

Architectural Design Development for Emergency Departments to Improve Operational Efficiency (Case Study of Agouza Hospital - Egypt)

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ABSTRACT: The process of developing emergency departments to improve operational efficiency is a complex process that requires a deep understanding of the behavior of the system in a very dynamic and unpredictable environment. It's very challenging to keep up with the continuous variabilities and objectives in such environments and so. Decision-making becomes very difficult. Therefore, researchers aim at developing novel multi-disciplinary approach to facilitate the decision-making process, necessary for developing architectural design for emergency departments that combines aspects and principles of Operational Research, Information Technology and Industrial Engineering to achieve high operational efficiency.

Architectural designer adopts this interdisciplinary approach to help with making decisions to optimize space requirements when redesigning emergency departments. It has already been applied, in two scenarios, to emergency department in one of the public hospitals in Egypt to increase its operational efficiency. The first scenario involved architectural redesign and resources reallocation within the existing structure (i.e., no structure extension) to increase resources of the emergency department. As a result, it achieved a reduction in the average patient waiting time with 10% and 27% for extremely critical and low-critical cases respectively, compared to the performance indicators for the traditional/actual operation. The second scenario involved building an extension to the existing structure to increase resources in the emergency department. It achieved a reduction in the average patient waiting time with 24% and 45% for extremely critical and low-critical cases respectively, compared to the performance indicators of the traditional/actual operation.

KEYWORDS: Emergency departments, Operational efficiency, Lean Manufacturing, Six Sigma

I. INTRODUCTION

The demand for emergency services in hospitals is increasing over years, not only in Egypt, but worldwide. This is due to several reasons, including but not limited to, aging of the population and epidemics (e.g., Covid 19). In addition to economic crisis in countries, where the emergency department represents the first line of defense that takes care of injured and critically ill patients. In many countries, ER is the only available healthcare option for uninsured patients.

Due tremendous pressure on emergency care facilities, it may become the bottleneck in patient flow. There is a set of indicators to identify bottlenecks and issues in patient flow, at which the most important one is waiting time of patients in the hospital.

The Arab Republic of Egypt has a large infrastructure of public hospitals with emergency departments that can operate effectively, if they are designed and developed appropriately to meet the needs and requirements of patients. Therefore, this research seeks to find a novel approach that helps the decision makers in the development process. This is crucial



as it involves complex operations and treatment protocols for patients of in broad spectrum of situations, at which many of these cases are critical and so delaying treatment may lead to death.

Our approach is multi-disciplinary that adopts methodologies and aspects from four scientific domains, which are operations research, information technology and industrial engineering and architecture.

II. EMERGENCY DEPARTMENT OPERATIONS

The emergency department is a medical treatment facility specializing in emergency medicine and acute care for patients who attend without an appointment; either on their own, by relatives or by ambulance. Patients arrive in an irregular and stochastic pattern, and the department must provide initial treatment for a wide range of diseases and injuries, some of which may be life-threatening and require immediate attention as they are suffering from unstable conditions, and therefore they must be treated quickly.

Once patients reach emergency departments in public hospitals, the patient is received and directed to one of the two main flows for health care patient flow operations within the emergency department, and these two flows are as follows:

- Patient Flow Process (Flow 1)

The logical/expected sequence of activities within the emergency department for patients arriving on foot:

Patient Arrival on foot, patient registration, waiting room, triage, initial examination, medical tests, special consultation then physical decision.

- Patient Flow Process (Flow 2)

The logical/expected sequence of activities within the emergency department for patients arriving in ambulance:

- Expedite transfer from a stretcher to the emergency department / recovery room.
- Medical Tests
- Specialist Consultation
- Physician Decision

Table (1): Clinical areas in emergency departments

areas	events and spaces
Triage Room	Patient has initial examination by an experienced nurse based on the patients' vital signs such as respiratory rate, blood oxygen saturation, heart rate, blood pressure, consciousness level, and body temperature. By the beginning of the year 1990, many countries, led by Canada and Australia introduced a triage of five levels, the Canadian Triage and Acuity Scale (CTAS) and the Australian Triage Scale (ATS) respectively ^[1] .
Exam Room	Where doctor/physician will examine the patient, focus on body parts that suffer from problems, and determine the appropriate diagnostic and subsequent procedures. Its area shouldn't be less than 8 m ² .
Resuscitation Room	It is a designated area for the immediate care of patients, in case of issues with cardiac arrest, airways, breathing and blood circulation. The "resuscitation" area consists of two or more resuscitation.
Observation Room	It is an area of the hospital located within or adjacent to the emergency department, where patients can receive additional treatments, and clinical observation for up to 24 hours, so that they are safely dispatched to the home and avoid the need for inpatient admission ^[2] .
Treatment Room	Where physical examination of the patient is carried out in addition to therapeutic procedures such as washing, dressing and stitching wounds, reducing and casting fractures, dislocations and other minor surgeries. Its area shouldn't be less than 12 m ² .
Storage	This includes sterile and non-sterile supplies, stationary supplies, storage of hazardous materials, a medical gas storage area, linen storage, wheelchair and trolley storage, clinical and non-clinical waste disposal. Minimum floor area for storage: the minimum acceptable floor area for storage is 2.2m ² /1000 patient attendances per annum.



The therapeutic events / activities in health care operations take place within specific rooms. These rooms and activities are presented in Table 1, as shown below:

III. DISCRETE EVENT SIMULATION (DES)

It is a process for building models to simulate the behavior and performance of complex systems. It represents the system as a sequence of events through time. Each event occurs at an instant of time and changes state(s) of the system. There is no change in the states of the system between consecutive events.

This process is considered the most suitable for modeling different health care systems compared to other mathematical modeling tools such as linear programming and Markov chain analysis [3]. Therefore, many researchers adopt it to develop health care systems such as outpatient clinics and emergency rooms (ER) for two main reasons, which are:

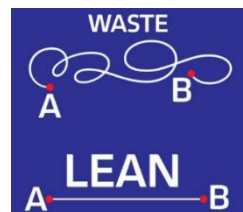
- It leverages digital computer programs, which are characterized by the high-speed calculation and storage capabilities. Therefore, it can be used to analyze, design and model large and complex systems.
- Experimentation with wide range of inputs (e.g., doctors, nurses, and spaces), patient flow rules and policies to create different scenarios to find the best solution(s) that achieve the desired indicators of operational efficiency.

This research uses Arena Simulation Software for simulating patient flow in emergency department. This program has the capabilities and provides advanced tools to enable modelling complex systems. It allows users to set the inputs and rules/conditions, and control their environment by representing them using several types of variables. It is easy to use as it is not based on programming, but rather on GUI that provides modules. These modules represent different functionalities and processes that are used to build the system based on user's selections. We are working on Arena, edition 16, which has been released in 2020. It uses SIMAN processor and simulation language [4].

IV. LEAN MANUFACTURING

It is a production management approach for a waste-free manufacturing. It adopts a process of continuous improvement by eliminating waste, inconsistencies, and unreasonable requirements in materials, time and labor.

The level of efficiency is measured by the ratio between the current productivity level and the best practice productivity level (3). For example, if the best productivity observed for machines is 90 units per hour, but machine A produces 80 units per hour, then the efficiency of machine A is 0.88 (i.e., 80/90). This efficiency definition has been introduced by Massachusetts Institute of Technology to describe the methodology adopted in car manufacturing by Toyota in Japan. Toyota introduced, Just-in-Time (JIT) philosophy that dictates "*what is needed, when it is needed, and in the amount needed*". It produces new cars to the market twice as fast as American competitors [5], and its main idea is to reduce time by eliminating unnecessary operations with no added value in the process [6].



The goal is to control and manage the inventory at every stage of production optimally, in order to prevent the accumulation of resources/materials across production lines. There should be system monitoring to ensure material circulation to prevent to any shortage on materials. This will improve the production efficiency of the systems that deal with manufacturing of physical products such as vehicle and electrical appliances industries [7].

V. SIX SIGMA PRINCIPLES

The Six Sigma is a statistical and data-driven approach that eliminates the ambiguity (e.g., decreases process variation) from the start of the design process for production. It improves the system performance within any service or manufacturing institution to make the product or service defects-free [8].

Robert Galvin innovated the six sigma when he was working in Motorola that obtained the Malcolm National Quality Award accordingly. Six Sigma was adopted by General Electric Company in 2000. It has been broadly used in many service and industrial institutions, as it has been approved by the American Association American Society for Quality [9].

The Six Sigma consists of five steps, known as (DMAIC: Define, Measure, Analyze, Improve and Control) ^[10], as shown below:

- Define: In this step, the characteristics, the stages and the timeline of the project/system are defined. It doesn't have to be for the whole system, it could be a section or even a small unit within the system. Also, it defines the problems facing the operational process, and sets the goal of the development process, the results and the expected benefits from process improvement.
- Measure: In this step, the process is fully and accurately understood through the data. The measurement phase is the most laborious phase, especially when the data is not available in digital forms, so the data for each activity needs to be collected. Researcher may have to construct and compose data from scratch. In some cases, a representative data samples need to be collected randomly and divide it according to the type of users (i.e., stratified sampling). They also determine the process metrics to compare between performance before and after improvements.
- Analyze: In this step, the data is analyzed using a set of tools and techniques to identify the root causes of problems. This can be achieved through building a model of the processes and using simulation of the model to identify the problems. It is crucial to ensure that the model is valid and is a good representative to the system. Such validation is done by comparing the model outputs with the measurement indicators data collected in the measurement step.
- Improve: In this step, brainstorming is necessary to come up with potential solutions to achieve high operational efficiency of the system. Simulation is done for each of the potential solutions and results are analyzed based on operational efficiency, economic benefits and cost. Best solutions are selected and applied.
- Control: In this step, we take into consideration all the recommendation coming from the "Improve" step while redesigning the process. Control plan takes place to ensure that the gain/improvements will continue for the longest period of time. It keeps tracking of all the changes that happen during the process redesign and measure the efficiency throughout the whole process.

VI. QUEUE THEORY

A Queue is a combination of elements of the same type, whereby the elements are added from one end called the back of the queue and removed from the other end, which is called the front of the queue.

Queue models are used to describe the waiting lines in real life (e.g., waiting line to receive any service). There are several queue models with different representations that are discussed in the following sub-sections ^[11].

VI.I Single server single stage queue:

This model is the simplest model that represents just one server and one queue with just a single stage. Units arrive consecutively to the service center and form one queue. The server provides service to units based on "first come first serve" order. A good example on this model is a private doctor's clinic.

VI.II Multiple Server Single Stage Queue:

This model represents a system that has multiple service centers with the customers forming a single queue to get served. The customer goes to one of the available service centers to receive the service. A good example on this model is the bank.

VI.III Single Server Multiple Stage Queue:

This model represents a system that has a single service center that provides a multi-stage (i.e., composite) service to customers waiting in a line/queue across using successive stages. A good example is a car wash center that sprays soaps and detergents for washing, then applies high-pressure water for rinsing, and finally there is a forced-air blower for drying as car exits. It serves a single queue of customers/cars.

VI.IV Multiple Server Multiple Stage Queue:

This model represents a system that has multiple service centers with multiple stages each. Customers form a single queue at which each customer is dispatched to one of service centers. Each center has multiple stages as shown in figure (1). A good example is Department of Motor Vehicle (DMV) where you issue vehicle licenses.

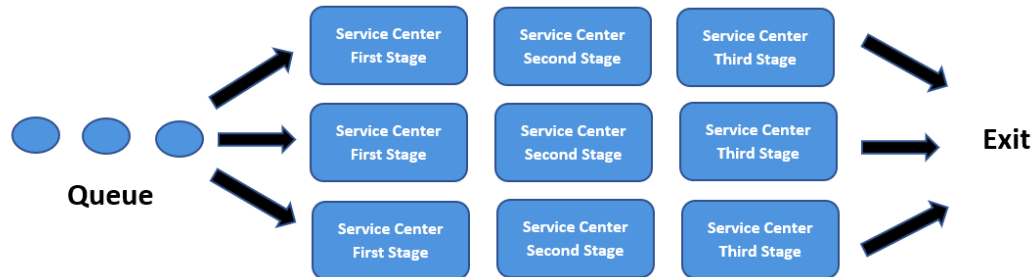


Fig.1. Multiple Server Multiple Stage Queue

VII. ELECTRONIC HEALTH RECORD

Nowadays, Information Systems in hospitals has a plethora of data that represent information about health care process inside hospital's facilities. Such data is very helpful for planning new hospitals or redesigning an existing section inside the hospital to overcome the existing problems, increase the efficiency of health care process and reduce overall operating cost.

Electronic medical records contain patient's medical history, diagnoses, medications, treatment, immunization, allergies if any, radiology images, and lab/test results. It is classified and stored in files that follow medical protocols. It is used to make decisions regarding patients at Emergency and other departments^[12]. In this research, we are interested in information that identifies the time of health care activities received and its location during the patients' treatment journey, such as Real-time Locating Systems (RTLS) technology^[13].

The patient flow process can be defined as a sequence of activities, such as examining and triaging patients or preparing patient for surgery, such that each activity consists of a set of specific steps as in assessing the patient's health status. Each step consists of a set of tasks such as taking patients' vitals (i.e., reading temperature, blood pressure, pulse and breathing, blood sample for lab, etc.) [1].

VIII. APPROACH

We propose a hybrid approach that comprises of eight steps that are discussed in this section. It combines multidisciplinary principles from four scientific domains, which are operations research, information technology, industrial engineering and architectural design.

Step 1. Define the existing problems of the health care system and objectives of the planned development/improvement process along with its indicators. This approach aims at improving the mechanism of the emergency department to reflect on a better utilization of its resources and capacity. Indicators shall be identified to measure the operational efficiency. It will be compared against the desired efficiency of the emergency department, by health care professionals. These indicators will work as a standard and a reference to the upper boundaries of waiting time of the patients in ER based on the recommendations of the Anglo-American system, which are:

- The Center for Medicare and Medicaid Services, and the Joint Commission recommend that critically ill patients shouldn't stay more than four hours from the arrival and until the admission to the nursing units. Also, non-critical patients' stay-time should not exceed two hours from arrival and until discharge and go home^[14].
- The United Kingdom's National Health Service (NHS) recommends the four hour rule, which was applied for the first time in the United Kingdom, followed by several countries such as Canada and Australia. It stipulates that the overall stay-time does not exceed four hours for about 95% of patients in the emergency department^[15].

Step 2. Collecting patient tracking data from electronic health records captured from the patient tracking systems (i.e., RTLS) during his/her medical journey in the emergency department. In case, such data is not available in the emergency department database, Patient Tracking Records (PTR) will be created and stored. These records include the

time and the location of the patient starting from the moment of arrival to the ER and through his/her treatment journey.

Step 3. Analyzing and processing data to prepare it in a form that can be used in simulation. Arena program is adopted for simulating the system. Data analysis involves deletion of unnecessary data that has no added value. Also, It reads/retrieves patient tracking records (PTR) that include start/completion time and location of the various health care activities that took place within the emergency department. These data is represented in Excel sheet(s) in the form of the mean and the median values.

Step 4. Building an actual model for the system's process. The model represents the different paths that the patient follows (i.e., patient flow) to perform all the necessary/needed activities with all the corresponding time and locations.

Step 5. Conducting the simulation and validating the model. In this step, the model should be verified that it is an accurate representation to the real system via simulation. This can be done through simulating model behaviors thoroughly and compare simulation output against the actual output. Predefined standard functional/performance indicators are used as a reference to identify problems that face the current health care system and improvements.

Step 6. Applying improvements and building newly proposed/enhanced model. Our approach is an interdisciplinary at which strategies from industrial engineering domain are considered to enhance our model. However, we are building a model for emergency department and its services, so two strategies are found to be very crucial for our system, which are:

- Queuing theory for model and apply changes in patient flow pathways
- Engineering Lean Manufacturing to remove any unnecessary activities with no added value to the patient during the healthcare process/journey.

Step 7. Building Decision for the different scenarios and the corresponding percentages for operational efficiency improvements. Conducts simulation as many times as necessary to analyze the impact of improvements based on the standard indicators. "What If" method is applied to create a set of scenarios and determine the percentage of the achieved improvements of each scenario to choose the most appropriate scenario/solution.



Step 8. Architectural design (layout redesign). It adopts the chosen scenario and meets the requirements of development decision(s). The design should follow the local code, international standards and the design factors that may change according to the annual occupancy of the emergency department (i.e., total number of visits) and the services provided.

IX. APPLIED STUDY

There has been an applied study on the emergency department of Agouza Hospital, which is one of the public hospitals. Its emergency department was recently developed, but it did not achieve the targeted impact on operational efficiency.

IX.I Introduction to Agouza Hospital

It was originally named as the hospital of the Islamic Charitable Society. It was established in 1939 and then redeveloped in 2015. It is a public hospital, and one of the most important and oldest public hospitals in the Arab Republic of Egypt. Here is more information on the hospital.

- Location: Nile Street - Agouza District - Giza Governorate.
- Capacity: 350 beds - and it consists of 8 blocks on an area of 35000 square meters ^[16].
- Area and population density: It serves the population of the central Giza area (i.e., Agouza, Mohandessin, and Dokki neighborhoods) with a population of 300,000 thousand people [2].
- Type of Hospital Planning: It is considered/classified as Pavilion hospital. It is considered one of the most important and oldest hospitals in the Arab Republic of Egypt. King Fouad allocated 16 acres and 17 carats (i.e., 70,175 square meters) for the hospital in the Agouza district in 1927.

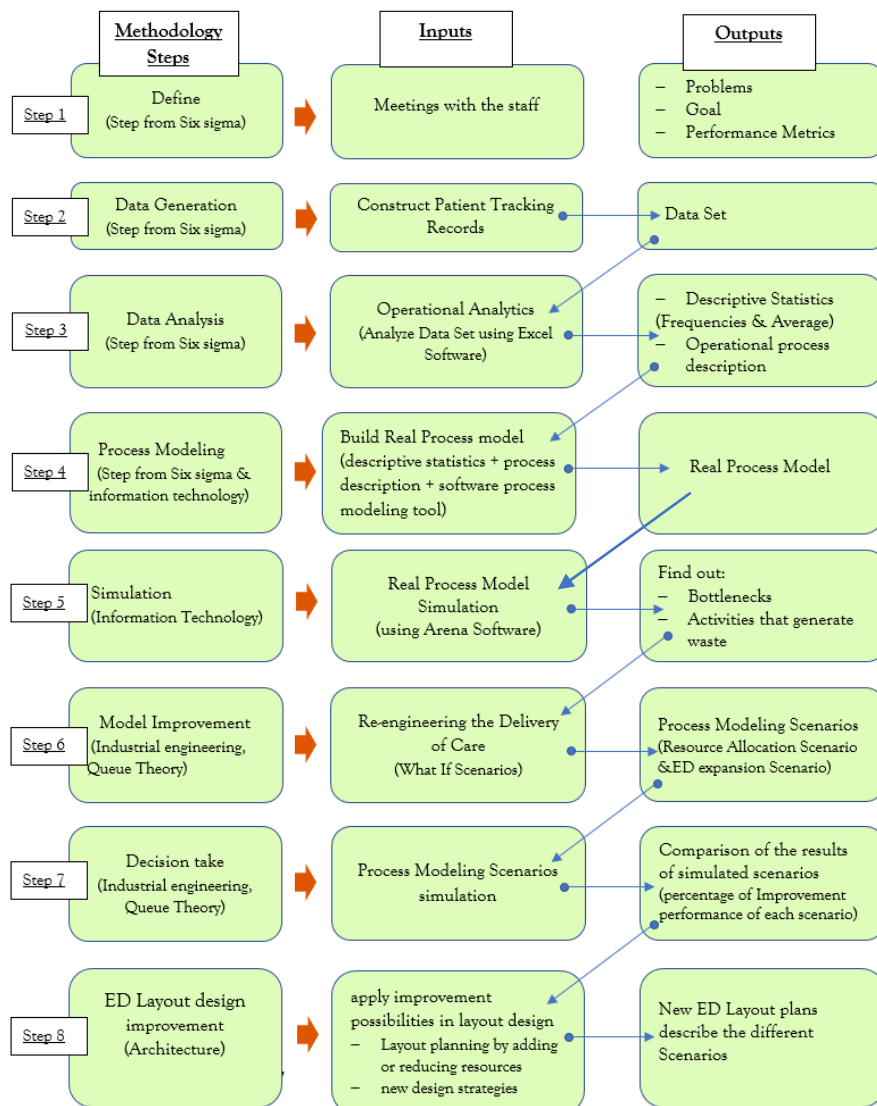


Fig.2. an illustrative and summary form of the methodology steps and what it contains of the scientific principles and theories

IX.II Emergency department(ED) in Agouza Hospital

The department is located within a building block associated/connected to the hospital building through main corridor. To reach to the ED, you have to use the hospital entrance, as it does not have a separate entrance from the outside fence of the hospital. It has an area of 1240 square meters and a capacity of 14 beds^[17]. It provides emergency medical service for about 40,000 patients annually. Therefore, it is classified as a mid-size ED (i.e., Annual cases/visits range is between 20K and 50K).

The health care system in the department works on bringing the patient to the department by ambulance or a nurse brings the patient directly to one of the examination rooms, if arriving on foot. A doctor conducts the necessary tests and X-rays in the department. However, there is no laboratory or CT scans performed inside the department. Doctors of the department are of different specialties. A consultant doctor is called to perform additional examinations and take a decision, either to dismiss the patient or admit him/her to stay in the nursing units.

The architectural formation/configuration of ED is undefined. It contains two intersecting corridors. The first corridor contains the examination ward and the recovery room and the second corridor contains treatment rooms distributed separately from each other, as shown in fig(3).

IX.III Application of the proposed approach and its evaluation

Step 1. Define the existing problems of the health care system and objectives of the planned development/improvement process. Field interviews were conducted with health care workers and caregivers in the emergency department. Based on the collected answers, we conclude the following.

The health care system is divided into two classes according to the protocol of the emergency department of Agouza Hospital, as shown in the figure (2) and they are as follows:

- Non-critical cases: the patient arrives, his data is recorded, then he goes to the examination and triage room, then to the examination room to be checked by the nurse, and then checked by the doctor. The patient has to remain inside the examination room until all the tests and examinations are done. After that the patient is to be transferred to the consultant's room to decide on whether to get admitted to the hospital, to stay in the emergency department for observation, or to go home.
- Critical cases: the patient arrives and to be taken directly to the intensive care unit (ICU) and stays there until his condition stabilizes. Then to be transferred to one of the examination rooms for observation and further examinations. Doctor is to decide on whether to perform a surgery, to admit the patient to the hospital, or to send the patient home.

The existing problems of the emergency department based on the complaints received from the patients and the health care workers are:

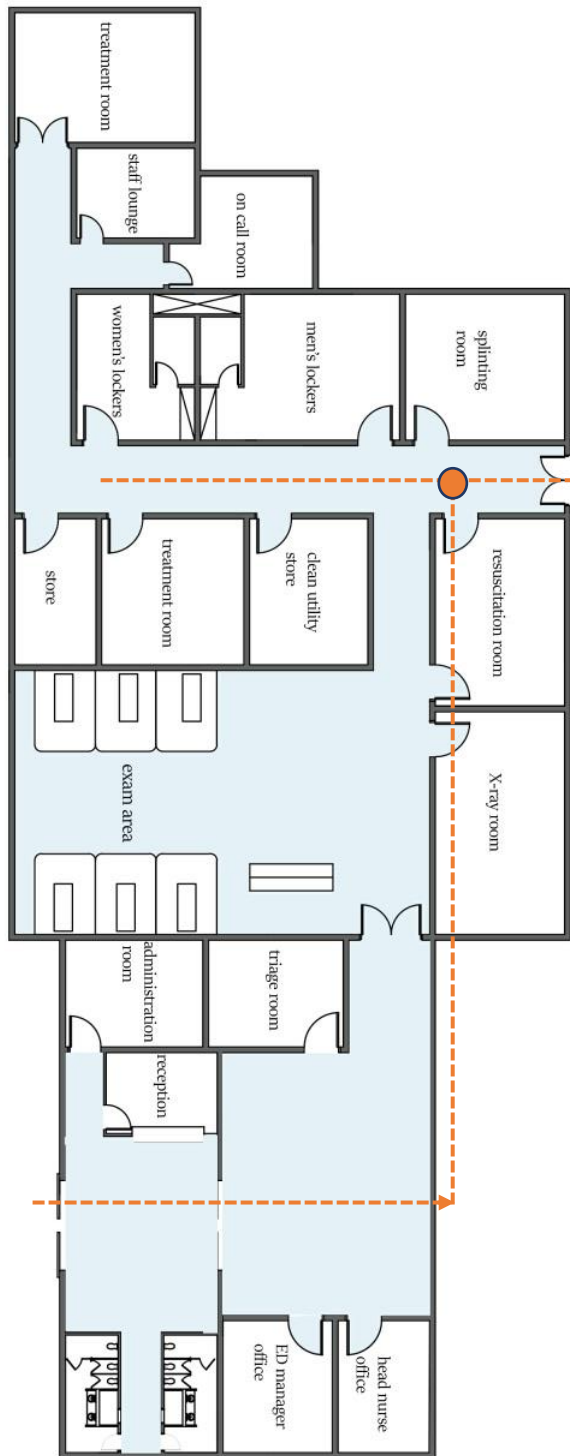
Overcrowding in the emergency department and the long waiting time of the patients inside the department. Therefore, workers suffer from mental and physical exhaustion. They feel drained, unable to cope, and tired. This adversely impact the performance.

The objective of health care providers according to the development process is to reduce the burden on workers, and to reduce the overcrowding and waiting times for patients. The “four hour” English rule is adopted as the standard indicators of efficiency (i.e., performance measures) in this research. By taking a look at the horizontal projection of the emergency department of Agouza Hospital, we’ve noticed the following.

- There are no observation or temporary care rooms. Patients who need care and observation are transferred to the nursing units of the hospital. Also, there is no isolation room, a room for psychiatric patients, or a room for children. Moreover, there is no waiting area for the companions.
- Examination wards are not equipped to treat patients. There is a single room to provide health care and treatment, and a single operation room.
- The emergency department represents about 5% of the total area of the hospital. The clinical bed is designed to accommodate about 3500 visits annually. This is considered as a large service provider that causes congestion within the emergency department.
- There is no central nursing station, but rather small stations distributed across the examination wards and the data entry/registration room.
- Areas/Rooms are not distributed based on the degree of criticality of the patient or function(s)/Services provided. Instead, they are spread throughout the departments rather than grouping areas/rooms that provide the same services.
- The resources used within the emergency department. The total number of employees is 24 (i.e., 9 emergency doctors, 15 nurses). And the number of employees per hour at any day of the week is 8 (i.e., 3 doctors, 5 nurses) , On the other hand, there is an average of five patients arriving per hour. So the ratio of doctors to patients is 1:2 per hour, and the ratio of nurses to patients is 1: 1. These numbers and ratios are consistent with international rates to achieve the high quality of health care services, while maintaining effective utilization of the resources.

Fig. (3): Architectural design for the emergency department before development process

Step 2. Collecting Electronic Healthc



The emergency department of Agouza Hospital, like other departments of public Hospitals in Egypt, suffers from a lack and inefficiency of data. Architectural designers need such data for the development and improvement process of the emergency department. To overcome the lack of data, the researcher took the following actions.

- Stay in the emergency department for 6 days, 24 hours a day, and record the data needed for the simulation process.
- Designing tables to record data (i.e., Arrival date, time, Illness and patient condition) of health care operations in an accurate manner to ensure the accuracy of the simulation program outputs, as shown in table (2)



table (2) : Arrival date, time, Illness and patient condition

EL Agoza hospital				
patient	Category	location	Activity	timestamp
p1	Orange (Shortness of breath)	ED Entrance	Registration	8:00:00
p1		Triage room	Triage	8:03:00
p1		exam room	Initial Examination	8:10:00
p1		exam room	cardiologist consultant	9:25:00
p1		exam room	emergency medicine	10:12:00
p1		exam room	observation	10:22:00
p1		Leave ED	Discharge	10:47:00
p2	Orange (Shortness of breath)	ED Entrance	Registration	8:25:00
p2		Triage room	Triage	8:28:00
p2		exam room	Initial Examination	8:38:00
p2		exam room	cardiologist consultant	9:25:00
p2		exam room	emergency medicine	10:12:00
p2		exam room	observation	10:22:00
p2		Leave ED	Discharge	10:47:00
p3	orange (Moderate Brain injury)	ED Entrance	Registration	8:33:00
p3		Triage room	Triage	8:41:00
p3		exam room	Initial Examination	8:51:00
p3		surgery room	stetches	9:12:00
p3		x ray	x ray	9:32:00
p3		Leave ED	Discharge	10:25:00
p4		red (accident)	ED Entrance	Ambulane Handover
p4	urgent room		emergency medicine	9:15:00
p4	urgent room		Lab test	9:35:00
p4	Radiology department		CT	10:10:00
p4	urgent room		waiting transfer to Surgery	10:25:00
p4	surgery Department		transfer to Surgery	11:30:00
p5	red(Appendicitis)		ED Entrance	Ambulane Handover
p5		urgent room	emergency medicine	9:27:00
p5		urgent room	Lab test	9:48:00
p5		Radiology department	CT	10:33:00
p5		exam room	waiting transfer to Surgery	10:58:00
p5		Abdominal Surgery	transfer to Surgery	11:45:00
p6			ED Entrance	Registration

Step 3. Analyzing and preparing data for use in system simulation

The goal of the data analysis process is to extract the information necessary to build a model for simulation. It could be a model that represents the actual current process, or the improvements applied on the existing process.

The Excel program was used in the analysis of the collected data in a format supported by simulation program. The information extracted from the analysis was as follows.

- Preparing health care activities and paths for each group of patients who share the reason for the visit.
- - The time required to perform each health care activity for patients within the emergency department. It is captured by setting meetings with individuals responsible for providing health care services to patients within the emergency department.
- Determine the number of patients arriving every hour for both critical and non-critical cases.
- Determine the percentage of patients for each complaint/illness, as shown in table (3).

Table (3): the percentage of patients for each complaint/illness

rank	type of health care paths	Percentage
Severe with threat (Life-threatening conditions)		16
1	Heart Failure	7
2	Stroke (loss of sensation or motion)	4
3	severe abdominal pain (Aneurysms, gallbladder inflam)	2
4	athma -	3
Severe without threat (severe pain - high risk situation - serious disability)		18
5	spinal cord injury	4
6	severe abdominal pain (Aneurysms, gallbladder inflam, Pancreatitis)	5
7	acute kidney injury	3
8	allergy	2
9	Diabetes	4
Moderate (symptoms) (need two or more resources)		39
10	Severe Fractured (Hip, Wrist, Ankle, Patella dislocation)	12
11	abdominal pain	14
12	urinary tract infection	3
13	Chest pain	5
14	Hypertension/Severe Headache	5
Low moderate (need one resource)		15
15	Vision problems (decreased vision - sudden loss of vision)	3
16	Skin disorders (rash, allergies)	6
17	Severe Muscle Strain	8
minor (non urgent) (need no resource)		12
18	cuts	9
19	food poison	3
20	brooken tooth	1
21	animal attack (dogs)	2

Step 4. Building a real model for the for Agouza Hospital's Emergency Department

The real model of the health care system within the emergency performs examination and triage based on two degrees, each of which has a different path from the other, as shown in Figure (4).

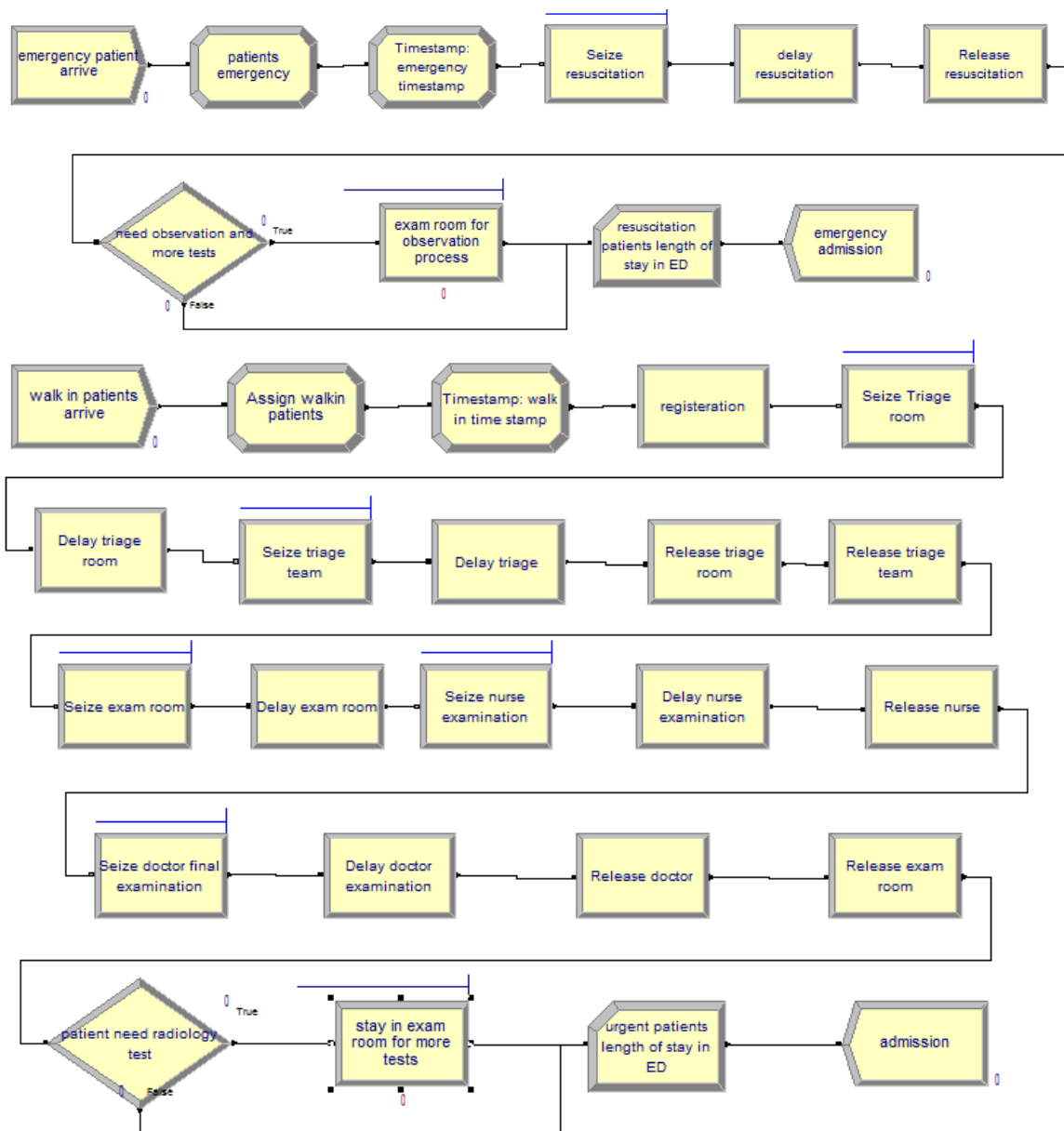
1. Emergency Cases: Patients of that degree are at risk of death within minutes of arriving at the emergency department.
2. Urgent cases: All other patients that come to the emergency department. They are treated according to the criticality of their cases on a first come first serve basis.

Step 5. Conducting the simulation and validating the model

The simulation is conducted using 680 cases/samples. These cases represent a week of visits of patients to the emergency department over 6 days, 24 hours a day. Model validation is done by comparing the model outputs with the aforementioned collected data through the interviews.

Actual Model Simulation Results: Simulation is carried out using Arena software. The output/result of the simulation:

- The length of stay at the emergency department as shown in table (4), The average waiting time for resuscitation patients in the emergency department is 4.1 hours and The average waiting time for urgent patients in the emergency department is 4 hours.
- The average waiting time of patients in the queues to receive the health care service as shown in table (5) ,The average waiting time for patients to use examination room for medical care is 1.6 hours and The average waiting time for patients to use observation room is 1.5 hours.



Fig(4): represents the work flowat the emergency department in the real model

Step 6. Applying improvements and building newly proposed/enhanced model

Once the process was mapped and simulated, it was realised that another activity was occurring – but wasn't included in the value stream, patients need to stay more for observation were occupying exam room (two exam rooms), In addition to the survival of non-critical patients for long times because of waiting for their turn after the completion of critical cases, which prolongs the average stay time for all patients.

In this step, queuing theory and engineering lean manufacturing methodology are adopted to map the improved model as in fig(4).

- Queuing theory is used to improve the paths of patient flow. It helps in reforming the system such that patients receive their treatments in parallel rather than sequentially. This will reduce the waiting time in queues and improve patients' movements/paths by following the quintuple triage and examination for the patients based on the severity of their condition. This is already applied in the Anglo-American emergency departments, at which the triage and examination is divided into five levels.



- Engineering Lean Manufacturing is adopted to eliminate unnecessary steps that do not add value to the patient during the health care journey. For instance, the patient used to have an initial examination in a room, then return to wait hall until transferred to the treatment room. That was introducing an extra unnecessary step that prolongs the waiting time. Therefore, will combine the two activities (examination and treatment) to be done in same room.

Table (4): the length of stay at the emergency department table (5): the average waiting time of patients

Interval	Average	Waiting Time	Average
resuscitation patients length of stay	4.1024	exam room for observation process.Queue	1.5669
urgent patients length of stay	4.0692	Seize doctor final examination.Queue	0.00006679
		Seize exam room.Queue	1.6692
		Seize nurse examination.Queue	0.00
		Seize resuscitation.Queue	0.5761
		Seize Triage room.Queue	0.5193
		Seize triage team.Queue	0.00

Step 7. Decision-making to choose the best scenario among the available scenarios

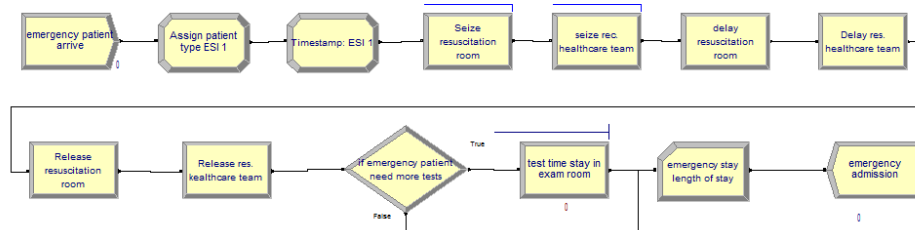
Simulation has been conducted several times, as much as necessary, to study the impact of the improvements according to the standard indicators. By applying the “What If” method, we came up with two scenarios as follows:

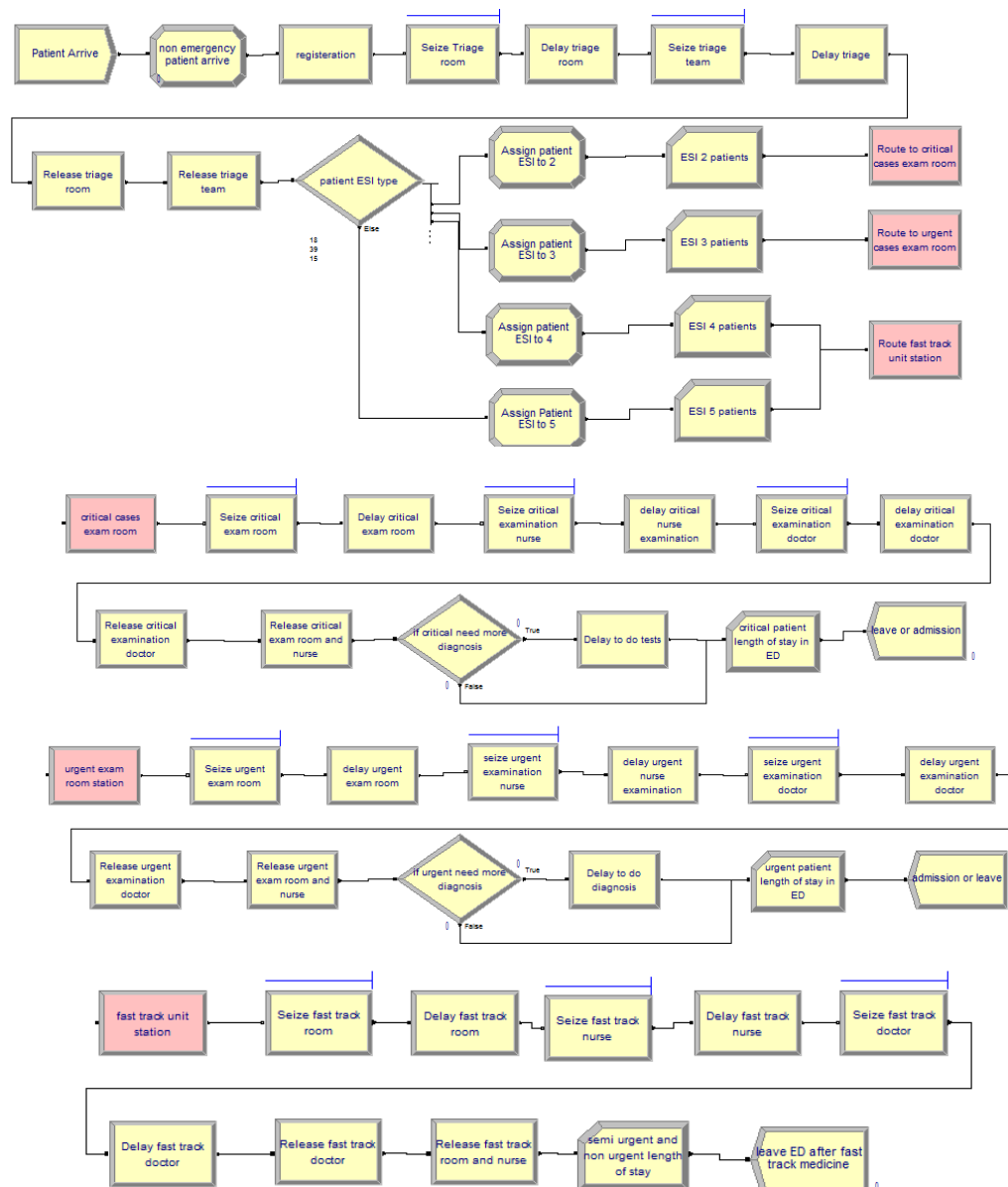
- The first scenario: rearranging and/or reallocation of the department’s resources to achieve the best possible improvement rate, without increasing the built environment area for the emergency department.
- The second scenario: Achieving the development/improvements goals, which include the desired increase in the number of resources of the existing built environment in the emergency department.

7.1 First Scenario Discussion

In this scenario, resources have been reallocated and increased to the maximum that the emergency department area can accommodate, which are seven rooms for examination and treatment arranged as two rooms for critical cases, four for urgent cases, and three for fast track case.

Although these improvements have reduced the severity of problems and the length of waiting in queues, and critically ill patients have reached the average time, the critical, semi-critical and non-critical patients in this model still suffer from waiting times and Long length of stay at the emergency department.





First scenario simulation outputs:

Table (6) shows that patients with critical conditions got served and sent home within four hours. However, the patients, who need to be transferred to the nursing units, stay in the examination rooms of urgent and fast track until they are transferred. This adversely impacts the flow of the patients, as others will have to wait until the nursing rooms are emptied before admitting them. In addition, observation rooms must be added/increased to accommodate these patients to be observed, until they move to the nursing units and complete the diagnosis.

The locations and causes of bottlenecks in the patient flow paths are shown in table (7), It appears that the waiting time is ~1.5 hours in order to get an examination room ready for follow-up and observation. Also, there is an average waiting time of 1.4 hours to a critical care examination room. And another average waiting time of an hour to get an examination room with fast track for non-critical and semi-critical cases.

With careful analysis of the patients’ movement during the simulation of the first scenario model, it is found that the lack of observation rooms allows patients who need follow-up and observation to stay with resuscitation and highly critical patients in the same examination room for approximately two hours until their condition is completely stable. This may severely prolong the waiting time of the critically ill patients and other patients as well.



Table (6): the average waiting time of patients at scenario 1 model

Waiting Time	Average
Seize critical exam room.Queue	0.3184
Seize critical examination doctor.Queue	0.00343093
Seize critical examination nurse.Queue	0.00
Seize fast track doctor.Queue	0.01193550
Seize fast track nurse.Queue	0.00
Seize fast track room.Queue	0.9482
seize rec.healthcare team.Queue	0.00
Seize resuscitation room.Queue	0.2084
Seize Triage room.Queue	0.2666
Seize triage team.Queue	0.00
Seize urgent exam room.Queue	1.4717
seize urgent examination doctor.Queue	0.01197319
seize urgent examination nurse.Queue	0.00
test time stay in exam room.Queue	1.5344

Table (7): patient length of stay at scenario 1 model

Interval	Average
critical patient length of stay	3.1711
resuscitation patient length of stay	4.3592
semi urgent and non urgent length of stay	2.4921
urgent patient length of stay	3.5643

7.2 Second Scenario Discussion

This scenario includes the modifications of the previous scenario in addition to an observation unit that consists of four observation rooms.

Second scenario simulation outputs:

Table (8): indicate that the modifications applied on the health care system improved the efficiency and performance of the emergency department to reach the desired goals as follows.

	Interval	Average
– The resuscitation patient length of atED is 3.5 hours.	critical patient length of stay	2.9938
– The critical patient length of stay atED is 2.9 hours.	resuscitation patient length of stay	3.4715
– The urgent patient length of stay atED is 1.6 hours.	semi urgent and non urgent length of stay	1.6313
– The semi urgent and non-urgent patient length of stay at ED is 1.68 hours.	urgent patient length of stay	1.6806

Step 8. The impact of simulation results on the architectural design of the emergency department

In this section, the impact of the simulation results for each of the first and second scenarios, on the development of the architectural design of the emergency department, will be discussed in Table (8), which provides a comparative table describing the architectural design of the actual system versus the modified/improved system according to the two aforementioned scenarios.



Table (8) – Comparison of actual model vs. first scenario simulation model vs. second scenarion simulation model

	Actual Process	First Scenario (Resource Allocation)	Second Scenario (Optimization)
Healthcare process Model	<p>After collecting/analyzing data of 680 patients and we find the following:</p> <ul style="list-style-type: none"> - The department provides emergency medical service for ~40K annual visits/cases, at which patients are classified, based on examination and triage, into two different classes with different paths: <ol style="list-style-type: none"> 1. Resuscitation cases - Patients are at risk of death within minutes of arrival to the emergency department. 2. Critical cases - All other cases that come to the emergency department with all degrees of criticality. <ul style="list-style-type: none"> - Health care is provided based on the criticality of the case. That means, most critical case will be of the highest priority and get served first. The health care system suffers from inefficiencies due to redundant and repetitive steps. 	<p>Design the health care system to enable parallel routes/paths for patients' therapeutic service. This will reduce the long waiting queues and improve the movement of the patients. In addition, quintuple triage and examination is applied based on the severity of their condition. It is already applied in the Anglo-American emergency departments and it is divided into five levels as follows:</p> <ol style="list-style-type: none"> 1. Level One: Resuscitation (ESI - Level 1) 2. Level Two: Extremely Critical (ESI - Level 2) 3. Level Three: Critical (ESI - Level 3) 4. Level 4: Semi-Critical (ESI - Level 4) 5. Level 5: Non-critical (ESI - Level 5) <p>The number of resources needed for each level is determined according to the number of patients and the target performance/goals (i.e., the average total stay time of patients of each level in the emergency department, and the average time required to provide the initial/first healthcare service for a patient).</p>	
Simulation Outputs	<p>The average stay time of patients in the emergency department as follows:</p> <ul style="list-style-type: none"> - The average stay time of resuscitation patients is 4.2 hours - The average stay time of patients with severe / very critical condition is 4 hours. <p>Bottlenecks are as shown in table (5):</p> <ul style="list-style-type: none"> - Examination rooms, at which there are long waiting times for patients with semi-/non-critical conditions, especially when having patients with severely critical conditions for observation in the examination ward. 	<p>The average stay time of patients in the emergency department, as follows:</p> <ul style="list-style-type: none"> - Average stay time of resuscitation patients (ESI 1) is 4.2 hours. - Average stay time of severely ill patients (ESI 2) is 3.2 hours - Average stay time of patients with critical condition (ESI 3) is 3.6 hours - Average stay time of patients with semi-critical condition (ESI 4) is 2.5 hours - Average stay time of patients with non-critical condition (ESI 5) is 2.5 hours. <p>Bottlenecks are as shown in table (6):</p> <ul style="list-style-type: none"> - Examination rooms for patients with critical and non-critical condition due to resuscitation patients are put under observation in it, because there are no rooms for observation. 	<p>The average stay time of patients in the emergency department, as follows:</p> <ul style="list-style-type: none"> - Average stay time of resuscitation patients (ESI 1) is 3.4 hours. - Average stay time of severely ill patients (ESI 2) is 2.9 hours - Average stay time of patients with critical condition (ESI 3) is 1.6 hours - Average stay time of patients with semi-critical condition (ESI 4) is 1.6 hours - Average stay time of patients with non-critical condition (ESI 5) is 1.6 hours. <p>As shown in table (8), after increasing the capacity of the emergency department by an attached unit for observation consisting of four individual rooms, the researcher was able to bring down the patients' stay times in the emergency department to the desired target</p>
Results	<p>The patient flow system suffers from bottlenecks in the paths/routes to the examination ward. There are long waiting times for patients due to the lack of beds in the examination ward and/or for using it for observation. In addition, there is lack of space and tools in the ward needed for treatment. And so, there is a need to transfer the patient to the treatment or orthopedic casting room, which is an extra step that incurs delay in the process. Therefore, it is recommended to be combined.</p>	<p>The average total stay time of severely ill and resuscitation patients is reduced by 10% compared to actual process.</p> <p>Although the stay time of patients with severe condition has achieved a remarkable improvement due to the availability of assigned rooms and resources to them, the resuscitation patients face long waiting times and continues to fall behind on the targeted performance.</p> <p>The average total stay time of patients with critical, semi-critical and non-critical conditions is reduced by 28% compared to the actual process.</p> <p>Patient flows are still not achieving the target based on Key Performance Indicators (KPIs).</p>	<p>The average total stay time of severely ill and resuscitation patients is reduced by 24% compared to actual process.</p> <p>The average total stay time of patients with critical, semi-critical and non-critical conditions is reduced by 45% compared to the actual process.</p> <p>Thus, there is 24% and 20% achieved improvement for severely ill and resuscitation patients, and others (i.e., critical, semi-critical and non-critical conditions) respectively.</p> <p>These improvements are capable of achieving the required operational efficiency/quality of the emergency department according to global performance indicators, even if there is increase in the number of cases.</p>

<p>Emergency Department Spaces</p>	<p>Architectural design forms a linear model (i.e., Linear Layout typology) with medical services distributed over the area. There are two nursing stations, one is in front of the examination and triage room, and the other is in the examination ward.</p> <p>Divided into five medical spaces/units, in addition to the administrative and service spaces, which are as follows:</p> <ol style="list-style-type: none"> 1. Examination and triage room. 2. 6-Bed emergency ward 3. 1-Bed orthopedic casting room. 4. Single bed treatment room. 5. Critical Cases Room. <p><u>Staff</u> Number of doctors: 3 Number of nurses: 5</p>	<p>The architectural design forms a ballroom layout typology, with a central nursing station surrounded by the examination and treatment rooms, medical service rooms.</p> <p>The first scenario is based on Rearranging and reallocate resources to achieve the best possible operational efficiency as shown in figure (6).</p> <p>Making all rooms individualized to reduces the transmission of contagious diseases, provides privacy, and protects patients from falling during transfers.</p> <p>Divided into five medical spaces/units, in addition to the administrative and service spaces, which are as follows:</p> <ol style="list-style-type: none"> 1. Examination and triage room. 2. Two rooms for resuscitation patients. 3. Two rooms for patients with severe / very critical condition. 4. Four rooms for patients with critical condition. 5. Three rooms for semi-critical and non-critical patients <p><u>Staff</u> Number of doctors: 3 Number of nurses: 5</p>	<p>The architectural design forms Pods layout typology, where there are two pockets, a main pocket for examination and treatment rooms and another pocket for observation rooms, with a central nursing station surrounded by the examination and treatment rooms, medical services rooms and stores, and a sub-nursing station for observation rooms</p> <p>The second scenario is based on Rearranging and reallocating resources in contiguous areas in addition to increasing the area of the section by 8% to add a new area for observation, as shown in figure (7).</p> <p>Making all rooms individualized and divided into six medical spaces/units, in addition to the administrative and service spaces, which are as follows:</p> <ol style="list-style-type: none"> 1. Examination and triage room. 2. Two rooms for resuscitation patients. 3. Two rooms for patients with severe / very critical condition. 4. Three rooms for patients with critical condition. 5. Two rooms for semi-critical and non-critical patients. 6. Observation unit consists of four rooms <p><u>Staff</u> Number of doctors: 3 Number of nurses: 6</p>
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Fig. (6) : Architectural design for the emergency department based on smart emergency department design solutions to Achieve the requirements of the first scenario



Fig. (7) : Architectural design for the emergency department based on smart emergency department design solutions to Achieve the requirements of the first scenario



X. CONCLUSION

The process of developing emergency departments efficiency and workflow does not belong to a specific scientific field, but rather a combination of four scientific fields due to the nature of the (ED complex system), which are the architectural field (redesign the layout), industrial engineering (Lean thinking and six sigma principles), operations research (Discrete event simulation) and information technology (Electronic health records). Combining these different scientific fields in a unified methodology is the way to make the process of developing the work system in the emergency department integrated and effective.

The importance of customization of emergency department medical record in developing countries to satisfy the national and international standards of emergency room record. Therefore, as part of each hospital performance

improvement activities, the hospital should regularly assess patient clinical record content and form as well as the completeness of patient clinical records to ensure the applicability and convenience of emergency record.

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