

ORIGINAL ARTICLE

Using Queuing Theory and Simulation Modelling to Reduce Waiting Times in An Iranian Emergency Department

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ABSTRACT

Background: Hospital emergencies have an essential role in health care systems. In the last decade, developed countries have paid great attention to overcrowding crisis in emergency departments. Simulation analysis of complex models for which conditions will change over time is much more effective than analytical solutions and emergency department (ED) is one of the most complex models for analysis. This study aimed to determine the number of patients who are waiting and waiting time in emergency department services in an Iranian hospital ED and to propose scenarios to reduce its queue and waiting time.

Methods: This is a cross-sectional study in which simulation software (Arena, version 14) was used. The input information was extracted from the hospital database as well as through sampling. The objective was to evaluate the response variables of *waiting time*, *number waiting* and *utilization* of each server and test the three scenarios to improve them.

Results: Running the models for 30 days revealed that a total of 4088 patients left the ED after being served and 1238 patients waited in the queue for admission in the ED bed area at end of the run (actually these patients received services out of their defined capacity). The first scenario result in the number of beds had to be increased from 81 to 179 in order that the *number waiting* of the “bed area” server become almost zero. The second scenario which attempted to limit hospitalization time in the ED bed area to the third quartile of the serving time distribution could decrease the *number waiting* to 586 patients.

Conclusion: Doubling the bed capacity in the emergency department and consequently other resources and capacity appropriately can solve the problem. This includes bed capacity requirement for both critically ill and less critically ill patients. Classification of ED internal sections based on severity of illness instead of medical specialty is another solution.

KEYWORDS: Computer simulation; Emergency department; Hospital bed capacity; Length of stay; Queuing theory

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INTRODUCTION

Hospital, as an important section of health care settings, has a major impact on disease prevention, early detection, treatment and rehabilitation of patients.¹ Hospital emergencies have an essential role in the health care system by now. In the last decade, developed countries have paid a great attention to emergencies department overcrowding crisis and its impact on increasing the serving time and ability to meet the medical emergency needs.²

Hospital services worldwide focus on occupancy and discharge rates to manage their executive capacity and the most practical approach is the use of queuing theory.³ The main elements in queuing theory include people seeking services, entry processes, queue form, queue discipline, and services process. EDs, like others in the service industry, must predict customer *waiting times* at different levels of services⁴ but lack of control over customer services demands can complicate an ED's capacity planning. Simulation analysis of complex models for which conditions will change over time is much more effective than analytical solutions and an ED is one of the most complex models for analysis.⁵

Many studies used queuing theory to simulate ED. Gracia et al. simulated ED with and without a fast track lane to serve non-urgent patients. They concluded that it could reduce the length of stay in non-urgent patients by almost 25% without increasing length of stay for urgent patients. The best scenario was to use one nurse and one bed for fast track.⁶

A study was conducted in Chile to predict how much emergency room's demand can be increased without increment in the waiting time over an acceptable level. The response variable "time in system", that represents the total time a patient spends inside the emergency room, was used as a service level parameter. The researcher found that 4.5 physicians (four fulltime and one halftime) are required to maintain "time in system" in

the acceptable level of 100 minute. They also concluded that the hospital can build just one extra examination room.⁷

Another study implemented a new approach to patients flow in ED. It evaluated the efficacy of placing an emergency physician at triage who works with triage nurses. The study showed that it could improve the ED operation.⁸

In our country, EDs provide services to approximately 30 million patients each year. The main priority of the Ministry of Health is, therefore, improving their condition as the heart of the health care system.¹ The rate of critically ill patients' admission to public hospitals is high because public emergency services are less expensive than private ones. Also, as a rule, emergency medical services have to transport patients to public hospitals' EDs and the EDs are obliged to accept all of these patients even when they are blocked.⁹ These factors can cause even more overcrowded and complicated public EDs.

A study in Iran indicated that the most common causes of prolonged stay in ED were its bed shortage, lack of clear guidelines for prompt hospitalization of near to death patients, assessing the patients by multiple services and the absence of a clear diagnosis for patients because laboratory and imaging results were not ready on time.⁹

Unlimited admission in EDs, high population coverage, and limited diagnostic and therapeutic facilities result in long queues and increased patient delay; therefore, increasing ED's efficiency is a priority of the Ministry of Health in Iran. However, due to the complexity and variability of patients' arrival process, improvement of its condition is difficult without using new technology.

The purpose of this study was to determine the number of patients currently waiting in queues and also patients' waiting time in an Iranian specialty and subspecialty hospital ED and offer some solutions to decrease these indicators by minimal changing of server utilization.

MATERIALS AND METHODS

This is a cross-sectional study in which simulation software (Arena, version 14) was used. Approval for this study was given by the Ethics Committee of Shiraz University of Medical Sciences with the code of EC-92-6533.

System Description

Shahid Faghihi Hospital is one of the two referral hospitals which provide services to about five southern provinces in southern Iran. Most critically ill patients who cannot be managed in other centers are referred to this hospital. There is overcrowding crisis here because of high arrival rate and inpatient bed shortage. Its ED works 24 hours a day and seven days a week. In spite of its physical space limitations, it must admit all patients indefinitely, regardless of their emergency or non-emergency condition. When the patient arrives at the ED and enters the triage area, a triage provider (a nurse) takes a brief history and enters the patient's data in the hospital database. This provider sends almost all patients to the screening section to be visited

by a general physician. In the screening section, some patients are discharged and others are admitted for more evaluations in internal, surgical and gynecology emergency rooms (IER, SER and GER). As a rule, in these emergency rooms, decision should be made for each patient in a maximum of six hours (decision-making indicator). These patients may have one of the following three plans: some are discharged from the hospital, others are admitted in internal or surgical urgent care units (IUCU and SUCU), or they are admitted in other specialist wards. Internal and surgical urgent care units are other parts of ED whose role is to deal with less critical cases than emergency rooms. Patients in these units are later either admitted in a specialty hospital ward or discharged from the hospital. The flow diagram is shown in Figure 1.

In fact, inpatient's beds shortage makes the patients stay in ED more than expected and due to lack of resources each ED's urgent care unit serves as inpatient wards with long length of stay.

Hospital services such as laboratories, CT scan, MRI, ultrasonography, radiology, endoscopy, echocardiography and electrocardiography

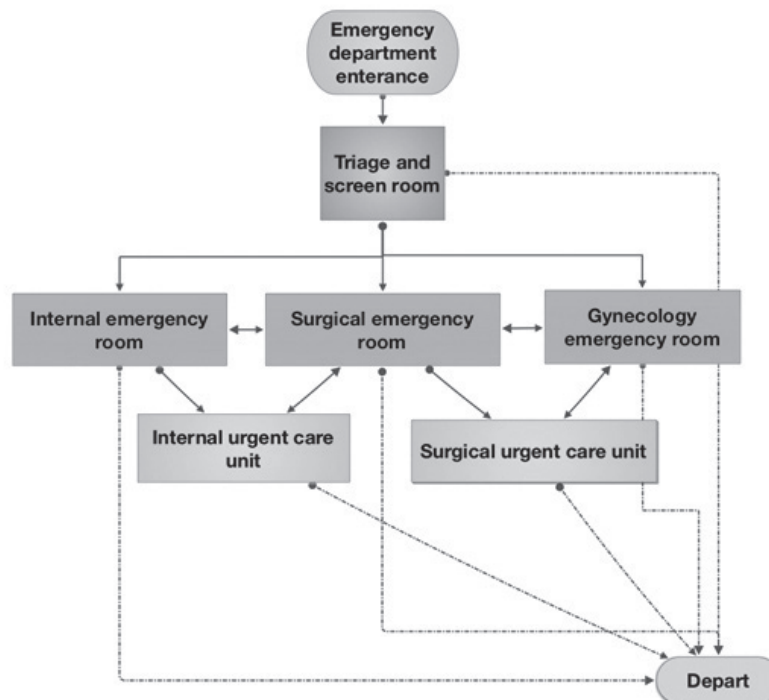


Figure 1: Patients' flow diagram in emergency department of Shahid Faghihi Hospital

provide services to the majority of inpatients as well as outpatients.

Simulation Model

Arena (version 14) (a discrete event simulation software) was used to simulate ED queues.

It should be mentioned that any destination other than admission in the five sections of ED bed area (IER, SER, GER, SUCU and IUCU) was considered as “departure”.

We simulated this ED at four levels in the software. We presented more details of the ED in the higher levels. The first level is an overall schematic of the whole ED that shows the flow of all patients that arrive at it. The second level represents different parts of the bed area and shows the flow of patients who are admitted in the bed area. The third level was divided into two subcategories of 3-1 and 3-2, each representing the details of the internal and surgical wards respectively and showing its arrival destination.

In the first level, the patients had two destinations: leaving the ED without

admission or being admitted in the bed area. A single server module was used for the bed area, which is representative of two urgent care units and three emergency rooms (Figure 2). A server module is defined as a station corresponding to a physical or logical location where processing occurs.¹⁰

In the second level, the bed area was expanded into 2 emergency wards (internal and surgical), and one gynecology emergency room. Each emergency ward consisted of one emergency room and one urgent care unit. The arrival of this model was a proportion of total emergency department arrival entering the bed area. These patients were admitted in one of these two emergency wards or the gynecology emergency room. Then, they might be transferred between these three servers due to change in their diagnosis. (Figure 3)

In the two subcategories of the third level, (Figures 4 and 5), each emergency ward was expanded into its emergency room and urgent care unit. The arrival of level 3-1 was a proportion of total ED arrival that enters the IER. They were admitted in IUCU or

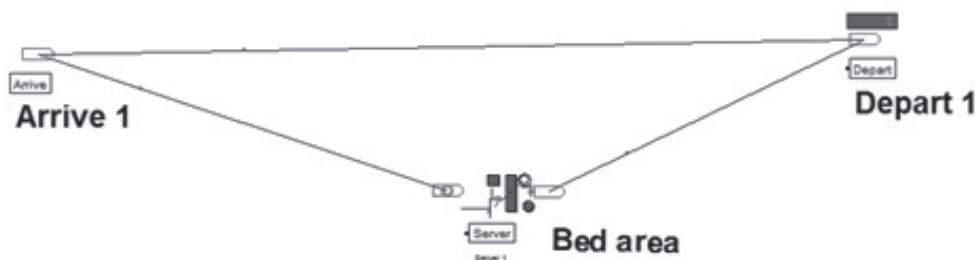


Figure 2: Level 1. Schematic of the whole ED entry divided into inpatients (admit in bed area) or outpatients (depart directly)

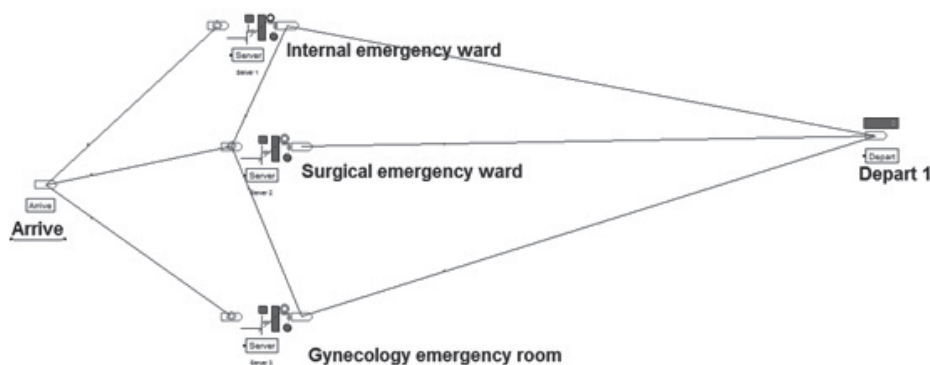


Figure 3: Level 2. Expansion of the bed area: Bed area’s entry divided into two wards and an emergency room

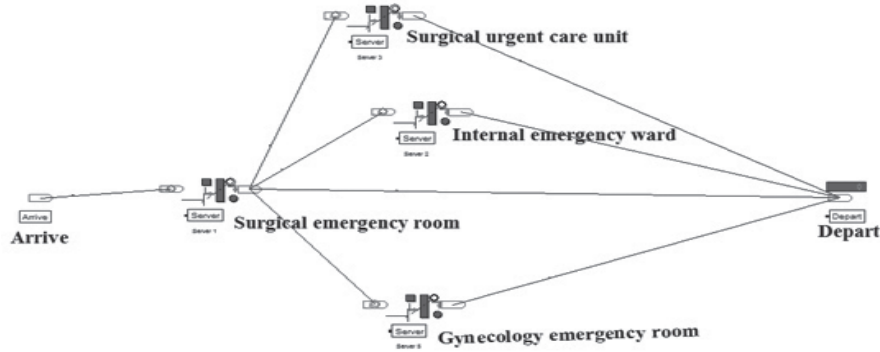


Figure 4: Level 3-1. Expansion of the internal emergency ward into an internal emergency room and an internal urgent care unit

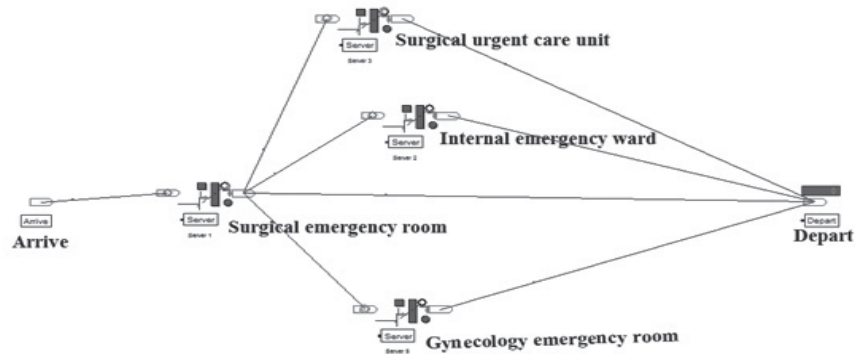


Figure 5: Level 3-2. Expansion of the surgical emergency ward into a surgical emergency room and a surgical urgent care unit

transferred to SUCU due to change in their impression. Arrival of Level 3-2 also consisted of those who entered SER like the previous model (3-1).

Parameter and Variable Definition

The parameters required for building the models included serving time, capacity of each server and route time for transferring between wards. Serving time was defined as the time interval between entrance and exit from a section. During admission in the ED, the majority of patients required some diagnostic workups such as radiography, laboratory test and ultrasonography and many treatment services were required for all patients. All these serving times were included in the interval between entrance and exit from a ward.

The capacity of each clinical ward and room module was equivalent to the number of approved fixed beds in these sections, because the number of beds was designed based on the physical area, and the number of staff

and devices, such as monitor, respiratory care support and so on, was fitted for them.

The route time data was estimated based on ED personnel's expression of minimum, maximum and modal times needed for transferring between wards.

In this study, response variables included: *Number Out*, *Waiting Time*, *Number Waiting*, *Instantaneous Utilization*, *Total Number Seized*, and *Number Busy*, *Number Out* is the average total number of entities for which Entity Statistics were recorded. *Waiting Time* is defined as the period of time since the client enters a queue until he/she exits the queue. *Number Waiting* is the number of entities waiting in each queue. *Scheduled Utilization* is calculated by dividing the average *Number Busy* by the average *Number Scheduled*. *Number Busy*: This section reports the number of busy resource units. Number busy is a time persistent statistic¹⁰ which means the function will repeat itself throughout the simulation at all points of time and return the average value at the end of simulation.¹¹

Data Collection

The input data for the models were obtained from both the hospital information system as well as sampling. Sampling was necessary because hospital database was inaccurate and imprecise in some areas such as patients' length of stay. All patients who entered the ED, irrespective of their urgent or non-urgent condition, were included in the study. For inpatients sections, all patients who received any care were included and if they did not accept to be served in ED, they were not included in sampling.

The arrival distribution function was fixed to one year's ED arrival data (from March 2012 to February 2013) by input analysis of arena software. The arrival data were extracted from the hospital information system. Also, the percentage of patients distributed indifferent sections of ED was obtained from the information system.

Sampling

A pilot study was carried out for calculating the serving time distribution function. The sample size for the pilot study was determined by a statistician and also by the ED experts' opinion. In ten random days of one month, 10 patients' serving time was collected from each of the two emergency rooms and three urgent care units (50 samples totally) Standard deviation (SD) was calculated for each of these sections separately. According to the consulting statistician, acceptable margin of error (d) was determined 0.2 SD and sample size was calculated using the Sample Size Calculator and Power Analysis (Power SSC) software.

The calculated sample sizes were as follows: IER (SD=738.09), sample size=96; SER (SD=920.11), sample size=100; IUCU (SD=1648.20), sample size=98; SUCU (SD=2858.53), sample size=97; and GER (SD=498.59), sample size=100. Therefore, overall 491 serving time samples were collected for the main study. Since the random sampling of individual patients was not possible, the samples were collected in random days of a randomly selected month of

a year. It means we randomly selected a month of a year and estimated the average number of ED entrance on its days from previous year hospital data. Then, according to estimation of the number of patients who enter ED in each day, the number of days was calculated appropriate to the determined sample size. So, the required number of days was randomly selected in that month. In these days, the patients' exact arrival times were registered as the patients entered the ED. Their departure times were recorded from the nurses' note in their charts.

Execution of the Models

The simulation models were run for one month to smooth out the variability of ER patients' entry on different days of a week and different consecutive weeks.

Due to the system starting in an empty state and the ER continuously operating 24 hours per day, the models had a warm up period of 6 days when the system predominantly reached a steady state.

The objective of this study was to evaluate the response variables of *waiting time* and *number waiting* in queues in each level of ED as well as *utilization* of each server, and offer scenarios to improve them. In this study, we intentionally evaluated univariate experiments to show the relative importance of individual factors that are thought to be most effective on ED overcrowding and no combination of factors was experimented.

To improve these variables in ED, we tested three univariate scenarios:

1. Increase the capacity of servers until the *number waiting* in the queue approaches zero (a negligible queue).

2. Limit the serving time by excluding the fourth quartile in our sample serving time distribution in each emergency room and unit separately.

3. Increase the capacity of servers until the *utilization* variable reaches approximately 80%, when the servers can overcome the variability of patients' arrival pattern. This is standard for an ED.¹² Above this level, the

risk of bed shortage becomes substantial.

It must be mentioned that for increasing the bed capacity there is a need to increase other resources and capacities appropriately. The second scenario was tested because the serving times in the upper quartile of the serving time distribution are not common and occur occasionally. It was assumed that this scenario did not harm the treatment process. It would be clear by this scenario that if we could improve the serving process as well as specialist wards bed access, how much change in *waiting time* and *number waiting* could be obtained.

RESULTS

The validity of the model was confirmed by comparison of simulation results with expert opinions and hospital actual data. This kind of comparison is the best way to validate simulating models.¹³ Multiple replications were done for each model and due to similarity with one replication result, it has not been reported.

The Results of the First Model (Level 1)

In this model, the patients were divided into inpatient and outpatient groups after arriving at the triage section. Approximately, 60% of incoming emergency patients required hospitalization and the rest of them were served on outpatient basis.

The simulation model was run for a period of one month. In this period, a total of 4088 patients left the ED after being served

and 1238 patients waited in the queue for admission in the ED bed area. Other variables are shown in Table 1.

In the first scenario, the number of beds had to be increased from 81 to 179 so that the *number waiting* of “bed area” server became almost zero. (Table 1)

The second scenario attempted to reduce the hospitalization serving time in the ED. For this purpose, it was assumed that if we wanted to exclude the upper quartile in the serving time distribution, we had to attempt to limit hospitalization time in ED bed area to the third quartile’s maximum of 6878.5 minutes (about 5 days) in the IUCU, 809.3 minutes (about 13.5 hours) in the IER, 5224.5 minutes (about 3.5 days) in the SUCU, 194.8 minutes (about 3 hours) in the SER, and 455.8 minutes in the GER (the upper value of inter-quartile range). (Table 1)

In order to achieve a *utilization* of 80%, when the emergency rooms and units could overcome the variability of patients’ arrival, the capacity had to be increased from 81 to 200 beds in the bed area of the ED (Table 1).

The Results of the Second Model (Level 2)

In this model, the “bed area” server in level 1 was expanded into 3 servers which included an internal emergency ward, a surgical emergency ward, and a GER. The numbers of approved fixed beds in the internal, surgical and gynecology emergency wards were 55, 21 and 5 beds, respectively (Table 2).

When both surgical and internal emergency

Table 1: Level 1 results (The model was run for 30 days)

Simulation	Variables Number Out	Waiting Time (min) All emergency wards and rooms	Number Waiting All emergency wards and rooms	Utilization	Number busy
Current situation	4088	16006	1238.81	1.00	81.00
First scenario: Queue approaches zero Beds=179	5824	5.4	0.43	0.89	160.1
Second scenario: Serving time limited to Quartile75%	4833	7425	586.78	1.00	81.00
Third scenario: utilization decrease to 0.8	5835	0	0	0.83	166.2

Table 2: Level 2 results (The model was run for 30 days)

Servers	Variables	Number Out	Waiting Time (min)	Number Waiting	Utilization	Number busy
Total level 2-1		1453				
	Internal emergency ward		17848	781.42	1	55
	Surgical emergency ward		18688	613.97	1	21
	GER ¹		3.10	0	0.41	2.07
First scenario: surgical and internal emergency ward's queue approaches zero						
Total level 2-1		3499				
	Internal emergency ward		78.54	3.55	0.95	134.94
	Surgical emergency ward		46.53	1.49	0.88	62.51
	GER ¹		4.38	0	0.36	1.82
Second scenario: serving time was limited to the third quartile						
Total level 2-1		2003				
	Internal emergency ward		11329.94	474.44	1	55
	Surgical emergency ward		16861.80	536.71	1	21
	GER ¹		1.30	0.007	0.39	1.94
Third scenario: internal and surgical emergency ward and GER utilization is about 80%						
Total level 2		3472				
	Internal emergency ward		0	0	0.81	129.27
	Surgical emergency ward		0.82	0	0.79	61.57
	GER ^a		154.14	0.88	0.67	2.01

^aGynecology emergency rooms

ward's queues approached zero, their capacities were 71 and 142 beds, respectively. (Table 2)

In the second scenario, the results of reducing serving time to the maximum upper value of the third quartile of the serving time distribution are shown in Table 2.

Finally, we simulated the model to obtain *utilization* value of 80% in all of these three sections. For this purpose, the capacity of internal emergency ward and surgical emergency ward had to increase from 55 to 160 beds and from 21 to 78 beds, respectively. Also, it had to be reduced from 4 to 3 in the GER. (Table 2)

The Results of the Third Model (Level 3-1)

In this model, we mainly focused on the IER and IUCU, which were two sections of the internal emergency ward. In level 3-1, we focused on the interaction between these two sections and also surgical emergency ward. Surgical emergency ward's whole arrival is not included in this model, so its utilization is only in relation to interaction with IER and

IUCU. Currently, the bed capacity in the IER, IUCU and surgical emergency wards are 14, 41 and 21, respectively. The results of the simulation are shown in Table 3.

In the first scenario, we tried to respond the question: how many beds are necessary in the IER and IUCU in order that no one has to wait for a bed?

After running the model with different capacities, this goal was finally met by having 40 beds in the IER and 83 beds in the IUCU (Table 3).

The results of the second scenario, in which serving time was reduced to the upper value of the third quartile, are summarized in Table 3. To obtain the *utilization* of 80% in both IER and IUCU, 40 and 85 beds were necessary, respectively. (Table 3)

The Results of the Fourth Model (Level 3-2)

In this model, we mainly focused on the SER (with 7 beds) and the SUCU (with 14 beds), which were two sections of the surgical emergency ward. The interaction details among these sections and the internal emergency ward

Table 3: Level 3-1 results (The model was run for 30 days)

Servers	Variables	Number Out	Waiting Time (min)	Number Waiting	Utilization	Number busy
Level 3-1		911				
IER			14511.60	667.80	1	14.00
IUCU			125.10	1.1	0.91	37.17
Surgical emergency ward			0	0	0.04	0.80
First scenario: IER and IUCU queues approach zero						
Level 3-1		1941				
IER ¹			14.40	0.65	0.83	33.27
IUCU ²			32.48	0.46	0.88	72.90
Surgical emergency ward			0	0	0.09	1.86
Second scenario: Serving time was limited to the third quartile						
Level 3-1		1745				
IER ¹			1750.87	78.80	1	14
IUCU ²			4165.69	58.38	1	40.99
Surgical emergency ward			0	0	0.05	1.14
Third scenario: IER and IUCU utilization is about 80%						
Level 3-1		1926				
IER ^a			7.65	0.34	0.80	32.10
IUCU ^b			0.68	0.01	0.84	71.11
Surgical emergency ward			0	0	0.07	1.55

^aInternal emergency room; ^bInternal urgent care unit

and GER are shown in Table 4.

The second scenario tested the reduction of the serving time to the maximum upper value of the third quartile of the serving time distribution in the SER and urgent care unit. As shown in Table 4, no patient was waiting in queue any more.

In this model, the first and third scenarios had the same result. As the SER capacity increased to 14, the queues of both SER and urgent care unit approached zero and their *utilizations* was almost 80%. (Table 4)

DISCUSSION

Evaluating the factors that affect the reduction of patient waiting queues in ED is one of the most important issues in many hospitals worldwide. The present study used queuing theory to simulate the effects of increasing the number of beds and decreasing LOS in an ED. In real life, there are many contributing factors. However, in any model a few of such factors can be used.

As the scenarios show, exclusion of forth-quartile of the current value in serving time

distribution can partially reduce the queues, so increasing the ED capacity (represented by number of beds) is inevitable. As a result, if we want to have no patients waiting in the queue for admission to the ED, we have to approximately double the number of beds. It is clear that this change needs to be associated with an appropriate increase in the number of physicians, staff, equipment and other necessities.

Before discussing the models, it must be noted that the people waiting in the queue are patients who have received care beyond the approved capacity, on stretchers and by doctors and nurses who have no suitable time to treat or take care of them. Also they are confronted with the shortage of necessary devices such as ECG monitors, oxygen capsules, respirators, etc.

Current Situation

The current situation in the ED was simulated in 4 levels. The higher the level, the greater the details of the ED presented in the model. It must be mentioned that all the results

Table 4: Level 3-2 results (The model was run for 30 days)

Variables	Number Out	Waiting Time (min)	Number Waiting	Utilization	Number busy
Servers					
Level 3-2	750				
SER ¹		12855.15	401.53	1	7.00
SUCU ²		0	0	0.49	6.92
Internal emergency ward		0	0	0.01	0.31
GER ³		0	0	0	0.02
Second scenario: Serving time was limited to the third quartile					
Level 3-2	1336				
SER ¹		0	0	0.26	1.83
SUCU ²		7.53	0.03	0.59	8.32
Internal emergency ward		0	0	0.01	0.33
GER ³		0	0	0	0.02
Third scenario: SER and SUCU utilization is about 80%					
Level 3-2	1282				
SER ¹		50.50	1.53	0.8331	11.66
SUCU ²		354	1.12	0.75	10.49
Internal emergency ward		0	0	0	0.12
GER ³		0	0	0.01	0.05

¹Surgical emergency room; ²Surgical urgent care unit; ³Gynecology emergency room

obtained from the models and scenarios are simulated for a period of one month.

Level 1 or the whole ED model (Table 1): Currently, the approved capacity of the ED is 81 beds. The simulation results show the following: 4088 patients (including inpatient and outpatient) are discharged from the ED and 1238 patients are waiting in the queue for the bed area. As mentioned earlier, these 1238 patients who are in queue will receive care beyond the approved capacity of the ED's bed area each month. More detailed examination of this process in the following levels makes the problem more visible.

Level 2 or the ED bed area model: (Table 2): In this model, the "bed area" was expanded into 3 specialized sections and their interaction was evaluated in detail. The number of approved fixed beds in the internal emergency ward was 55 beds, in surgical emergency ward 21 beds and in gynecology ward 5 beds. As mentioned, 1453 patients were served according to the approved capacity and 1395 (614+781) patients waited in the queues for the internal and surgical wards. It means that from 2929 (1453+1395+81) patients who entered the ED bed area, about 50% (1395)

received care on stretchers and beyond the approved capacity. As the *utilization* in the internal and surgical wards is equal to one, on average their capacity is full in any given period. At this time, only 40% of the capacity is occupied in GER in the same given period and on average 2 out of 5 beds are busy. So, the resources are wasted in this section. Although, in critical conditions, 3 unoccupied beds in the GER were used by other services (internal and surgical wards), this occurred rarely.

Level 3-1 or the extended model for internal emergency ward (Table 3): In this model, sections of the internal emergency ward, IER (14 beds) and IUCU (41 beds), were studied separately. As the results show, the IER is a bottleneck with patients' *number waiting* 40% (667 patients) of the entry to the IER (911+667+41+14). This means only 60% of the patients who enter the IER are served according to the approved capacity and the other 40% receive treatment on stretchers in corridors and beyond the capacity which was originally designed for. All its beds are occupied in any given period while *utilization* is nearly 1 in the IUCU and its queue is almost zero. By increasing the IER capacity,

the bottleneck will be shifted to the IUCU. However, it can be concluded that both the IER and IUCU capacity should be increased simultaneously to solve the problem.

Median LOS in the IER is 6.25 hours with inter-quartile range (IQR) of 225-809 minutes, while in the IUCU, median LOS is about 74 hours (IQR of 45-114 hours). As can be seen, more than half of the patients stay more than 6 hours in the IER, which is beyond the standard of “decision-making indicator” and much higher than the LOS in two Tehran hospital’s emergency rooms (about 283 minutes).¹⁴ Although comparison between the hospitals due to their special situations is difficult, it may be necessary to have a basis for comparison. On the other hand, LOS is over 3 days for more than half of the patients in the IUCU. A probable cause is hospital access blockage which prevents admission of patients who need specialized care.

Level 3-2 or the extended model for surgical emergency ward (Table 4): In this model, the two sections of the SER (with the current capacity of 7 beds) and SUCU (current capacity 14 beds) were studied separately. SER is identified as the bottleneck in this model. Its capacity of 7 beds keeps 400 persons in the queue monthly. It means that about 34% of the 1511 patients received care beyond the approved capacity.

The median LOS in the SER and SECU is about 1 hour (IQR: 10-194 minute) and 51 hours (IQR: 30-84 hours), respectively. This indicates that most patients are discharged from the SER in less than 6 hours (decision-making indicator). Nonetheless, there is more than one quarter stay over 3 days in the SUCU. Although these statistics are much better than the IER and IUCU, the LOS is still very high in the SUCU.

The overall findings in all four levels of the ED show that between 34% -50% of patients were served beyond the fixed approved capacity in each section; this means crowding. According to the definition of the American College of Emergency Physicians, “crowding occurs when the identified need

for emergency services exceeds the available resources for patients care in the emergency department, hospital or both”.¹⁵

In addition to the low capacity, this ED suffers from capacity discrepancy between sections and induces bottlenecks which worsen crowding.

ED crowding is common in 15 non-USA countries described in an article. It is a major problem in Iran with 438 EDs and no clear policies outlined by its government to handle this issue. Current policies are to develop EDs in the country with the goal of increasing the ED’s capacity.¹⁶ One of the best ways is to understand how much is required to raise the capacity. Predicting the required beds in this study is one of the best ways to solve this issue.

First Scenario: Increase Bed Capacity to Reduce the Number Waiting in the Queue to Almost Zero

One of the most common causes of delay in patients’ admission is ED access blockage, which means no bed is available for any patient requiring emergency admission.^{16,17} But how many beds are required to reduce waiting patients to almost zero? This question was answered in the first scenario.

Level 1 or the whole ED model (Table 1): The number of beds must increase more than two-fold and has to reach 179 beds (from 81 beds) in order to no one having to wait in the queue.

This result is not unexpected because as the HIS data shows, 77% of the patients discharged from the bed area are identified as cured. Given the fact that this hospital is one of two referral hospitals in the south of the country, the majority of the patients in this setting are critically ill. The fact that about 80% of the patients receive treatment in the ED and are discharged without any need for specialized interventions in the relevant sections is up to debate.

One probable reason for this predicament is overcrowding of the specialized wards (hospital access blockage). The patients queuing for these wards have to stay for a long period and receive specialized treatment in the

ED (LOS ranging between 3-30251 minutes).

Level 2 or the ED bed area model (Table 2): In order to achieve the goal of no one waiting for admission in the internal and surgical wards, 71 beds (3.4 times increase) and 142 beds (2.6 times increase) are required respectively (overall 213 beds). These figures are somewhat different from the results of the first scenario of level 1 (179 beds). One probable reason is that the wards team up with each other if necessary and the “bed shortage risk” will pool between the wards in level 1. It means that the capacities of all five sections of bed area have been used for accommodating ED admission in level 1, so the bed shortage is less than the expanded models (level 2, 3-1, 3-2). In these expanded models, each section serves patients separately and sections do not cover the shortages of each other. These latter models are more realistic in this hospital because little collaboration exists between the sections of the ED except in critical conditions. This result may indicate that classification of patients into surgical and internal groups is inappropriate for this crowded ED because overloading of one of these services in critical situations, such as vehicle accidents, epidemic of influenza and so on, can block one ward while the other services have the capacity to serve patients.

The other reason is that the GER in level 2 has unoccupied capacity which results in more overall bed requirement than level 1.

It must be mentioned that despite 22% (51662 to 63054) increase in patients’ entry from 2010 to 2012, this hospital’s ED capacity has not had a significant increase from several years ago. However, increasing the ED capacity to this number will be very difficult due to some limitations.

Level 3-1 or the expanded model for internal emergency ward (Table 3): To achieve the goal in this scenario, 40 and 83 beds are required for the IER and IUCU, respectively. Because they are serial servers, IER to IUCU’s capacity proportion should be kept at 1:2. As seen, in this study, only the ED was simulated and other specialized wards in the hospital

were not included in these simulation models. However, with increase in ED capacity, the bottleneck will shift to specialized wards where currently there is also a shortage. So it is reasonable to increase the hospital bed resources simultaneously.

What this study confirms is that without increasing the bed capacity of the hospital wards, or developing a holding unit, incrementing the ED bed resources will only cause the bottleneck shifting and will not have long term effect.

Level 3-2 or the expanded model for surgical emergency ward (Table 4): In this level, the model suggested a reduction in the SUCU capacity in order to achieve the goal of the scenario, which is not logical. Overall, in order to achieve the first scenario’s aim in all four levels, there is a need to raise the number of beds 2-2.5 fold. This number of beds includes those which are required for more stable patients so adding a holding unit can partially solve the problem. Increasing inpatient beds is another solution. A systematic review showed that one of the best solutions for this problem is adding a holding unit to the ED which serves non-critically ill patients.¹⁵ In another country, one of the most important causes for overcrowding is bed shortage in the ED and the best solution is to increase the number of ED and hospital beds as well as establishing a holding unit.¹⁷ In our setting, this problem can be solved by adding a holding unit to ED or increasing inpatient beds to improve ED departure rate.

To deal with the ED overcrowding in Canada, current policies have focused on increasing the number of critically ill patients’ beds in appropriate intervals according to changes in population size, demographic conditions, patients’ vigilance and technology. Developing holding units and building capacity of hospital wards as well as increasing trained and qualified personnel are other solutions for consideration.¹⁸

For increasing the number of ED beds suggested by the present study, we recommend adding a holding unit as an attachment to

ED in order to serve less critical patients and decrease the ED load.

Second scenario: Exclusion of the Fourth Quartile of the Serving Time Distribution

One of the possible solutions to ED crowding is facilitating early discharge.¹⁹ This scenario tests how helpful this can be.

Level 1 or the whole ED model (Table 1): In this scenario, the assumption of earlier discharge was examined. The high value of the upper quartile in "serving time probability distribution" was excluded from the data. So, LOS was limited to the upper value of 75% in each ward. The maximum LOS in the IER, SER, GER, IUCU and SUCU is reduced to about 13.5, 3, 7.5 hours, 5 days and 3.5 days, respectively. The results show a decrease in ED queue and *waiting time* to less than half of the current values but all of the beds in ED are still occupied (*utilization*=1). This fact suggests that such reduction in LOS, by itself, cannot result in *number waiting* not even close to zero.

Level 2 or the ED bed area model (Table 2): In the second scenario, queue status was examined under the condition of earlier discharge. With this reduction in service time, despite a decline of about 40% in internal and about 13% in the surgical emergency ward's queue, the number of waiting patients is still very high. This scenario implies that even early discharge of patients does not reduce waiting patients significantly, perhaps due to the high level of patient entry to ED. However, as other studies show, this approach has some limitations, but along with other strategies, it can somehow reduce ED overcrowding.¹⁹ Several strategies can be implemented to discharge patients much earlier. One of these strategies is to employ highly qualified and experienced staff and doctors who have the ability to make quick decisions and have swift performance.²⁰ Also, availability of a holding unit as well as specialized hospital beds to admit patients as soon as possible is another important and effective solution. With these strategies, patients will receive their treatment in the wards instead of staying for a long

period of time in the ED.

In general, as seen in this model, the GER *utilization* changes with any type of manipulation in the capacity or LOS at internal or surgical emergency wards because of complexities in the interactions between them. Predicting interactions without the usage of a simulation model is very difficult (albeit not impossible). As a result, before changing any part of this system, its effect must be predicted on the other parts and sections, because sometimes by increasing the capacity of a section, the other section will be faced with crisis of bed shortage.

Level 3-1 or the expanded model for internal emergency ward (Table 3): When serving time (LOS) decreases to less than 13.5 and 114 hours in the IER and IUCU respectively, a reduction of about 90% is induced in the IER queue while *number waiting* in the IUCU increases. This occurs because of shifting in bottlenecks. However, the number of patients who receive health care according to approval capacity (*number out*) increases approximately by 2-fold.

Level 3-2 or the expanded model for surgical emergency ward (Table 4): If the LOS can be limited to 194 minutes and 84 hours (upper value of IQR) in the SER and SUCU respectively, then no one needs to wait in queue. As it is seen, busy bed to fixed bed percentages are 26% and 60%, respectively. Likewise, another study showed further reduction in LOS is likely to be finite and the long term potential of this kind of policy is limited.¹⁹

Alavi-Moghadam et al. in 2012 also found that occupancy capacity declined by 50%, when the discharge capacity increased by 50%. However, although it could reduce working pressure, it had no significant effect on the average patients' length of stay. The average leaving time of the emergency beds was 28 minutes, but over 50% of the patients did not leave the bed for more than 20 minutes after discharge. They concluded that patients who are going to be discharged must wait for final paraclinic results and final decision. They recommended using discharge areas for

this purpose.²¹

It is possible to speed up serving the patients with better use of the existing resources such as employing experienced personnel and physicians with power, speed and accuracy of decision-making, performance and ability to work in the stressful and high-speed environment of ED. Inexperienced nurses and physicians in an ED can congest the system, increase medical error, and waste the resources.²⁰ In other previous studies, authors argued that increasing the patients' departure rate has more impact on improving overall ED length of stay than increasing the total number of ED beds.^{22,23} In fact, earlier departure can also be effective but has some limitations in this hospital. In fact one of the main causes of the ED overcrowding is inpatient bed blockage. There was no significant increase in its capacity since many years ago despite the increase in target population. As it was shown in the second scenario, decreasing LOS can lower the patients' waiting time but it is hard to eliminate it.

Reduce the Utilization to Approximately 80%

Level 1 or the whole ED model (Table 1): A benchmark for ED is to reduce bed occupancy to about 80% to overcome the degree of variability in patients' entry. For this purpose, the second scenario was designed to achieve the "utilization" 80%. In this case, the number of beds should be increased to 200 beds (2.5 times of the current capacity) to overcome the crisis such as floods, earthquakes, epidemics and so on.

Level 2 or the ED bed area model (Table 2): Assuming that all other variables remain constant, to standardize the ratio of active beds to fixed beds (80%), 160 and 78 beds are required in the internal and surgical emergency wards, respectively. By reducing the number of beds from 5 to 3 in GER, utilization will be increased to 66%. Any more reduction in the number of beds will elevate the utilization to more than 90%, which is not desirable.

Level 3-1 or the expanded model for internal emergency ward (Table 3): To achieve the scenario goal, 40 and 80 beds are required in the IER and IUCU, respectively (2 and 3 fold increases respectively). The 1:2 ratio is preserved here, too. In all scenarios in this level, 1-2 beds are required as a result of surgical emergency ward's interaction with the IER and IUCU. This capacity should be added to the number of bed requirement predicted in level 3-2 results.

Level 3-2 or the expanded model for surgical emergency ward (Table 4): In this scenario, if the number of beds in SER becomes 14 (a 2 fold rise), then the utilization (busy bed to fixed bed ratio) approximates 80%. Even more beds in the SER will increase the SUCU utilization more, so the first scenario (both utilizations approximating to 1) is unachievable. The number of bed requirement in the internal emergency ward as a result of the interaction with the SER and SUCU is not more than 0.3. So, this number should be added to the capacity of the internal emergency ward, resulting from the level 3-1 model.

As far as we have searched, other simulation studies have focused on two or three para-clinical workups for patients.^{5,7-24} In practice, physicians request multiple workups at multiple times for one patient. So, these studies simulate a simplified ED. The present survey used real patients' LOS which included all workups and treatments to simulate a real ED. On the other hand, in our country, most of the previous studies have focused on waiting time in reception and visiting by a physician in ED.^{25,26} In contrast, in the present study, queues of the ED bed area are under consideration.

This study had some limitations in collecting data because the hospital information system's data was not correctly registered by nurses. On the other hand, sampling of patients' serving time was difficult due to overcrowding of the ED. Since accurate information is an important part of any research, it is recommended that data entry of this database should be improved.

CONCLUSION

This study showed the magnitude of this ED's overcrowding. We concluded that decreasing the LOS can somewhat resolve the problem but cannot eliminate it. The other solution and the fundamental one is to increase bed capacity to more than 2 fold. Establishment of a holding unit can partially help. On the other hand, any increase in section bed capacity should be appropriate to other sections and also to hospital beds.

Also, the classification of patients into surgical and internal specialty is not appropriate for such a crowded ED because critical conditions can cause blockage of one of these services, while the other services have the capacity to serve the patients. So, classification of ED internal sections based on the severity of the illness may be more appropriate in this ED. Future studies should focus on the bed requirement for critical care and holding units separately.

Except for increase in hospital bed capacity, other solutions will decrease blockage in the ED but cannot eradicate it. There is only one real solution: increase hospital bed capacity. But the question is: when should we address this problem?

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