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Discrete Event Simulation of a Multi-Facility Healthcare System

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***Abstract*—** *The quality of health services can be measured by productivity, waiting times, efficiency, patient satisfaction and stress on medical staff. Despite the high attention on the health sector, they undergo many challenges due to increase in high demand for health services that is attributed to the population growth rate and increase in the waiting time leading to patient dissatisfaction. The increased demand for radiology department services has lead to a considerable increase in the patient waiting times and subsequently has negatively affected the patient's satisfaction. The purpose of this study was to reduce patient waiting times, improve system throughput and improve resources utilization in radiology department by formulating and implementing a model that is based on Appointment scheduling system. A discrete event simulation model was developed using Arena simulation software to investigate different alternatives to improve the overall system delivery based on the Appointment scheduling system. The result shows that the implemented Appointment Scheduling system has a great impact on the system by reducing the waiting time by 85% at the consultation room and 12.5% at the cash office.*

I. INTRODUCTION

Over the years, simulation tools and techniques are applied in problem detection and process improvement of many manufacturing and services systems. The flexibility of the simulation programs enable organizations to monitor the whole aspect of their systems and plan for business development prior to facing the real behavior (Masoud, 2012). Among the various services organizations, healthcare industry has a fundamental and significant role in upgrading lifestyle standards. Simulation is a modeling tool widely used in operational research (OR) where computer models are deployed to understand and experiment with a system (Pidd, 2004). A true benefit of simulation can be harvested when the simulation models are fully integrated into the routine of healthcare delivery i.e. the existing information systems applications which support the daily operations of the healthcare provider (Gaba, 2004).

The power of simulation lies in the abilities to model alternatives systems for comparison studies and estimate a number of varying performance measures (Mark, 1999). Essentially, simulation is not a tool for conducting a one-time set of experiments when a major change is planned but the simulation models run in parallel to other application as a routine part of everyday work environment. The current economic situation, policy shift and the environment in which healthcare is delivered are ripe for using simulation as a standard tool for supporting the steering, management, and control of healthcare delivery.

Furthermore, healthcare simulation can be extended beyond the traditional role of comparing scenarios or visualizing workflow. A simulation model can be built and incorporated as a component of ongoing efforts to monitor and improve performance and increase efficiency. A simulation language called Arena was used to model the operation of the radiology and the outpatient department in the clinic.

The quality of health services can be measured by productivity, waiting times, efficiency, patient satisfaction and stressed medical staff (Shankar et al, 2007). Despite the high attention into the health sector, public healthcare sector undergoes many challenges due to increase in high demand for health services that attributed to the population growth rate. This increase in demand for health services requires new policies and strategies to be adopted by the Ministry of Health to face challenges from hospital such as services in emergency department, outpatients departments (OPD), laboratories and radiology department (Mwafar Shakoor, 2013)

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 time and subsequently will affect the patients' satisfaction negatively. Thus there is a need to improve the radiology department performance which will lead to reduced patient waiting times, increase throughput and improved patients satisfaction.

The radiology department under study provides several radiology services like Accident and Emergency Radiology and the Conventional and Special radiological examinations,

This study was streamlined to the patients at the radiology department and the General Outpatient Department of the clinic. At the radiology department, patients that are being referred from other hospitals for x-ray are negligible and not considered at the time of this research. The research is done by using the empirical observation made cautiously. This study allows the clinic to be aware of the impact of improving the appointment system on its flow of operation. The research methodology used in this work is case study where an in-depth examination of a large volume of information about unit(s) is done for a period of time (Fatma et al).

Therefore this work implemented an individual block schedule. An appointment system was used to implementing

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this which enables the clinic serve the patients better and increases their satisfaction. The discrete-event simulation software ARENA, Version 12.0, was selected on the basis of its graphical user interface, ease-of-use as well as its robust modeling options and features. A description of ARENA and other simulation packages can be found in Kelton (2009).

The ARENA simulation software is applied because of its strength and flexible features as a powerful and popular Visual Interactive Simulation Modeling system for discrete event simulation. ARENA is capable of designing complex processes of manufacturing, service industries and healthcare institutions through accurate and modeling using comprehensive assessment and evaluation report. Arena® software allows you to bring the power of modeling and simulation to your business. It is designed for analyzing the impact of changes involving significant and complex redesigns associated with supply chain, manufacturing, processes, logistics, distribution and warehousing, and service systems. Arena software provides the maximum flexibility and breadth of application coverage to model any desired level of detail and complexity. (Allen Brandley, 2010)

II. Case Study: A Health Center in Nigeria

A healthcare center in the Eruwa in the Ibarapa East Local Government in Oyo State, Nigeria is considered. This medical centre provides health services including medication, laboratory services, radiology service, dental and eye clinics from 8.00AM to 6.00PM daily. They also have emergency at any time of the day. Like many hospitals in Nigeria, Awojobi Clinic, is located in Eruwa in the Ibarapa East Local Government of Oyo State in the South West Nigeria. Awojobi clinic, a renowned Rural Health System, is a 60 bedded community hospital. Awojobi clinic serves not only the greater Ibarapa area, but also the whole Nigeria at large. Last year**,** Awojobi clinic treated seven thousand, two hundred and twenty-one (7221) patients and admitted one thousand, nine hundred and thirty-two (1932) patients into their main ward, maternity ward and CVO wards through their Radiology Department**.** Awojobi Clinic management team is struggling to decrease patient wait times, decrease the amount of time a patient must wait to see a doctor, and decrease patients' total length of stay in order to improve performance.

A. Process Mapping and Data Collection

The data was collected for the X-ray section and the Ultra-Sound Scan section of the radiology department. The data collected include the number of equipment, the staff capacity, arrival times and processing time for each type of x-ray. The processing time was calculated from the time the patient register, time to call the patient in, time to undress and dress, the time taking for the x-ray, time taken at the dark room (depends on the number of exposures taken) and the time taken to drying the film (depends on the weather). At the x-ray section, the waiting time for patients were calculated as the time interval from the moment patients schedules to receive imaging procedure to the time they were collected by the imaging staff. At the Ultra-sound section, the time taken for processing is maximum of ten (10) minutes while the waiting time depends on the number of patients that were around before the patients arrived. For examples, if there are five (5) patients on ground, then the waiting time for the sixth (6th) patients will be fifty (50) minutes. If the ten (10) minutes for the processing time is added, then the length of stay for the sixth (6th) patient will be an hour at the radiology department. Finally, the patients go to the pharmacy to receive their medication.

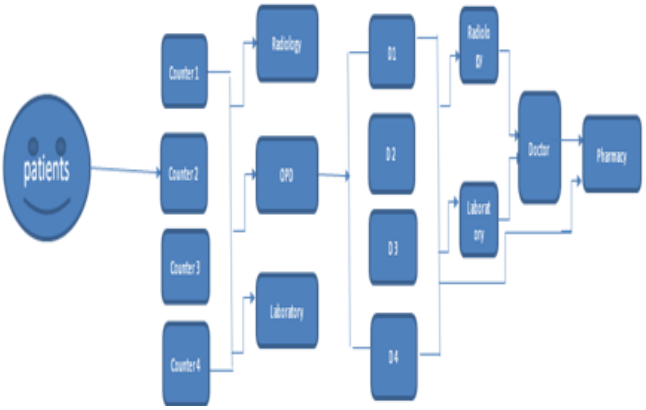

Fig. 1. The conceptual model of the general outpatient department.

The counter represent the clerk that i.e, there are four (4) clerks on duty who direct the patients to either go the radiology department, OPD or the laboratory as the case may be. The D's represents the doctors on duty. The figure above shows that there are four doctors on duty who after consulting with the patients direct the patient to the radiology for x-ray, laboratory for test or to the pharmacy for drugs prescription.

The radiology department operates only a single shift between 8.00 am and 5.00pm every day. There are two resources (1 scanning machine and 1 X-ray machine) in this department. We collected the arrival time and the exit time for simulation. The waiting time at each process can be estimated from the results of the simulation. During the period of study,1798 new patients and 4033 returning patients were included in this study out of which 1981 patients goes to the radiology department. It was also observed that the number of patients reduces as the week runs out. However, because of the volume of the data collected, a weekly average report of the number of patient's arrival per hour for the radiology department was used and displayed in the Table 1. Time between arrivals of patients is less than 2 minutes in the morning between 8.00am and 9.00am and it increases to more than 2 minutes for the rest of the working hour. This condition leads to a long waiting queue and increase the patient waiting time.

Table 1 shows the number of patients that visited the radiology department and the types of x-ray test that was carried out on the patients. It depicts a high number of patients on Mondays with Chest X- ray and the Ultra sound scan taking the lead.

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Table 1: The average number of patients per day.

X-ray Type	Mon	Tue	Wed	Thur	Fri
Chest X-ray	15	19	11	9	15
Skull X-ray	1	2	1	1	-
Abdominal X-ray	-	-	-	1	3
Extremities	2	11	5	1	3
Ultra Sound Scan	17	22	19	19	10
Pelvis	2	3	3	1	2
Mandibles	-	1	-	-	-
HSG(HysteroSalpingo Gram)	1	-	-	-	-
L/S spine	-	-	-	-	1
RUG	-		-	-	1
Total	**38**	**58**	**39**	**32**	**35**

B. Simulation Model Development

The discrete event simulation of the clinic involves designing a new system which was based on the appointment system of patients. Here, when a patient is done with the x-ray and laboratory department, he returns to join the queue waiting to see the doctor. Only the new and the planned patient will have the opportunity to see the doctor except on emergency case. This will greatly reduce the time a patient stay in the clinic. The process flow of the designed model is given in figure 2 below.

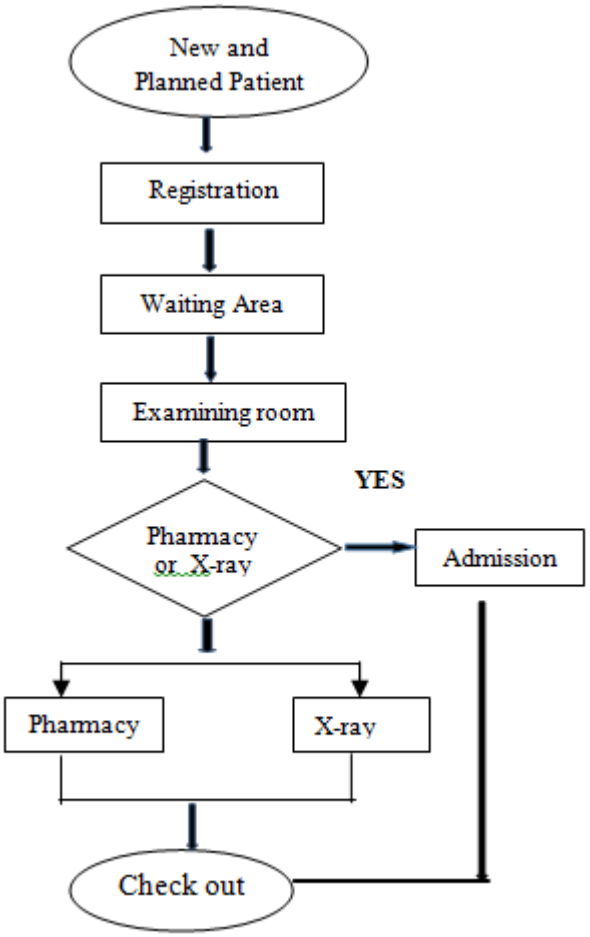

Fig. 2. Process flow of the developed model.

Based on the conceptual model of the system, the collected data and the distribution functions of the parameters used, a simulation model of the health centre is built using ARENA simulation software. Figure 3 shows the simulation model of the health center.

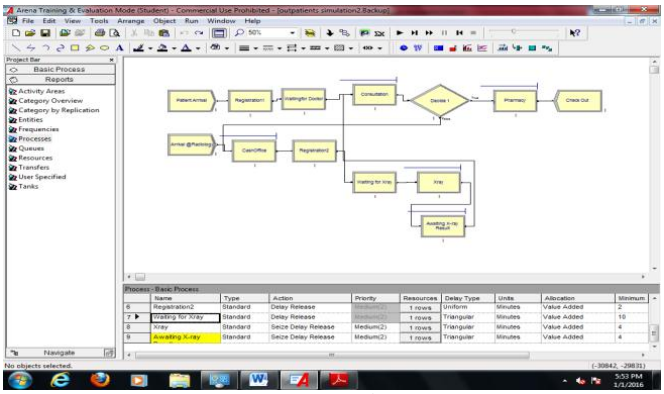

Fig. 3. Simulation model of the health center.

III. Model Experimentation and Result

After the verification and evaluation process, the result of the model experimentation was obtained. One important factor in performance measurement is the average time each customer or patient spends in a system. In this study, the average time each patient spends is around 75 minutes which is a long time. Table 2 depicts the average waiting time for x-ray at the Radiology department for the base model. As shown in the table, the average time a patient will spend waiting for his turn for X-ray is approximately 70 minutes for minimum and a maximum time of approximately 90 minutes. Table 3 shows the **a**verage waiting time for x-ray at Radiology Department of Designed Model.

Table 2: Average waiting time for x-ray at radiology department for base model.

Replication	Min. Time (minutes)	Max. Time (minutes)	Maximum Time (minutes)
1	112.620	147.504	147.504
2	48.204	55.994	55.994
3	15.624	46.872	46.872
4	96.492	102.300	102.300
5	72.828	79.374	79.374
Average	**69.1536**	**86.408**	**86.4088**

Table 3: Average waiting time for X-ray at radiology department of designed model.

Replication	Min Time (minutes)	Max time (minutes)
1	51.8960	108.380
2	58.7000	36.124
3	49.1824	12.459
4	86.1580	76.312
5	67.6750	68.156
Average	**62.7223**	**66.2862**

Table 4: Comparison between base model simulation output and historical data for average waiting time.

Phases	Average Waiting Time (minutes)	
	Historical data output	Base model Simulation Output
Consultation room	171.0536	158.9536
Cash Office	28.3984	26.4984
Radiology unit	74.3536	69.1536

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IV. Discussion of Result

The tables presented above shows a difference of about seven (7) minutes when the minimum time of the based model is compared to the designed model. Also an observation on the maximum time of both the base model and the designed model reveals a difference of twenty (20) minutes. The reason for this is the implementation of the individual block schedule through the use of an appointment system. This approach is tested on the historical data and the result is tabulated as the base model simulation. It depicts the difference of twelve (12) minutes in the consultation room and five (5) minutes in the radiology unit.

Table 5: Comparison between base model output and designed model (Appointment Scheduling) simulation result for average waiting time.

Phases	**Average Waiting Time (minutes)**	
	Designed Model Output	**Base Model Simulation Output**
Consultation room	23.8430	158.9536
Cash office	9.6668	26.4984
Radiology registration	3.4620	0.00
Radiology unit	62.7223	69.1536

V. Summary and Conclusion

This study was streamlined to the patients at the radiology department and the General Outpatient Department of the clinic. At the radiology department, patients that are being referred from other hospitals for x-ray are negligible and not considered at the time of this research. The research is done by using the empirical observation made cautiously. This study allows the clinic to be aware of the impact of improving the appointment system on its flow of operation. The research methodology used in this work is case study where an in-depth examination of a large volume of information about unit(s) is done for a period of time (Fatma et al). The study has showed varying degrees of waiting time in the Radiology department of the study area. Many of the patients at the radiology department spent over an hour before they can be attended to. This has being the cause of the long waiting time at the clinic. Thus there is a need to review the registration and the appointment processes of the radiology department to reduce the length of time patients spent in the department and also to improve service delivery. This will go a long way in reducing the long waiting time spent by the patient in the clinic and thereby increase patient satisfaction.

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