

A SIMULATOR TO IMPROVE WAITING TIMES AT A MEDICAL IMAGING CENTER

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ABSTRACT

Medical Imaging Centers (MIC) are critical units in every hospital or medical center because they are an important step in generating a patient's diagnostic. This paper shows a simulator designed to facilitate the development of simulation studies of MIC, which departs from traditional modeling because it uses a pull paradigm for the patients. A group technology approach was used to minimize the number of objects in the simulator, which includes objects that have the functionality of the equipments and processes found in these facilities, so that the analyst only needs to provide the parameters of the center. All the data is provided to the simulator through a Graphic User Interface (GUI), requiring no programming capacities. As an application of the simulator, an example is provided where the simulator is used to improve the waiting times and equipment rate of utilization at a research hospital in Chile.

1 INTRODUCTION

There is a worldwide concern for increased efficiency and cost effectiveness in healthcare delivery which in the USA represents about 16% of the Gross Domestic Product. The variability and complexity of the processes within healthcare systems demand the analytic power of discrete event simulation, which is recommended by a recent joint study by the National Academy of Engineering and the Institute of Medicine in the USA (NAE 2005), that calls for the use of simulation, among other systems engineering tools, as a way to improve the delivery system. The potential for widespread application of discrete event simulation technologies in healthcare has lead to the development of healthcare specific modeling environments aimed at enhancing modeler productivity, an example being the well known Medmodel environment (Harrell and Lange 2001) and Hospital Navigator (Hay, Valentin and Bijlsma 2006),

which use a completely different modeling point of view, where the patients do not drive the process.

Most applications have being built using a general purpose simulation package, such as the ones reported for an ambulatory surgery center (Ramis, Palma, and Baesler 2001), a clinic lab (Ramis et al. 2002), pharmacy staffing (Spry and Lawley 2005), emergency departments (Gunal and Pidd 2006) and a cancer treatment center (Baesler and Sepulveda 2006).

Several researchers have modeled Medical Imaging Centers (MIC) or parts of them to improve its operation. For example, the use of simulation for a radiology department with a view to increase the overall efficiency of the services (Centeno et al. 2000) and the modeling of a CT Scan area to quantify the benefits associated with the implementation of the digital image archiving system (Rama-krishnan et al. 2004).

The traditional modeling philosophy is that the entities, the patients, as they pass through the system request different resources and wait in queue for the resources if they are not available. This is a push paradigm and we claim that most healthcare processes respond better to a pull modeling approach, where the doctors, nurses and technicians call the patients needing services.

This paper presents a simulator for MIC based on a pull paradigm, which was designed after studying the patient's flow at four different hospitals and with the final objective of facilitating the modeling of these facilities. The configuration of a particular imaging center is done through the use of a Graphic User Interface (GUI), requiring no programming capacities. The analyst only need to provide the parameters of the center, such as arrivals rates, distances, processing times, resources and schedules, to obtain and estimation of the average utilization of resources, waiting times and productivity of the center for a given demand. Both input and output from the simulator is through a GUI interface, being possible to read/export from/to excel files. As an application of the simulator, an

example is provided where the simulator is used to improve the waiting times and equipment rate of utilization at a research hospital in Chile, which has 550 beds and a state of the art MIC.

The study shows the advantage of using a simulator, the possibility of computing activity-based costs (ABC) of the different exams and the usefulness of simulation as a tool for modeling and improving the operations of these facilities.

2 PATIENT FLOW

The flowchart of a typical patient's process is presented in Figure 1. The process begins when a patient and his or her companions arrive to the reception of the MIC. The arrivals could be scheduled, spontaneous or from an emergency room. The receptionist asks the patient about the type of exams that he/she requests, payment method and all the paper work required. Once assisted, the patient waits to be called by a technician/doctor to carry out a preliminary evaluation, preparation prior to the exam in case the patient may need anesthesia, contrast medium or other preparation, and the requested exams. The exams were classified as: magnetic resonance, CT, X-Ray, digestive radiology, ecography, angiography, mammography and others. Once the exam is performed, the patient leaves the area of the exam and meets with her/his companion and back office activities are performed to digitalize/print the image or make a CD, inform the exam and communicate the results to the patient or reporting physician.

3 CONCEPTUAL MODEL

Understanding MIC workflow is usually conducted in a brute-force fashion; that is, by taking a stopwatch and physically timing each step of the clinical examination process. This process can be viewed as taking a snapshot of the doctors/technologists daily activities revolving around a patient examination, including the room preparation prior to an examination, the examination itself, and the discharge of the patient from the MIC (Wideman and Gallet 2006).

The conceptual model of the simulator was designed after careful observation of imaging centers at four different hospitals in Chile, each one of them having between 400 and 1000 beds capacity. It was possible to generalize the patient's flow at these centers, which included all possible flows, resources, schedules and exams. The generalization process was represented using unified modeling language (UML).

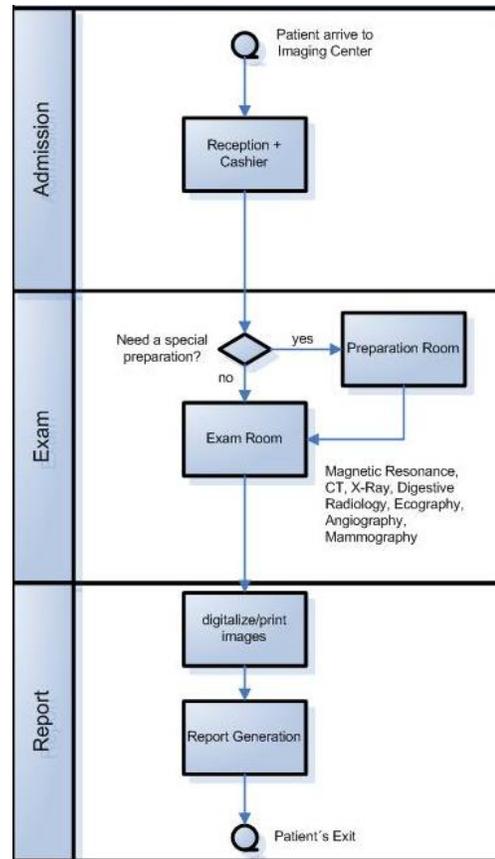


Figure 1: General MIC Process

Major differences among the different MIC were if the reception had admission with a multi-purpose receptionist or receptionist and cashier, a common admission for all the exams or different admissions for some of them, the types of exam performed, the number of dressing rooms in the exam box, the business hours during a day, the level of personnel at the different areas of the MIC, the type of technology used in the exam rooms and if they performed exams with special requirement; for example sedation before a scanner exam. These differences were considered as modeling options in the simulator

From a schematic point of view, the generic simulator consists of a collection of objects customized to represent the activities in the three areas shown in Figure 1, admission, exam and report. Using a group technology approach, it was possible to minimize the number of objects to be included in the simulator to only seven objects. The objects included are: an Arrival Generator for generating the different type of patients (scheduled, spontaneous and emergency), Reception for modeling receptionists and cashiers, Waiting to model queues with the capacity of renegeing, Exam Room as a unique object to model the different types of exam rooms and machines, an object for Processing the Images, one for Generating the Reports and one Sink for

destroying the entities leaving the MIC. The general view of the simulator is shown in Figure 2, where in the left side is the arrival/departure area and to the right are the different exam and processing rooms.



Figure 2: General view of the simulator

A major departure from traditional modeling of imaging centers are three characteristics built into the simulator: 1) the use of a pull paradigm, 2) the generation of any particular model is controlled through a GUI and 3) the generated model is layout free. The use of a pull paradigm was explained in the introduction, which we claim is a more natural way to modeling healthcare processes, where the scarce resources (doctors, nurses, technicians, receptionists) call the patients for service. The generation of any particular model using a GUI interface removes most of the complexity of model building, such that a person without an engineering background could build or modify a model of his own. The simulator is layout free because the objects can be arranged in any configuration and the distance among the different areas can be specified in a virtual format.

4 SIMULATOR DESCRIPTION

The simulator was built using Flexsim GP, which is a discrete object oriented simulation package. The seven objects selected were incorporated into a library, but the control of the library and the building of any model are done through the GUI shown in Figure 3, where the information about the arrivals, exam rooms, admission, digitizing and report rooms, distances and working shifts is provided.

The information to the simulator is provided through tables or excel tables, which are read by the simulator and results reported back in the similar format and graphs.

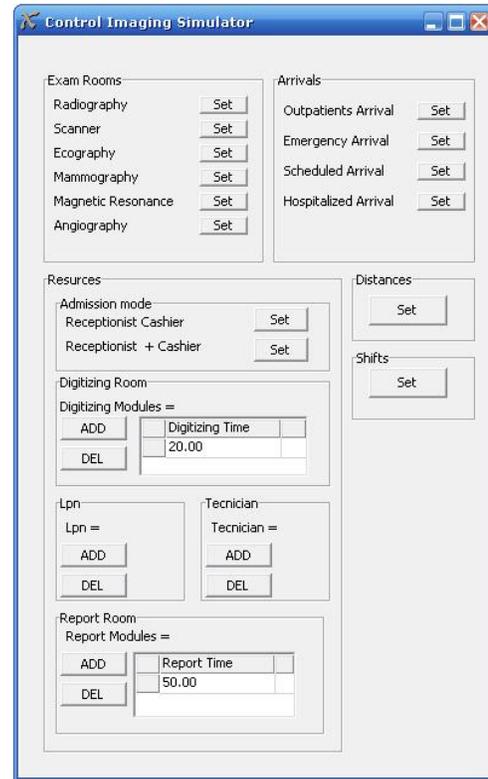


Figure 3: Control GUI of the simulator

An example of the input tables required by the GUI is provided in Figure 4, where it is specified the information for the radiography rooms: the number of rooms, the technology, the number of dressing rooms, the type of exams performed and their processing times, and the personnel required for each room. For the processing times, a distribution or a deterministic time could be used.

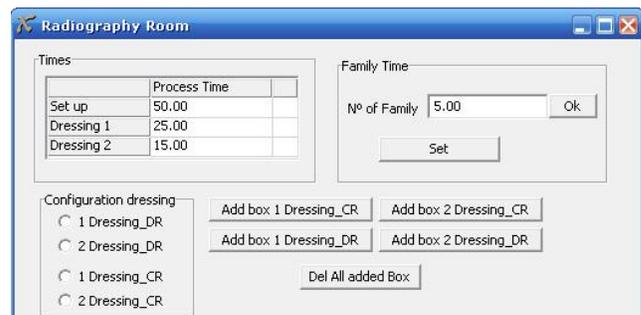


Figure 4: Configuration of a Radiography Room

Similarly, in Figure 5 it is shown for the outpatient's arrivals the percentages corresponding for the different types of exams, and in Figure 6, the walking distances in seconds, among the different areas or rooms within the imaging center.

Figure 5: Input Parameters for the Outpatients.

Figure 6: Distances within the MIC

To validate the simulator, production runs were made and the results discussed with physicians, nurses and technicians. At one of the locations, production runs were validated against actual data and not rejected with a 95% confidence. An interesting result at one MIC was that they had enough demand to justify having X-ray rooms with 3 dressing areas. In general, the animation was of help, allowing tracking patients as they moved through the system, but it did not provide face validity because it did not reflect an actual layout.

5 SIMULATOR EXAMPLE

As an application of the simulator, it is shown an application made at a Clinical Hospital from Universidad de Chile, which is a research hospital, having 550 beds and a state of the art imaging center with digital technology and scheduling software to optimize the appointments. The objective of the study was to test if different assignments of the personnel at the reception area (receptionists and cashiers) could affect the productivity of the center. Preliminary studies suggested that the bottleneck of the center was at the reception area where long queues could be observed and complaints from the patients were received.

Input data was obtained by studying 60,000 records from past exams plus observations taken over a period of two months. This allowed estimating the interarrival times

and fitting distributions for the processing times of the different family of exams. An example of the demand curve for the patients is given in Figure 7, which shows that this is not uniformly distributed throughout the day, with a very low demand throughout the night and a decreasing demand in the day hours.

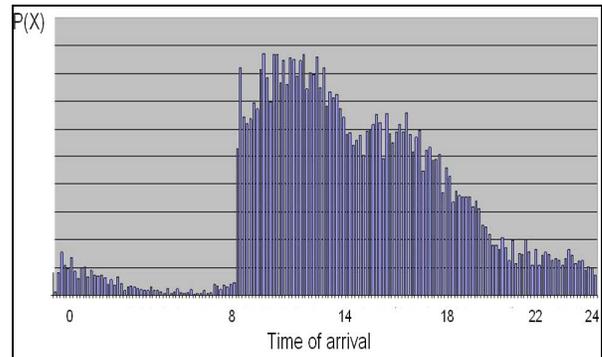


Figure 7: Demand curve

The interarrival time pattern of the spontaneous patients was represented by a generalized gamma distribution having a different parameter throughout the day and the same for every day of the week (see Figure 8), where the parameters were estimated using Experfit (Law 2006). The average hourly arrival rate is shown in the following table.

Figure 8: Arrival rate for spontaneous Patients

Seven different scenarios involving different assignments for the personnel at the reception area were designed (see Table 1), where the base situation was the current situation of 4 receptionists, 2 cashiers and no discrimination between patients with and without appointments. The performance index to compare the different scenarios was the total waiting time of the patient in queue, which includes the waiting times in front of the receptionist, the cashier and the exam rooms. The simulator was run over a month with ten replicates and the Bonferroni method (Law 2007) was used to compare multiple alternatives.

Table 1: Simulation scenarios

Scenario	Description
1	Current situation, 4 receptionists and 2 cashiers
2	4 receptionists and 2 cashiers, giving separate attention to patient with and without appointment
3	4 receptionists and 2 cashiers, giving separate attention to patient with and without appointment during peak hours, from 8:30 hrs. to 13:00 hrs.
4	6 receptionist/cashiers clerks
5	6 receptionist/cashiers clerks, giving separate attention to patient with and without appointment.
6	6 receptionist/cashiers clerks, giving separate attention to patient with and without appointment during peak hours, from 8:30 hrs. to 13:00 hrs.
7	3 receptionists and 3 cashiers

6 SIMULATION RESULTS

The results of the multiple runs allowed estimating that the average total waiting time for the current situation was 1857 seconds, with a minimum of 1012 and a maximum of 2481 seconds. The multiple comparisons for all the scenarios are shown in Table 2 (difference with respect to the base scenario). It can be seen that scenario number 6, where we have multi purpose receptionist/cashier clerks, giving separate attention to patient with and without appointment during peak hours (8:30 hrs. to 13:00 hrs.), is the best alternative (and the only one significantly better than the current situation). The total waiting time for this scenario is 1174 second, with a minimum of 743 and a maximum of 1458.

An additional experiment was conducted, where for the scenario number 6 it was assumed that there was a situation of infinite demand and studied how many patients could be passed through the system. The result was an increase of 54% with respect to the current situation, which tells that the current design of the system is limiting the maximum rate of utilization of the equipments of the center.

Table 2: Multiple scenarios comparison

Lower bound	Difference	Upper bound
-331.51	$\leq S_2 - S_1 \leq$	1081
-663.86	$\leq S_3 - S_1 \leq$	1025.35
-1010.72	$\leq S_4 - S_1 \leq$	701.56
-1285.02	$\leq S_5 - S_1 \leq$	295.84
-1169.25	$\leq S_6 - S_1 \leq$	-197.21
-1261.2	$\leq S_7 - S_1 \leq$	3878.41

7. CONCLUSION

The paper presented the use of a generic simulator developed to facilitate the development of simulation studies at Medical Imaging Centers (MIC). The conceptual model of the simulator was designed after careful observation of imaging centers at four different hospitals in Chile, each one of them having between 400 and 1000 beds capacity. It was possible to generalize the patient's flow at these centers, which included all possible flows, resources, schedules and exams. The generalized process was represented using the unified modeling language (UML) and the simulator implemented in Flexsim GP.

A major departure from traditional modeling of imaging centers are three characteristics built into the simulator: 1) the use of a pull paradigm, 2) the generation of any particular model is controlled through a GUI, and 3) the generated model is layout free. The use of a pull paradigm, which we claim is a more natural way to modeling health-care processes, where the scarce resources call the patients for service. The generation of any particular model using a GUI interface removes most of the complexity of model building, such that a person without an engineering background could build a model of his own. The simulator is layout free because the objects can be arranged in any configuration and the distances among the different areas can be specified in a virtual format.

Seven different scenarios were compared, and concluded that with the same personnel, but assigning common functions, a 35% decrease in the total waiting time could be achieved. Similarly, by assuming an infinite demand for the best scenario selected, the productivity of the center could be increased a 54% with respect to the current situation.

As a final discussion it can be said that the use of the simulator made the exercise of running a simulation extremely easy, removing the complexity of building the model, which is on the average takes about 50% of the total time required for a simulation study. The most significant part remains getting the right estimates of the parameters, but once this is done, a non simulation specialist could easily run new scenarios. The major draw back is precisely from using a simulator, that it does not provide face validity to the model, because it considers a generalized layout.

This last could be solved with a good validation of the model built.

As part of a research project among the three universities involved, the simulator is undergoing improvements to better reflect the flexibility of sharing personnel among different equipments and to consider cost under the activity based costing paradigm.

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