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Research paper

Modeling the Patients Flow Behavior in Hilla Emergency Departments

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Abstract

Emergency department (ED) represents a crucial and suitable for most patients' emergency cases at any time. It is extremely associated health services dedicated mostly to treat the arriving patient's with uncertain illnesses and without previousappointment.Patient flow sequences representa very complex processdue to the different uncertain requirements and different possible paths that patients may guide to complete their treatment. An Agent Based Modeling (ABM) approach is implemented and appliedin an emergency department in Hilla hospital as a case studyin this paper.Thisstudy combinesABM with queuing and discrete events simulationas an evaluation process for the patients flow behavior and staff utilization in an emergency department. ABM is a flexible tool that can be created to imitatecertain complex environment. It can offer certain level of supports for managers to consider the relative influence of current or suggested strategies. It provides a suitablesituation in studying andpredicting the interactions and behavior's in ED operations. This study aims to maximize the patient's throughput, minimize their waitingtimesand optimize the resources utilization. The methodology that followed in this study is to estimate the optimal required number of ED staff's, which involves doctors, triage nurses, and receptionist, lab and x-raytechnician. Patients were modeled as agents having an ability to interact with others and with staffs and to select whether to wait and stay in the system or to leave at any stage of treatment. The simulation results is implemented according to the real collected data and the managers experiences about the averages of arrival and service rates with flow sequence probabilities. Waiting and idle times for the patients and staffs showed a good indication about the quality of services.

Keywords: *Healthcare, agent-based modeling, discrete event simulation, emergency department.*

1. Introduction

Emergency department (ED) is the major unit in each hospital. It represents the central entering and a crucial section to the hospital. EDs in all hospitals are suffered from high demand on vital care, the overloading and constrained resources (Taboada *et al.*, 2013).
Healthcare structures are composite, enormous, and very dynamic environments. Through the preceding years healthcare services are developed, especially ED. The main specialists in health care systems are how to provide excellent services. Designing medical processes structures to provide best treatment to patients at right time utilizing the available resources are the main challenges in Healthcare systems. The resources in health care systems are limited, so their utilization must be in an optimal manner in order to achieve patients requirements in certain quality level.(Mustapha and Frayret, 2016)
Overloading in EDs leads to increase the waiting time, influence the quality of service. So new or developed techniques and solutions must be implemented in order to meet the patients favorite, flow and crowding. Discrete-Event Simulation (DES) has been widely used in such complex systems. Merging agent tools are being one of the alternative choices to be applied in healthcare problems.(Cabrera *et al.*, 2011)(Cabrera *et al.*, 2012)
All the literatures indicate that no standard models are suitable to deal with such systems. In other words, the analytical models are failed to represent such complex systems due to the impact of random happenings. Computer simulation is one of the best possible solutions due to the vast growth in information's technology.(Liu *et al.*, 2014)
In this study a historical average data is collected from Hilla ED about their arrival, service, waiting and idle times. The flow sequences of patients are followed according to the ED structure after estimating certain probability limits. Estimation is suggested to represent the tables and graphs in certain regression equations.

2. Healthcare System

Health Care (HC) services representan extensivefield for complex simulation studies. Simulationis mostly aims at investigating and analyzingvarious valid management strategies or structuralschemes in anorganized environment to diagnoseand develop their different significances(Mustapha and Frayret, 2016).Human interactions represent the back bone in analyzing any HC system while the EDis being one of its significantsegments.The quality of service (QoS) in ED has anexcitingimpact on the entireHC(Liu *et al.*, 2014)
CrowdedHCfrequentlydeliveradditional challenges to their planner and managers due to the extraordinaryrequisite for treatment, restrictedfinance, high costs, and limited HC resources. So, managers are alwaysreviewingthe ability and the efficiency of presentHC systemwith its outcomes.Any suggested modification to the current system or creating new one must be evaluated carefully.The essential HCmanager'sobjective is to maximize their available resources utilization subject tocertainfinancial restrictions.

To meet this challenge, managers needto apply verywell-organized systems to minimize the costs of deliveringa confident level of treatment(Ahmed and Alkhamis, 2009).

3. Emergency Department (ED)

ED is the heart of healthcare system where it represents theessentialcontact point beforeentering the HC system. It representsone of the entire complex systems. Patients are visiting the ED to get treatment fromseveral problems.Actionor response is done according to certain features and level of priority.All Ed's sharesrelated resources such as administrators (receptionists), nurses, doctors, specialists, beds, and laboratory and medical apparatus's.Large number of individuals visits ED each day in different places and different countries looking for certain level of treatment. Any erroror wrong diagnosis in ED may lead to human death ordisability (Yousefi and Ferreira, 2017)
The principal objectives of ED studies are to develop the QoS using excellence administration insights, decreasing patients' waiting time and to analyzeits complexity using simulation approaches, ABM and optimization techniques(Taboada *et al.*, 2013)(Yousefi and Ferreira, 2017)

4. Agent Based Simulation (ABS)

DES is frequently used to simulate, control and evaluate the flow of patients in EDs. It was highly utilized in estimating thepatient's bottlenecks places.This approach is dealing with human behavior, so it may have reflected many limitations in representing their interactions(Nahhas, Awaldi and Reggelin, 2017).
Usually, human is represented by a principal agent, and let theseagents interact with each other and with their around environment.The interactions results between agents (i.e.patient with receptionist, nurse or doctors) may dominate the result of the essential treatment process.
Two different types of agents have been recognized, passive and active. Reactive schemes and services (such as the information technology tools, devices and equipment's used to perform tests) are represented as passive agents, while the involved individuals (such as patients, doctors, nurses and other admission staffs) are represented as active agents.The interaction between a patient and a nurse a sample of a one-to-one, when patient's received information in any service stage, this communication type is called a one-to-n. (Yousefi *et al.*, 2018)
Inthis paper, an ABS with DES and queuing fundamentals aremerged to simulate patient behavior and most of its outside interactions.

5. Patient Flow

The flow of patients will analyze and study according to the existingsequence kept by the ED. Different departments that each patient canenter and pass through. Each one must be analyzed and indicated in orderto record all the required variables. The ED possible flow map must bestated carefully.
At the first step, Patients visiting the EDfollow certain behavior described in Figure 1.
The treatment sequence begins when apatient reaches the ED entrance and usually terminated when a patient iseither leave the ED with or without treatment or guide to certain hospital for extratreatment. Patientsare visiting the ED by walking, ambulance, police custody in different levels of intensity depending on certainprobabilistic arrival rate (estimated from historical data of ED Hilla hospital and shown in table 1.

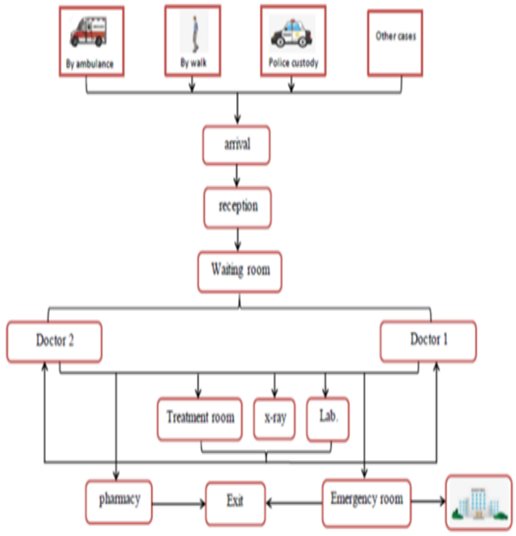

Fig. 1: Sequences of patients flow in ED

Table 1: Reception arrival rate

Arrival rate fractions		
Ambulance	Walk	Police custody
0.094	0.831	0.075

Once the patient arrives he/she enters reception room. In reception room staff will registerthe arrived patient with a sequence number (ID).Then the patient willguide to thewaiting room and waits for the availability of the triage nurse. In thewaiting room a nurse checks the case of the patient to give certain priorityin queuing. Then transit to the doctor room in order to starttreatment cycle. In doctor's stage, the doctors perform the firstdiagnosis. There are many steps can be followed by doctors with differentprobabilities. Patients may requirevisiting one or more of the following: (x-ray, laboratory, treatment room, emergency room) and/orPharmacy.
In this study, we utilize the behavior of agents instead of the real patients. Agents in each stage can be stated as an IF/THEN formation as (IF [hint is existing] THEN [perform an action]). If a staff (as agent) is busy and a patient is arrived, then the patient must wait (join a queue) until the previous patient finished or the staff is being free. Such formulation is simple, understandable, easy to abstract, and can be represented in a programming language.
Table 2 shows the used probability distributions with their suggested parameters to generate services as random variate for each stage. Some of these parameters are suggested either according to certain similar literature cases (Ahmed and Alkhamis, 2009)(Zeinali, Mahootchi and Sepehri, 2015) or according to the observed real situation in Hilla ED. Waiting, idle, enter service time and departure times are estimated according to the following logical equations:

$$\text{Wait (i)} = \text{depart (i-1)} - \text{arrival (i)} \quad (1)$$

$$\text{Idle (i)} = \text{arrival (i)} - \text{depart (i-1)} \quad (2)$$

$$\text{Enter (i)} = \text{arrival (i)} + \text{wait (i)} \quad (3)$$

$$\text{Depart (i)} = \text{enter (i)} + \text{service (i)} \quad (4)$$

Table 2: Service time distributions at each stage of the process

Stage	Distribution (minutes)
Reception	Uniform (3,5)
Waiting room	Uniform (3,5)
doctor	Uniform (10,20)
Lab.	Triangular (15,22,30)
x-ray	Uniform (8,12)
Treatment room	Uniform (20,100)

6. Simulation Results

A discrete event simulation is developed using net logo (6.2). Real data is utilized in generating random variates as inputs to the simulation processes in each stage.
Table 3, shows the simulation setup implemented in this study. This setup is created according to the real configuration of Hilla hospital ED and its staff's duty availability.

Table 3: The simulation setup

No.	Staff description	Number of gates
1	Reception	1
2	Waiting room (nurse)	1
3	Doctor	2
4	Lab	1
5	x-ray	1
6	Pharmacy	1
7	treatment	1

Simulation scenarios are suggested and implemented according to the collected data about the building configuration, patients probable flow sequences, average arrival rate and service times. Many simulation iterations are performed to get the average results. The following figures illustrate the final average results collected from implementing the simulation program in net logo (6.2). Figure 4, shows the waiting, idle and service times in reception room. The value of (13.4 per hour) is used as patients arrival rate, with one service unit (one gate) having a uniform service distribution.

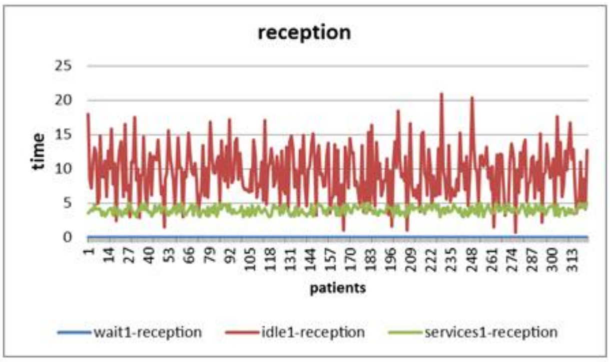

Fig. 4: waiting, idle, service times in reception stage

Figure 4 shows high staff idle time with no tangible waiting time according to the rate of the arriving patients. A satisfaction about the sufficient and appropriate staff to offer services for the arriving patients is achieved in this stage.
Figure 5, presents the average waiting, idle and service times in a waiting room.The patients departs from reception entering the waiting room as arrivals. This stagehaving one service unit serving the arriving patients as FIFO according to certain uniform distribution.

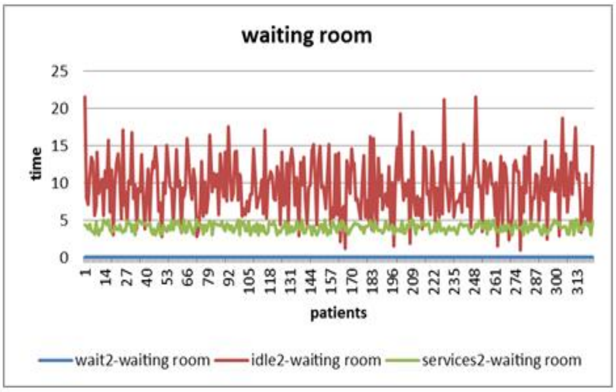

Fig. 5: waiting, idle and service times in a waiting room

According to the data generated in figure 5, it is clear that the staff idle time is too high and no tangible waiting time is seen for the arriving patients. One gate (one nurse) is enough to meet the arriving patient's requirements in this stage.
Figure 6, shows the patients waiting times (in minutes) before seen by the doctor. This stage is the third stage where the patients arrives in the same departing rate from the waiting room. It contains two gates (doctors) so the entering patient will checkup for the available doctor, if the first doctoris busy the patient will check the second one, if both are busy then patients must wait to see the first available doctor. Both doctors have a similar service time uniformly distributed. In this stage doctors may able to diagnose the patient or may require additional tests from lab. and/or x-ray.

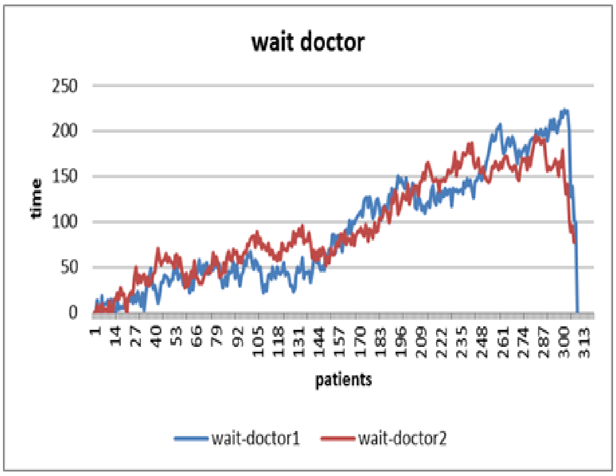

Fig. 6: Patients waiting times (in minutes) before observed by the doctor

Data collected in figure 6 shows a close patients waiting times to see each of the doctors. The waiting time for each patient is increasing with the sequence of the arriving patient in a directly proportional manner. For example the waiting time for the first 40 patients is less than 60 min, while the last 40 patients must wait between 150 to 250 min. Some patients are visiting the doctor two times due to their additional diagnoses requirements. The average waiting time to see the first doctor is 91.74 min and the average waiting time to see the second doctor is 94.80min. Figure 7, shows the doctors idle times.

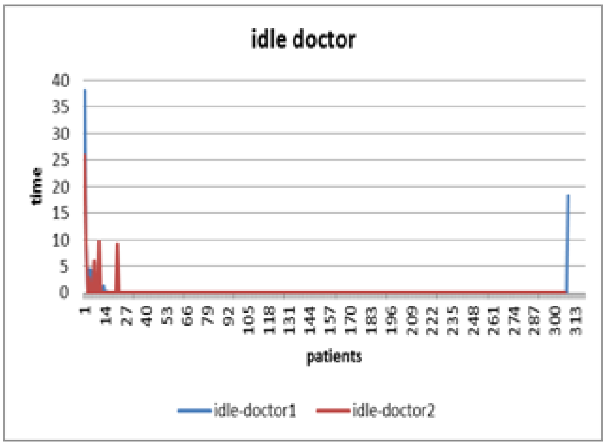

Fig. 7: Doctors idle times

Figure 7, shows about 0.24 min. average idle time for the first doctor and 0.20 min. average idle time for the second doctor. In this stage a full doctor utilization is achieving. This means that assigning one doctor only in this stage is leading to generate high waiting time for the patients, so it is not suitable case.
Figure 8,presents the patients service times in both doctors rooms.

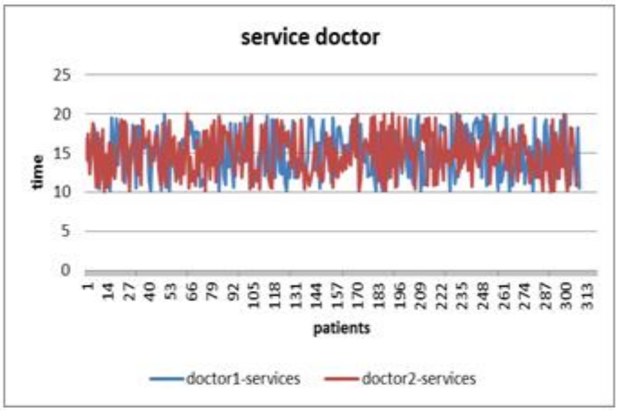

Fig. 8: patients service times in doctors rooms

Figure 8, shows about 14.96 min.average service time for the first doctor and 14.86min. average service time for the second doctor. The generated results are uniformly distributed and tend to be very close to the real collected service times which are about 15 min.

Figure 9, summarize the waiting, idle and service times in labrotary. The service time in lab. is suggested to follow the triangular distribution as a one gate entrance.

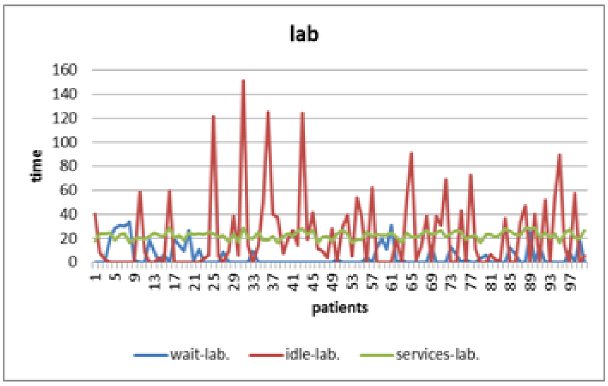

Fig. 9: waiting, idle and service times in lab

Figure 9 shows an average idle time in laboratory about 22.63min., average service time of 22.754 min. and average waiting time of 5.001 min. Figure 10,summarize the waiting, idle and service times in x-ray. The service time in x-ray is suggested to follow the uniform distribution as a one gate entrance.

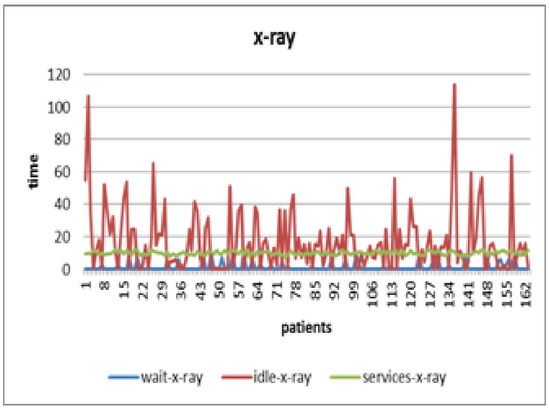

Fig. 10: waiting, idle and service times in x-ray

From figure 10, shows an average idle time in x-ray about 16.55min., average service time of 9.933min. and average waiting time of 1.240min. Figure 11, shows the waiting, idle and service times in a treatment room. The service time in treatment room is suggested to follow the uniform distribution as a one gate entrance.

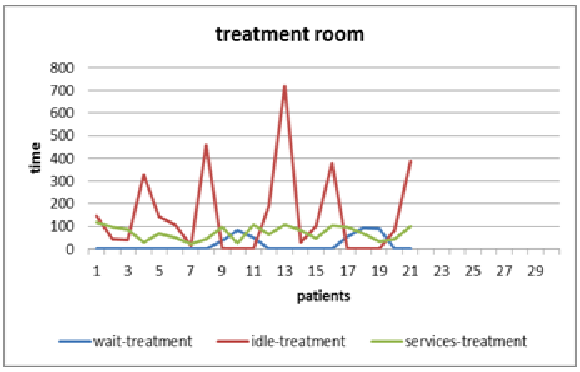

Fig. 11: Shows the waiting, idle and service times in a treatment room

From figure 11, shows a relative high average idle time of about 151.44 min., average service time of about 71.86 min. and average waiting time of about 19.119 min. Figure 12, shows the waiting, idle and service times in pharmacy. The service time in pharmacy is suggested to follow the uniform distribution as a one gate entrance.

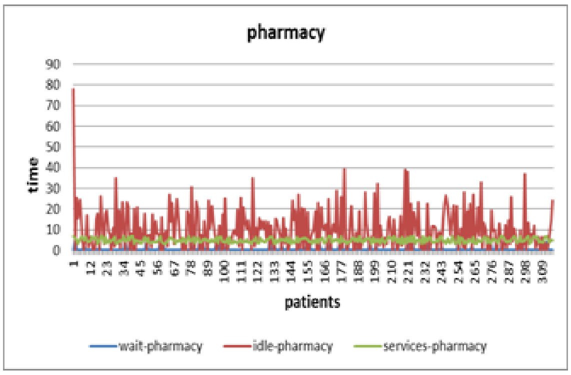

Fig. 12: waiting, idle and service times in pharmacy

From figure 12, it is clear that the idle time in pharmacy is relatively high and waiting time is not tangible. Figure 13: shows a comparison between the patient's arrival times to ED and departure times from ED.

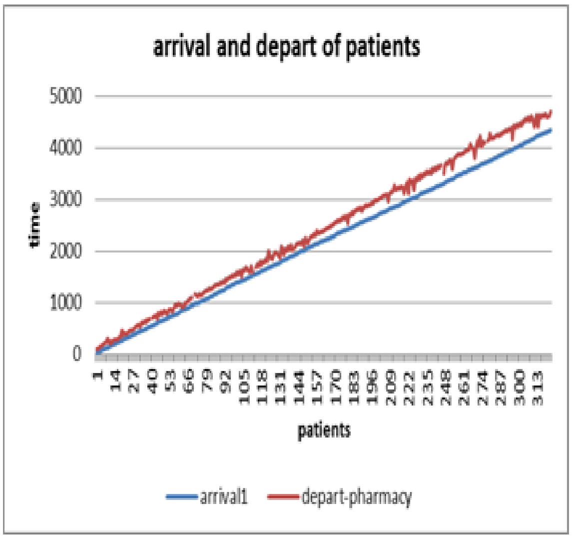

Fig. 13: comparison between the patient's arrival and departure times

Figure 13 shows the difference time is increasing for the latest patients compared with the earliest patients.Figure 14: presents the patients length of stay in ED.This time is measured for patients from their entrance to their leave time. Its average is found to be about 242.3 min.

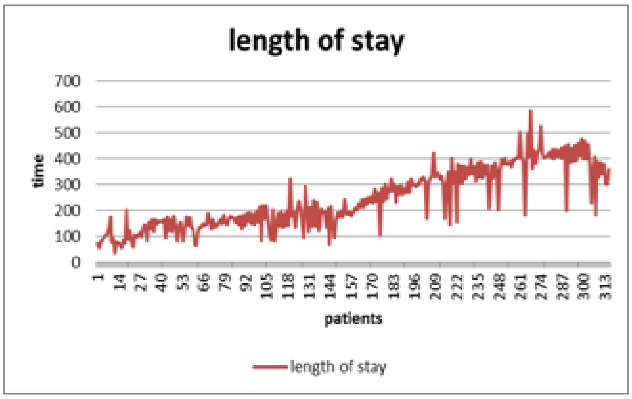

Fig. 14: patients length of stay (LOS) in ED

7. Conclusion

This study offers a common evaluation study using agent based simulation for ED in Hilla hospital. The performance of each agent type was derived from personal opinion and the literatures. Agents have an ability to communicate with others to make decisions and contribute in improving the ED performance.

This approach is used as an analyzing and evaluation tool to help administrators in testing and setting their future policies to optimize the EDs performance. The suggested approach in this study takes into account the dynamic, complexity and vitality nature of the EDs.

The simulation experiments are carried out using real data about the patients flow sequence, staff allocation and the building construction. The created simulation is providing a very tangible impact in testing any change in staffs number or places. It represents a crucial evaluation tool before implementing any plan in an efficient manner.

The estimated results after many simulation runs show an efficient staff distribution to offer good treatment services according to the current configuration and patients arriving levels.

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