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Abstract. Recently, the emergency departments of hospitals are experiencing an exponential growth of their activities. As a consequence, we list the impact of their loads on the length of the waiting time (for patients) and on the optimal use of resources for the treatment of vital emergencies.

This requires a reflection on the management of patient flow (or journey) in arriving to-the emergency services. Given the heterogeneity of emergency levels and the diversity of expectations of patients, it is necessary to analyze the dynamics governing the flow of patients. In this perspective, we are interested in this paper in the modeling and simulation of the flow of patients in the emergency department (ED) at Al-Zahraa Hospital University Medical Center in Beirut (Lebanon). Our goal is, in fact, to identify the factors that have significant impact on the length of stay spent by the patients in the ED. In order to improve the quality of the patient supervision, our target is to minimize the total length of stay and waiting times, we use two scenarios for the resources scheduling in the ED: the first one was used before March 2018, and the second is the actual schedule.

In our methodology, we build a simulation model based on the collected data, then the simulation model is validated by the head of Emergency Department and by the experts. Therefore, we propose many scenarios applied in simulations instances realized using Rockwell ARENA simulator to evaluate the impact of these proposals to give the ED supervisors many recommendations that improve the issues identified during the modeling phase.

Keywords: Simulation, Modeling, Patient Flow, Key Performance Indicators, Emergency Department, Resource Scheduling.

1 Introduction

The hospital system is among the preferred domains of research for many medical organizations and researchers who want to introduce new management strategies for hospital managers to minimize costs while maintaining optimal quality of care (Marcon et al., 2008).

Today, hospitals, laboratories and health centers try to offer patients the best service and in the best time. The performance of the hospital service requires a good level of optimization, a high quality, a reasonable costs and a low service time. In these perspectives, the challenges are growing up significantly specifically in hospital emergency departments, due to the increased number of patients (Hsia et al., 2015), the appearance of new kind of pathologies, and the absence of a deep study of ED needs. The main problems that reside in such a system are summarized by the lack of resources (human and material), the long waiting times of patients and the highest rate of patients who leave the emergency department without having been seen by a practitioner. These problems affect the quality of care provided (Derni et al., 2019).

A survey (Elder et al., 2015) is based on many databases that were searched for articles published between 1980 and 2014 using the key search terms ED flow/throughput, ED congestion, crowding, overcrowding, models of care, physician-assisted triage, medical assessment units, nurse practitioner, did not wait (DNW) and ED length of stay (LOS). As result, this study shows that advanced practice nursing roles, physician-assisted triage and medical assessment units are models of care that can positively impact ED throughput. They have been shown to decrease ED LOS and DNW rates. Confounding factors, such as site specific staffing requirements, patient acuity and rest-of-hospital processes, can also impact on patient throughput through the ED.

Furthermore, the time management has an important role to define the quality of treatment and the satisfaction of patients (Saghafian and al. 2015). With the intention to decrease the patient's total length of stay at the ED and to enhance the care quality, many techniques have been used like the associations of workflow interruptions with ED professionals' work stress (Weigl et al., 2017).

The Emergency Department at Al-Zahraa Hospital University Medical Center (ZHUMC) is a 24-hour emergency care facility with approximately 22,500 patient visits annually (~62 patients per day). It provides the community with vital health care for the acutely ill and injured. The main function of the emergency department at ZHUMC, or ED, is to treat patients who are suffering from an acute serious illness or injury that would lead to severe complications if not treated quickly. It is not designed to provide ongoing care. Patients requiring urgent attention will always be checked first. The Emergency department contains a total of 19 beds for patient care divided into:

- Triage room: first assessment (Emergency Severity Index (ESI) triage system (Ward, 2006)).
- Intensive care unit: responsible of rapid assessment of urgent and life threatening patients.
- Pediatric unit and a room for critical (neonate and pediatric)
- Surgery unit: assessment of surgical patients
- Transfer unit: admission of seriously unstable patients who are not candidate for transfer to another hospital in case of non-available places at ZHUMC.

For many diseases and injuries, the initial phase of care is very critical. It is in the stage where accurate diagnoses are made and appropriate treatments are initiated to obtain rapid recovery and prevent complications. Patients are cared for, not necessarily in order of their arrival, but according to the severity of their illnesses, and the impact of potential complications if not immediately treated. According to the ESI system (Emergency Severity Index) (Ward, 2006), the patients are divided into 5 categories: 1-critical, 2- emergent, 3- urgent, 4- less urgent, 5- non-urgent. The most cases treated are between: Urinary system (Flank pain, Hematuria, Urinary retention), Immune system (Fever), Endocrine system (Diabetes, hypothyroidism, hyperthyroidism), Respiratory System (Dyspnea, Cough, Epistaxis), Cardiology (Hypertension, Electric shock), Neurology (Vertigo, Headache, Level of Consciousness, Gastroenterology (Vomiting, Diarrhea, Abdomen pain), Skin (Skin rash, Cellulitis, Dehydration) and Surgical cases.

In this paper, our main objective is resumed in the minimization of the Length of Stay (LOS) of patients inside the ED with better performance. In addition, we try to propose new scenarios for ED staff scheduling in order to

reduce the duration of the different operations in the process of admission of a patient. To realize this main objective, we tried to use a Workflow approach to model the system applied in the case study at the ED of ZHUMC.

Discrete event simulation (DES) is a method of simulating the behavior and performance of a real-life process, facility or system. DES models the system as a series of 'events' (e.g. a birth, a stay in an intensive care unit (ICU), a transfer or a discharge) that occur over time. In our case, we use DES in the measurement of the impact of many proposed optimization scenarios on the performance. Our simulation models are constructed using the Rockwell Arena simulator V15, which is a DES software for process automation and simulation. It has been effectively used in many recent kinds of research ((Lim et al., 2013), (Derni et al., 2019), (Zeinali et al., 2015)).

2 Modeling of ED: Related works

In recent years, the pressure on the Emergency Departments (EDs), as the main point of entry into hospitals, increased due to remarkable growth in demand, low productivity, and the limited budget and resources which mostly led to overcrowding and long queues in EDs (Trzeciak et al., 2003). To identify bottle-necks that contribute to over-crowding, Unified Modelling Language (UML) models were used for the modeling of patient journey in a regional Australian emergency department (ED) to develop an accurate, complete representation of ED processes and drive the collection of comprehensive quantitative and qualitative service delivery and patient treatment data as an evidence base for hospital service planning (Martin et al., 2011).

Many research studies about the staff scheduling in hospital were conducted. A case-study based on the Emergency Department at the University of Virginia Medical Center in Charlottesville (Virginia) with computer simulation to test alternative ED attending physician staffing schedules and to analyze the corresponding impacts on patient throughput and resource utilization (Rossetti et al., 1999). The complexity of operating room scheduling is discussed by (Ajmi, 2014) with a proposed model that interest lies on the fact that it identifies the weaknesses in the hospital and derives ways of improvement. To optimize the flow in the hospital, a tool is used to serve as a decision-making support to the block, since it allows real-time assessment of operations, besides. The requirement of sufficient resources for critical push researchers to study the resource planning that is a most important scenario which needs to be considered while treating the patients in ED of hospitals by providing sufficient resources (Mangai et al., 2016)): they used a simulation-based metamodels optimal resource allocation to obtain a minimum waiting time. Human error is a significant and ever-growing problem in the healthcare sector (Yazdanparast et al., 2018). In this paper, the resource allocation problem is considered along with human errors to optimize utilization of resources in an emergency department: they used an algorithm composed of simulation, artificial neural network (ANN), design of experiment (DOE) and fuzzy data envelopment analysis (FDEA); it is a multi-response optimization approach to optimize human error, cost, wait time, and patient safety, and productivity. With the using of the queueing network analyzer (QNA) algorithm and discrete event simulation (Alenany et al., 2017), and based on the analysis of the waiting times, two approaches are suggested for improving performance: Separating patients into service groups, and adopting different service policies for sequencing patients through hospital units (Patient flows mostly match real flow for a hospital in Egypt).

To optimize the paths in the Pediatric Emergency called the "Pediatric Emergency Path", a study was made in the Pediatric ED of the Regional University Hospital Center (CHRU) of Lille (France) (Ajmi et al., 2018). The goal was: improve the quality of the patient handling while mastering the wait time, produce an analysis allowing to identify the dysfunctions of the PED and also to propose and to estimate prevention indicators of tensions. Another case-study was done in Ibn Rochd Hospital (Morocco) by (Saadi et al., 2006) who proposed a simulation model of patient flow at the emergency department of Ibn Rochd Hospital in Casablanca to define indicators to evaluate performance.

Since EDs are complex systems, they are difficult to model thorough analytical methods, consequently computer simulation is widely used for the modeling of these systems like (Augusto et al., 2019) who treated the problem with taking into account new challenges related to the optimization of the patient care pathway in the emergency unit in the context of major crises, and proposed a flexible tool that can be used by health-care practitioners as a decision aid in various situations under the shape of a digital twin of the emergency unit. Another study was done by (Gul et al., 2015) who developed a DES model to investigate and analyze an ED under normal conditions and an ED in a disaster scenario which takes into consideration an increased influx of disaster victims-patients. In (Lim and al., 2013), an alternative approach was presented where physicians and their delegates in the ED are modeled as interacting pseudo-agents in a discrete event simulation (DES) to compare it with the traditional approach ignoring such interactions. Another research study was done by (Zehrouni et al., 2017) who presented a simulation model that evaluates health care emergency plan and assesses the resilience of the Ile-de-France region in case of a major flood, they combined in the model the health care process with a Markov chain flood model. In Canada, (Duguay et al., 2007) used a discrete event simulation study of an emergency department at Dr. Georges-L. Dumont Hospital in Moncton. Their main objective was to reduce patient waiting times and to improve overall service delivery and system throughput: as patient waiting times are linked to resource availability; a number of alternatives were designed based on adding resource scenarios. (Miller et al., 2006) discussed how Radio Frequency Identification (RFID) technologies were used on a recent consulting engagement at a hospital to capture simulation data in the ED: data collected through RFID can validate or replace activity duration estimates from traditional sources.

With the appearance of new kind of pathologies, and the absence of a deep study of ED needs, specifically in Lebanon motivate us to make this study to face the growing of the ED importance in the hospital which provides health care to patients, and which faces several problems, highlighted by the limitation of resources (human and materials).

The remainder of the paper is organized as follows: in Section 3, we provide a description of our methodology, data collection, basic elements of the simulation model, and the problem issues. Experimental results and comparing those with new scenarios are given in Section 4. Finally, Section 5 contains conclusions and perspectives (some suggestions for future work).

3 Methodology

As explained before, our methodology is based on three main phases. First, we start by collecting the necessary data given by the HIS (Hospital Information System) concerning the ED patients. Then we use the data as input parameters to build the simulation model, which is the second phase. Finally, we run many scenarios of simulation to improve the performance and discuss the results obtained. The gains obtained via our approach consist, in fact, a proposal for the ED supervisors to improve the solutions. In addition, we have measured the impact and the improvement achieved with each of these solutions.

3.1 Description of Al-Zahraa Hospital University Medical Center emergency department

The area of study, the ED at Al-Zahraa Hospital University Medical Center (ZHUMC is an Educational Establishment) is situated in Jnah- Beirut, Lebanon. This department Is receiving more than 22,500 patients per year (~62 patients per day as average) based on the collected data for three years, from January 2016 to September 2019 (Figure 1 presents the Plot of the estimated arrival rate of patients during this period).

It has a capacity of 19 beds, and it receives critical and non-critical cases. The emergency department includes a waiting room, which is used for the triage process by a triage nurse. Patients are classified into five categories based on their states (critical, emergent, urgent, less urgent, non-urgent.) according to the ESI system (Ward, 2006). Critical level is the most dangerous, patients needing immediate treatment and they have the highest priority in the emergency department, whereas level 5 is the least urgent and often represents clinical type patients.

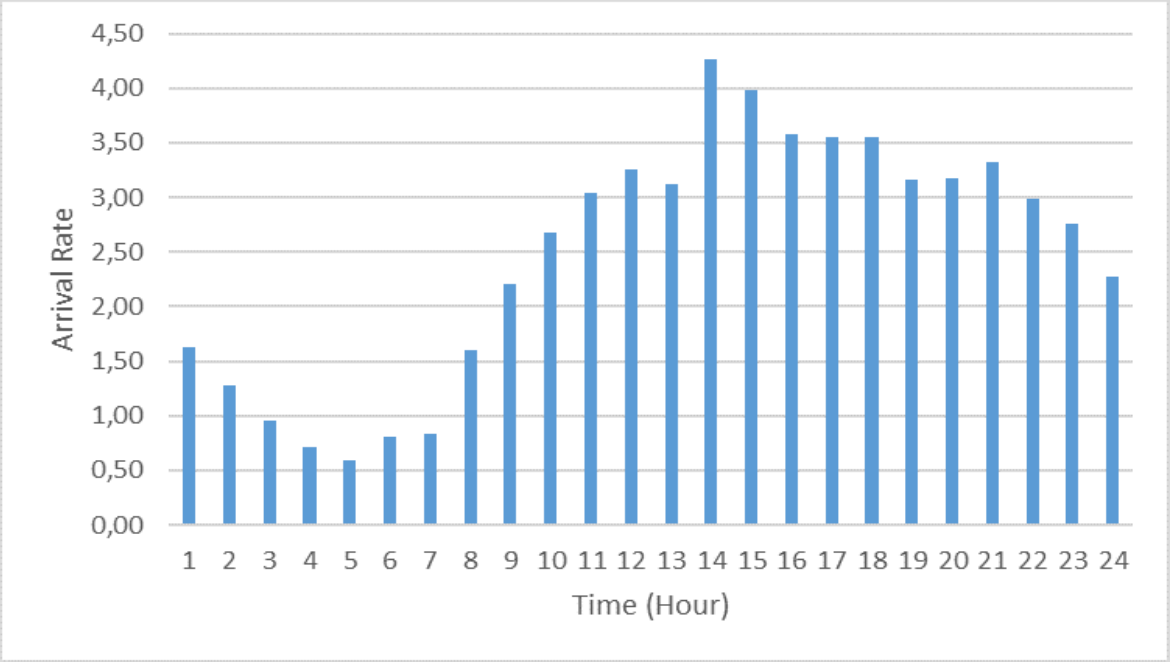

Figure 1: Plot of the estimated arrival rate of patients.

Emergent, urgent, less-urgent and non-urgent patients (Acuity levels 2-3-4-5) can have waiting time to be served. The average time to be served depends on the level: emergent (5-15 min); urgent (10-30 min); less urgent (30-60 min) and non-urgent (120 min). We consider these times as recommendations and we don't take them into consideration in our simulation model. For the patients who leave the ED without been seen (LWBS), we don't collect the necessary statistics and we will treat this issue in another research study.

3.2 Workflow model for patient admission at ED

The flowchart of the workflow of the patient admission process at the ED of ZHUMC is represented by Figure 2. It shows the possible patient trajectories inside the emergency department. Workflow provides a basis for the discrete event simulation model. The model is based on the existent patient flow of the studied system. Patient arrival is either walking or by the ambulance, then patients are classified on arrival by a triage nurse. The triage nurse has an initial evaluation of the patient state, based on their signs and symptoms. Next, according to ESI, she classifies the patient in one of the 5 severity levels. A patient in level 1 has a critical state and should be treated immediately while a patient in level 2-5 is, in fact, is a non-critical case. After this step, we figure two typical patient trajectories, patients with severity level 1 take a first aid. Then, all patients pass by an analysis phase (laboratory tests and/or radiology) if necessary. After analysis phase, the patients who need treatment, take complementary treatment and are discharged to home, another department, or are transferred to another hospital (in case of no-place is free in the hospital).

The occurrence at which these different paths occur in the model is decided probabilistically, based on historical data of the three years (2016-2019) retrieved from the emergency department records given by the Hospital Information System (HIS).

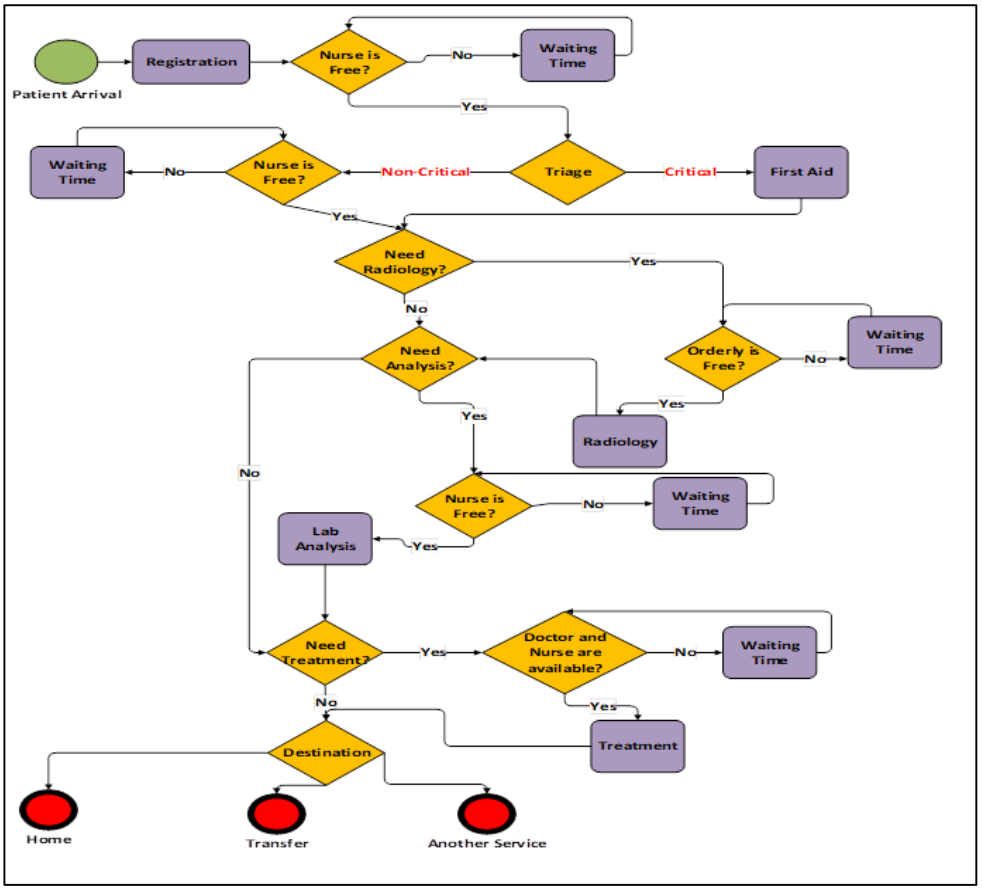

Figure 2: The workflow of the patient admission process at the ED of ZHUMC.

3.3 Data collection phase

Because having enough information about the current state of the ED is crucial for the validation of simulation model, the data collection is one of the essential phases before moving on to any advanced step. It is one of the important phases due to the absence of complete data in the extracted statistics from HIS (the needed data might not be sufficiently accurate and mostly not be available in detail). Therefore, we have based on ED archives of the three years (2016-2019), and we discover that the date out of patients is not accurate especially before 2018 and we use the collected data after 2018 to validate our model.

3.4 Resource schedule

In fact, the ED supervisors changed the schedule of resources (doctors, nurses) on march 2018. With the inaccuracy of data before 2018, we used collected data and compared the results given by the simulation model for two months (January-February 2018 and January-February 2019). So, we have two scenarios for the described below:

Scenario 1 (before March 2018): Two shifts:

- 07:00 am to 04:00 pm: two Doctors (General Physicians) + four Registered Nurse + two Orderly + two Receptionists.
- 04:00 pm to 07:00 am: two Doctors (Residents) + four Registered Nurse+ two Orderly + two Receptionists.

Scenario 2 (after March 2018): Two shifts:

- 08:00 am to 04:00 pm: three Doctors (two Emergency specialists + one Resident) + seven Registered Nurse + two Orderly + two Receptionists.
- 04:00 pm to 08:am (+1 day): four Doctors (one Emergency specialist + three Residents) + seven Registered Nurse + two Orderly + two Receptionists.

For the radiology technicians, they have two shifts: 7:00am-7:00pm (4 technicians), 7:00pm-7:00am (two technicians).

3.5 Simulation model

When studying such a system, the length of stay of the patients (treatment time, diagnostic time, waiting time) is considered to be a key for the performance and the quality of the state of the system. We can observe that the total time spent by the patient in ED has an average of 126 minutes (scenario 1, January-February 2018) and 98 minutes (scenario 2, January-February 2019).

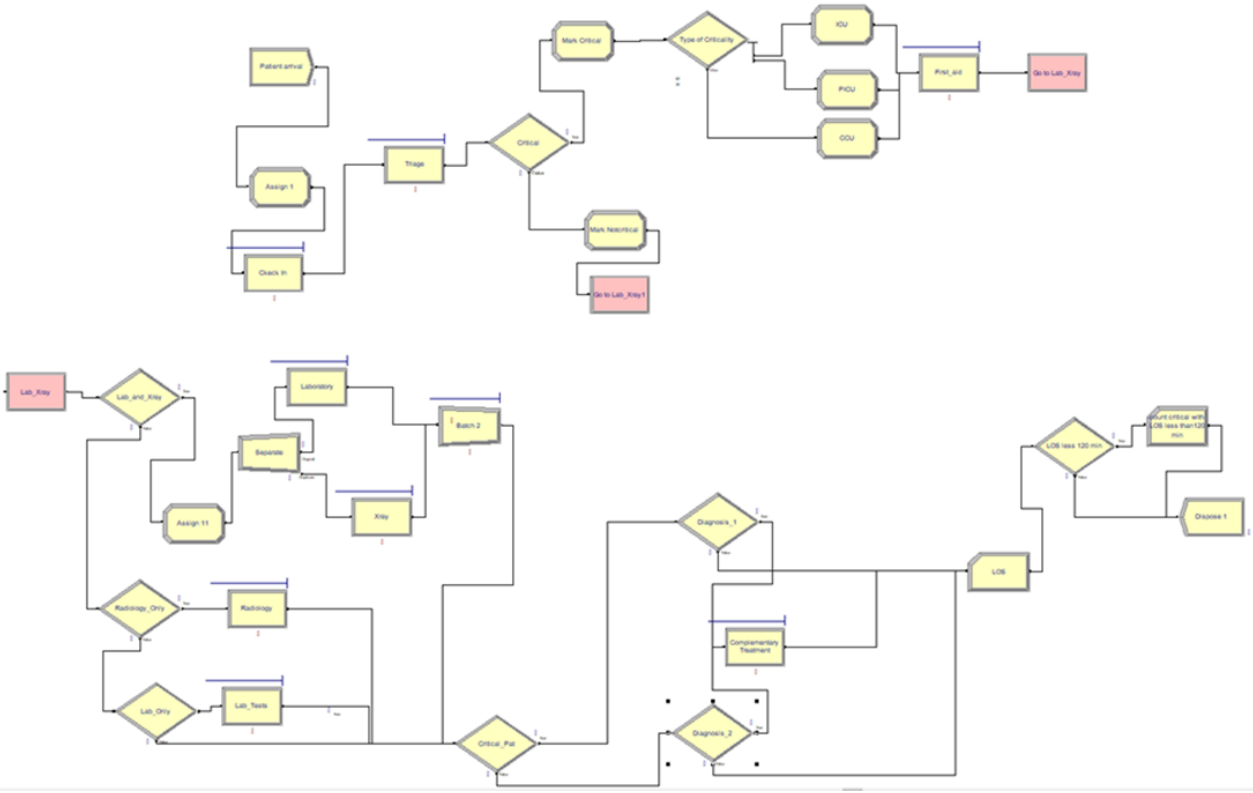

Figure 3: Simulation model of the case study of ZHUMC under the Rockwell Arena simulator V15

We run the simulation model for 365 days, 5 days warm-up period, and 10 replicated times. The warm-up period is set for the simulation run to eliminate any bias at the early stages of the process. The realized model was validated by domain experts and by the ED supervisors. By applying many simulation instances, we compare the results with the real data based on the LOS (length of stay) as a key performance indicator. First, we finished the

collection of data (reasonable estimates for the service times as seen by the physicians), then we built our model using statistical distributions in order to use them as input parameters for the simulation model (see Table 1).

The simulation model was constructed (using the Rockwell Arena simulator V15) based on a good understanding of the ED processes. Figure 3 shows the design of the simulation model that encompasses six processes (registration, triage, first aid, laboratory tests, radiology diagnosis, complementary treatment). Each process needs a fixed number of resources. The flow of patients from one process to another is defined using decision components which are implemented respecting to the probabilistic model extracted from the collected data. The arrival of the patient is simulated using an entity that follows an exponential distribution, which is effective for modeling the arrival process in such a case. Table 2 shows the comparison between the real data and simulation results of the system.

Table 1: Simulation parameters

Parameters	Distribution functions of random variables(minutes)	Description
Patient arrival rate	Exponential(24)	Exponential distribution is used with time between two patient's arrivals has a mean of 24 minutes.
Registration time	Uniform(3,10)	The registration time from the arrival until the entrance to the waiting room.
Triage time	Triangular(5, 10, 15)	Duration of triage operation: 5, 10, 15 minutes.
First Aid for PICU cases	Uniform(10,45)	The time of First Aid for critical patients: case Pediatric.
First Aid for ICU cases	Uniform(20,60)	The time of First Aid for critical patients: case Intensive care.
First Aid for CCU cases	Uniform(30,90)	The time of First Aid for critical patients: case Cardiac care.
Complementary tests durations: laboratory	Triangular(15, 45, 90)	Duration of complementary tests: lab tests.
Complementary tests durations: radiology	Triangular(15, 45, 90)	Duration of complementary tests including X-ray radiology, scanner…
Complementary Treatment	Uniform(10,60)	the average time for complementary treatment has uniform distribution between 10 and 60 minutes.

After analysis of our model, we consider that the longer length of stay of patients at the treatment phases is caused by the lack of nurse, and the insufficient number of orderlies required for the radiological diagnosis. So, we tried new scenarios by adding these types of resources.

Table 2: Comparison between the real data and simulation results of the system

ED key performance indicator	ED collected data: Scenario 1 (January-February 2018)	Simulation data	ED collected data: Scenario 2 (January-February 2019)	Simulation data
Average patient total length of stay (minutes)	130	126.67	100	98.43

4 Results analysis

To reduce the longer length of stay of patients at ED, we identified some factors that affect this issue. So, we evaluated two improvements adjustment proposed as following:

- Adding a nurse.
- Adding a nurse with an orderly.

The impact of the proposed adjustments for the two scenarios compared to the current state of the system are shown in Table 3. We improve the average of patient's length of stay (LOS): from 98 minutes to 93 minutes by adding a nurse and from 98 to 92 minutes by adding a nurse and an orderly. The half width shows that the 95% confidence intervals are: [97.89- 98.97] for benchmark scenario (current scenario), [92.99- 93.59] for scenario A (adding a nurse), and [91.66- 92.64] for scenario B (adding a nurse and an orderly). This study will be extended soon to ensure more efficient solutions.

Table 3: Simulation results of the proposed solutions

ED key performance indicators	Benchmark scenario (current system)	Scenario A (adding a nurse)	Scenario B (adding a nurse, an orderly)
Average patient LOS (minutes)	98.43	93.29	92.15
Half width (minutes)	0.54	0.3	0.49

5 Conclusion and perspectives

In this study, we propose a solution to improve the performance of ED at ZHUMC (Lebanon). First, we collected the required data from HIS (Hospital Information System). Then, we built our model to simulate the patient flows in the ED using the Rockwell Arena simulator V15. After validation of our simulation model, we tested many scenarios to improve the performance of the system. Finally, we conclude that adding a nurse and an orderly is an efficient recommendation for ED supervisors to improve their system.

We extend this study by taking into account another key performance indicator like LWBS (Left Without Been Seen). In addition, as perspective, the statistics about pathology will be done in the new model. Finally, the mathematical formulation of the ED with reservation of beds will be included in our study with the use of optimization and simulation methods to improve the solutions.

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