Simulation Model for Patient Workflow at Selected Emergency Rooms During Hajj

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Abstract **- Improving patients' workflow is a crucial role for emergency rooms (ER) worldwide. The complexity, dynamic, and unpredictable patient visits at ERs make them most challenging to manage. Reduction in crowding and waiting times enhance the patient satisfaction and reduces the cost of resources. More than 2.5 million people gather every year from around the world in Mecca and Al Madinah, Saudi Arabia, to practice their religion. Excessive overcrowding in ERs across the city during peak times puts massive pressure on healthcare management to bring more resources into service. This research was designed to investigate the use of simulation tools ("what if" scenarios) to improve patient workflow in a selected emergency department in the Mecca region during Hajj time. Altering scenarios significantly enhance patient workflow during peak times without increasing current resources using FlexSim HC. The simulation results show that the best scenario can optimize staffing and reduce the average stay by 42.3% in the ER system. Furthermore, the model can improve the ideal number of resources in the main processes and estimate the waiting time and ER capacity in the coming years of the Hajj event.**

Keywords – Simulation, Patient flow, Stay time, FlexSim, Emergency Room

I. INTRODUCTION

Emergency room (ER) overcrowding is one of the most significant problems in healthcare worldwide. This is due to its numerous negative effects on public health at international and local levels [1]. Authorities and healthcare management are challenged by unpredictable and quick patient arrival at the ER. Improving healthcare management by reducing ER overcrowding and waiting times enhances patient satisfaction and increases ER productivity [2]. The annual Hajj pilgrimage event attracts millions of Muslims who visit the Holy Capital Mecca in Saudi Arabia. This ritual is a significant celebration in the Islamic religion and attracts people from around the world who converge in Mecca [3]. More than 2.5 million people gather every year in Mecca and Al Madinah, Saudi Arabia, to practice the Hajj (see Figure 1) [4].

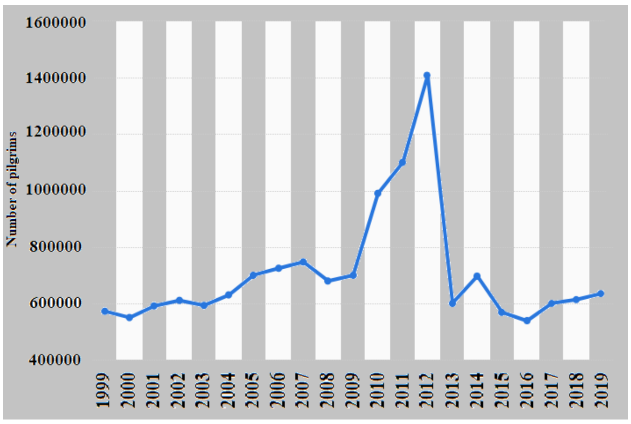

Figure 1. Number of pilgrims during the last 21 years [4].

Most pilgrims come with poor health conditions, and nearly 200,000 cannot afford medical needs (pre-Hajj health care) in their home countries, which increases their attendance at local ERs [5]. Moreover, accidents that occur during peak hours put pressure on authorities and ER management teams to improve the service efficiency.

In hospitals, management and decisions are based on a system that aims to offer good services, high-quality care, and resource efficiency. However, the process of designing and operating such systems for ERs can be highly complicated. This is primarily due to the high number of various resources involved in the actions of providing such care. In addition, the results from these activities happen at different periods, and resources may be required simultaneously [6]. As a result, overcrowding and long patient waiting periods become apparent problems experienced by ERs worldwide [1].

The emergency department is one of the most significant hospital departments because most critical situations come through in normal and non-normal conditions. These reasons are some of the motivating factors that enable using a discrete event simulation (DES) model to improve ER efficiency. Simulation is successfully used in different sectors with broad applications in the healthcare field [7].

DES defines a specific point in time which helps in evaluating the behavior of complex systems as an ordered sequence of well-defined events [2]. DES has improved significantly within the healthcare field over the last few years. The purpose of this paper is to apply DES to support ER decision-makers to demonstrate and discuss the scenario-based parametric uncertainty and risk analysis during the Hajj event. This approach provides information about the design alternatives, system bottlenecks, improved scenarios,

DOI 10.5013/IJSSST.a.22.04.08

ISSN: 1473-804x online, 1473-8031 print

and the recognition of optimal system configuration, which minimizes waiting periods, as well as the determination of design regulations to advance the system's performance.

II. RELATED WORK

Emergency departments (EDs) have been facing the phenomena of overcrowding since the late 1990s [8] and have become a national problem [9], which has numerous negative consequences, including the potential for increased mortality [10]. In recent years, various simulation models have been applied in a wide range of complex systems such as manufacturing [11] and diagnostic services [12], as well as in airport terminals to model passenger flow during peak times [13].

In the healthcare sector, cost and resource allocation per hospital continuously varies based on the length of patient stay. Therefore, long-term projections in healthcare help with bed modeling and the assessment of staffing needs over given periods, e.g., months and years. This data is crucial for administrative and clinical decision making. Various methods were explored in [14] to improve the workflow within the ED and understand the proper workload requirements of patients specified by acuity, diagnosis, and demographics, including discrete event simulation (DES).

A study conducted in Malaysia by [15] assessed the effect of patient increase at ED performance and patient flow based on a DES and system dynamics modeling approach. Another study at Saint Vincent Hospital in (Worcester, USA) [16] created a DES model of 17 scenarios to improve patient wait times and reduce length-of-stay. They split the flow process to manage ED processes by separating patient flow according to level of acuity and enabled parallel processing. Similarly, a study was conducted in a large hospital in Iran [17] to improve the performance in ED using DES, where the long wait times and unbalanced utilization create problems for patients and ED staff.

On the other hand, the authors in [18] advised modeling the patient workflow in healthcare institutions for tactical and strategic projection, such as compartmental, queuing, and simulation models were applied. Furthermore, bed occupancy [19], patient arrivals, and individual patient lengths of stay metrics were analyzed to understand the long-term patient flow [20]. Consequently, different, and more sophisticated methods have been used for patient workflow analysis and patient lengths of stay, including forecasting and regression methods [21].

Moreover, during 2019, a study conducted in the airport terminal to model the passengers flow used a DES in Jeddah. The study results showed that the model with the fourth scenario could be reduced the waiting time in the system up to 15% compared to the current system [13]. Earlier in 2016 study by [17] conducted a DES to determine practical scenarios with a lower reduction of patients' overall waiting time. The results showed the first scenario reduced the waiting time by 5% at an emergency department system. Afterward, in 2020, the authors in [22] established a simulation model in a governmental hospital in Kuwait for emergency service and designed an aid decision. The model improved patients' average stay time by 40% reduction.

Following another study in 2021 by [23] presented a simulation model of historical time-stamped clinic operations, the results showed overall, a 10% decrease was identified for redesigning the clinic in the average length of a clinic visit. Subsequently, in another study, FlexSim software was used to develop a simulation model to optimize raw material manufacturing line ordering batch size published in 2021. The idle time for various stations was analyzed, and a significant reduction made was 30% [24]. Recently, the study presented a simulation model and used Flexsim software for patient flow at an imaging center to reduce the patient waiting time in Chile. The model in this study reduces the total patient waiting time by 35% without adding any rescues such as staff [25].

The current study applied DES in the ED healthcare system to improve patient workflow by altering scenarios and resources allocation using FlexSim HC software. The significant reduction in the system's total average stays time resulted from the first scenario by 42.3% were compared to the previous results.

III. METHODOLOGY

Discrete Event Simulation modeling and what-if scenarios were adopted in this study to improve the emergency department's patient flow. The goal was to reduce patient overcrowding and visit wait time during peak hours without increasing resources. The model was built to reflect the system based on intelligent objects using 3D Simulation Modeling and Analysis Software (FlexSim version 2020). First, the current state of the system was simulated. Second, the logic of the patient workflow process in the system was described. Next, different scenarios in the model were subsequently defined, including different improvement scenarios. Finally, the OptQuest optimization engine was used to automatically create, test, and find a scenario that best meets a model goal.

A. Current DE System Description

The layout in Figure 1 illustrates the current (exits) system of the emergency department of the government hospital in the Mina region, Mecca, Saudi Arabia. It provides healthcare services to approximately 150,000 patients per year. The ED is open 24 hours a day, seven days a week, and receives an average of 13,892 visits during Hajj, including 2,106 pilgrims, while the number of outpatients has reached upward of 26,500—including 1,740 pilgrims.

Besides its internal capacity, the ED shares resources, and staff with other hospital departments, such as the pediatric ward, imaging units (e.g., x-ray and CT), and the laboratory. The ED is divided into four different areas according to patient classification: emergency care rooms, specialty rooms (intravenous, recovery), an observation area, and the triage area. Some of the emergency resources, including surgery, orthopedics, and medicine, are not shown in the layout because they are situated in other areas of the hospital.

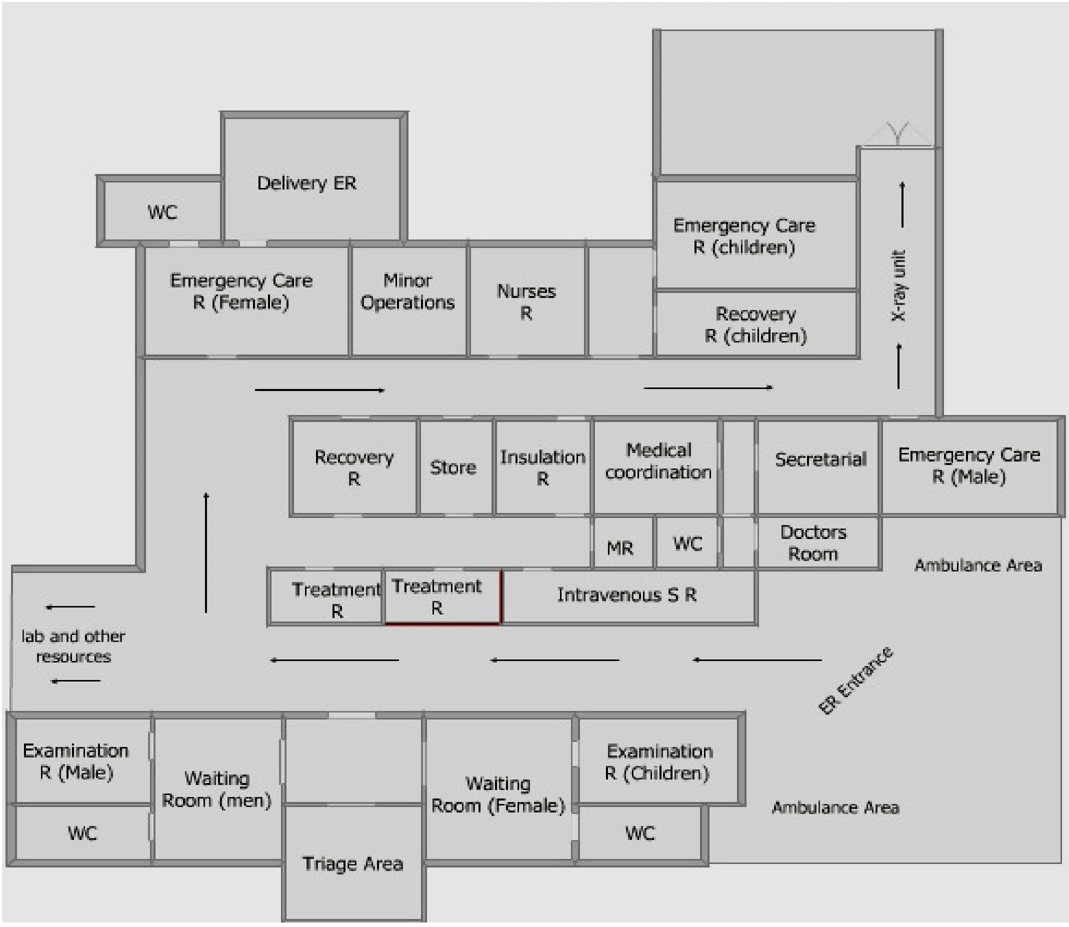

Figure 2. Layout of the emergency department.

The patient process flow begins when a patient enters the ED (see Figure 2). Patients arrive at the ED in two ways: via walk-in or ambulance. Ambulance patients usually have access to triage in the ambulance. Once they arrive at the ED, depending on the acuity level (1 to 5), and the type of care needed, they are redirected to an emergency care room (male or female) or specialty room.

The walk-in patients are directed to the waiting room until they are transferred to a triage room (except for high acuity patients who are assigned to an emergency room directly). The registered nurses conduct the first examination of the patient. Then, the necessary diagnostics are taken, the care priority is established, the required documentation is completed, and the routine for each patient is established before being seen by a physician. Next, the patient is registered and sent back to the waiting room or a designated specialty room (e.g., intravenous, recovery). The patient then waits for examination by a physician. After that, if the treatment has finished, the patient is sent home. Otherwise, if samples need to be taken for laboratory analysis or scans need to be carried out in the X-ray unit (e.g., orthopedic patients), the patient stays in the waiting room until the results are finished and evaluated by the physician. Laboratory results are often ready within one hour documentation is completed. The patient workflow logic process is modeled by the ProcessFlow tool in FlexSim HC and illustrated by several blocks and subprocesses in Figure 3.

B. Data Distribution

Data was collected from selected general hospitals' emergency departments (ED) in Mecca for their system layout resources, patient arrival distribution and stochastic element such as tasks process time at each area (triage and exam estimated time), between 18 and 23 July,2021. Thus, the primary simulated resources were patients, rooms, beds, MDs, triage nurses, imaging staff, and reception. The number of modeled resources per department and area are shown in Table I.

As shown in Figure 3, we used Source Patient Arrival to import data for one-day schedules from selected ED for patient arrival distribution. These data are in an excel spreadsheet table for repeated weekly arrivals. A date-based interface defines when (time) and how many tokens should be created (number of patient arrival).

TABLE I. THE ED RESOURCES DISTRIBUTION

Department/area	MDs	Staff	Rooms	Beds
Emergency care	1	7 nurses	4	12
Specialty rooms	2	4 nurses	6	7
Pediatrics	2	2 nurses	1	5
Surgery	2	2 nurses	1	1
X-rays and OR	2	4 technicians	2	2
Triage	-	2 receptionists	1	-
Total	9	21	12	27

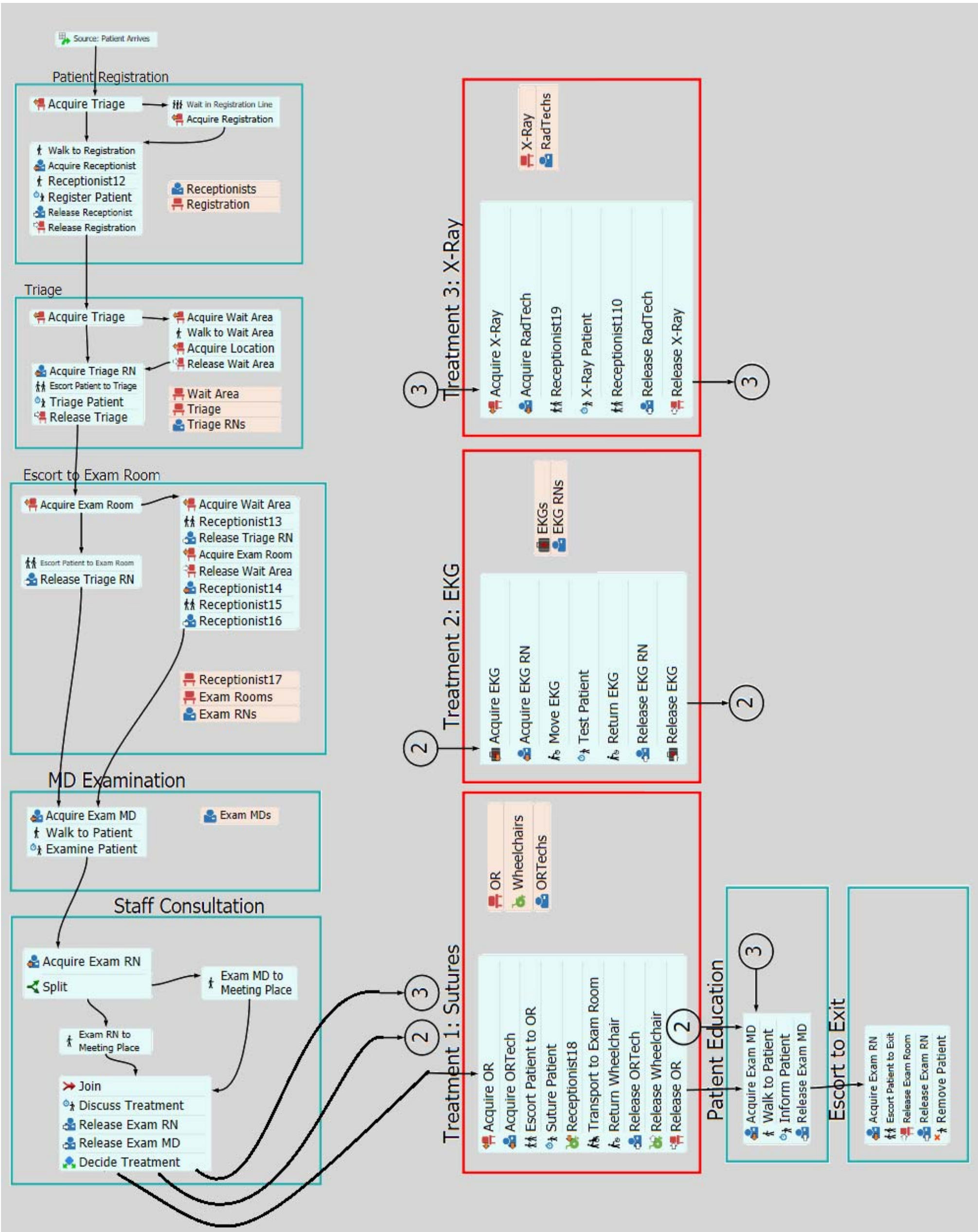

Figure 3. The logic of the simulation model in process flow.

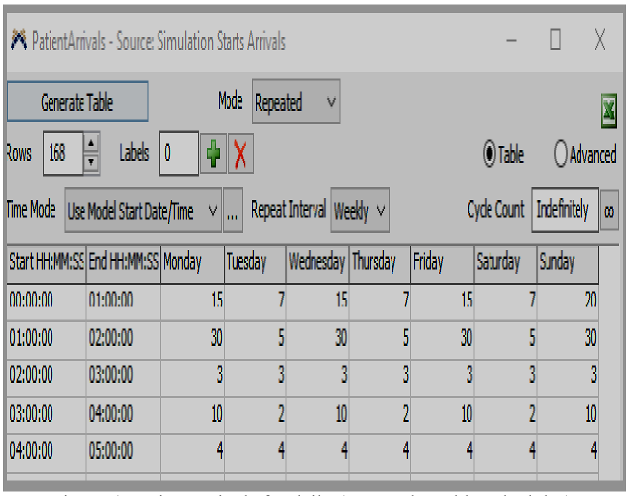

Figure 4. Patient arrivals for daily (repeated weekly schedules).

The spreadsheet table has 24 tokens (places) created (24 hours) and seven days of random arrival distributions of these tokens entered at the randomly spaced between the start and end time. The beginning and end of the time intervals were created by defaults HH:MM:SS as shown in Figure 4 above corresponding headers days of the week (e.g., the first arrival will be 08:00 or 00:08:00, if the model start time is Monday at 08:00 AM. Or the first arrival will be 00:00 or 01:00:00, if the model start time is Tuesday at midnight.).

Table II shows the stochastic element entered the model through the patient process flow track in FlexSim software. It is designed to adjust the theoretical distributions and the observed data by estimating time parameters for each task process.

TABLE II. STATISTICAL DISTRIBUTIONS USED IN MODEL

Tasks	Process time
Register patient	minutes (5.00)
Triage patient	minutes (10.00)
Examine patient	minutes (5.00)
Discuss treatment	minutes (5.00)
Suture patient (Treatment 1: OR)	minutes (10.00)
Test patient (Treatment 2: EKG)	minutes (5.00)
X-Ray patient	minutes (10.00)
Inform patient	minutes (5.00)

C. Simulation Model (What-if-scenarios)

Different "what-if" scenarios were defined in the model and ran for 15 replications with a warm-up time of three days to minimize the effects of any startup bias. The results were calculated during a run of 48 days to represent the Hajj period (pre-ritual period: 21 days; peak Hajj period: 6 days; post-ritual period: 21 days).

FlexSim HC Software was used to implement the details of DES. The ED resources and rooms distribution are described above and summarized in Table I. The patients, rooms, beds, MDs, receptionists, triage nurses, RNs (surgery, orthopedics, and children), staff, and imaging staff were used in the simulated model. Most of the scenarios described and selected match the EDs' needs and perceptions.

The ED management became involved in different analyses when the model scenarios were created. They agreed that the long waiting times were restricted to some of the examined parameters in the tested scenarios. Several variables (e.g., triage process time, number of MDs, and exams room) were used; the simulation model shows a noticeable improvement in the ED system by increasing its service level and efficiency. In addition, some variables with a length of stay and patient waiting time were significantly reduced, which resulted in an overall ED system time reduction.

Different numbers of scenarios and assumptions were created and implemented into the model. Also, to ensure the data still accurately reflected the system, assumptions were made when data were missing. Some of these assumptions are summarized in two parts. First were scenarios without significant impact on the results. Three scenarios included opening the X-ray department 24 hours a day, opening a second triage room when more than two patients were waiting for triage, and increasing the number of staff by 50% (triage nurses, technicians, and receptionists). Second, scenarios deemed to have a significant impact on the results included reducing 50% of the time needed for the X-ray and small operation (OR) processes, reducing the time required to walk patients to OR and X-ray rooms by 50%, and reducing 50% of the exits to the hospital for all MDs.

A powerful discrete event simulation tool was the design alternative (e.g., "what-if" scenarios) described previously. The goal of using "what-if" scenarios was to improve the ED system by finding different optimal configurations, as well as to achieve the primary purpose of this research: reduce the overall length of stay. In addition, this reduces risks that may result from patient's' length of stay or long waiting times in ED during peak times (e.g., Hajj event). Therefore, the ED service level and efficiency of patient workflow increased.

The service level and efficiency initially increased according to several system changes ("what if" studies), leading to an evident ED system improvement. Moreover, the patients' length of stay and total waiting times were significantly reduced.

To ensure the model behavior was an accurate representation of the current system, the model was validated by analyzing different parameters such as the length of stay (Removed), the time to triage (TTT), and the time to see MD (TSMD) for all patients in the ED system. Figure 5 shows results achieved by running the simulation model for 48 days with multiple replications. The histogram shows the starting time of each milestone activity in the model and the parameters analyzed (average waiting time versus patient milestones). The green column is the average time of waiting from the patient arriving to be triaged, the orange column is the average time from arrival to be seen by a physician

DOI 10.5013/IJSSST.a.22.04.08

ISSN: 1473-804x online, 1473-8031 print

(MD), and the blue column represents the average time for a patient unit arrival to leave the DE system.

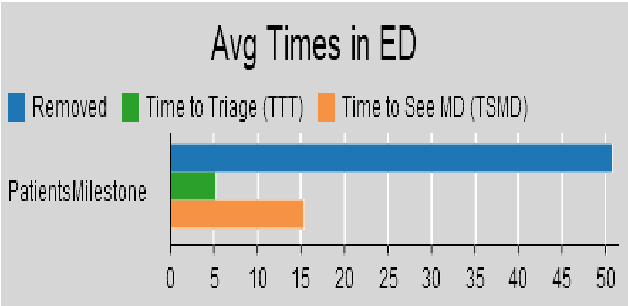

Figure 5. Patient average time (minutes) milestone in ED the system.

IV. RESULTS

The ED model was built and validated successfully for the current-state model, and different “what-if" scenarios were applied to find the best use of ED configurations. The experimenter tool from FlexSim HC Software was used to run the same simulation model for multiple scenarios. Each time the simulation ran with each scenario, we changed variables to see the best possible solution.

The plot result for different scenarios with the total average stay time in the system is shown in Figure 6. Five scenarios are present in the figure including the existing scenario, where this scenario presents the current state model. The other “what-if” scenarios (scenarios 1, 2, 3, and 4) resulted.

First Scenario: Time needed for X-ray imaging was reduced by 50%. Orthopedic patients are required to wait for X-ray results for 30 to 90 minutes, on average, depending on whether it is a morning or afternoon/night shift. In this scenario, the time was reduced by 50% to analyze the impact on the total length of stay results. Also, the time required for minor operations was reduced by 50%, including the time needed to transfer patients to the OR room. The conclusion drawn from this experiment is that the reduction has a significant impact (approximately 42.3% reduction on LOS values) on the results, with a significant decrease in the total average stay time in the system, as shown in Figure 6.

Second Scenario: The possibility of opening a second triage room when more than ten patients were in the waiting room was analyzed. In the existing system, the first triage room is open 24 hours a day, while the second triage room is open only as needed. The conclusions revealed that the impact was insignificant in the average time in the system with (approximately -2.77% reduction on LOS values).

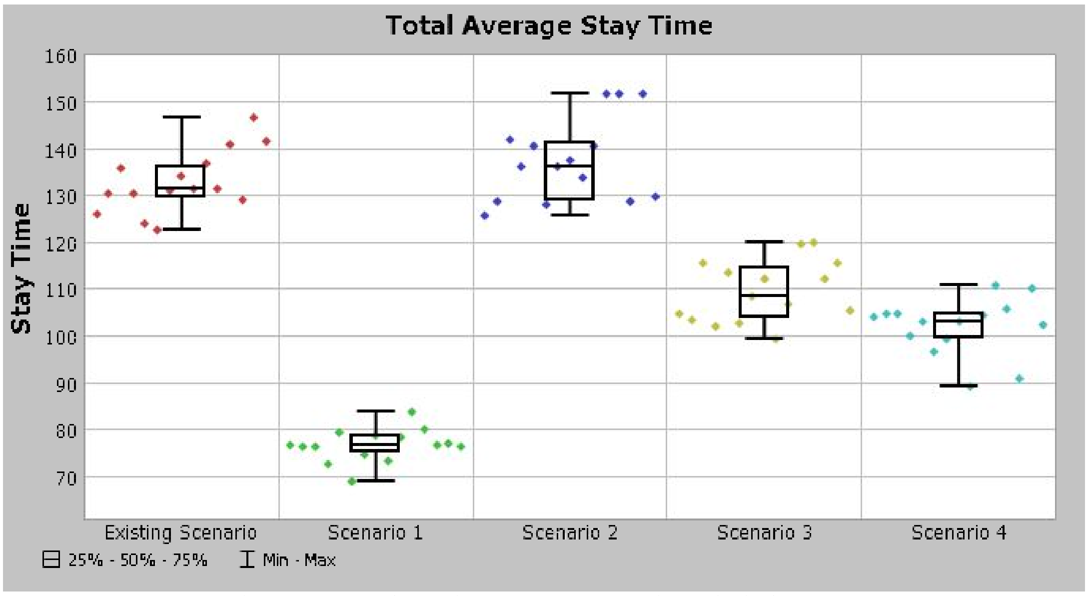

Figure 6. Compared scenarios versus average stay time (min) in the system.

Third Scenario: Time needed to walk patients to the OR and X-ray rooms was reduced by 50%. Some rooms are far from the waiting area. In the existing system, these rooms are situated in other areas of the hospital. In the simulation model, the distances were analyzed to test the impact on the total average length of stay. The conclusion drawn from this experiment was that the reduction has a minor effect (approximately 18.01% reduction on LOS values) on the total average stay time in the system.

Fourth Scenario: MDs' exits from the ED reduced by 50%. Resident MDs spend approximately 20% to 30% of their time outside the ED treating patients in the main sections of the hospital. This scenario removed half of these exits to demonstrate the impact on the results. This scenario reduced the total average time in the system by (approximately 23.57% on LOS) compared to the existing system.

Also, we found the best scenario using an optimizer. The optimizer, OptQuest, is a tool that changes parameters, runs scenarios automatically, and searches for optimal solutions built with sets of effective algorithms including metaheuristics optimizations and evolutionary algorithms. OptQuest allows to search for optimal solutions with multi-objectives.

For example, if we want to minimize both the number of MDs and the stay time, it chooses the lowest number of MDs that could be used to reduce the stay time.

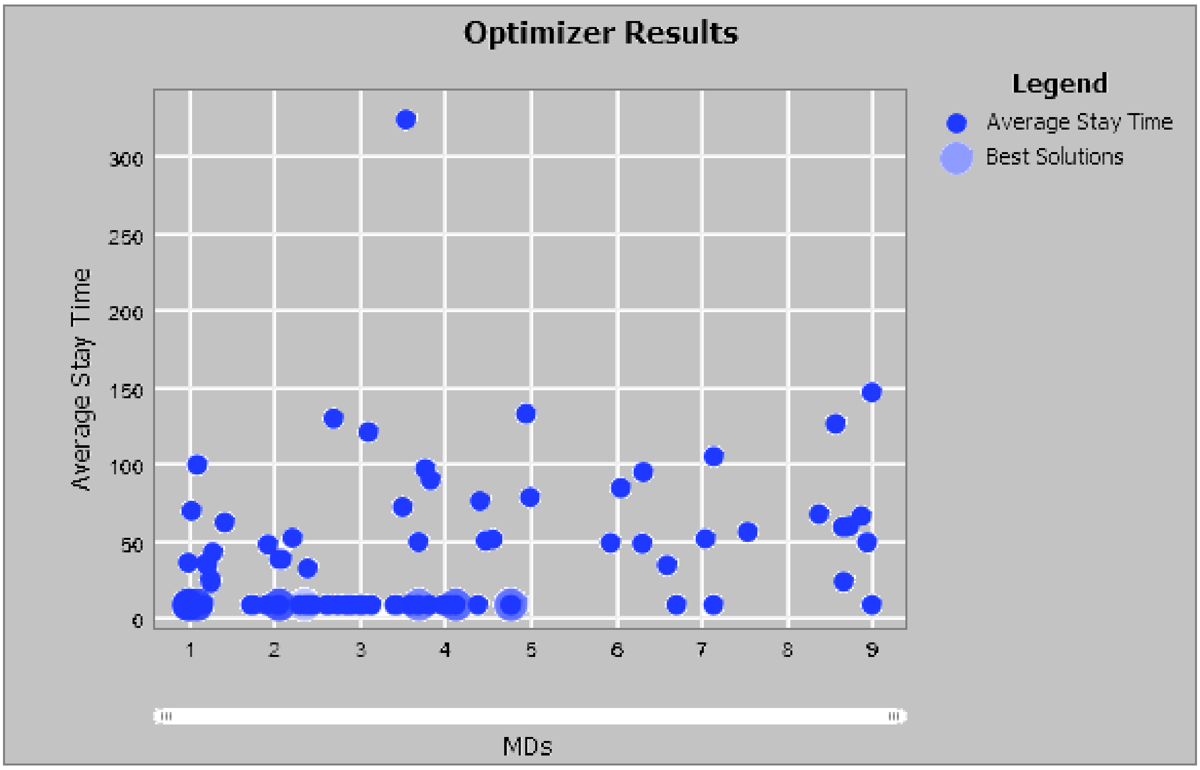

Figure 7. Optimizer results for MDs configurations.

Figure 7 is based on the results and suggests that 2-5 MDs are an optimal solution that is reflected in the significant impact on stay time. Also, we can change from what if scenario to what is the best scenario; here, keeping only 50% of MDs at ED can reduce the stay time but we can choose the exact number of MDs at ED that is best for stay time. Moreover, different objectives can be defined as performance measures which can be used to score the model. This includes the number of RNs versus stay time; we can select RNs to find the best combination of parameter values in any area of ED system.

V. CONCLUSION

Discrete event simulation (DES) is used to improve EDs as well as healthcare systems at large. Moreover, it shows that there is a need to simultaneously improve several variables to achieve a significant system improvement and explanations of the “what-if” scenarios, including their significance and limitations. Therefore, this study is insightful in system performance, and peculiarities provide adequate knowledge to guide the work of managers toward finding improvements. Accordingly, this process has proven to be timesaving as well as cost-efficient for the ED. In addition, it is a foundation for reducing patients' wait times and overall length of stay and will assist in lowering waiting-time risks. The “what-if” scenario proposed reduced 50% of the time needed for X-ray and OR processes, which significantly reduced LOS by 42.3% compared to the existing ED system. Also, the applied scenario reduced 50% of the exits from all hospital MDs. This scenario reduced the total average time in the system by 23.57% on LOS compared to the current ED system. The optimization of this study has led to the discovery of several possible combinations for improvement. The testing of further optimizations with different configurations and working methodologies of the ED are being performed to establish the required results. More details, such as the patient’s arrival, could be studied in future work, and different EDs can be compared to the current results. The experiment in this study provides a strong foundation for further research. It makes optimized decisions based on 3D simulation analysis to support digital transformation in healthcare and many ways of industry 4.0 areas. For example, in the production process environment, the software could be connected between the current state of the system and future possibilities of improvement by reporting back to the real-world scenario.

ACKNOWLEDGMENT

The authors would like to acknowledge the management teams at the selected EDs who were involved in this project.

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