outcomes about as clarified in data collection section, the lack of statistical distribution that fits precisely into the arrival rate and processing time with zero percentage error, and the time needed to filter gathered data from the imaging office which affects the volume of the sample.

7. Conclusion

In this study, a DES approach is applied for the modeling and simulation of an MRI radiology room in a local nonprofit governmental hospital to analyze, reduce the patients' waiting time and enhance the nature of provided services in this radiology room. The present status in the radiology room exhibited a tremendous waiting time in this room. Thus, the point of the examination was to upgrade the quantity of the scanning machines in the MRI radiology room with a specific end goal to reduce the patients' waiting time, to enhance service quality and to increase clients' fulfillment by considering diverse choices and situations. Also, test "What-If" question to accomplish this objective. In order to achieve the goal of this study, Arena simulation software is utilized in building the required models and it is uncovered that the system requires two extra MRI scanning machines. The required aggregate number of /machines in the system is three as shown in option 2 which is turned to be the optimum one among other alternates options in order to provide great quality healthcare services with significant waiting time reduction. The results of the study clarified the allocation impact of extra resources on waiting time reduction.

Including two more MRI scanning machines to the system decreased the patients' waiting times significantly. In addition, the system in the radiology office requires the contribution of the hospital administration to research for the purposes of the lower number of patient scanned every day and to improve the patient planning process. Likewise, including another little changing area can help in easing the waiting time issue the MRI radiology division.

Moreover, this study clarified the utilization of modeling technique in studying, exploring and comprehending sophisticated systems, such as the imaging division. The study demonstrated the applicability of the Arena modeling packages in the healthcare systems and support managerial decision-making. Additionally, modeling can motivate medical services administration to conduct a thorough study taking into account the qualitative and the quantitative measures to diagnose any imperfection in the system. The model output resulted in revealing that one scanning machine is insufficient for serving the patients in the radiology division. The waiting time reduces substantially with an extra venture to expand assets quantity in the radiology room by two machines. This arrangement will considerably diminish patients' holding up time in an imaging division. Nevertheless, modeling permits experts to explore all choices and situations with no disturbance to the system in place.

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