

Investigating and Analysis of Hospital Performance Using Discrete Event Simulation

Mehdi A. Kamran^{1,2}, Behrooz Karimi^{3,*}

²Department of Industrial Engineering, Urmia University of Technology, Urmia, Iran

³Department of Industrial Engineering, Amirkabir University of Technology, Tehran, Iran

ABSTRACT: The quality of providing health care services is one of the factors used to compare countries' development, and hospitals account for a major share of this. In this study, the discrete event simulation is employed to measure the performance of a health care center in terms of various Key Performance Indicators (i.e., the number of patients admitted, time spending in the system, waiting time and resource utilization) and to improve capacity management. For this purpose, different parts of a hospital, from the entry of the patients to the exit door including Specialized Clinics, General Clinic, Emergency Department, Cashier Desk, and Pharmacy are considered from a comprehensive perspective. Arena Simulation software is applied as the platform for building the simulation model. Real hospital data is used to validate the proposed model. The collected real data are analyzed using Input analyzer tool available in Arena to feed up the simulation model with the required data, information, and structural and parametric assumptions of the system as inputs. In order to improve hospital performance in its key performance indicators, eight scenarios are proposed in comparison with the current situation. After running the scenarios, the results and impact of the proposed scenarios are discussed and compared with each other

Review History:

Received: 2020-02-02

Revised: 2020-05-24

Accepted: 2020-06-01

Available Online: 2020-12-01

Keywords:

Health care center

Capacity management

discrete-event Simulation modeling

Key Performance Indicators

1. INTRODUCTION

Health care systems are large and complicated and consist of a network of hospitals, clinics, diagnostic facilities, physicians, nurses, pharmacists, patients and information systems. Hospitals are one of the most important components of this network, and hospital management either in terms of capacity planning or processes routines plays a pivotal role in the health care management and medical services in each country [1]. In order to measure the performance of hospitals, different Key Performance Indicators (KPIs) have been brought up and surveyed. In public hospitals, discussed in this study, some KPIs should be considered which provide the proper assessment of such overcrowded systems. Number of patients admitted, time spending in the system, waiting time and resource utility rate are the most prevalent KPIs which are taken into account in such systems [2].

Although most of the public hospitals are under pressure of growing demand, they are facing limited funding and inadequate human and/or facility resources. Perhaps a solution to the problem is increasing the capacity by providing suitable facilities and personnel (including physicians, nurses and staff). But this is not always the best approach and also may not be achievable in most cases. Therefore, hospital managers should seek ways to make a fruitful use of existing resources.

*Corresponding author's email: b.karimi@aut.ac.ir

Computer simulation provides an opportunity to examine the effects of different ways to improve the current situation and to reduce the cost and risks of the practical implementation of the solutions in complicated systems. Consequently, it has been widely used in the realm of health care management [2] and it is still growing [3]. In the following, some of the research related to improving the quality of services in accordance to different KPIs in the health care field by applying simulation approach will be discussed.

McAlear et al. [4] described a study of six operation theatres in a hospital which concerned about the throughput of the system. There was a viewpoint that insufficient recovery space and the shortage of porters and recovery nurses are the main causes which generate problems; therefore, they built a computer simulation model to investigate to what extent this viewpoint is true. They also run a worst case scenario to put an upper limit on recovery space increases. Kirtland et al. [5] using a computer simulation, modeled an emergency department (ED) in the US. They aimed at improving the patient's length-of-stayed, throughput times and staffing levels. They showed that keeping patients in treatment space than sending them to the waiting room when they have to wait before transferring to the assigned bed, will save 14,1 minutes in their length-of-stayed. Aharonson et al. [6] conducted a simulation-based research in a Hong Kong Government hospital to suggest



solutions to the problem of severe queuing found in the accident and emergency department. Patients inter-arrival times, waiting time, duration of stay, total time spent in the system, queue length and the number of patient in the department are the features examined by the research. They found out that keeping the service rate steadily will reduce the severe queueing problem to an acceptable level. Evans et al. [7] simulated the personnel's schedule to reduce patients' waiting time in the system. They considered thirteen types of patients. Length-of-stay is considered the chief performance measure and the results have determined the standard time for the treatment and proper working shifts for personnel (i.e., nurse, technicians, and physicians). Saunders et al. [8] considered factors such as triage priorities, laboratory tests and delays caused by consultations in their ED model. They considered patient throughput times, queue sizes, and resource utilization rates as performance measures. The effect of key resources on waiting times was surveyed in the results. In [9] the discrete event simulation is employed for modeling the operations of an ED. The authors focused on excessive waiting times in ED and the impact of departmental resources on this important performance measure. Duguay and Chetouane [10], with the aim of reducing waiting time, improving overall service delivery and system throughput, modeled an emergency center in Canada by Arena Simulation Software. Model control variables included the number of physicians and nurses. This research shows that by properly changing control variables, the waiting times decrease toward to standard time. Aeinparast et al. [11] surveyed an outpatient clinic, in Iran, using a computer simulation model. They showed that 42-62% of patient's waiting time was before the physician arrival at the clinic. They showed a 34.37% reduction in waiting times will be achieved in the case the clinic make required changes in the starting time of physicians' activity. Brenner et al. [12] developed a computer simulation model and studied an ED in the US. They investigated patient flow and process of treatment and identified the bottleneck resources by means of what-if analysis. Kozlowski et al. [13] offered an emergency department simulation model in Denmark to improve the patient flow and reduce patients' waiting times. They showed that it is possible to reduce waiting times by considering proper resource variables during the day. Maleki et al. [14], using the computer simulation approach, investigated an ED in Iran. They focused on improving workflow and performance indicators in the ED through four different scenarios. They considered different features such as resource bottlenecks, triage priorities, different shifting, etc. Zeinali et al. [15] developed a decision support system to improve the patients flow and relieve congestion in an ED. They developed a simulation model of the ED to evaluate the performance criteria of the system and applied different metamodel techniques to find a near-optimal resources allocation solution. They implemented their approach in an emergency department in Iran. Experimental results showed remarkable improvements regarding the performance measures of the ED. Ben-Tovim et al. [16] outlined the design, development, and application of a support tool for managing the patients flow

in a hospital. In doing so, A comprehensive (i.e., from arrivals to discharge) hospital event simulation model including of mathematical and statistical modeling techniques, as well as the concept of modular design is developed based on patients flow patterns of Flinders Medical Centre, a teaching hospital located in South Australia. They showed the proposed model is capable of assessing alternative intervention scenarios at the attempted hospital. As an extension of [16], Qin et al. [17], with the aim of improving patient flow, and minimizing frequency and duration of congestion episodes, investigated different occupancy and discharge strategies. They benefited from the computer simulation approach in assessing different proposed strategies.

To the best of our knowledge, in most studies researchers have concentrated on a particular section of the health care center, i.e., emergency department, and the bottleneck resources related to that section. Although concentrating on such important department in hospitals and addressing the details is, without any doubt, essential but taking into account the effect of this section on other sections and the relation between sections, which is mostly neglected, could give comprehensive insights in capacity and workflow routines management in hospitals. Therefore, in this study, a comprehensive model including general and specialized clinics, emergency department, pharmacy and cashier's desk is developed according to a real hospital and in order to improve the service quality and key performance indicators, various scenarios are designed and offered. Simultaneously considering all the requirements of a medical center, the best scenario is introduced. The remainder of the paper is organized as follows: In Section 2, the input data, key performance indicators, and the modeling process are explained in detail and also the simulation model is presented. In Section 3, the proposed scenarios are described and implemented in the software. The obtained results are reported and discussed in this section as well. Finally, the conclusions and future study directions are discussed in Section 4.

2. MODELING

In this study, a discrete event simulation approach is employed in order to investigate the performance of a hospital. Arena software environment is selected as a platform for modeling. A simulation model is developed in which it is compatible with most customary hospitals, but as a real case, a hospital in Urmia, Iran is considered and surveyed in this study. For this purpose, the processes of various departments in the hospital (i.e. general and specialized clinics, emergency departments, pharmacy and cashier's desk) are considered and designed in the model in a comprehensive manner.

2.1. Model input data

In order to explore and analyze system behavior in various conditions, simulation models need to be fed up with data, information, and structural and parametric assumptions of the system as inputs. In this regard, a one-month study is carried out to collect data from the statistical society of the above-mentioned hospital patients concerning the time of

Table 1. Input distribution functions of service times and patients entries in different departments of the examined hospital

Service Time*		Distribution	
Time of visiting by general physician in ED		Triangular (5, 10, 15)	
Time of visiting by specialists in the specialized clinics	Gynecologist	Triangular (7, 9, 11)	
	Pulmonologist	Triangular (4, 6, 8)	
	Orthopedist	Triangular (4, 6, 9)	
	Cardiologist	Triangular (7, 8, 10)	
	Neurologist	Triangular (5, 6, 9)	
	Ophthalmologist	Triangular (4, 7, 11)	
	Nephrologist	Triangular (6, 8, 10)	
	Pediatrician	Triangular (8, 10, 12)	
Time of visiting by the physician in the general clinic	General Physician	$1+Gamma(0.732, 2.2)$	
Time of receiving services from cashier		Triangular (2, 3, 5)	
Time of receiving services from pharmacy		Triangular (5, 10, 14)	
Patients Entry	Morning	Afternoon	Night
Emergency patients entry	Poisson (12)	Poisson (11)	Poisson (8)
Outpatients entry (to general/specialized clinics)	Poisson (30)	-	-
Patients entry (general clinic)	-	Poisson (12)	-

* Service times distribution parameters are in term of minutes

entry, time of receiving services (from different parts designed in the model), etc. Collected data are analyzed using the Input Analyzer tool available in Arena and behavioral distribution of different sections in the model are obtained, and reported in Table 1. It is worth noting that Input Analyzer tool applies different criteria and tests such as p-value, Kolmogorov-Smirnov tests to determine the behavioral distribution of the data.

2.2. Key performance indicators investigated in the system

Another requirement of the simulation models is the determination of the performance measures which should be investigated. The following performance measures are considered and analyzed as key performance indicators in this study [2, 6]:

1. The average total time that patients spend in the system (hospital)
2. The average of total patients' waiting time in the system according to the classification of their illnesses.
3. The average patients' waiting time (direct and indirect) for receiving services from different sections and resources
4. The Resources' utilization rate
5. The number of patients admitted

2.3. Designed Model

Designed model in this study, comprehensively investigates general clinic, specialized clinics, emergency department, pharmacy and cashier's desk in a health care center. Specialized clinics include eight specialty groups of Cardiology, Maternity, Nephrology, Neurology, Ophthalmology, Orthopedic, Pediatric, and Pulmonology. In model details firstly, entities (patients) are created in two groups of emergency patients and outpatients with a given distribution function (Table 1) to enter the model. The emergency department will be

discussed later, but according to outpatients, studies on the collected data in the benchmarked hospital showed that patients are 30%, 35% and 35% child, female, and male, respectively. The outpatients are twofold. Some of them are aware of their illness and directly refer to the specialty which they need to receive treatment. The other group is the patients who refer to the general clinic. Some of the recent group just need general treatment services, therefore, they refer to a general physician (GP); and some of them are the patients who are not aware of their illnesses, or what clinical services they exactly need, to directly refer to the specialty which they need to be visited by, and therefore, they refer to the general clinic to get the proper consultation. In some cases, they may receive their needed treatment services by the general physician and in some other cases, they may be referred by the general physician to the specialized clinics to a specific specialty for diagnosis. Therefore, the outpatients' process of receiving treatment services is continued by entering to general and/or specialized clinics with the proportions of 38% and 62% respectively. After the determination of the type of the clinic/department, all patients (or of course may be their companions) will be conducted at the cashier's desk to pay the visiting bill. Modeling this process was made possible through a separate sub-model developed in the cashier's desk part (Figure 1). This sub-model consist of four inputs (a) from specialized clinics patients (outpatients who are aware of their illness and the specialty which they need to refer, and emergency patients who, according to ED physicians, need to be visited in the specialized clinics by a specialty group), (b) general clinic patients, (c) general clinic patients requiring specialized services, and (d) emergency patients, going to the cashier's desk to pay the visiting and consultation bill; and three outputs to the specialized clinics, general clinic, and the pharmacy. Each entity is guided through the general clinic and/or specialized clinics output to complete treatment based

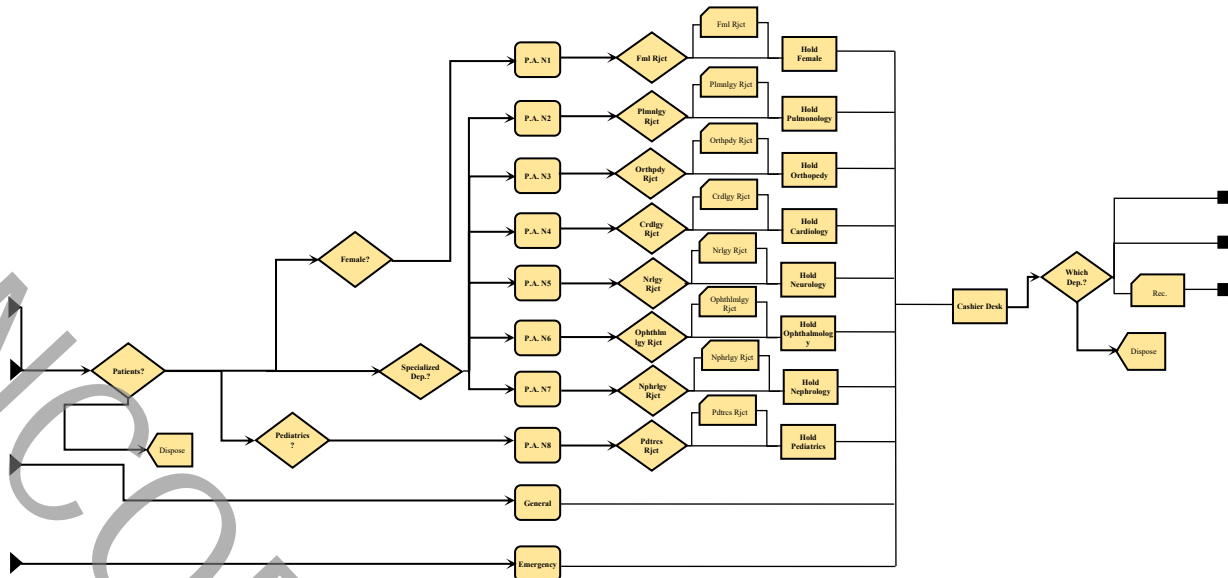


Fig. 1. Cashier's desk sub-model

on the type of his/her illness or to the pharmacy to receive his/her pharmaceutical requirements and leave the health care center (Figure 1). In order to distinguish between different types of patients with different clinical requirements, in the model each entity is allocated a code from 1 to 10 which shows the illness type of the patients. Illness codes 1 to 8 is assigned to different patients who refer to specialized clinics (there are 8 specialty groups of Cardiology, Maternity, Nephrology, Neurology, Ophthalmology, Orthopedic, Pediatric, and Pulmonology in the specialized clinic). Illness code 9 are patients referred to the general clinic and code 10 imply to the emergency patients who receive treatments and then refer to the cashier and pharmacy and leave the hospital. In the case the patients of the general clinic or emergency department need to receive specialized clinical services, trivially, they get codes from 1 to 8 additionally.

In another part of the model which is called as specialized clinics (shown in Figure 2), according to a predetermined presence timing of different specialty groups (Table 2), each specialist is responsible for visiting and serving the attending patients. Patients with codes 1 to 8 are referred to the related appropriate specialist in terms of their codes. It is worth noting that in the absence of a physician or a specialist in general or specialized clinics, patients should wait for one or more days until the physician's or the specialist's scheduled attending time arrives, regarding Table 2. This waiting time is called *indirect waiting time* in this study and it is considered and calculated in the model separately from regular waiting time (called *direct waiting time*).

Patients with code 9 are the patients who refer to the general clinic. Two modes are possible: (a) these patients receive proper treatments and leave the general clinic to get their pharmaceutical requirements, (b) these patients cannot be cured by GPs and for exact diagnosis and completion of

treatment, the GP refer them to the expedient specialist, then, similar to patients with codes 1 to 8, they will be treated in the specialized clinics. Finally, both entities from the two clinics refer to the pharmacy to receive pharmaceutical requirements.

Emergency patients enter into the system based on entry distribution function in different working shifts. They require resources such as beds, nurses, and emergency physicians to complete diagnosis and treatment. This group of patients, after being admitted to the emergency department, either receive the proper treatment in which in this case they go to the cashier and then to the pharmacy (patient with code 10) and then leave the hospital, or, by physicians of the ED, transferred to the expedient specialist in the specialized clinics to pursue their diagnosis and completion of treatment (Figure 3).

Checking and confirming the validity of a simulation model should be carried out regarding the scope and intended purposes of such a study. In this study, also, the validation process is conducted through a constantly refining procedure. Model input-output transformation validation is conducted as one of the main procedures of model validation. In this regard, different selected metrics of the attempted system is investigated and compared between the results obtained from various runs of the designed model (in the current state: scenario #1), with what has been happening in the real world (historical data). The results showed an acceptable concordance level based on the measures of the carried out statistical tests (e.g., *t*-test, paired samples *t*-tests, etc.). Besides model input-output transformation validation, face validation, structure and input validation, extreme condition validation are the techniques employed in the verification and validation phases. The developed model is also validated by experts familiar with the system in terms of the system measures and face validity. In doing so, and for a better

Table 2. The shifting schedule: each day the presence of different specialty groups at the hospital

Day	Specialist at the hospital (morning shift) †			
1:	Cardiology	Nephrology	Ophthalmology	Orthopedic
2:	Maternity	Neurology	Pulmonology	Pediatric
3:	Cardiology	Nephrology	Ophthalmology	Orthopedic
4:	Maternity	Neurology	Pulmonology	Pediatric
5:	Cardiology	Nephrology	Ophthalmology	Orthopedic

†Two specialist of each specialty group will attend at the hospital at each day

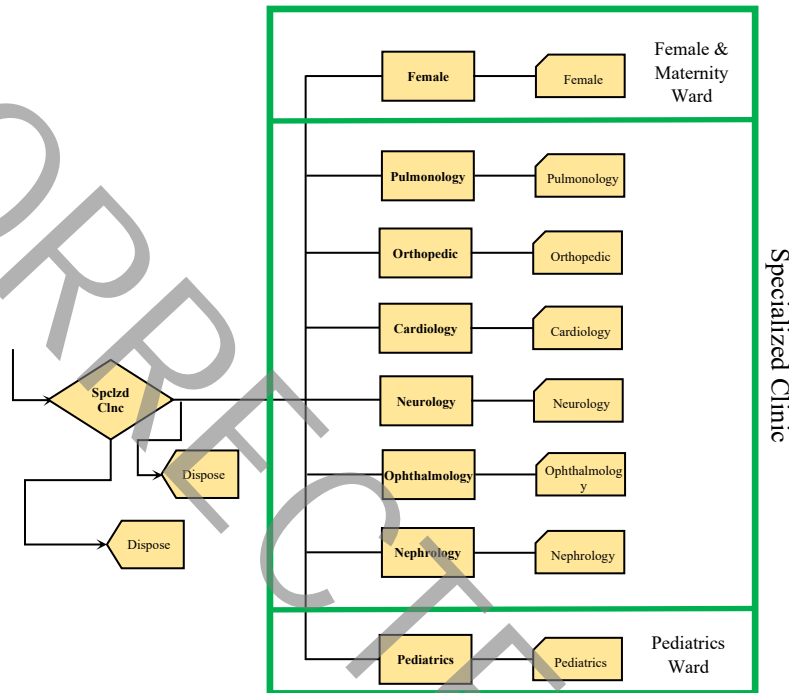


Fig. 2. Specialized Clinic sub-model

understanding of the process and procedures happening in the hospital, an animation of the processes of the investigated hospital is developed and presented. Figure 4 shows a snapshot of the animation of the model while running.

3. THE PROPOSED SCENARIOS

One of the strategies that are commonly used in the capacity planning and resource allocation (especially simulation-based) research, in confronting with resource shortage/bottleneck issue, is increasing the capacity of resources. The main objection to this policy is the excessive costs of the resources which incur to the hospitals. In addition to these kinds of scenarios, scenarios proposed in this study pursue to upgrade two important goals of hospitals: increasing incomes and/or decreasing costs, and responsibility and providing high-quality services to patients. This study tries to analyze the system performance and to promote it by introducing several scenarios regarding capacity management through proper working shift scheduling, making changes in process structure, and using available resources without increasing

capacity. Calling the health care center current situation as scenario #1, new scenarios will be designed in the following.

Specialists are not present at the hospital every day or all day long and usually visit their patients at certain times of the day. If there exists no arrangement in the physicians' presence time, it leads to chaos and long queues. On the other hand, using a large number of physicians' causes physicians' wasting and idle times and raises costs. So both conflicts should be avoided by proper planning and an efficient visiting/shifting schedule. In the hospital benchmarked in this study, physicians and specialists of the specialized clinics are present at the hospital according to a visiting/shifting schedule presented in Table 2. Also, there are one physician and three nurses providing medical services to emergency patients all day long. One physician is working the whole day in the general clinic. Six beds are available in the emergency department. Two cashiers work in the morning and evening shifts and one works in the night shift and three pharmacists provide pharmaceutical services to the patients all day long. It can be seen in Table 2 that patients who need specialized

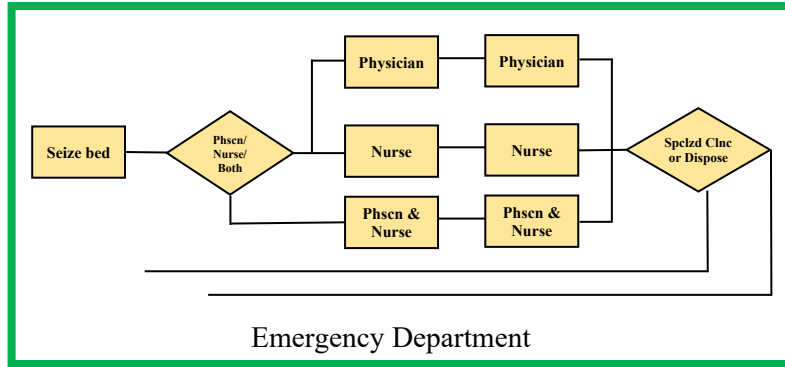


Fig. 3. Emergency Department sub-model

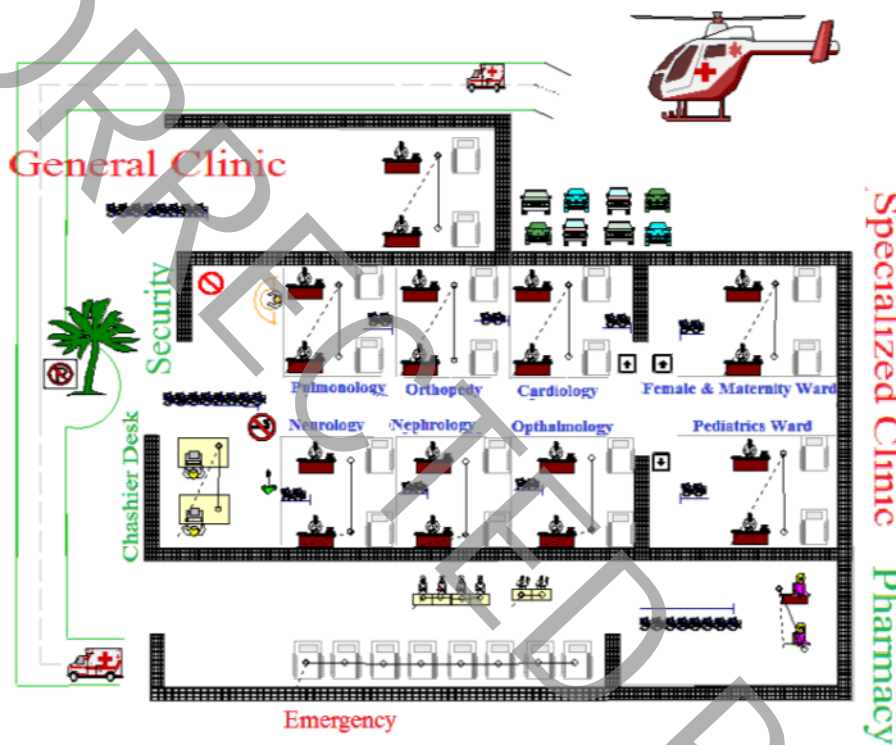


Fig. 4. Snapshot of the animation of the model

services should go to the hospital on special days, otherwise they have to endure their illness and wait for the specialists on a certain day. This causes patients dissatisfaction and may be clinically condition deterioration. Accordingly, scenarios #2, #3 and #4 are proposed without increasing human resources.

In the current situation (scenario #1), regarding shifting schedule of Table 2, each day, four specialties serve the patients, two specialists of each specialty group are present at the hospital simultaneously and only in the morning shift. In scenario #2, a new shifting schedule is replaced with the existing one in which it provides a broader patients coverage without increasing resources capacity and their related costs.

According to new visiting schedule, we will have specialists from all eight specialty groups in the morning shift four days a week, out of five days (days 1, 2, 4, and 5). And on the third day of the week, we have the same schedule as in scenario #1 (see Table 3).

Also, due to overcrowding and problems that exist in the pharmacy and cashier desk especially in the morning, and given that the evening and night shifts are less crowded, we can get help from the capacities in those shifts and recruit them in the morning shift. For example, instead of three pharmacists in all three working shifts, one or two pharmacists can be transferred from the afternoon and/or night shift to the

Table 3. The shifting schedule: each day the presence of different specialty groups at the hospital in scenario #2

Day	Specialist at the hospital (morning shift)							
1:	Cardiology	Maternity	Nephrology	Neurology	Ophthalmology	Orthopedic	Pediatric	Pulmonology
2:	Cardiology	Maternity	Nephrology	Neurology	Ophthalmology	Orthopedic	Pediatric	Pulmonology
3:	Cardiology	Cardiology	Nephrology	Nephrology	Ophthalmology	Ophthalmology	Orthopedic	Orthopedic
4:	Cardiology	Maternity	Nephrology	Neurology	Ophthalmology	Orthopedic	Pediatric	Pulmonology
5:	Cardiology	Maternity	Nephrology	Neurology	Ophthalmology	Orthopedic	Pediatric	Pulmonology

Table 4. The shifting schedule: each day the presence of different specialty groups at the hospital in scenario #3

Day	Specialist at the hospital (morning shift)							
1:	Cardiology	Maternity	Nephrology	Neurology	Ophthalmology	Orthopedic	Pediatric	Pulmonology
2:	Cardiology	Maternity	Nephrology	Neurology	Ophthalmology	Orthopedic	Pediatric	Pulmonology
3:	Cardiology	Maternity	Nephrology	Neurology	Ophthalmology	Orthopedic	Pediatric	Pulmonology
4:	Cardiology	Maternity	Nephrology	Neurology	Ophthalmology	Orthopedic	Pediatric	Pulmonology
5:	Cardiology	Maternity	Nephrology	Neurology	Ophthalmology	Orthopedic	Pediatric	Pulmonology

morning shift.

In scenario #3 similar policy is pursued. In the proposed shifting schedule in scenario #3 (see Table 4), one specialist in each specialty group attend the hospital in the morning shifts and five days a week. In the current schedule, according to Table 2, Ophthalmologists, Cardiologists, Orthopedists, and Nephrologists are allocated six shifts per week (three days a week and two specialists on each day). With the new schedule in scenario #3, their shifts will decrease to five shifts (One specialist and one shift every day). Instead, Pulmonologists, Neurologists, Gynecologists, and Pediatricians who are allocated four shifts per week in the previous schedule (two days a week and two specialists on each day), will have five shifts per week (five days morning shift). It can be seen that the total specialists working hours and the number of specialist per shift will remain unchanged, and therefore, by assuming the same specialist's expenses, no further costs will impose to the hospital and again a broader patients coverage will offer.

The same will work in the pharmacy and cashier desk sections as in scenario #2.

According to Scenario #4, those two specialists from the same specialty group, who have to provide clinical services to the patients in the morning, regarding shifting schedule in the current state (see Table 2), should provide their services one in the morning and the other in the afternoon. Thus, without increasing resources capacity, we will have a broader patients coverage.

Rendering the problems exist in the emergency department (Tables 5-7) and due to the critical and special conditions of emergency patients, it seems inevitable to increase resources like physicians, nurses, and beds in the emergency department. Thus, in scenarios #5-7, the same policy will be run according to scenarios #2-4, respectively, but with some increase in the resources capacities of the emergency department. The number of beds is increased from six to eight beds, and the number of physicians and nurses to two and four respectively in the morning and evening shifts.

In other departments, we maintain the capacity of resources and act similar to scenario #2.

Finally, scenarios #8 and #9 are proposed in the case that we have the authority in increasing the capacity in the specialized clinics. In both scenarios, four capacities (specialists) are added to the current eight capacities each day. In scenario #8, these four capacities are added to the current situation (scenario #1). Therefore, each day we will have two specialists in four specialty groups (existing capacity), and one specialist in four other specialty groups in the morning shift (newly added capacities). And in scenario #9, those four capacities are added to the specialized clinics in such a way that each day we will have a specialist, from all eight specialty groups, in the morning and a specialist of four specialties in the afternoon shift. The capacity and the schedule of resources in the pharmacy, cashier desk, and the ED remain the same with scenarios #5-7.

3.1. Scenarios Implementation

To evaluate and improve the parameters or KPIs of the system, the current situation and the proposed scenarios were run and investigated (see Tables 5-7). All scenarios were simulated for a total of 24000 hours in 5 days, 24 hours and in 200 iterations. The framework is modeled in the ARENA 14. All the scenarios have been run on a computer with Core (TM) 2 Duo CPU with 2.50 GHz speed and 4 GB of RAM.

3.2. Scenarios Implementation Results

Results from scenario #1, current state, revealed that there exist considerable disadvantages in the current system in terms of considered KPIs (e.g., direct and indirect waiting times, time spent in the system, etc.) in the same way as in reality.

Scenario #2 and #3 showed widening the patients' coverage time, even without increasing the resources capacities, could have meaningful achievements. As it can be seen from Tables 5-7, the patients' indirect waiting time considerably reduced

Table 5. Time spent in the system and the number of admitted patients in different scenarios

Scenario	Time spent in the system (min)				The number of admitted patients				
	Child	Male	Female	Emer. Pat.	Child	Male	Female	Emer. Pat.	Total
1	717.07	703.25	707.49	467.27	313	388	374	1124	2200
2	540.93	467.84	524.77	456.41	332	399	400	1123	2253
3	420.73	403.44	407.01	456.37	341	401	400	1121	2263
4	438.81	419.62	426.77	440.93	329	403	394	1124	2250
5	550.39	486.05	545.6	83.17	333	400	399	1233	2365
6	439.58	419.23	425.77	81.27	342	399	400	1234	2375
7	444.38	427.58	434.44	63.99	327	401	390	1234	2353
8	234.98	224.72	224.61	85.61	355	415	413	1230	2414
9	261.93	255.23	256.88	64.18	343	405	402	1231	2381

and the patients' time in the system is reduced to a better level which is very impressive in hospitals responsibility and commitment to the patients in providing their satisfaction. Also, the number of patients admitted increased, and higher quality services offered to the patients in the pharmacy and cashier desk, too. The waiting time in the queues of these sections has been reduced without adding human resources. The new schedule, showed improvements in the general clinic, as well. All of these are achieved without unreasonable further pressure on the resources utilization in all sections (see Tables 5-7). But, since the emergency department remains unchanged, patients waiting time is still higher than normal, especially in cases with emergent and critical conditions.

Scenario #4 revealed that there could be a great achievement, especially in direct waiting times, if we have the possibility to serve the patients in the specialized clinics in the afternoon shift. It indicated to some progress in other sections as well. Besides, serving the patients in a more extended period of time, morning and afternoon shift, will provide a more peaceful and uncrowded environment for patients. But adding the evening shift to physicians working hours certainly causes problems and oppositions (at least from the physicians' point of view). Therefore, the scenarios should be investigated not just from the KPIs, but also from the applicability perspective.

Augmenting the facilities and staff resources in the emergency department with two more beds and two physicians and nurses in the morning and evening shifts, which are more crowded, to scenario #2-4 (i.e. scenarios #5-7, respectively) clearly improved serving of emergency patients in terms of their waiting times, their average total time spent in the system and even in the number of admitted emergency patients, in comparison to the scenarios reviewed so far (see Tables 5-7).

Finally, in the cases that we have the authority in increasing the capacity in the specialized clinics (i.e., scenarios #8 and #9),

as it could be guessed, the results implied that the additional capacity added to the specialized clinics could improve the KPIs in terms of time spent in the system, direct and indirect waiting times, number of admitted patients. But unexpectedly, in the case of adding the additional resources to the current situation, scenario #8, we could achieve more efficient results than in the case of adding them to the afternoon shift. The capacities and shifting in other sections are set up and tailored to the scenarios.

The summary of the results of implementing such scenarios into the attempted system in terms of the examined KPIs is reported in Tables 5-7.

4. CONCLUSION

In this study, different segments of a hospital including general and specialized clinics, emergency department, pharmacy and cashier's desk are modeled in an integrative approach that leads to a more realistic analysis. To investigate the hospital's key performance indicators (the number of patients admitted, time spent in the system, direct and indirect waiting time and resource utilization factors) the discrete event simulation approach was used by Arena software platform. A hospital in Urmia, Iran is considered and surveyed as a real case. In order to improve the performance measures, different promoting scenarios (i.e., scenarios #2 to #9) were proposed in comparison with the current situation (scenario #1). The proposed scenarios pursue to upgrade two vital purposes for hospitals: increasing income and/or decreasing costs, and responsibility and providing high-quality services to the patients.

In Scenarios #2 and #3, new visiting schedules are proposed in which the capacity of the total resources remains unchanged (i.e., without imposing additional costs to the hospital) but a broader patients coverage is proposed. Most hospital performance measures including time spent in the system, patient's direct waiting time and the number of admitted patients showed concise improvements, but patients'

Table 6. Direct and indirect waiting time of patients (min) in different scenarios

Direct waiting time in specialized clinic								
Scenario	Cardiology	Maternity	Nephrology	Neurology	Ophthalmology	Orthopedic	Pediatric	Pulmonology
1	194.76	157.10	177.51	156.53	183.69	164.61	168.93	166.07
2	201.05	234.05	204.10	214.68	202.95	203.77	275.40	214.56
3	198.97	211.07	208.57	199.77	209.32	203.97	212.6	201.53
4	38.64	28.94	40.17	13.80	33.07	25.93	61.13	13.98
5	197.99	237.81	207.32	231.33	211.39	204.09	280.12	230.03
6	200.29	209.55	211.57	204.59	212.39	203.96	213.15	214.99
7	41.65	30.74	39.77	19.53	33.49	27.18	68.11	13.54
8	35.16	32.69	34.77	33.82	33.81	31.44	46.76	32.95
9	49.29	45.12	50.03	37.58	47.18	44.56	54.08	34.35
Indirect waiting time in specialized clinic								
Scenario	Cardiology	Maternity	Nephrology	Neurology	Ophthalmology	Orthopedic	Pediatric	Pulmonology
1	638.28	776.05	652.3	765.34	633.17	632.64	759.28	747.88
2	114.79	411.95	105.07	397.17	108.29	108.27	392.10	406.88
3	107.93	111.78	99.68	100.35	103.81	106.29	111.27	107.08
4	488.58	603.6	497.21	610.49	493.54	495.91	600.89	596.41
5	113.48	407.02	119.14	406.74	114.00	111.81	390.51	395.82
6	110.09	112.73	115.35	110.09	112.82	112.45	111.99	107.42
7	488.55	590.84	483.43	602.7	485.13	491.44	594.83	606.74
8	55.48	56.00	56.63	55.69	55.52	55.54	55.00	53.63
9	188.55	200.41	194.12	197.51	192.65	185.49	205.69	199.54
Direct waiting time in ED				Direct waiting time				
Scenario	Nurse	Physician	Physician and nurse	General Physician	Pharmacy	Cashier's desk		
1	0.14	20.98	21.05	78.59	30.35	20.56		
2	0.15	20.89	20.92	72.81	19.27	23.36		
3	0.15	21.14	21.05	75.32	18.16	22.25		
4	0.15	21.11	20.88	74.03	14.23	14.83		
5	0.10	2.60	2.65	72.72	18.86	24.6		
6	0.10	2.58	2.61	74.28	18.15	23.53		
7	0.10	2.64	2.58	73.61	14.03	14.42		
8	0.10	2.56	2.56	73.87	15.04	14.81		
9	0.10	2.69	2.71	74.74	14.86	13.88		

Table 7. The resources utilization^{*} in different scenarios

Resources utilization in specialized clinic								
Scenario	Cardiology	Maternity	Nephrology	Neurology	Ophthalmology	Orthopedic	Pediatric	Pulmonology
1	0.38	0.38	0.36	0.31	0.33	0.29	0.60	0.28
2	0.37	0.50	0.36	0.39	0.33	0.28	0.70	0.34
3	0.45	0.40	0.43	0.31	0.40	0.35	0.63	0.28
4	0.40	0.42	0.40	0.33	0.36	0.31	0.65	0.30
5	0.37	0.48	0.36	0.38	0.33	0.29	0.71	0.35
6	0.45	0.40	0.43	0.31	0.39	0.34	0.63	0.28
7	0.41	0.42	0.39	0.34	0.36	0.30	0.66	0.29
8	0.30	0.30	0.29	0.24	0.26	0.23	0.48	0.21
9	0.30	0.27	0.29	0.21	0.27	0.23	0.44	0.19
Resources utilization in ED				Resources utilization				
Scenario	Nurse	Physician	Bed	General Physician	Pharmacy	Cashier		
1	0.42	0.94	0.96	0.86	0.69	0.67		
2	0.42	0.94	0.95	0.87	0.89	0.82		
3	0.42	0.94	0.95	0.86	0.76	0.81		
4	0.42	0.94	0.96	0.87	0.89	0.90		
5	0.34	0.52	0.59	0.87	0.89	0.82		
6	0.34	0.51	0.59	0.86	0.90	0.82		
7	0.34	0.52	0.59	0.87	0.89	0.91		
8	0.34	0.51	0.59	0.87	0.91	0.90		
9	0.34	0.51	0.59	0.87	0.91	0.91		

*The level of resources utilization is based on total time.

indirect waiting time improved considerably. In scenario #4, it assumed that it is possible to use the afternoon shift to serve the patients, again without increasing the total working hours of the staff. The results indicated that in this case, there could be remarkable achievements in the direct waiting times of the patients. In order to improve the performance in the emergency department, it seemed inevitable to increase the capacity of resources in this section. Therefore, the resources capacities in ED are increased in scenarios #5 to #7, which are the same as scenarios #2 to #4 respectively in other sections. Finally, in scenarios #8 and #9, the resources capacities in the specialized clinics are also increased. Not surprisingly, all the considered key performance indicators showed significant improvements. In scenario #8, those additional resources capacities are added to the current situation shifting and in scenario #9, additional capacities are added to the afternoon shift, according to the good experience in the obtained results

of using afternoon shift. Surprisingly, scenario #9 showed better results according to considered KPIs.

The proposed framework and the results of the scenarios can give comprehensive fruitful insights to hospital managers and decision-makers in order to improve capacity and workflow routines management in their hospitals. In fact, making the best decision and selecting the best scenario, should be done inclusively according to the hospital general goals and of course applicability features.

There could be many extensions to this work which should consider more details in the framework such as considering the connection between the emergency department and the operating rooms; considering the relation between the related sections such as Laboratory, Radiology, Ultrasound, MRI, etc. with the general and specialized clinics and emergency department; investigating more applicable scenarios and proposing efficient workflow routines.

REFERENCES

- [1] Kamran, M.A., Karimi, B., Bakhtiari, H.R., & Masoumzadeh, S. (2016). A resource allocation model in a healthcare emergency center using goal programming. *Journal of Engineering Research*, 4(4), 81-97.
- [2] Diyanatkah, f., Shams, A., Riyazinia, S., & Zargari-Samani, D. (2007). Comparing Duration of Clinical and Para-clinical Services of Dr.Shariati Hospital 2004 with 2006 after editing. *Hospital Executive Management*.
- [3] Villamizar, J., Coelli, F., Pereira, W., & Almeida, R. (2011 March). Discrete-event computer simulation methods in the optimisation of a physiotherapy clinic. *Physiotherapy*, 97(1), 71-77.
- [4] McAleer, W.E., Turner, J.A., Lismor, D., Naqvi, I.A. (1995) "Simulation of a hospital's theatre suite", *Journal of Management in Medicine*, 9(5), 14-26. <https://doi.org/10.1108/02689239510096785>.
- [5] Kirtland, A., & et al. (1995). Simulating an Emergency Department "is as much fun as...". Proceedings of the 1995 Winter Simulation Conference (pp. 1039-1042). Arlington, Virginia.
- [6] Aharonson-Daniel, L., Fung, H., Hedley, A.J. (1996) "Time studies in A&E departments - a useful tool for management", *Journal of Management in Medicine*, 10(3), 15-22, <https://doi.org/10.1108/02689239610122270>.
- [7] Evans, G., Unger, E., & Gor, T. (1996). Simulation Model Evaluating Personnel Schedules in a Hospital Emergency Department. *Proceedings of the 28th Conference on Winter Simulation*, (p. 1995). Washington.
- [8] Saunders, CE., Makens, PK., Leblanc, L). (1989). Modeling Emergency Department Operations Using Advanced Computer Simulation Systems. *Annals of Emergency Medicine*, 18(2), 134-140.
- [9] Komashie, A., & Mousavi, A. (2005). Modeling Emergency Departments Using Discrete event simulation techniques. *Proceedings of the 17th Conference on Winter Simulation*. Orland, California.
- [10] Duguay, C., & Chetouane, F. (2007). Modeling and Improving Emergency Department System Using Discrete Event Simulation. *International Journal of Systematic and Evolutionary Microbiology*, 83(4), 311-320.
- [11] Aeinparast, A., Tabibi, S., Shahanaghi, K., & Aryanejhad, M. (2009). Estimating outpatient waiting time: a simulation approach. *payesh*, 32(4), 327-333.
- [12] Brenner, S., Zeng, Z., Lui, Y., Wang, J., Li, J., & Howard, P. (2010). Modeling and Analysis of the Emergency Department at University of Kentucky Chandler Hospital Using Simulations. *Journal of Emergency Nursing*, 36(4), 303-310.
- [13] Kozlowski, D., Mogensen, C., & Petersen, N. (2012). Discrete event simulation modelling for an improved patient flow at the Emergency Department, Sygehus Lillebaelt, Kolding. *Scandinavian Journal of Trauma Resuscitation and Emergency Medicine*, 14.
- [14] Maleki, A., Sajadi, S., & Rezaee Khaboushan, B. (2014). Explanation and Improvement Performance Indicators of the Emergency System Using Discrete Event Simulation (Case Study: Arak Imam Khomeini Hospital). *Health Information Management*, 11(1), 16.
- [15] Zeinali, F., Mahootchi, M., Sepehri, MM. (2015). Resource planning in the emergency departments: A simulation-based metamodelling approach. *Simulation Modelling Practice and Theory*, 53, 123-138.
- [16] Ben-Tovim, D., Filar, J., Hakendorf, P., Qin, S., Thompson, C., Ward, D. (2016). Hospital Event Simulation Model: Arrivals to Discharge – Design, Development and Application. *Journal of Simulation Modelling Practice and Theory*, 68(11), 80 -94.
- [17] Qin, S., Thompson, C., Bogomolov, T., Ward, D., Hakendorf, P. (2017). Hospital occupancy and discharge strategies - a simulation based study. *Internal Medicine Journal*, 47(8), 894-899.

HOW TO CITE THIS ARTICLE

M.A. Kamran, B.Karimi, *Investigating and Analysis of Hospital Performance Using Discrete Event Simulation*, *AUT J. Model. Simul.*, 52(2) (2020) 1-11.

DOI: [10.22060/miscj.2020.17697.5195](https://doi.org/10.22060/miscj.2020.17697.5195)

