SSRG International Journal of Industrial Engineering
ISSN: 2349 – 9362 / https://doi.org/10.14445/23499362/IJIE-V11I2P102
Volume 11 Issue 2, 16-30, May-Aug 2024
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*Original Article*

# Optimizing ER Flow: Strategies and Insights from An Emirates Case Study

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Received: 28 May 2024 Revised: 03 July 2024 Accepted: 20 July 2024 Published: 08 August 2024

***Abstract*** - *Overcrowding and long wait times in emergency departments are serious issues that can impact patient safety and health. Reduced waiting time, on the other hand, allows the system to provide faster services in such emergencies. Therefore, the main objective of this study was to apply the discrete event simulation method and DMAIC to reduce patient waiting time, overcrowding, and system efficiency in the emergency department of Burjeel Hospital. The results showed that the average waiting time can be reduced from 37.88 minutes to 29.36 minutes. Furthermore, the reduced waiting time helped decrease the number of patients inside the ED by three at one time, leading to less ED overcrowding. Moreover, the overall average system efficiency was improved. In addition, the proposed reconfiguration of Burjeel's Hospital Emergency Department (ED) aims to enhance patient flow and resource utilization. By introducing specialized treatment pathways and nurse allocation strategies, the hospital seeks to address waiting time challenges and improve overall efficiency. Expected outcomes include reduced wait times and improved patient outcomes. Advanced methodologies such as Data Envelope Analysis (DEA) will assist in selecting the most effective scenario for optimized ED performance.*

***Keywords*** - *Emergency department, Simulation, Waiting time, Utilization, ED, DMAIC.*

## 1. Introduction

In several countries, the problem of overcrowding inside hospital Emergency Departments (ED) has become an essential and notable challenge. The overcrowding phenomenon has a varied impact on ED operation, specifically by extending the time required to administer sepsis-related antibiotics, as evidenced by many ED studies. Furthermore, the harmful consequences of crowding extend to the delay in the treatment of fractures and the provision of care for individuals suffering from asthma-related conditions. An interesting observation in the context of ED overcrowding is that it often necessitates the diversion of incoming ambulances. However, it does not significantly influence overall mortality rates.

An investigation conducted by [1, 2] into this subject matter has revealed a significant association between ED crowding and an elevated likelihood of in-hospital mortality among admitted patients. The primary objective of this project is to provide practical and highly effective resolutions to the well-defined challenges at hand. The recommendations represent fundamental components of a robust and high-quality healthcare system that enhances patient safety and overall satisfaction by reducing waiting times to a minimum.

The core objective of this project is to utilize the discrete event simulation tool for modeling and conducting an in-depth analysis of waiting times and operational efficiency within the Emergency Department (ED) of Burjeel Hospital. We will adopt the (Define, Measure, Analyze, Improve, Control) methodology called the Six Sigma DMAIC methodology. The primary focus of this objective is to significantly reduce patient waiting times while concurrently enhancing the overall efficiency of the ED, thus mitigating issues related to overcrowding and expediting service delivery to emergency patients. To assess patient wait times accurately. We will factor in variables such as resource availability and potential errors or variations that may arise during treatment. Our approach will involve using simulation techniques to construct and analyze multiple scenarios. These scenarios will incorporate considerations like adding resources and identifying various sources of errors and variations, which will subsequently be suggested and thoroughly evaluated. This extensive analysis will act as a foundation for addressing the ED's operational challenges and increasing the quality of patient care.

This paper is organized as follows: a literature review of strategies to increase waiting times in emergency departments is shown in Section II. Section III focuses on the Six Sigma research methodology and discusses the structured approach adopted for process improvement and its application within the study context. Experiments and results are introduced in Section IV. Section V shows various aspects related to the planning, execution, monitoring, and control of the project and focuses on evaluating and discussing the effects and implications of the proposed

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engineering solution. Finally, the conclusion of the paper is provided in Section VI.

## 2. Related Work

### *2.1. Discrete Event Simulation in Emergency Departments*

Within the scientific literature, various research studies have utilized the power of simulation modeling, particularly Discrete Event Simulation (DES), to reduce patient wait times effectively within hospital settings. One notable illustration is the work presented in [3], conducted in Wisconsin, USA, where the author employed a discrete event simulation approach to assess the performance of an Emergency Department (ED). This simulation model examined the difference between the number of patients admitted to and discharged from the ED. The study incorporated a comprehensive, complete factorial design, with a particular emphasis on two essential components. The author's findings ensure the significance of not categorizing ED diversion when patients were discharged from the ED in under five hours or when admitted patients did not exceed a six-hour stay within the ED. In a significant contribution to the field, the authors of [4] introduced an innovative model designed to enhance the performance of hospital emergency departments within the United States. This strategy is specifically developed to solve the issues that hospitals face, such as the absence of medical staff and bed availability, to minimize patient wait times.

In a study by [5], patient dissatisfaction within the emergency departments of Quebec hospitals in Canada was comprehensively investigated. The authors conducted extensive research into factors that lead to patient delays, which increased patients' overall length of stay in the emergency department. The primary aim of [6] was to determine the optimal resource allocation necessary to address resource shortages within the context of radiation therapy. To achieve this, the research team developed a robust model that employed discrete-event simulation techniques to map out the entire patient journey from consultation with radiation oncologists to radiotherapy treatment. This model considered every step and resource involved in the process.

In 2023, a comprehensive analysis of healthcare services within the Ethiopian context was conducted by [7], focusing on performance enhancement. Their research focused on using discrete event simulation to measure critical parameters such as patient output, service rate, and service efficiency, aiming to mitigate patient waiting times and optimize resource utilization. Authors of [8] utilized the power of FlexSim software to construct a queuing model tailored to a healthcare center located at Mississippi State University. The study [9] introduced a simulation model designed for the emergency department (ED) at Lexington Hospital in the USA. Their study evaluated patient flow, minimized patient length of stay, and identified critical processes to enhance ED performance. Concurrently, the authors of [10] directed their research towards enhancing the efficiency of ED processes, reducing patient length of stay, and improving overall ED performance across US hospitals.

The authors [11] conducted a study on the application of discrete event simulation in modeling the processes and operations of emergency departments in London hospitals. Their approach aimed at developing a comprehensible model for managers, facilitating the identification of factors causing delays in patient services. Employing a cost-effective methodology and evaluating the impact of various tools on Key Performance Indicators (KPIs), the authors explored multiple scenarios to determine the most effective one.

In 2023, authors [12] conducted a study focusing on the impact of incorporating physicians into the triage process on the performance and efficiency of reducing patient length of stay in Canadian emergency departments. Utilizing a discrete-event simulation model, the authors aimed to forecast the effects of introducing a physician into the triage phase on patient length of stay while enhancing overall performance and efficiency in the emergency department.

Additionally, authors in [13] advanced their research by addressing ongoing challenges, specifically targeting a reduction in patient numbers and an augmentation of service capacity at bottleneck stations. In 2023, authors [14] introduced an Arena simulation model to optimize the appointment system and patient scheduling to minimize waiting times and maximize doctor utilization. The proposed procedure was executed in an outpatient clinic situated at Doha Hospital.

### *2.2. Implementations of Six-Sigma and DMAIC Methodology*

Several authors have utilized the Six Sigma methodology, specifically the DMAIC steps, to enhance the performance of Emergency Departments (ED). Authors [15] used the Lean Six Sigma method to decrease and minimize the time spent in surgical rooms in Taiwan hospitals. The authors brought 820 beds and 11 rooms, gathered data, and used the DMAIC technique. They discovered a need to evaluate staff training, identify variances between individuals to address the challenge, create a physician schedule, and speed up laboratory tasks.

An Integrated Lean Six Sigma approach was created in [16] to identify and study patient flow issues in hospital emergency departments. That technique consisted of qualitative data collection methods explicitly created for the quality department's staff, emergency department staff, and patients to collect field data within a single case study. DES and Six Sigma DMAIC were used by [17] to optimize operations in an outpatient eye clinic in Singapore. The Six Sigma DMAIC steps are used to discover areas for improvement. Then, during the improvement phase, a simulation model is constructed to examine the stochastic behavior of the system.

A Lean Six Sigma project was implemented by [18] in the Outpatient Department (OPD) of a super specialty hospital associated with an Indian manufacturing company using the DMAIC approach. Their research focused on the issue of higher patient wait times in that healthcare system.

In 2015, authors [19] studied Lean Six Sigma tools and methodologies to address challenges in Malaysian hospital EDs. Employing the DMAIC methodology, they systematically addressed the root causes of waiting times, including equipment errors, registration and treatment processes, and factors associated with patients and medical staff. The results emphasized the importance of continuous improvement, highlighting the need for support from hospital managers and policymakers to ensure sustained high performance in decreasing and minimizing waiting times in the ED.

In the study [20], authors applied the Lean Six-Sigma DMAIC methodology to enhance throughput in healthcare, specifically measured by a significant reduction in the length of stay for patients by 30% within a concise three-month period. Another research focused on validating the advantages of implementing RFID (radio frequency identification) technology within hospital outpatient surgical procedures [21]. Through different experiments and hypothesis tests, the study [22] demonstrated that implementing a redesigned appointment system led to an average reduction of 23.7% in patient waiting time. Their study utilized the lean Six Sigma DMAIC approach to address waiting times, specifically in the registration department. Using Arena software, the authors simulated registration waiting times to identify and test the root causes of prolonged waiting times identified during the analysis phase.

*2.3. Waiting Time in Emergency Departments*

Many studies have been conducted to minimize ED waiting times, such as [23], which investigated the impact of restricted resources on patients' waiting times at Tunisian emergency departments. The authors attempted to optimize the treatment process by studying six ED patient queues and focusing on the number of nurses, doctors, and beds. Several researchers adopted a combined simulation and six-sigma technique to increase the ED's performance. Authors of [24], for example, intended to reduce overcrowding in emergency departments. It emphasized how the use of medical equipment and changes in medical equipment technology affect the patient's waiting time and satisfaction. Six Sigma technique was utilized to examine the emergency department overcrowding problem, diagnose the causes, and control performance improvement applications.

Authors [25] studied methods to shorten and minimize patient wait times at a community healthcare center in Indonesia. The authors discovered that the patient takes a long time in the ED stages, and this issue must be resolved for the system to function correctly. The authors used six-sigma technologies such as the (DMAIC) approach and a simulation model to improve the system's efficiency. Authors [26] designed, analyzed, simulated, optimized, and enhanced patients' workflow and resource allocations at an Iranian emergency department. The authors used ARENA to create a new structure of discrete-event simulation models to analyze, estimate, and fulfill the patients' needs by reducing waiting time and fulfilling the staff's optimized resource allocations.

Authors [27] conducted a study on the queuing efficiency of an Indian hospital, employing discrete event simulation. The experiment was constructed using collected data on patients' arrival rates and server service times derived from the system's original and historical data. The authors identified the distribution of patients' waiting times through this comprehensive approach. In 2023, authors [28] introduced an approach to improve the performance of emergency departments in Istanbul hospitals by addressing patient overcrowding. Their methodology involved a hybrid technique, combining a lean six-sigma (LSS) tool with a discrete event simulation (DES) model. The authors employed value stream mapping and constructed two discrete models to anticipate the system's future state. In addition, [29] integrated lean thinking tools with discrete-event simulation (DES) to effectively reduce the length of stay (LOS) for patients in a Canadian emergency department. Finally, authors [30] presented research to shorten the total patient wait time in the ED, improve nurse utilization, and increase the number of patients served. A cellular service system is proposed and used to create ten nurse assignment configurations.

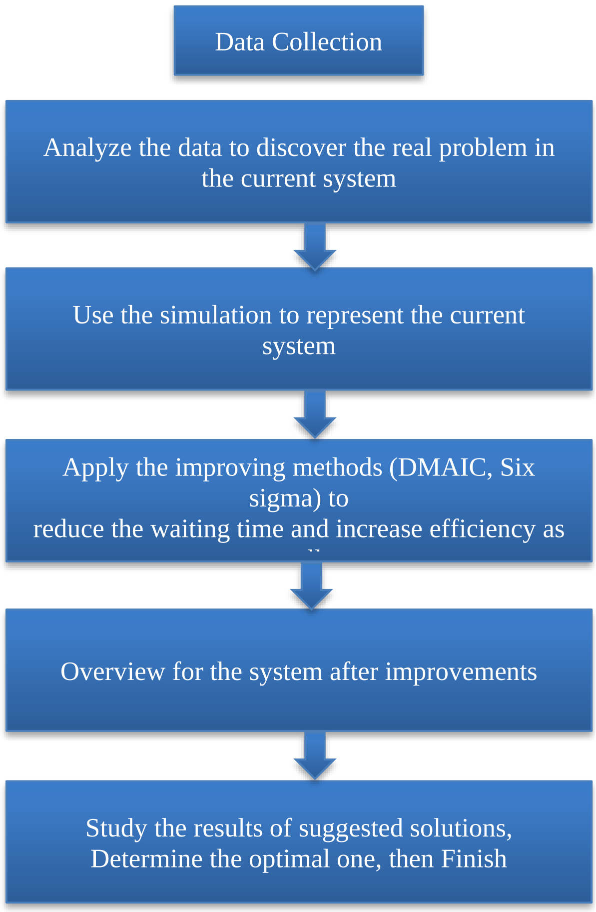


**Fig. 1 Design overview**


**Fig. 2 Design overview**

## 3. Methods and Materials

This section will describe the technique used in the study, displaying the Six Sigma-DMAIC design and procedures used to minimize the waiting time in the Burjeel Hospital ED.

### *3.1. System Design and Components*

Figure 1 shows the flow chart of the steps used to complete this project in its best form.

Figure 2 shows the strategy implemented in this study. It is an integrated approach between simulation and the DMAIC technique.

The DMAIC procedures and steps of the Six Sigma Project are discussed in Table 1.

**Table 1. DMAIC steps in the project**

| Phase | Description |
|---|---|
| Define | Project Charter |
| | • Project Overview |
| | • Problem Definition |
| | • Project Goals |
| | • Project Scope |
| | Critical to Satisfaction Characteristics |
| | • Patient's waiting time |
| | • Patient's length of stay |
| | • Overcrowding in the ED |
| | SIPOC Analysis |
| | • Define the suppliers, inputs, processes, outputs, and customers. |
| Measure | Measure the current system performance. |
| | • Detailed processes description |
| | • Data collection plan |
| | • Data collection |
| Analyze | Analyzing the current system |
| | • Describe the performance measure. |
| | • Identifying the added value and non-added value times and steps |
| Improve | Improving the system by solving its problems |
| | • Finding possible solutions |
| | • Testing different scenarios of improvement |
| | • Comparing the current and suggested system performances |
| Control | Controlling the future process performance |
| | • Developing plans for monitoring the performance |
| | • Sustainability of the system performance |
| | • Continuous improvement plans |

### *3.2. DMAIC Methodology*

This section explains the practical implementation of the DMAIC technique within the Emergency Department (ED) of Burjeel Hospital, systematically going through its five integral steps. We will focus on an in-depth exploration of the first two steps of the DMAIC technique.

#### *3.2.1. Define Phase*

This phase is crucial in clearly defining the issues within the Emergency Department (ED), establishing the project's objectives, defining the project's scope, and identifying the Critical Satisfaction Characteristics. The project charter, Critical to Satisfaction Characteristics, and SIPOC Analysis were developed during this phase.

*Project Charter*

The Project Charter involved the overview, problem definition, project goals, and project scope. Figure 3 serves as a structured representation of the Project Charter, providing the essential elements that guide the improvement project within the Emergency Department (ED).

*Critical to Satisfaction*

The CTS characteristics are crucial components that impact overall satisfaction and efficiency within the Emergency Department (ED). Table 2 defines these characteristics, which involve patient waiting time, length of stay, and overcrowding in the ED. Each characteristic is discussed in detail, providing a clear understanding of its significance in the context of improvement projects. These definitions are the base for assessing and addressing the key elements influencing patient experience and operational efficiency within the ED.

**Table 2. Critical to satisfaction characteristics**

| **Title** | **Description** |
|---|---|
| Patient's waiting time | The time spent by the patient is not processed (non-value-added time). |
| Patient's length of stay | The total time a patient spends in the emergency department from arrival until discharge -including service and waiting times. |
| Overcrowding in the ED | Number of patients at each process and in the system. |

*SIPOC Analysis*

Figure 4 shows the SIPOC analysis (Suppliers, Inputs, Processes, Outputs, and Customers) for Burjeel's ED system. This analysis provides an integrated view of the system by identifying key elements at each process stage. The suppliers, inputs, processes, outputs, and customers are systematically outlined, offering a structured framework to simplify the interaction within the ED system.

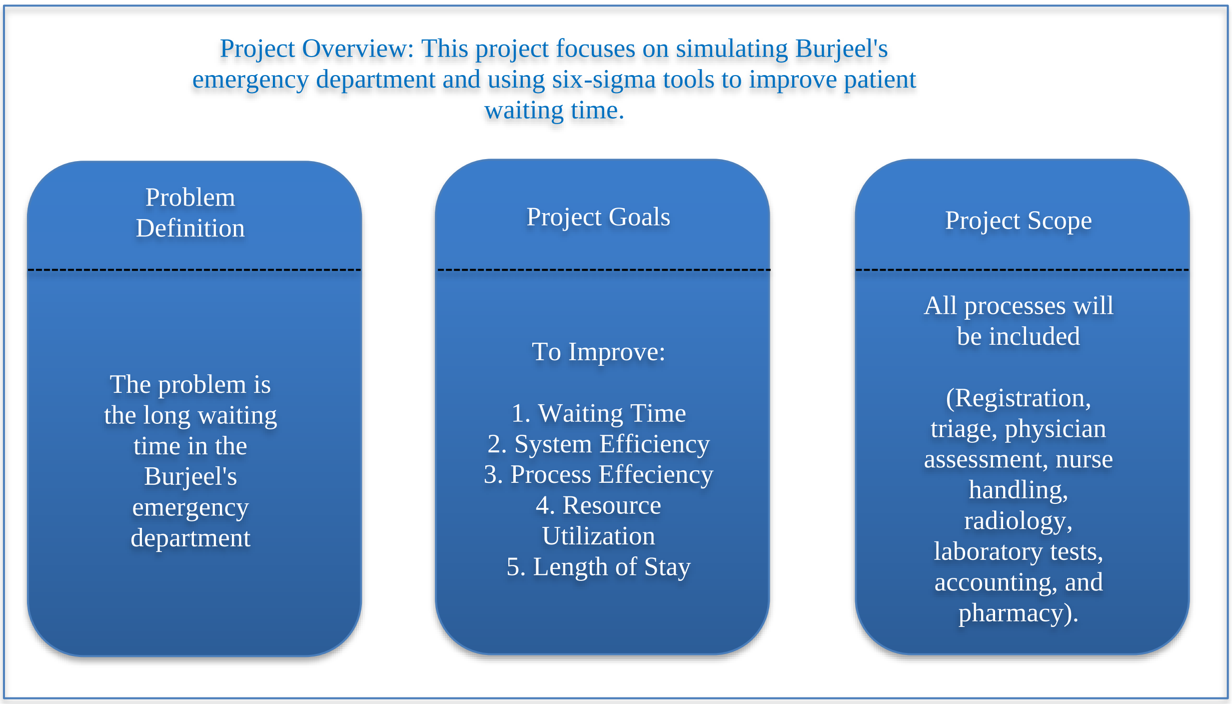


**Fig. 3 Project charter**

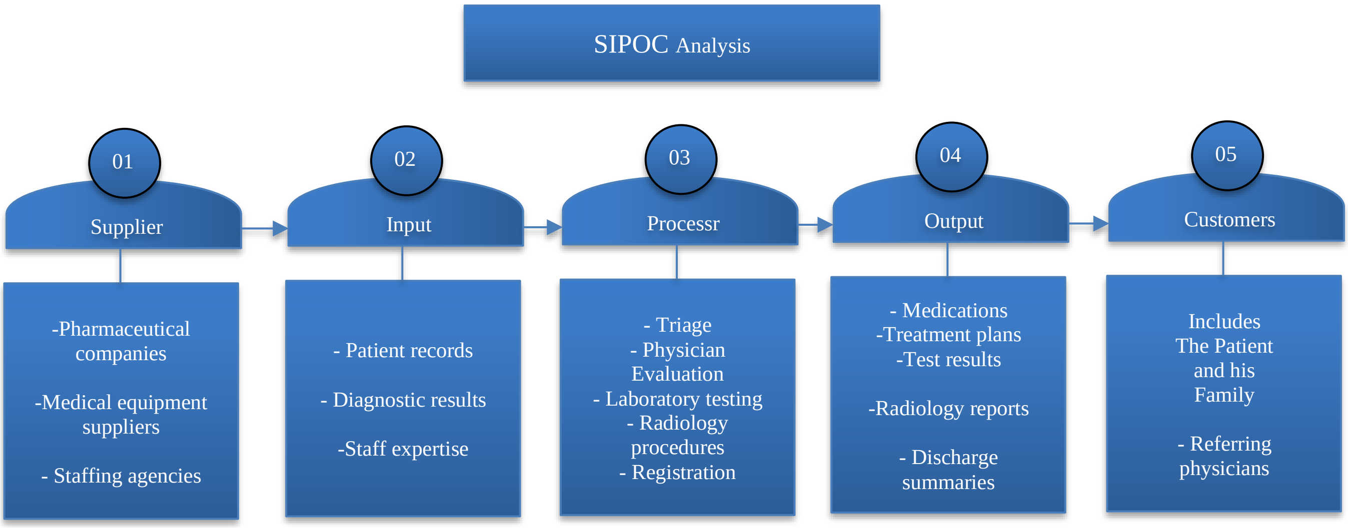


**Fig. 4 SIPOC analysis**

*3.2.2. Measure Phase*

All necessary data to construct and advance the simulation model were collected in this phase. Figure 5 shows a general flow chart outlining the processes within the system. This flow chart visualizes the sequential steps involved in the ED system at Burjeel Hospital, providing a foundational understanding of the critical processes and their interconnections. This tool helps visualize the overall structure of the emergency healthcare system, facilitating a more accurate analysis of its dynamics.

The patient proceeds to the triage room when completing the registration process, where a dedicated triage nurse conducts a comprehensive analysis. This assessment includes evaluating general indicators, measuring the patient's temperature, and assigning an appropriate acuity level index based on the severity of the case. Table 3 details the number of patients who visited Burjeel Hospital's emergency department between July 1 and August 31, 2023, along with their corresponding acuity level values as documented in hospital records. Patients with acuity level indices 1 and 2 are directed to the physician and nurse rooms. As indicated in the previous table, these cases constitute 2.02% of the total and are excluded from the study since they do not experience wait times. Cases with acuity levels 3, 4, and 5 will be queued for consultation with a physician. When entering the physician's room, these cases will adhere to a first-come, first-served (FCFS) approach.

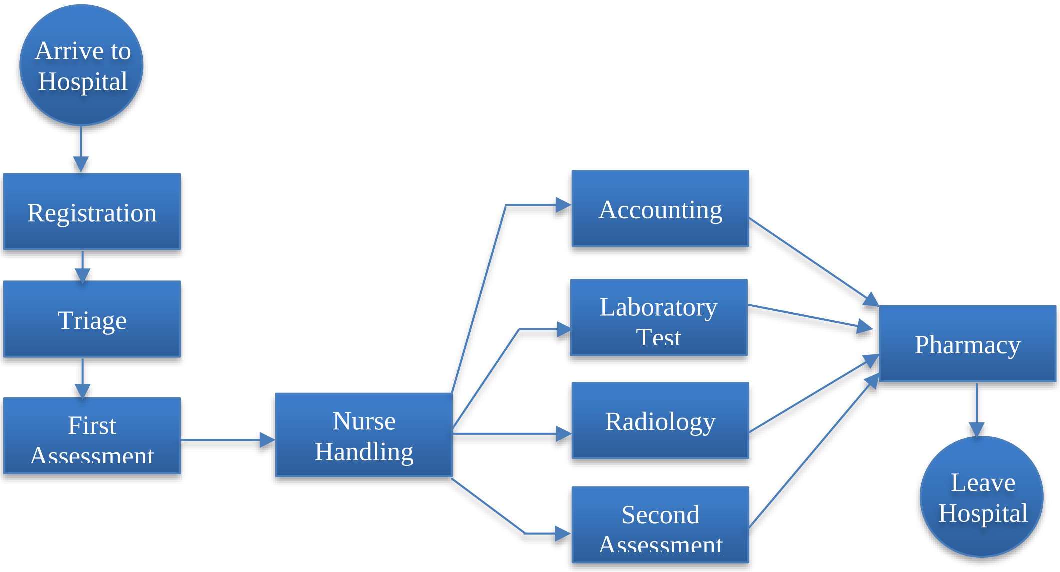


**Fig. 5** Process flow chart

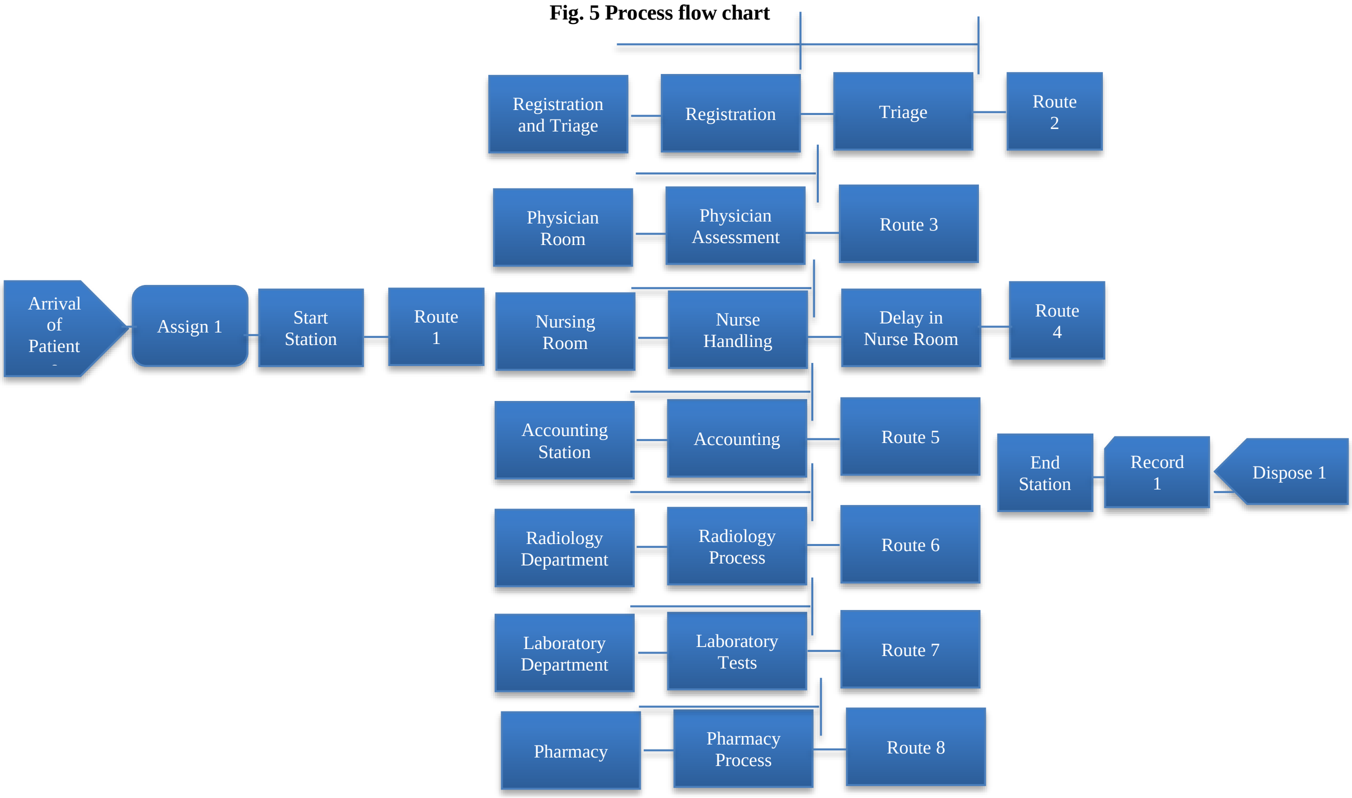


**Fig. 6** Model design using arena software

**Table 3.** The number of patients visit Burjeel's Hospital ED with their acuity level index

| **Acuity level index** | **1** | **2** | **3** | **4** | **5** | **Total** |
|---|---|---|---|---|---|---|
| **Description** | Life threatening | Urgent | Serious | Medium serious | Unserious | |
| **No. of patients** | 27 | 236 | 3856 | 6405 | 2552 | 13076 |
| **% of the total** | 0.21% | 1.81% | 29.49% | 48.98% | 19.51% | 100% |

### *3.3. Simulation Model, Parameters, and Scenarios*

DES was used to test several alternatives to the problems identified in the "Analyze" phase. Arena software was used to model the process. This subsection contains the constructed model, model verification and results validation.

#### *3.3.1. Model Construction*

The simulation model was constructed using Arena Rockwell software, specifically the 16th version. Figure 6 provides the finalized model.

In Burjeel's emergency department, a total of nine processes occur. When representing a process in Arena, defining the action type (such as delay, seize delay, seize delay release, or delay release), the resources responsible for the process, and the corresponding delay type with its associated value (service time) is essential.

Each process was carefully observed to determine its service time, and the collected data points were then fitted using Arena Input Analyzer to determine the optimal statistical distribution representing the process's service time. Table 4 details the action type and service time distribution for each process.

**Table 4. Processes with their action type and service time distribution**

| Process | Action type | Service time distribution (in minutes) |
|---|---|---|
| Registration | Seize delay release | 0.5 + GAMM(0.863, 3.19) |
| Triage | Seize delay release | 0.5 + 10 * BETA(3.91, 14.1) |
| 1st Physician assessment | Seize delay release | 13 * BETA(1.77,4.11) |
| Nurse handling | Seize delay release | 1.5 + 17 * BETA(1.83, 2.92) |
| Delay in nurse room* | Delay | Based on sequence |
| Accounting | Seize delay release | 0.5 + WEIB(2.06, 2.7) |
| Radiology | Seize delay release | EXPO(7.01) |
| Laboratory tests | Seize delay release | CONT(0.09,15,0.75,33,1,105) |
| 2nd Physician assessment | Seize delay release | LOGN (2.35,1.35) |
| Pharmacy | Seize delay release | EXPO(3) |

The delay in the nursing room represents the time the patient spends while receiving intravenous or nebulizer medication, which consumes a certain amount of time.

Entities in the system often contend for resources like staff, equipment, tools, or storage space. When a unit or units of a resource become available, an entity seizes it (or them) and releases it (or them) upon completion of the service or process. Table 5 provides an overview of the resources available in Burjeel's ED, as observed during the data collection period.

Given that patients (entities) undergo various combinations of processes based on the physician's assessment of their condition, Burjeel's emergency department model incorporates the concepts of stations and sequences. The process initiates with the physician assessment process, and each patient's route is documented, along with the number of patients taking each path. This allows for determining the probability of patients following a specific path. Research shows that any patient arriving at Burjeel's emergency department can take one of nine paths. Figure 7 depicts these paths (sequences) and their associated probabilities.

**Table 5. The details of available resources in Burjeel's ED**

| Resource | Process/es that performed | Available units per shift | | |
|---|---|---|---|---|
| | | A | B | C |
| Registrar | Registration | 2 | 2 | 2 |
| Nurse in Triage | Triage | 2 | 2 | 1 |
| Physician | 1st and 2nd physician assessment | 2 | 2 | 2 |
| Nurse | Nurse Handling | 2 | 1 | 1 |
| Accountant | Accounting | 2 | 2 | 2 |
| Radiologist | Radiology | 2 | 1 | 1 |
| Laboratory Technician & Device | Laboratory Tests | 2 | 2 | 2 |
| Pharmacist | Pharmacy | 2 | 2 | 2 |

*3.3.2. Model Verification and Validation*

This process is called model verification or validation to ensure the model functions as required. It is a crucial task in the research process. Multiple interviews were conducted with various personnel to achieve this. The model was run in the presence of the hospital's quality assurance department staff and a physician who expressed an interest in the study. During these sessions, observers observed the movement of entities (patients) through different stations and processes, including long queues at physician and laboratory processes. They also assessed the overall logic of the model and reviewed the resulting reports. The model underwent 62 replications, each lasting 24 hours, without encountering any errors. Based on these outcomes, it can be concluded that the model has been verified successfully.

Following the verification process, the next step of model validation is significant in demonstrating that the model accurately reflects the behavior of the existing system. In this stage, the model is put under validation by comparing two outputs from the simulation model with the actual outputs observed in Burjeel's emergency department. The first output related to the daily average number of patients served by the system, while the second output focused on the average total time patients spent in the system (length of stay). Through this comparative analysis, the validity of the simulation model was assessed and confirmed.


**Fig. 7 The system paths with their probabilities**

Table 6 provides a comprehensive overview of the statistical comparison between the existing system and the simulated model regarding the daily number of patients in the system. The calculated mean difference between the Real and Model values amounts to 2.90, with a corresponding two-tailed P value of 0.355. Based on the traditional criteria, it can be concluded that this disparity is considered statistically insignificant.

**Table 6. Statistical summary for the existing and simulated model in the number of patients served by the system**

| Group | Real | Model |
|---|---|---|
| Mean | 210.933 | 208.323 |
| SD | 20.322 | 8.946 |
| SEM | 2.583 | 1.134 |
| N | 56 | 56 |

## 4. Results and Discussion

This section focuses mainly on the “analyze” and “improve” phases of the DMAIC methodology by analyzing the current and improved models’ simulation results. The first part provides a detailed analysis of the current system's performance to identify its problems. The second part measures the system's performance after applying the improvements.

### *4.1. Results of the Current State*

In this section, an examination is conducted to assess the present performance of the system, focusing on its existing challenges. It aims to identify the fundamental causes of issues and proposes potential solutions for enhancing the efficiency of the ED system concerning waiting time and resource utilization. The initial segment provides a comprehensive outlook on the system's demand and capability. The subsequent segment examines the performance of individual processes within the system. The third part analyzes the queues at each process, while the fourth part studies and utilizes resources throughout the system. Ultimately, queuing theory models will be employed to analyze the system comprehensively.

#### *4.1.1. Patients’ Time and Quantities Analysis*

This section examines the patient's duration within the system and the volume of patients accommodated by the existing state system. The analysis aims to analyze the system's capacities and identify potential enhancements. Illustrated in Table 7 is the breakdown of the patient's time distribution within the current system. The average waiting time for a patient in the system is approximately 37.88 minutes, a lengthy duration for emergency departments and posing potential risks to the patient's well-being. Consequently, minimizing this non-value-added time is imperative for the patient's benefit and safety.

**Table 7. Patient’s time in the system in the current state**

| Time | VA Time | Wait Time | Transfer Time | Total Time |
|---|---|---|---|---|
| Average | 22.87 min | 37.88 min | 4.55 min | 65.3 min |

Table 8 presents the daily averages for the number of patients entering the ED (number in), those discharged and fully serviced daily (number out), and the patients currently undergoing treatment within the ED. Reducing the number of patients treated (PUT) can help reduce congestion in emergency departments, improving safety, productivity, and overall patient satisfaction.

**Table 8. Patient quantities served in the system in the current state**

| Number of patients | Number In* | Number Out* | Number PUT* |
|---|---|---|---|
| Average | 235 | 208 | 21 |

#### *4.1.2. Processes Analysis*

An analysis of each process in Burjeel’s emergency department system, including the number of patients served and their times in each process, is done to understand the system better and identify potential causes for improving its performance.

Figure 8 compares the current and improved states regarding the average VA time, wait time, total time, number in, number out, and number PUT. The average waiting time was reduced from 37.88 min to 31.54 min, significantly improving. Furthermore, the number of patients under processing was reduced from 21 patients to 19 patients, which helped reduce the ED's crowdedness. It is shown that the waiting time was reduced to around 0.23 of the current waiting time. Moreover, the number of patients under treatment was reduced to around 0.52 in the suggested state.

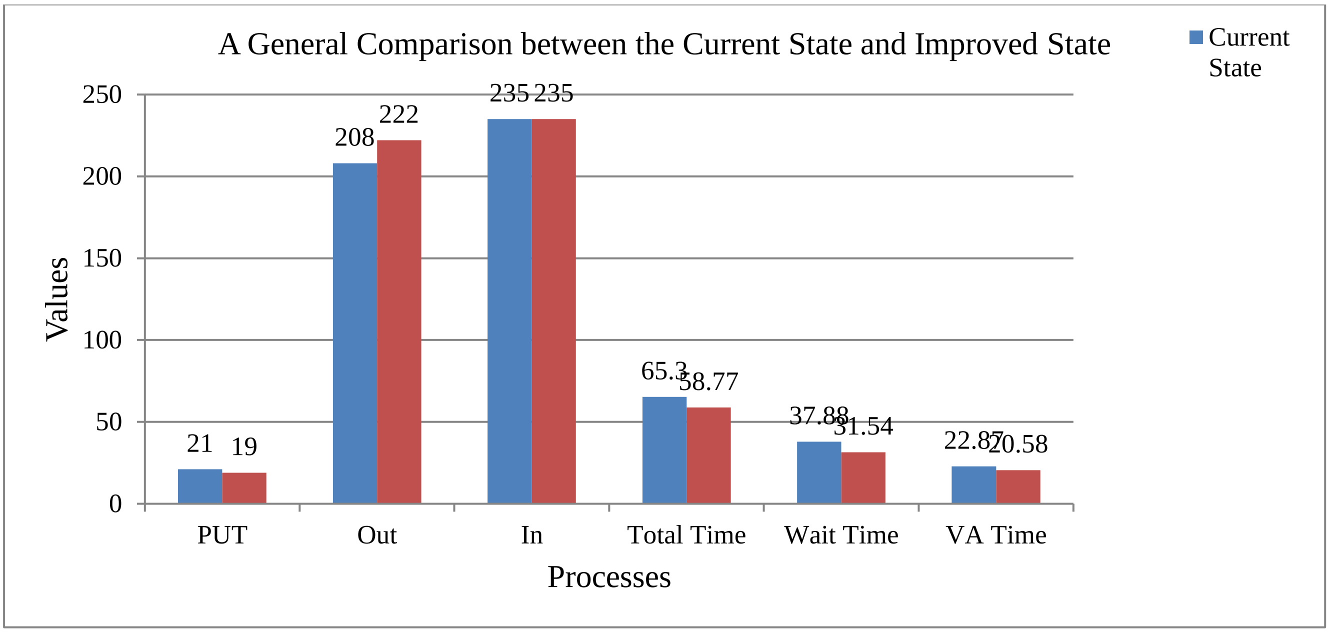


**Fig. 7 A general comparison between the current state and improved state**

**Table 9. The configuration of resources in the proposed scenarios**

| **Resources** | **Physician** | | | **Reg** | | | **Lab** | | | **Radio** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Shift<br>Scenario | A | B | C | A | B | C | A | B | C | A | B | C |
| Current state | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 2 | 2 | 2 | 1 | 1 |
| 1 | 2 | 2 | 2 | 1 | 1 | 1 | 3 | 3 | 2 | 3 | 2 | 1 |
| 2 | 2 | 2 | 2 | 1 | 1 | 1 | 3 | 3 | 3 | 1 | 1 | 1 |
| 3 | 2 | 2 | 2 | 1 | 1 | 1 | 3 | 3 | 2 | 2 | 2 | 1 |
| 4 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 1 | 1 | 1 |

This section examines four scenarios by exploring the impact of altering resource configurations on each process's performance. These scenarios come from proposed solutions addressing resource constraints in the physician assessment and laboratory processes. Table 9 provides a comparative overview of the current and proposed scenarios.

The average time per patient in each process is determined by combining the average value-added (VA) time with the average waiting time. Figure 8 presents a graphical representation of the average time per patient in each process extracted from the Arena simulation model.

For example, the average duration of the medical assessment process is 12.26 minutes, of which 1.37 minutes are value creation time and 10.89 minutes are waiting time. These total time values will play a crucial role in the subsequent calculations related to process cycle efficiency.

The efficiency of a process cycle is defined as the average time spent adding the value divided by the average total time spent. This metric indicates the efficiency of each process, which is a critical parameter for evaluating the system's performance. Evaluating each process's efficiency is crucial in assessing the overall system performance. Thus, the process cycle efficiency values were calculated and are presented in Figure 9.

The process cycle efficiency values, determined from the Arena simulation model across 62 replicates, serve as critical metrics. The results indicate that the physician assessment process exhibits the lowest efficiency, at 12.23%, mainly attributed to its extended waiting time.

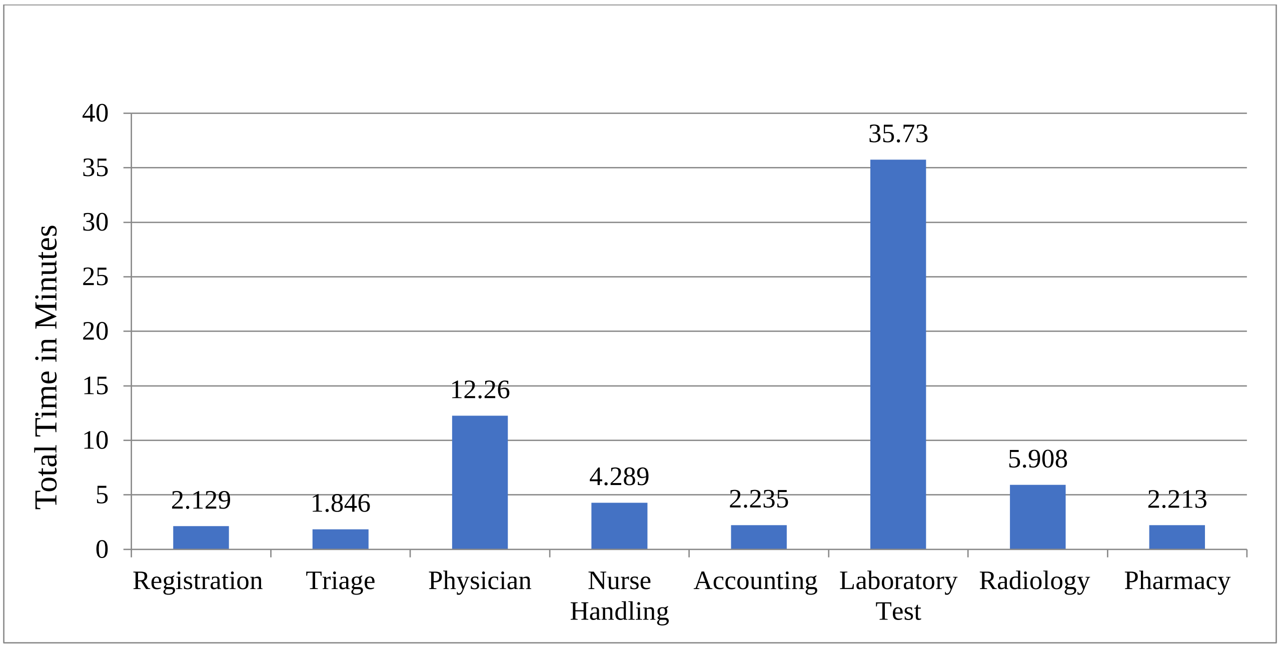


**Fig. 8 The average total time for the current state model**

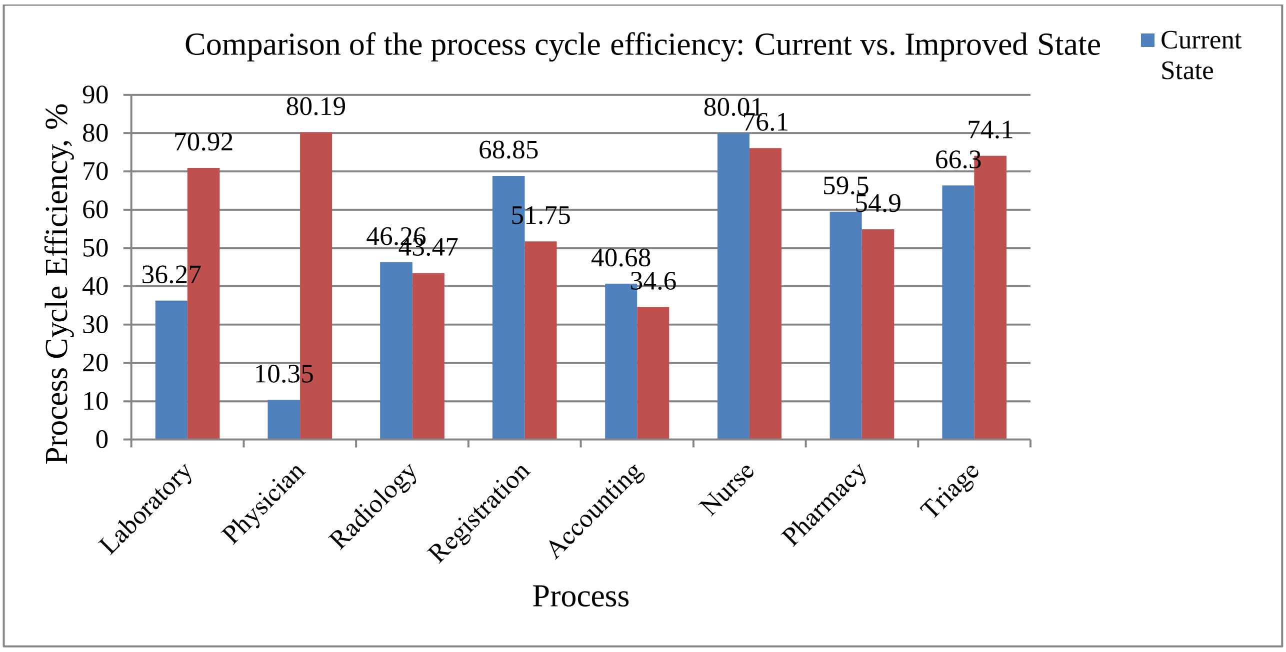


**Fig. 9 Comparison between the current state and improved state regarding the process cycle efficiency**

**Table 10. Number of patients who enter and discharge for each process**

| Process | Number In | Number Out | Ratio (Out/In) |
|---|---|---|---|
| Accounting | 381.15 | 380.04 | 1.00 |
| Laboratory | 108.42 | 97.60 | 0.90 |
| Nursing | 172.59 | 171.45 | 0.99 |
| Pharmacy | 175.12 | 174.46 | 1.00 |
| Physician | 364.26 | 355.67 | 0.98 |
| Radiology | 96.3 | 94.99 | 0.99 |
| Registration | 235.37 | 234.71 | 1.00 |
| Triage | 234.71 | 234.13 | 1.00 |

In addition, the efficiency of accounting, laboratory, and radiological processes falls below the optimal level at 53.02%, 43.18%, and 53.14%, respectively. In contrast, the nurse handling process boasts the highest efficiency, reaching 84.40%, showcasing its minimal non-value-added time.

Analyzing the number of patients entering each process is a crucial metric for assessing the efficiency of individual processes and computing the cumulative time spent in each stage. This crucial data, extracted from the Arena simulation model and documented in Table 10, provides an in-depth understanding of the dynamics within each process.

As shown previously, the average daily influx of patients into the system is around 235 individuals, while the physician assessment process registers an approximate influx of 364 patients daily. Recognizing that a patient's entry into the physician assessment process may occur at varied levels, such as preceding a scheduled laboratory test, is necessary. It is also essential to underscore that the accounting process is similar to the physician assessment process. Differently, specific processes show entry figures below the system-wide daily average. This variance comes from the fact that not all patients necessitate undergoing each distinct process; for example, the radiology process is not a prerequisite for all patients. This understanding of patient entries into each process is fundamental in measuring the operational dynamics and resource utilization across the emergency department system.

*4.1.3. Resource Usage Analysis*

In this section, the instantaneous utilization metric has been employed to analyze resource usage efficiency, leveraging data extracted from the Arena simulation model and shown in Figure 10.

*4.1.4. Root Cause Analysis*

The previous findings indicate that the immediate utilization for the physician and laboratory processes is slightly higher than the average, registering values around 82.4% and 77.9%, respectively. However, this is not ideal for registration and pharmacy processes. There are two significant problems in the system, including the following. Firstly, there is a shortage of resources in the physician assessment and laboratory process because the waiting time is very long, and efficiency is very low.

Secondly, there are excessive resources in the registration process. Table 11 lists the identified causes that increase the service's variability and waiting time for each process. Three main ways were used to determine these causes: first, observation for more than two months of data gathering in the ED; second, different discussions with the workers there; and finally, surveying the literature for common responses.

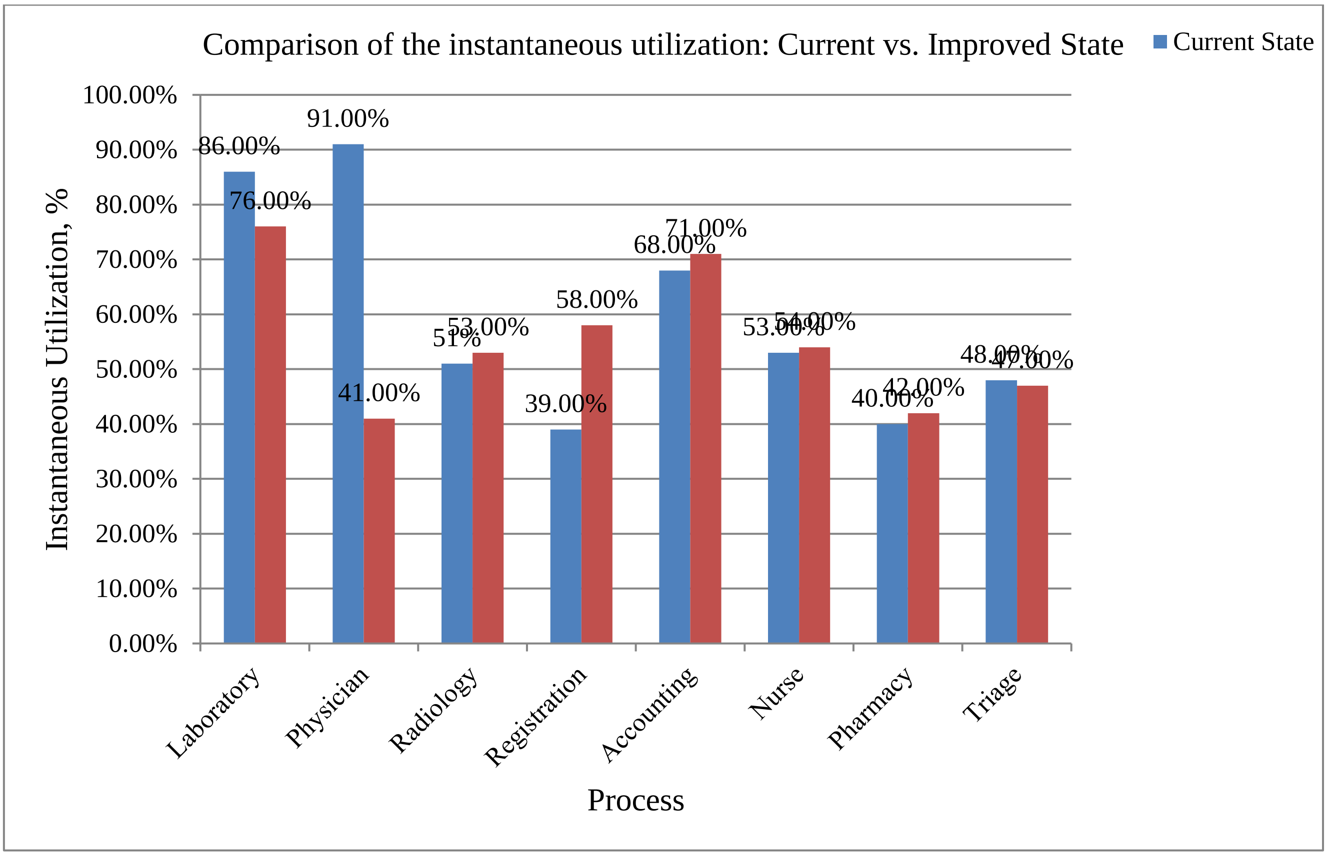


**Fig. 10 Comparison between the current state and improved state regarding the instantaneous utilization**

*4.2. Improve Phase*

A key proposal suggests adding more resources while reducing those allocated to registration to address issues in the physician assessment and laboratory processes. This leads to four scenarios for testing using Arena simulation. Table 12 outlines potential solutions to minimize variability in service and waiting times.

*4.2.1. Analysis of the Improved State*

In this section, a comparison between the proposed scenarios in terms of the average time, waiting time, total time, number in, number out, and number of PUTs is done. The average waiting time is reduced from 37.88 minutes to 29.36 minutes. Also, the overall system efficiency was improved impressively. This enhancement in waiting time contributed to a reduced number of patients within the ED simultaneously, dropping from 21 to 18 patients, effectively reducing overcrowding.

Figure 9 compares the current and improved state regarding process cycle efficiency. The process cycle efficiency was also enhanced for laboratory, physician assessment, and triage processes. In contrast, the other processes had a slight drop in efficiency except for registration; the registration process's efficiency dropped from 68.85 % to 51.75 % due to reduced registration process resources.

However, this reduction in efficiency does not significantly affect the system's total efficiency and performance. On the other hand, physician assessment process efficiency increased from 10.35 % to 80.19 %, whereas laboratory process efficiency increased from 36.27% to 70.92%.

**Table 11. Variability causes in the service and waiting time of each process**

| | | |
|---|---|---|
| Physician Assessment process | 1) | Second assessment service time increased at each shift because the new physician would start asking about the patient's status from scratch. |
| | 2) | Sometimes, many people in the physician's room distract the physician's concentration, which increases the time the physician assessment service takes. |
| | 3) | Medical students are present in the physician's room. |
| | 4) | Representatives of drug companies come to the physician in the emergency department. |
| | 5) | The patient's family wrongly understands the ED job. They come to it in situations that are not urgent and even insignificant. |
| | 6) | The patient's family comes for a second physician assessment before the laboratory test results are released/ready. |
| | 7) | Conflicts between medical staff and patient's family in some cases. |
| | 8) | The patient is going back to the physician because medicine is unavailable in the pharmacy or the patient's family cannot read the prescription. |
| Registration | 1) | The patient's family does not bring a document containing the national ID number. |
| | 2) | Sometimes, weaknesses in internet connections. |
| | 3) | Maintenance and updates of Hakeem Information System. |
| Triage | 1) | The many existing people in the triage room distract the triage nurse's concentration, increasing triage service time. |
| Other | 1) | Children fear medical procedures such as taking blood samples. |
| | 2) | The absence of some employees from their work site when no patients are led to queue at their stations. |

The resource utilization for each process in both states is taken from Arena software and plotted in Figure 10. The reduced utilization of the laboratory and physician assessment processes is typical due to increased resources at these processes. On the other hand, the registration process's resource utilization increased from 39.5% to 58.5 % due to reduced resources. However, having less than 60 % resource utilization makes the system more flexible and capable of receiving higher rates or any sudden increase in demand.

*Control Phase*

This phase is dedicated to ensuring the proposed improvements' lasting effectiveness, ensuring a sustained quality level, and attaining the study's overarching objectives. The following strategies are important in saving the requested quality standards within the examined emergency department:

- Implementation of Recommendations: After incorporating the suggested alterations to the resource configuration, monitoring plans must be established. Regular process control and monitoring duties should be assumed, ideally overseen by the quality assurance department at Burjeel Hospital.
- Worker Training: Keeping the emergency department staff abreast of emerging technologies and updated knowledge is crucial. Conducting training sessions to teach best practices for each process and strengthen effective communication with patients and their families is integral to ensuring continuous improvement.

- Strategic Plans: The emergency department should take proactive action by implementing plans to reduce potential future challenges, such as unexpected increases in patient arrivals. Utilizing prediction models or tools to anticipate future demands and proactively address them is a valuable objective for operational excellence.

## 5. Conclusion and Future Work

The study aims to increase efficiency, reduce patient waiting times, avoid overcrowding, and optimize resource utilization by integrating discrete event simulation with Six Sigma DMAIC methodology. The evaluation involved testing and analyzing four proposed scenarios through simulation models. Notably, the third scenario, involving the addition of one physician, one laboratory technician, and removing one registrar, demonstrated an optimal balance between resource efficiency and utilization.

The suggested model achieved remarkable results, significantly reducing the average waiting time from 37.88 minutes to 29.36 minutes. Also, the overall system efficiency was improved impressively. This enhancement in waiting time contributed to a reduced number of patients within the ED simultaneously, dropping from 21 to 18 patients, effectively mitigating overcrowding. Specifically focusing on the laboratory and physician assessment processes, substantial improvements were observed, and the waiting time for both processes also decreased significantly.

In contrast, there was no significant alteration in the average waiting time for other processes. The average waiting time in the laboratory was substantially reduced. This significant decrease in waiting time indicates a more streamlined and efficient workflow within the laboratory. Moreover, the standard deviation, which reflects the variability of waiting times, also experienced a noteworthy decline. This reduction in standard deviation underscores a considerable improvement in the consistency and predictability of waiting times for patients undergoing laboratory procedures. Overall, these changes positively impact the reliability and efficiency of the laboratory process within the emergency department.

**Table 12. Possible solutions to reduce the variability in the service and waiting time**

| | |
|---|---|
| Physician Assessment process | 1) The new physician should arrive 15 minutes before the shift begins, or the previous physician may need to wait an extra 15 minutes to complete ongoing cases. |
| | 2) Implement measures to avoid simultaneous admission of multiple cases to a physician and limit one companion per patient. |
| | 3) Educating the public about the emergency department's functions can help minimize disputes. |
| | 4) Patience is a valuable quality for medical staff. |
| | 5) Explain the medication procedure to the patient's family before leaving the physician's room. |
| Registration | 1) Create pre-designed forms for such cases and fill in the remaining registration information after completing treatment. |
| | 2) Postpone system maintenance and update periods with lower patient volumes to minimize disruptions. |
| | 3) Implement preventive maintenance measures for all devices. |
| Triage | 1) Enforce a policy to avoid simultaneous entry of multiple cases into the triage room and limit one companion per patient. |
| Other | 1) Enhance employees' commitment to their assigned workstations throughout their working hours. |

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