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Research paper

Performance Improvement of the Yellow Zone in Emergency Department using Discrete Event Simulation Approach

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Abstract

Overcrowding is a major concern for the Emergency Department (ED) management at the public hospital under study. Although the number of patients in the Yellow Zone (YZ) of the department represents only 30% of the total visiting patient per day, the Key Performance Indicator (KPI) of the zone's patients' LOS (LOS) as well as waiting time are not achievable due to the resources constraints. Therefore, this paper discusses the application of Discrete Event Simulation (DES) approach on modeling the YZ's daily operations. The model was developed using Arena software to assist the ED management to better understand their system behavior and causes for the high patients' LOS and waiting time. The simulation outputs show that the bottleneck of the system is waiting for an available resource. A few scenarios were designed based on the discussion made with the ED management for possible improvement. The results show a significant reduction of 25% and 35% in the total average of patients' LOS for the patients of the observation unit and the intensive unit respectively. Meanwhile, for the total average patients' waiting time, the results show a reduction of 34% for the observation unit and 29% reduction for the intensive unit.

Keywords: *Discrete Event Simulation; Emergency Department; LOS; Waiting Time; Utilization Rate.*

1. Introduction

The Emergency Department (ED) understudy serves more than 150,000 patients annually and operates non-stop for 24 hours daily. There are three zones in the ED: green zone (non-critical patients), yellow zone (YZ; semi-critical patients) and red zone (critical patients) but only YZ will be the focus in this study. The ED management has been working hard to achieve their Key Performance Indicators (KPIs) target for each zone in the ED to measure their performance.

Based on several interviews with the ED management, they understood that the increase in patients' LOS (LOS) and waiting time (WT) were caused by the mismatch in the department's capacity and demands. They believed and aware that they need to add more human resources to solve the problem, but before it can be done, they need to identify exactly the number of resources required and which resources are to be added in the system. Therefore, to help the ED management in the decision-making process, the Discrete Event Simulation (DES) approach was proposed to develop the YZ's daily operations model.

Previous studies have shown that the problem ascends due to resources constraints in the department, where it is seriously important to have a proper planning and reallocation of the resources [1, 2]. ED management has implemented various actions to deal with these issues. Adding and reallocating the resources directly into the current system are common ED management decisions to overcome the problem. The decision-making process are mostly being done manually by trial and error basis. In some cases, the outcomes of such decision may lead to even disastrous situation. Any decisions with uncertain implications will only risk the whole operation of the ED, thus the management need to study every detail in the operation before the final decision can be made.

One of the best approaches to help the ED management is DES. DES is chosen for its capability to model a replication of complex system such as the ED [1]. DES is proven to be the most efficient and cost-effective tool to apply modifications to the system without affecting the actual operations [3]. It has been used widely in healthcare field especially in modeling the ED's operations and for the analysis of patient flow [4, 5]. Some of the studies use DES to estimate the capacities of ED, suggest for some improvements, reduce waiting time as well as LOS and throughput time [6]. DES supports animations and also graphics visualization which makes it a right approach to easily communicate with the ED management. The animations provide better understanding of the system and justification for factual figures.

The objectives of this study are to model the system operations for better understanding, to determine the impact of resources to the ED's KPIs and to provide possible improvement scenarios for system improvement.

The next section briefly discusses the flow of patient through the YZ system. Section 3 describes the development of YZ simulation model including the verification and validation process. Section 4 presents the simulation results and experimentation of the suggested improvements. The last section discusses the conclusion and future work.

2. Yellow Zone System Overview

2.1. Patient flow

Patient usually arrives at the ED by ambulance or personal or public transport (walk-in patients). Upon arrival, patient will be triaged at the triage counter before they proceed with the registration at the registration counter. Critical patients will be immediately sent to the red zone and patient's registration process will took place later by the relative(s). The registration process for semi-critical patients (YZ) also will be performed later. Then, patient will go through the secondary triage by nurse on duty to monitor the health condition of the patient.

YZ under study are divided into two units, observation unit (OBU) and intensive unit (IU). Many patients are not fit enough to be discharged immediately and need an extra observation before released home. They will be temporarily observed for more than 2 hours at the OBU until their condition is stable. For those who cannot sit or stand, they will be placed at the IU for initial assessment before being admitted to the designated ward. Usually, 90% of the YZ patients will be admitted.

After receiving an initial assessment from the medical officer (MO), the patients will be informed either further investigations (e.g. lab tests, CT-Scan, X-rays) are required or not. Results from the processes are reviewed by the MO and decision will be made either they should be discharged or to be referred to the specialist of the ED or other departments (based on their illnesses). A specialist together with ED's MO must decide whether the patients need to be admitted, discharged or require more tests and procedures such as toilet and suturing, plaster of paris, close manual reduction, etc.

Any admitted patients will have to wait in the ED until ward bed is available. Non-admitted patients' health conditions will be observed at the observation unit before being discharge. MO will prescribe them with medicine to be collected at the pharmacy counter before leaving the hospital. Figure 1 shows the patient flow through YZ which begins from the patient's arrival until they are discharged or admitted to the ward.

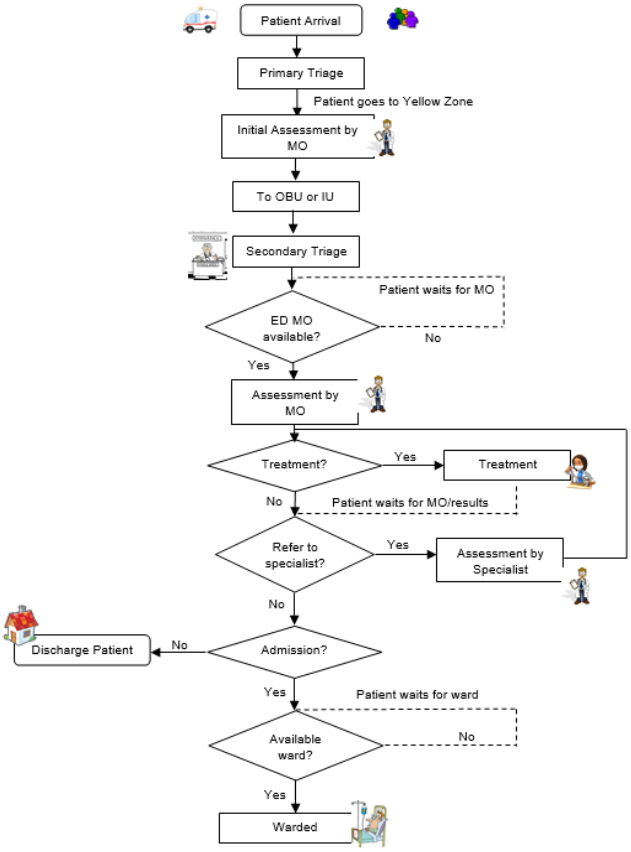

Fig. 1: YZ patient flow

2.2. Departmental resources

Currently, the YZ operates with 2 MOs (1 for OBU and 1 for IU), 1 specialist, 3 to 4 nurses and 6 medical assistants (MAs) as shown in Table 1. The work shifts are shown in Table 2.

Table 1: Departmental resources

Resource	Other Units	OBU	IU
Medical officer (MO)		1	1
Medical assistant (MA) • Triage • Laboratory • X-Ray	 2 2 2		
Nurse (N) • Shift 1 and 2 • Shift 3		 4 3	 4 3
Specialist (S)		1 for both unit	
Bed		12	12
Chair		10	

Table 2: Human resource work shifts

Resource	Shift 1	Shift 2	Shift 3
MO and S	10 am – 5 pm	5 pm – 12 am	12 am – 10 am
MA and N	7 am – 2 pm	2 pm – 9 pm	9 pm – 7 am

3. Simulation Model Development

The modeling phases in constructing the simulation model of YZ is based on the phases defined by [7] as shown in Figure 2.

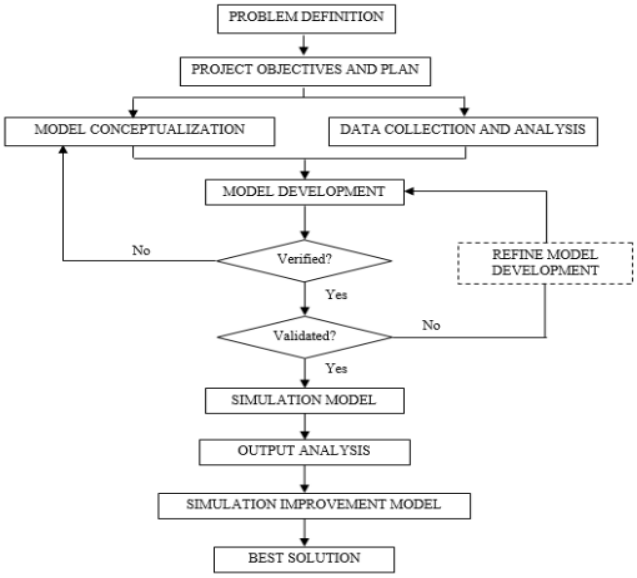

Fig. 2: Simulation modeling phases

3.1. Data collection

The first phase in simulation model development is data collection. A few meetings and discussions were conducted with the ED management to clearly understand the process flow and operations of the YZ. This step is followed by reviewing ED documents through database system and conducting a few field observations. Based on previous activities, we found that the data of the processing times for certain activities in the YZ is not available and need to be collected manually. Based on discussion with the manager, a data collection form was designed and were distributed among the data collection team.

The team members are placed at each required activity (triage counter, X-Ray, etc.) to observe the processing times (such as time taken to draw blood or time taken to do X-Ray). The data are collected for 24 hours in one-month period. However, other data were also obtained from daily log books, database system and interviews (such as number of resources occupied, number of patients served and patient's arrival time). The collected data are validated

by ED specialists to minimize errors and later it will be converted into distribution functions in Arena software. It will be used in the simulation modeling.

3.2. Model construction

Simulation model development starts with investigating the system, which includes observations of the ED layout, patient flows, relationship for each activity and available resources. The early investigations help us to understand the YZ system and its day-to-day operations. It involved identifying what processes are required and the constraints. A few assumptions were defined together with the ED management to limit the complexity of the flow because some of the assumptions does not affect the system.
The main resources (patients, units such as OBU, IU, triage, laboratory and X-Ray, human resources and beds) of YZ are illustrated into the conceptual model. It represents the patient flow through YZ while getting treatment. This model is translated into simulation model using the Arena software 14.1. All processes involved were designed into modules and then they are connected based on the conceptual model.

3.3. Model verification and validation process

Completed simulation model is verified by the ED experts to ensure the model replicates the current YZ system operations. The model is executed and reviewed by the experts to inspect for any occurrence of errors in the flow, and improvement will be made until the experts agreed with the implemented flow. Next, the simulation model is executed for a few iterations and the outputs such as number of patients for each activity are used for the validation process. Validation is a process of confirming the simulation model represents the actual operating environment [8].
Authors in [9] stated that if the model is not a close approximation to the current system, any conclusions draw from the model are likely to be erroneous. Therefore, for this purpose, we used 2 validation steps in this study; the expert judgments and validation calculations. The results of the model are presented to the ED experts and we confirmed the validity of the results based on their knowledge and experiences. The results are compared to the original data collected using the formula in (1):

$$Difference\ (\%) = \frac{|\,Simulation\ output - Actual\ data\,|}{Actual\ data} \times 100\% \quad (1)$$

Based on the above formula, the calculated difference must be no more than 10% for the simulation model to be valid and achieved its accuracy level [10].
The simulation model is executed for 7 days period and the results obtained compared to the original data collected for 7 days are shown in Table 3. Since all the validation percentage are less than 10%, we concluded that the simulation model is valid and can be used as a tool for the next phase.

Table 3: Validation results between original data and simulation outputs (in minutes)

Process	Original Data	Simulation Output	Validation (%)
Total number of patients			
• OBU	237	241	1.68
• IU	101	98	2.97
Total number of patients out from X-Ray	202	197	2.47

4. Results and discussion

The ED management under study is intended to serve every patient arrived and eliminate the overcrowding situation. However, when the YZ is full, some patients who are supposed to be admitted were treated along the corridor until they are released. In this case, the YZ's nurses must also monitor those patients regularly before they are transferred to the designated ward.
There are 3 outcomes monitored in the simulation model as follows; total average patients' LOS, total average patients' waiting time and resources utilization rate. The results are as presented in Table 4.

Table 4: Simulation model outputs

	OBU	IU	Other Units
Total average patients' LOS (minutes)	423.16	356.63	
Total average patients' waiting time (minutes)	376.24	294.22	
Utilization rate			
• MO	79	80	
• Nurse	83	86	
• MA			81
• Specialist	79 (both OBU and IU)		
• Bed	87	89	
• Chair	89		

From Table 4, the total average LOS per patient is 423.16 minutes (7 hours) for OBU patients and 356.63 minutes (5.9 hours) for IU patients. Meanwhile, the total average patients' waiting time is 376.24 minutes (more than 6 hours) for patient in OBU and 294.22 minutes (4.9 hours) for patient in IU. Based on the meetings with the ED management, sometimes the patient must wait at YZ for more than 24 hours before being transferred to the designated ward. In this study, we also look at the result of resources utilization rate because to design the improvement scenarios, we need to identify either the available resources do affect the system or not. According to [11], the acceptable range of good utilization rate for service sector is between 70% to 80% and this is not achievable as the utilization rate for all resources are between 79% to 89%.

4.1. Designing an improvement model

Based on the above simulation results, several modifications to the YZ simulation model were presented and discussed with the ED management to improve the model. This is because only the ED management know their current available resources and physical layout of YZ. The improvement model is designed by adding resources to the current system where necessary and reschedule their timetable.
There are 4 improvement scenarios suggested and implemented in the current simulation model as shown in Table 5. The suggested improvement scenarios are implemented in the simulation model and executed for 24 hours per week as same as the original simulation model. Some human resources are rescheduled based on the patient's arrival pattern. Based on ED's record, number of patients for YZ are usually increased during shift 2 and shift 3 (between 2 pm to 1 am).

Table 5: Suggested improvement scenarios

Simulation Model Improvements (SMI)	Scenarios
SMI_1	Add: 2 MO (each for OBU and IU) at every shift, 1 Specialist, 2 nurses at shifts 2 and 3.
SMI_2	Add: 12 beds at IU, 12 beds and 6 chairs at OBU, 1 MA at triage during shifts 2 and 3.
SMI_3	Add: 2 MO (at shifts 2 and 3), 1 Specialist at shift 3, 2 nurses at shifts 2 and 3, 1 MA at triage, 6 beds and 6 chairs at OBU.
SMI_4	2 MO from shift 1 reschedule to work at shifts 2 and 3. Add: 1 Specialist at shift 3, 12 beds at IU, 12 beds and 6 chairs at OBU, 4 nurses at shift 3 and 2 MA at triage for shifts 2 and 3.

SMI_5	1 specialist reschedule to work at shift 2 and 1 for shift 3. Add: 2 MO, 2 nurses at shifts 2 and 3, 1 MA at triage every shift, 12 beds at OBU and 12 beds at IU.

4.2. Improvement model results

The best simulation improvement model is determined by its outputs of average total patients' LOS, average total patients' waiting time and the utilization rates of resources. Based on the results obtained, SMI_4 is selected as the best improvement model and the results are presented in Table 6.

Table 6: Simulation improvement model 4 (SMI_4) results (in minutes)

	OBU		IU	
	SMI_4	Reduction	SMI_4	Reduction
Total average patients' LOS (minutes)	315.55	25%	231.27	35%
Total average patients' waiting time (minutes)	248.32	34%	208.50	29%
Utilization rate				
• MO	68	14%	71	11%
• Nurse	64	23%	73	15%
• Specialist	65 (both OBU and IU) 18% reduction			
• Bed	74	15%	78	12%
• Chair	71	20%		
• MA (other unit)	69 (15% reduction)			

Table 6 shows the comparison in percentage reductions between original simulation model results in Table 4 with SMI_4. The total average patients' LOS for OBU patients is reduced by 25% which is about 107.61 minutes reduction. Meanwhile, the total average patients' waiting time for OBU patients is also reduced by 34% (127.92 minutes reduction). For the IU patient, the total average patients' LOS is reduced by 35% which is about 125.36 minutes reduction. Meanwhile, the total average patients' waiting time is also reduced by 29% (85.72 minutes reduction). The ED management has set the KPI of total average patients' LOS is to be less than 4 hours and total average patients' waiting time is to be less than 2 hours. Even though, the new total average patients' LOS and waiting time does not meet the KPI of the YZ but still the reduction does help the ED management. The results have shown that the number of resources does affect the system performance. Because of that additional and rescheduling of resources, the utilization rate of resources also reduced significantly within the range of 70% to 80% as compared to the current system. This result is important to the ED management, so they can use it to present to the top management of the hospital and justify the need for an additional resource in the YZ.

5. Conclusion

The simulation model developed in this study has allowed the ED management to perform risk-free what-if analysis that can be used to reduce the total average patients' LOS as well as patients waiting time. The early results of the simulation model show that the OBU patients must be monitored at YZ for about 7 hours on average before they were transferred to the designated ward and wait for about 6 hours in total for the availability of resources. Meanwhile, for patient in IU, they must be monitored for almost 6 hours on average before being admitted to the ward and wait for resources availability for almost 5 hours in total. This may contribute to the overcrowding situation because when the number of patients keeps increasing while the current patients are not released from the YZ, the ED management must allocate the new patients along the corridor. This situation might be dangerous and life threatening to the patients themselves. Besides, it will also contribute to dissatisfaction among patients and human resources (will cause medical errors and fatigue).

Based on such situations, the improvement scenarios were designed and proposed to the ED management. The simulation improvement model has shown that human resources are critical resources that highly impacted the performance of the YZ. The total average patients' LOS, patients' waiting times as well as utilization rates of the resources have been reduced significantly. Even though the results have improved the system performance, there are still many limitations encountered due to the constraints involved. Many assumptions had to be made to reduce the complexity of the model development. Those will be included in the next phase of the study. Some of the external constraints such as CT scan or inpatient beds, which is from other unit of the hospital that also affected patients' LOS and waiting time, are not included in the model development. We believe that the external resources also give an impact to the YZ performance. For incoming research, these constraints will be included and studied in detail to achieve a more accurate and reliable results.

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