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Modelling and Improving Efficiency of Emergency Department's Green Zone Using Discrete Event Simulation

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***Abstract*—This study aims to optimize patient flow within the Green Zone of a Hospital Emergency Department in Kuala Lumpur by focusing on reducing patient waiting times and improving staff workload caused by overcrowding and operational inefficiencies. A model was developed to replicate current Green Zone operations and evaluate scenarios to optimize staff allocation and identify the bottlenecks by using Discrete Event Simulation (DES) in ARENA software. The model has been verified by medical professionals and validated against real-world data with an acceptable deviation of less than 10%. Implementation of the optimized model significantly reduced average patient waiting times from 174.50 minutes to 60.65 minutes. Doctor utilization rates also decreased from 97.00% to 76.66%, indicating improved resource efficiency and workload distribution. The application of DES in optimizing patient flow within the Green Zone demonstrated significant improvements in both patient experience and operational efficiency. The approach holds potential for broader implementation across other departments and healthcare facilities in Malaysia.**

***Keywords*—Emergency department, overcrowding, efficiency, discrete event simulation**

I. INTRODUCTION

A hospital is a medical facility equipped with an organized team of medical and professional staff and beds for the continuous hospitalization of patients admitted for medical observation, care, diagnosis or both surgical and non-surgical treatment [1]. Within a hospital, one of the most critical units ensuring immediate patient care is the Emergency Department (ED).

As mentioned by Aminuddin *et al*., (2016), the ED plays a vital role as the frontline of patient care and often serves as the hospital's "front door", where patients first receive medical attention before being referred to other departments [2]. Operating 24 hours a day, the ED provides services for a wide range of cases including critical, semi-critical and non-critical patients.

Despite its essential role, overcrowding remains a persistent issue worldwide. A survey conducted by the American College of Emergency Physicians and reported by NBC News revealed that 97% of emergency physicians had patients waiting in the Emergency Room for more than 24 hours, while 28% reported patients being held for over two weeks before admission [3]. Similarly, Brivedelli *et al*., (2021) found that in Canada 60% of ED visits were non-urgent and 30.8% were urgent with risk of death and hospitalization increasing at higher priority levels [4]. In Turkey, the Social Security Institution defines emergency health situations as conditions that require immediate medical attention within 24 hours due to sudden illness, injuries or other circumstances that could threaten life or health integrity if not promptly treated or transferred [5].

In Malaysia, demand for ED services has risen significantly with statistics showing a 3.3% increase in cases at the University Malaya Medical Centre and a 5.8% increase at Tengku Ampuan Rahimah Hospital in 2012 [6]. It is also reported that the non-critical cases, commonly managed in the Green Zone represent 62.1% of all ED visits [6]. The increase has led to overcrowding as more patients seek immediate treatment for non-life-threatening conditions [7]. Contributing factors of the problem include rising patient numbers, limited resources, and delays in transferring admitted patients to wards. In addition, staff shortages—particularly among doctors and other healthcare workers—further exacerbate the problem. Due to that, they have been forced to extend their working hours that affecting service quality and increasing the risk of medical errors [8]. The Green Zone is notably more congested than the Yellow and Red Zones that cause longer waiting times, treatment delays, reduced patient satisfaction and higher staff workload. In some hospitals such as Hospital Kulim, patients wait up to five hours before receiving care due to limited medical personnel [9]. Addressing these challenges requires strategies to reduce waiting times and optimize staff utilization.

Several methods have been employed to address overcrowding in EDs with the Discrete Event Simulation (DES) method emerging as a primary approach especially for the Green Zone. Ibrahim *et al.*, (2023), applied DES in Arena Software to model patient flow by identifying bottlenecks in consultation rooms, x-ray facilities and laboratories [10]. By introducing additional resources, the study successfully reduced consultation waiting times from 126.36 minutes to 48.14 minutes and shortened the overall patient length of stay by 36.48%. These results demonstrate that resource augmentation when guided by simulation can directly mitigate congestion.

Besides that, other researchers have focused on process optimization rather than simply adding resources. Atalan (2023), employed DES to test alternative patient flow models in the Green Zone by achieving modest improvement in waiting times. While less impactful than resource augmentation, the study highlighted that even minor workflow adjustment could ease overcrowding [11]. Similarly, Aminuddin (2021), combined DES with Data Envelopment Analysis (DEA) to optimize resource allocation without increasing staff numbers [6]. By restricting shift schedules, it led to cost efficiency especially for public hospitals operating under budget constraints.

Beyond ED settings, DES has also been applied to improve efficiency in inpatient care. Rasidi *et al.*, (2024), developed a DES model to optimize nurse scheduling and bed allocation across inpatient zones by reducing nurse overutilization from 100% to an optimal 70-80% while improving patient flow [12]. These findings are consistent with Sartini *et al.*, (2022), and Savioli *et al.*, (2024),, who emphasized that simulation-based approach is well suited to address throughput and resource management issues that drive overcrowding [13, 14]. Building on these insights, the present study applies DES to enhance efficiency in the Green Zone. The study integrates both resource augmentation and process optimization by offering a balanced solution for a real-world Malaysia hospital context. By simulating alternative staffing schedules and operational workflows, the research aims to reduce patient waiting times, improve staff performance and alleviate overutilization. This dual approach ensures not only short-term improvements but also long-term sustainability, thereby contributing to the growing body of evidence that DES can be effectively tailored to local healthcare systems.

II. METHODOLOGY

This study employs DES to model and analyze the Green Zone system at a Malaysian hospital. Data for this study were collected through hospital records, direct observation and staff input by focusing on patient arrival patterns, service durations and resources availability.

In the first step, data were collected from an ED located in Kuala Lumpur with the scope limited to the Green Zone. The collected data included patient arrival patterns, service times and resource utilization. The second step involved developing the simulation model which was constructed based on patient flow in the ED using Arena Software. In the third step, the model was verified and validated to ensure accuracy and reliability. The next step involved running the model to generate results which were to identify bottlenecks and inefficiencies. Finally, the findings were documented and improvement strategies were proposed based on the simulation outcomes. Fig. 1 illustrates the flowchart outlining the steps involved in building the DES model.

Fig. 1. Steps to build Discrete Event Simulation Model

III. DISCRETE EVENT SIMULATION

A. System Description

Green Zone is designated for non-critical patients, where the process flow begins with patient arrival, registration and triage before proceeding the consultation with doctors. During the problem analysis and data collection stage, this workflow was carefully examined to capture the sequence of activities and the utilization of available resources. The analysis indicated that the consultation stage emerged as the most significant bottleneck with higher doctors' utilization rates and longer waiting times for a patient before the treatment. Such inefficiencies in resource allocation highlighted the urgency of developing a simulation model to accurately replicate the system by enabling systematic evaluation of current performance and identification of potential improvements within the zone. Nurses in the ED work in three shifts. Table I presents the shift schedules, while Table II outlines the number of doctors assigned to the Green Zone.

TABLE I. NURSE'S TIMETABLE

Shift	Time
Morning	7.00 a.m. – 2.00 p.m
Evening	2.00 p.m. – 5.00 p.m
Night	9.00 p.m. – 7.00 a.m.

TABLE II. NUMBER OF DOCTOR ON DUTY IN EVERY SHIFTS

Time	Numbers of Doctors on Duty
7.00 a.m. – 10.00 a.m	1
10.00 a.m. – 5.00 p.m	3
5.00 p.m. – 11.00 p.m	3
11.00 p.m. – 7.00 a.m.	2

B. Simulation Modelling

Following the data collection process, the ARENA Input Analyzer was employed to fit appropriate probability distributions to the collected data. Table III presents the distribution and expression generated through the Input Analyzer that were subsequently applied in the DES model.

TABLE III.THE DISTRIBUTION AND EXPRESSION USED IN THE DES MODE

Item	Distribution	Expression
Arrival	LogNormal	-0.5 + LOGN (7.98, 6.39)
Primary Triage	Gamma	0.5 + GAMM (0.844,1.89)
Triage 1	Triangular	TRIA(5, 10, 20)
Triage 2	Triangular	TRIA(5, 10, 20)
Registration	Triangular	TRIA (2, 3, 5)
Green Zone	Triangular	TRIA(14, 21, 68)

C. Model Verification and Validation

Verification was conducted by reviewing the model's logic, flow and parameters to ensure that it accurately represented the intended system. The model was presented to medical professionals for evaluation and their feedback confirmed that the model appropriately reflected the real operational processes. Besides that, validation was achieved by comparing simulation output with actual hospital data on waiting times and staff utilization. The model was considered valid when results fell within a 10% error margin from real-world observation [15].

To ensure the accuracy and reliability of the developed model, a validation process was carried out by comparing the outputs of the simulation with actual ED data. In addition, sensitivity analyses were conducted to test the robustness of the model under different scenarios and to evaluate its response to variations in input parameters. This step was essential to verify that the simulation not only replicated real-world performance but also maintained consistency when subjected to changes in system condition. The validation process followed the approach suggested by [16] in which percentage difference between the simulation results and the actual ED data was calculated using the equation below.

$$Difference\ (\%) = \frac{|Simulation\ Output - Actual\ Data|}{Actual\ Data} \times 100$$

According to this criterion, the model is considered valid when the difference between simulated and real data falls within an acceptable threshold, typically not exceeding 10%. In this study, the validation results confirmed that the differences were consistently within this range, thereby demonstrating that the simulation model closely represented the actual performance of the ED system. This provided confidence in the model's ability to serve as a reliable decision-support tool for analyzing and improving the Green Zone's efficiency. The percentage of model error has been presented in Table IV.

TABLE IV. THE PERCENTAGE OF MODEL ERROR

Item	Actual Data	Simulation Output	Error (%)
Number of Patient Arrival	200	215	7.5
Number of Patient in Green Zone	130	143	10.0
Number of Patient Arrival	200	215	7.5

D. Simulation Output

The analysis in Table V indicates that the main cause of congestion in the emergency department is the long waiting time in the green zone treatment area, where patients wait an average of 174.5 minutes before receiving treatment. This significantly exceeds the recommended standard of 120 minutes set by the hospital management. In contrast, the waiting times at the primary and secondary triage stages are relatively short, showing that these processes are managed efficiently and are not contributing to the bottleneck.

Meanwhile, the utilization data in Table VI reveal that doctors are operating at an exceptionally high rate of 97.53 percent, well above the recommended optimal range of 70 to 80 percent [17]. Such overutilization suggests that doctors are overburdened, which increases the risk of burnout and reduced quality of care. By comparison, primary triage, secondary triage, and registration nurses have utilization rates within the ideal range, indicating that the staffing challenge lies primarily with the availability of doctors. These findings emphasize the urgent need for better resource allocation and workload distribution to reduce delays, improve patient flow, and maintain staff well-being in the emergency department.

TABLE V. AVERAGE PATIENT WAITING TIME

Activity	Waiting Time (min)
Primary Triage	0.21979
Secondary Triage	25.372
Registration	0.22784
Green Zone	174.50

TABLE VI. UTILIZATION RATE OF STAFF

Source	Staff Utilization (%)
Nurse Triage 1	21.886
Nurse Triage 2	61.091
Nurse Registration	22.776
Doctor	97.526

E. Design of Alternative to Resource Allocation

Once the simulation model was validated, it was employed to evaluate alternative resource allocation strategies with the objective of minimizing patient waiting times and optimizing staff utilization. Several adjustments were tested by focusing on adjustments to staffing levels and patient triage processes and the results were carefully analyzed to identify the most effective approach. The most effective solution was the strategic addition of one doctor during each peak period specifically from 7:00 am to 10:00 am and 10:00 am to 5:00 pm, to ensure that staffing levels are more closely aligned with the patient arrival patterns. By introducing this adjustment, the model seeks to address the challenge of prolonged waiting times while promoting a more balanced distribution of workloads among doctors. This approach emphasizes the importance of matching resources to demand at critical hours while enhancing the overall responsiveness and efficiency of the healthcare delivery system. The detailed adjustments have been presented in Table VII.

TABLE VII. THE ADJUSTMENTS IN DOCTOR'S SCHEDULE

Time	Number of Doctor	
	Before Improvement	*After Improvement*
7.00 a.m. – 10.00 a.m	1	2
10.00 a.m – 5.00 p.m.	3	4
5.00 p.m. – 11.00 p.m	3	3
11.00 p.m – 7.00 a.m .	2	2

IV. RESULTS AND DISCUSSION

The findings from the study indicate that the DES model demonstrated an acceptable level of accuracy during validation with error differences less than 10%. While waiting times at the primary and secondary triage stages were relatively short. A major concern was observed in the Green Zone where patients experienced an average waiting time of 174.5 minutes before receiving improvement and reduced to 60.65 minutes while optimizing doctor utilization from 90% to 76.66% which considered the efficiency standard. According to [17], the ideal range for effective manpower utilization in emergency department resources is between 70% and 80% while the ideal waiting times is below 120 minutes for the Green Zone. These modifications not only improved patient flow and minimized delays but also ensured a more sustainable workload for medical staff, ultimately supporting the delivery of timely and high-quality patient care. Table VIII shows the results of waiting times in Green Zone and doctor utilization rates after improvement in doctor's schedule.

TABLE VIII. VIMPROVEMENT RESULT

Source	Improvement	
	Before	*After*
Waiting Time (min)	174.50	60.658
Doctor Utilization Rate (%) .	97.526	76.657

The findings of this study highlight that the most effective solution for addressing overcrowding in the Green Zone of the Emergency Department is the optimization of doctor schedules through the addition of staff. This adjustment successfully reduced the average waiting time from 174.50 minutes to 60.65 minutes and lowered doctor utilization from an unsustainable 97.53 percent to an optimal 76.66 percent. These outcomes directly fulfill the study's objectives of reducing patient waiting times and ensuring more efficient use of medical resources.

The improvement in waiting times carries important implications for healthcare delivery. Shorter waiting periods not only reduce the overall length of stay in the emergency department but also contribute to better patient outcomes, as timely medical intervention lowers the risk of condition deterioration. Fewer complications are also likely when non-critical patients are treated promptly, leading to higher levels of patient satisfaction. For medical staff, balancing workloads helps prevent fatigue and burnout, ensuring that the quality of care is consistently maintained. Collectively, these results demonstrate that operational efficiency brings both clinical and organizational benefits.

When compared with other studies, this research offers a distinct contribution. [10] proposed resource expansion, such as adding consultation rooms and equipment, which effectively reduced waiting times but required significant financial investment. [11] focused on process refinement, although the improvements reported were only marginal. [6] combined Discrete Event Simulation with Data Envelopment Analysis to reallocate staff across zones, producing strong results in a broader context. This study differs by demonstrating that scheduling-based reallocation within the Green Zone alone can yield substantial improvements, making it a practical and sustainable solution for resource- constrained hospitals.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

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