*Proceedings of the 3rd GCC International Conference on Industrial Engineering and Operations Management*
*Tabuk, Saudi Arabia, February 2-4, 2026*

*Proceedings of the International Conference on Industrial Engineering and Operations Management*

Publisher: IEOM Society International, USA DOI: 10.46254/GC03.20250085
Published: February 2, 2026

# Digital Triage Training, Spatial Optimization and Color-Coded Prioritization: A Simulation Study to Improve Emergency Department Efficiency

**Mumen Rababah, Ayman Al-Hayek, Yazan Jaradat, Tamara Alnawaiseh and Razan Aldowery**
Department of Industrial Engineering
Faculty of Engineering, The Hashemite University
P.O. Box 330127, Zarqa 13133, Jordan
mumenh@hu.edu.jo, 2044076@std.hu.edu.jo, 2145162@std.hu.edu.jo, 2034344@std.hu.edu.jo, 2037499@std.hu.edu.jo

## Abstract

Emergency Departments (EDs) frequently encounter overcrowding, extended waiting periods, and inconsistent triage accuracy, resulting in negative effects on patient outcomes and staff wellbeing. This research examines these challenges within a Jordanian hospital by integrating optimization and waste management methodologies with Discrete-Event Simulation (DES) and specific operational interventions. Three interventions were developed and assessed: (i) a Python-based Triage Game aimed at nurse training and performance evaluation, (ii) a restructured intake "Smart Area" featuring spatial and workflow enhancements, and (iii) a color-coded overhead lighting system designed for visual prioritization. A validated DES model, developed from approximately 20,000 historical patient records and corroborated with hospital operational data and expert evaluation, was employed to compare baseline and improvement scenarios. The redesigned system enhanced triage accuracy from 67% to 92% and decreased misclassification rates from 25% to 5%. Average patient waiting times reduced from 98 minutes to 27 minutes, and staff satisfaction improved from 55% to 88%. The sensitivity analyses conducted for peak-season demand validated the robustness of these enhancements. The integrated framework is scalable and provides a practical, evidence-based guide for hospitals aiming to enhance ED throughput while ensuring patient-centered care.

## Keywords
Emergency Department, Discrete-Event Simulation, Triage, Patient Flow Optimization, Healthcare Operations.

## 1. Introduction
The healthcare sector is fundamental to societal well-being and economic development (World Health Organization 2022). EDs function as essential access points for patients in need of immediate medical care. EDs present distinct challenges stemming from the unpredictability of patient arrivals, the variety of medical conditions, and the necessity for prompt and precise care (Van der Linden et al. 2016; O'Connor et al. 2014). Inefficiencies in operational processes, including extended patient wait times, inaccurate triage, inadequate staff allocation, and poor resource management, can adversely affect patient outcomes and satisfaction (Mandahawi et al. 2017; Johnson et al. 2021). Further challenges, such as staff fatigue due to prolonged shifts, medication shortages, and overcrowding resulting from patient companions, hinder EDs' capacity to deliver timely and high-quality care (Grissinger et al. 2019; Hedding et al. 2021). In certain nations, EDs function as primary access points to healthcare for underserved populations, thereby increasing their strategic significance within the healthcare system (Varndell et al. 2019; Farrokhnia and Goransson 2011).

Confronting these problems necessitates analytical instruments capable of encapsulating the complexity and diversity of ED situations. Simulation has become a potent approach in this environment, enabling academics and practitioners to model patient flows, assess different triage procedures, and improve staff and resource allocation without interfering with real-world operations. Simulation facilitates evidence-based decision-making and risk-free experimentation by replicating the stochastic characteristics of arrivals and care procedures. In healthcare, this results in diminished waiting times, more patient safety, augmented staff efficiency, and more robust systems overall (Lamé and Dixon-Woods 2020; Elendu et al. 2024). Consequently, simulation functions both as a tool for identifying bottlenecks and as a practical means for developing more flexible and efficient emergency care systems.

This study aims to enhance the efficiency and quality of operations in the ED by addressing critical operational and clinical challenges. The objectives are to:

1. Reduce patient wait times to improve their overall experience.
2. Boost the efficiency and accuracy of triage procedures.
3. Provide adaptable systems to ensure that critical cases receive appropriate prioritization.

The initiative simultaneously seeks to enhance resource allocation by equitable distribution of medical workers, modification of work patterns, and provision of continuous training programs to augment staff competencies while reducing fatigue. The effort employs quality management principles to minimize waste, and organizational and technology strategies to alleviate congestion and enhance the workplace environment. Ultimately, it emphasizes the necessity of enhancing communication and knowledge inside the ED to elevate patient happiness, foster transparency, and streamline departmental processes.

## 2. Literature Review

Triage is an essential procedure in EDs that ranks patient care according to the severity of illness, thereby enhancing patient safety and outcomes (Johnson et al. 2021). The process entails a swift evaluation of clinical history and physiological measures, followed by the assignment of an urgency code to guide patients to the suitable treatment area, generally within five minutes to ensure a balance between thoroughness and efficiency (Van der Linden et al. 2016; O'Connor et al. 2014). Accurate triage is influenced by factors such as ED crowding, staff shortages, patient anxiety, and the presence of family members. These elements can elevate the risk of under-triage or over-triage, leading to delays in treatment or misallocation of resources (Johnson and Alhaj-Ali 2017; Hitchcock et al. 2014; Silva et al. 2017). Multiple structured triage systems have been established to standardize the assessment of patients. The Emergency Severity Index (ESI) classifies patients into five levels according to acuity and anticipated resource use, with higher levels necessitating prompt intervention (Viola et al. 2014). Pediatric populations frequently employ modified strategies, including JumpSTART triage, which considers age-specific physiological variations and offers emotional support (Yalçin and Anil 2022). Other international systems, such as RETTS© and the Canadian Triage and Acuity Scale (CTAS) (as shown in Figure 1), emphasize dynamic reassessment, resource forecasting, and workflow optimization, underscoring the operational advantages of standardized triage beyond immediate patient classification (Farrokhnia and Goransson 2011; Varndell et al. 2019).

| CTAS level | Level description | CTAS time to physician assessment for timely care, min |
|---|---|---|
| I — Resuscitation | Conditions that require resuscitation or threaten life or limb, requiring immediate aggressive intervention | "Immediately" (< 5) |
| II — Emergent | Conditions that are a potential threat to life, limb or function, requiring rapid medical intervention or delegated acts | ≤ 15 |
| III — Urgent | Conditions that could potentially progress to a serious problem requiring emergency intervention. May be associated with significant discomfort or affecting ability to function at work or activities of daily living | ≤ 30 |
| IV — Less urgent/ semiurgent | Conditions related to patient age, distress, or that have the potential for deterioration or complications would benefit from intervention or reassurance | ≤ 60 |
| V — Nonurgent | Conditions that may be acute but are nonurgent or part of a chronic problem without evidence of deterioration | ≤ 120 |

Figure 1. Descriptions of Canadian ED triage and acuity scale levels and guidelines for time to assessment by an emergency physician (Viola et al. 2014).

Errors in emergency care, particularly during triage, can significantly extend patient waiting times and undermine the quality of care. Patient misclassification, inefficient resource utilization, and communication failures frequently result in prolonged ED stays and postponed interventions for critical cases. Staffing shortages, peak-time surges, administrative inefficiencies, and electronic record errors contribute to delays (Taguti et al. 2013; Gul and Celik 2020). Mitigation strategies for these impacts include enhancing triage accuracy through improved training, optimizing staff allocation in line with patient inflow, applying data analytics to forecast demand peaks, and refining interdepartmental coordination and bed management. Simulation-based approaches, in particular, have been shown to reduce waiting times, improve triage reliability, and support evidence-based planning in EDs (Mandahawi et al. 2017; Mandahawi et al. 2010).

Leveraging these benefits, simulation is progressively recognized as a potent tool in healthcare for clinical training and operational improvement. Simulation enhances the cultivation of essential decision-making abilities in healthcare practitioners by emulating aspects of clinical care or hospital processes inside a regulated and risk-free setting (Lamé and Dixon-Woods 2020; Elendu et al. 2024). In addition to personal training, simulation facilitates the detection of systemic inefficiencies, the assessment of alternative solutions, and the enhancement of workflow procedures before actual deployment. In ED settings, simulation has been extensively utilized to evaluate patient flow, resource allocation, and staff distribution, providing meaningful insights into operational constraints and inefficiencies (Astolfi et al. 2012; Johnson and Alhaj-Ali 2017; O'Connor et al. 2014).

While structured triage, operational optimization, and modeling have independently demonstrated enhancements in ED performance, few research integrates these concepts holistically. This work mitigates this deficiency by integrating simulation modeling with novel interventions, such as intelligent triage zones, process reengineering, and predictive analytics, to augment patient flow, diminish waiting periods, optimize resource allocation, and elevate care quality and safety. The results present a new, methodical framework for enhancing ED performance, providing practical recommendations for hospital administration and making a substantial contribution to the literature on integrated operational and clinical improvement.

## 3. Methodology

This study utilized a thorough and methodical approach to improve operational efficiency, the quality of patient treatment, and overall satisfaction in hospital EDs. The methodology was organized into five principal phases as illustrated in Figure 2: Data Collection, Problem Identification, Problem Analysis, Solution Design, and Implementation. To comprehensively comprehend and rectify inefficiencies, analytical instruments such as fishbone diagrams, issue tree analysis, and simulation modeling were employed to ascertain fundamental causes and assess the possible effects of suggested actions. The research emphasized treatments that decrease patient wait times, enhance staff and resource distribution, eliminate triage inaccuracies, and foster a safer, more supportive atmosphere for both healthcare providers and patients, including individuals with special needs. The technique seeks to attain permanent enhancements in operational performance, personnel efficiency, and the resilience of emergency care services through the integration of meticulous analysis and focused, innovative solutions.


Figure 2. Systematic methodology for enhancing ED efficiency and care quality.

### 3.1 Data Collection

The data collection process lasted around two months and entailed organized efforts in both the emergency and records departments. During this period, comprehensive patient data were collected to capture a wide range of variables relevant to ED operations. The data encompassed demographic information, including age and gender, clinical details, such as allergies, medical history, surgical history, triage codes, and operational metrics, which included patient arrival time, mode of arrival, duration for a doctor to attend to each patient, and discharge time. The collection process documented contextual information such as peak arrival times, patient flow patterns, and the presence of accompanying family members to enhance the understanding of factors affecting triage and treatment efficiency. A total of 20,000 patient records were compiled, creating a substantial dataset for further analysis. In addition to quantitative data, comprehensive field observations were performed to collect qualitative insights regarding workflow, staff interactions, and operational bottlenecks. The observations encompassed the monitoring of nurse-patient interactions during triage, patient transitions through various treatment areas, and the real-time documentation of delays or errors in care processes.

Interviews and informal discussions with nurses, physicians, and administrative staff complemented the observational data, offering further context and insights into procedural challenges and persistent inefficiencies. This phase was essential for developing a comprehensive understanding of the operational environment of the ED. The research team identified patterns, potential sources of delay, and areas of inconsistency in patient handling by integrating quantitative data with qualitative observations. This data collection established a robust basis for analyzing current processes, identifying root causes of inefficiency, and developing evidence-based solutions to enhance patient flow, resource allocation, and overall quality of care.

### 3.2 Problem Identification and Analysis

The Problem Identification phase entailed the collection of comprehensive data via interviews and structured discussions with nurses, physicians, and patients, supplemented by site visits to other hospitals to expand perspectives and improve the generalizability of proposed solutions. One the other hand, the Problem Analysis phase involved a comprehensive evaluation of each identified problem to ascertain fundamental causes, utilizing qualitative methods such as fishbone diagrams and problem tree analysis for enhanced understanding. Observations and feedback were systematically recorded to inform subsequent analysis. A key issue identified is the variability in patient triaging, which significantly affects emergency care outcomes yet remains inconsistent in practice across numerous healthcare systems. This variability arises when patients exhibiting similar symptoms are assigned different priority classifications by various nurses, resulting in inconsistencies in care delivery. Root causes encompass variations in nurse experience, inadequate training, absence of standardized guidelines, environmental pressures such as overcrowding and time constraints, limited ongoing evaluation, and insufficient access to diagnostic tools and IT support, as depicted in the cause-and-effect diagram (Figure 3A). These factors collectively lead to delays in critical care, misallocation of resources, increased staff burden, and reduced patient satisfaction, ultimately compromising patient safety, operational efficiency, and trust in the healthcare system.

Based on these findings, a significant issue identified during the analysis was the selection of the most appropriate nurse for the triage role, a challenge prevalent in various healthcare institutions. Triage necessitates that nurses quickly evaluate patients and prioritize care based on severity; however, assignments are often determined by availability rather than by expertise, skill, or specialized training. This practice increases the likelihood of misclassification, delays in care, and inefficiencies in the ED. The primary factors contributing to this issue are the lack of specialized training programs, assignments based on availability that neglect competence, excessive workload and stress that hinder judgment, and the absence of clear criteria for evaluating and assigning nurses to triage responsibilities. The contributing factors are depicted in the cause-and-effect diagram (Figure 3B). The consequences are substantial, resulting in delayed treatment for critical patients, inappropriate case prioritization, heightened stress and burnout among nurses, and reduced patient satisfaction, which undermines trust in the healthcare system.

Overcrowding in the ED, primarily caused by the presence of companions and visitors, has become a consistent obstacle to effective care delivery. This challenge limits staff mobility, produces excessive noise, and disrupts overall workflow, thus compromising patient safety and satisfaction. The root causes of this issue, as depicted in the cause-and-effect diagram (Figure 3C), encompass multiple companions per patient, inadequate waiting areas, insufficient regulation of visitor access, and ineffective management of waiting times. In addition to overcrowding, a significant issue was the substantial time required by triage nurses for patient classification, leading to persistent workflow bottlenecks and delays in the commencement of care. The analysis indicated that triage nurses were tasked with prioritizing patients while also managing administrative duties, including the completion of personal and medical information, manual data entry due to a lack of digital support systems, and the physical transfer of patient files to physicians. The cumulative factors illustrated in the cause-and-effect diagram (Figure 3D) notably extended the triage process and diverted essential time and attention from patient assessment, thereby worsening delays in the ED.

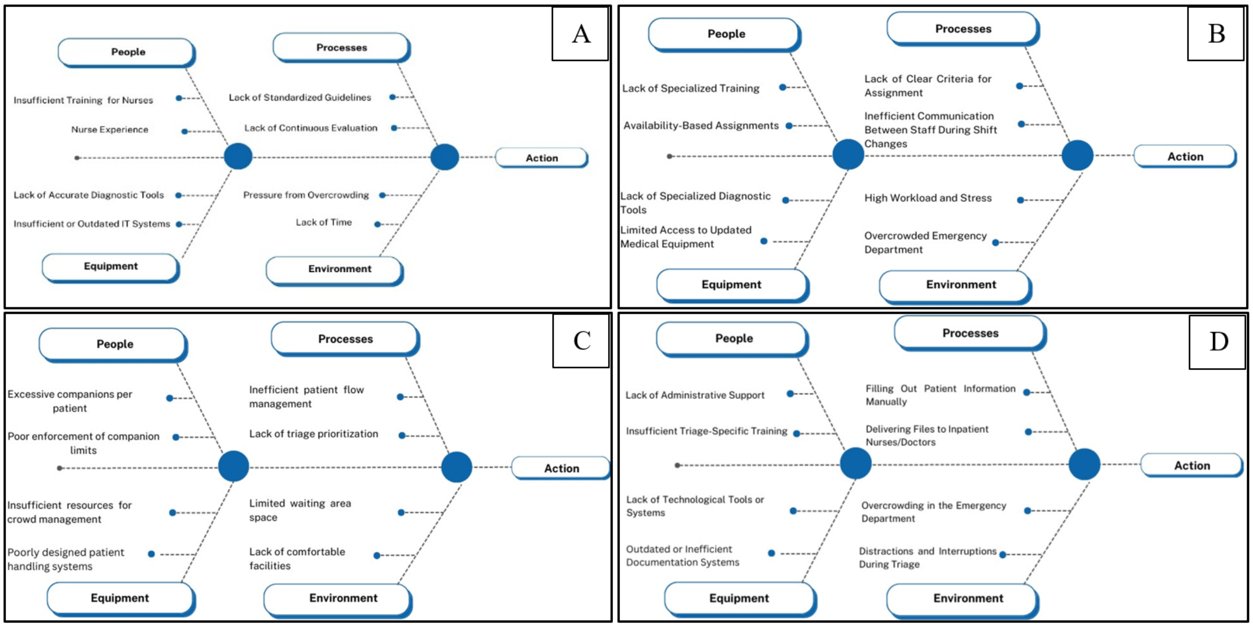


Figure 3. (A) Cause and effect diagram of variability in patient triaging. (B) Cause and effect diagram of choosing triage nurse. (C) Cause and Effect diagram of overcrowding at the ED. (D) Cause and Effect diagram of the significant time spent by triage nurse.

The Solution Design phase utilized brainstorming to produce a variety of potential strategies, which were subsequently evaluated through simulations to assess their impact on ED operations and determine the most effective interventions. The implementation phase entailed executing the chosen solutions, prioritizing the most critical issues. Each improvement underwent rigorous testing, with performance validated through simulation to confirm enhancements in patient flow, resource utilization, and overall operational efficiency. The Results and Discussion section provides a thorough analysis of the Solution Design and Implementation phases, detailing the impacts of each intervention. This methodology provides a systematic, data-informed strategy for enhancing ED performance while prioritizing patient-centered care.

## 4. Results and Discussion

This study's results indicate that targeted, data-driven innovations can enhance ED performance by systematically addressing triage variability, overcrowding, workflow inefficiencies, and resource management. Simulation served as the analytical foundation, directing the creation of three primary interventions: The Triage Game, the Smart Area, and a color-coded Lighting System. These solutions collectively establish a cohesive ecosystem of technological and organizational innovations.

### 4.1 Innovative Training and Decision Support: The Triage Game

The Triage Game was created to mitigate variability in patient classification, a significant bottleneck in the ED. Developed using Python, this tool offers nurses realistic scenarios based on the Canadian Triage Manual and assesses their performance through scoring and response time metrics. It includes ten scenarios in which nurses categorize cases into one of five triage codes: White, Green, Yellow, Red, or Blue. The database comprises 100 distinct scenarios and has the capacity for expansion to incorporate thousands additional scenarios. The system generates a score out of 100 upon completion and logs the response time, facilitating the ranking of nurses based on accuracy and speed. The game facilitates data analysis by recording performance metrics and providing an option to export results for additional evaluation. Figures 4 and 5 depict the interactive interface, whereas Figure 6 illustrates how supervisors can identify the most competent staff for triage responsibilities. The data visualization features facilitate ongoing monitoring and inform workforce decisions.

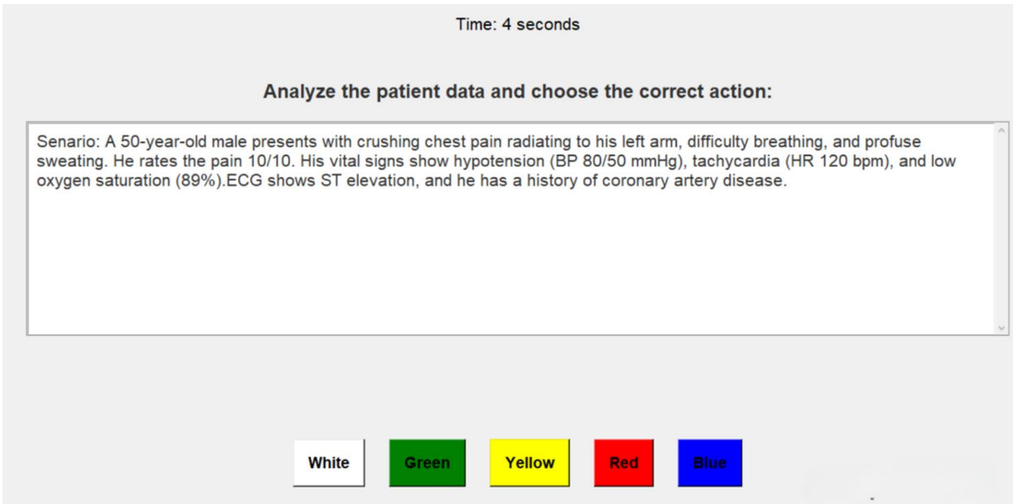


Figure 4. An example of triage game question layout with levels to choose from.


Figure 5. Interface options displayed after game completion.


| NURSE NAME | NURSE ID | GRADE | TIME |
|---|---|---|---|
| Nurse4 | 4 | 60 | 13.392367124557495 |
| Nurse5 | 5 | 60 | 13.714470624923706 |
| Nurse1 | 1 | 50 | 7.912036418914795 |
| Nurse9 | 9 | 50 | 9.329482555389404 |
| Nurse2 | 2 | 50 | 12.194665908813477 |
| Nurse3 | 3 | 40 | 9.199378967285156 |
| Nurse7 | 7 | 40 | 9.330832481384277 |
| Nurse6 | 6 | 40 | 10.120619535446167 |

Figure 6. Software interface showing past results of nurse times and scores.

Table 1 indicates that the average triage accuracy increased from 67% to 92%, misclassification rates decreased from 25% to 5%, and the standard deviation significantly diminished. This illustrates the system's dual function as a training platform and a decision-support tool.

Table 1. Before and after triage accuracy (triage game results).

| Metric | Before Training | After Training |
|---|---|---|
| Average Triage Accuracy | 67% | 92% |
| Misclassification Rate | 25% | 5% |
| Standard Deviation | 8.2 | 3.1 |

### 4.2 Space Optimization and Workflow Innovation: The Smart Area

The Smart Area was implemented to address overcrowding and enhance intake processes through spatial and technological advancements. The Smart Area, featuring a policy that limits companions and a designated space of 8 × 4 meters approximately, effectively minimizes congestion while ensuring patient comfort. Figure 6 illustrates the bilingual input interface, which decreases nurse workload by 1 to 2.5 minutes per patient. Figure 7 presents the Smart Area concept, which incorporates educational displays, including sign-language accessibility, and a designated wheelchair collection zone to enhance logistics.

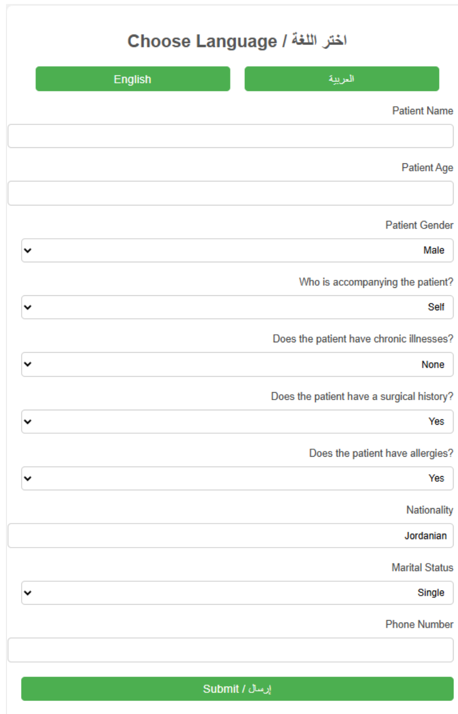


Figure 6. Input system user interface.


Figure 7. Smart area concept.

The performance impact was significant: as indicated in Table 2, average waiting times for minor cases reduced from 150 to 35 minutes, whereas critical cases declined from 60 to 18 minutes. Staff satisfaction exhibited a notable increase, as indicated in Table 3, with overall satisfaction advancing from 55% to 88%. This improvement, measured through a structured staff survey, demonstrates that design innovation improves efficiency and inclusivity.

### 4.3 Visual Prioritization: The Lighting System

A color-coded lighting system was proposed to enhance triage prioritization as shown in Figure 8. Each bed features an overhead light that indicates the patient's triage level: Blue for life-threatening, Red for critical, Yellow for moderate, Green for low, and White for minimal urgency. This system offers prompt visual indicators, minimizing dependence on paper or verbal communication and ensuring that patients with varying urgency levels do not encounter comparable delays. Deactivating lights upon discharge and integrating the system with electronic medical records facilitates real-time updates. The Lighting System serves as a cost-effective and low-maintenance enhancement to the Smart Area and Triage Game, further optimizing patient flow.

Figure 8. Proposed lighting system.

Table 2. Average waiting time reduction.

| Category | Before Project | After Smart Area & Lighting |
|---|---|---|
| Minor Cases | 150 minutes | 35 minutes |
| Critical Cases | 60 minutes | 18 minutes |
| Overall ER Avg. Wait | 98 minutes | 27 minutes |

Table 3. Staff satisfaction.

| Aspect | Before | After |
|---|---|---|
| Workload Manageability | 2.3/5 | 4.1/5 |
| Communication Clarity | 2.6/5 | 4.5/5 |
| Shift Fairness | 2.1/5 | 4.0/5 |
| Satisfaction Index | 55% | 88% |

### 4.4 Simulation Analysis as a Foundation

A DES model was created utilizing around 20,000 patient records gathered from historical data at the hospital. Statistical analysis indicated that patient interarrival times conformed to an exponential distribution, Expo(8.71) minutes. In peak winter months, this duration decreased to 5.13 minutes, reflecting a 60–100% increase in arrivals. The identification of patient arrivals, service times for each process and server, and the number of available resources, including nurses, doctors, and technicians, was achieved through the analysis of collected data and consultations with domain experts.

The simulation model was executed with the following explicit parameters to ensure robustness and reproducibility:

- Warm-up period: 2 hours, determined through the method of Welch to eliminate initialization bias.
- Replication count: 30 independent replications to capture variability in patient flows and service times.

- Run length: 30 days per replication, representing typical operational cycles in the ED.
- Convergence diagnostics: The half-width of 95% confidence intervals for key performance measures (e.g., patient waiting time, number in system) was monitored to confirm sufficient replication and statistical stability.
- Performance measures: Metrics included average and maximum patient waiting times, length of stay in the system, resource utilization rates, and queue lengths for each service node.

The model underwent a comprehensive verification and validation process to ensure simulation accuracy and reliability. The verification involved an examination of the model's logic, process flows, and outputs in comparison to historical hospital data to ensure accurate representation of patient arrivals, service times, and resource utilization. Validation was enhanced through consultations with hospital experts, including clinicians and administrative staff, who affirmed that the model accurately represented operational practices and decision-making processes in the ED. The steps taken ensured that the simulation results accurately represent real-world conditions and can reliably guide the evaluation of proposed interventions.

Analysis of patient flow indicated that 52% of cases were assigned to normal beds, 26% to the Pediatric Room, 12% to minor rooms, and 8% to the Cast Room. These insights provided a thorough and realistic basis for evaluating the impacts of proposed interventions on waiting times, triage accuracy, and overall efficiency. Figure 9 depicts the system prior to the interventions, whereas Figure 10 demonstrates the redesigned model following their implementation.

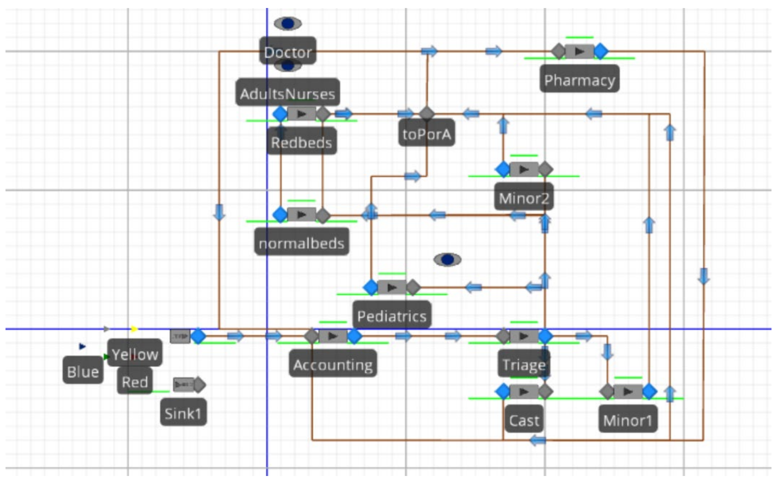


Figure 9. Baseline ED model.

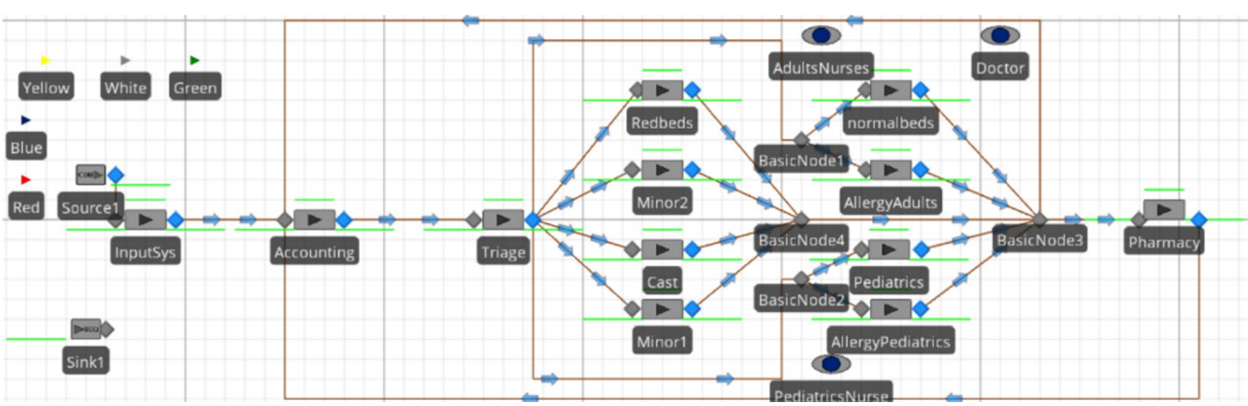


Figure 10. Redesigned ED model following implementation of improvements.

Tables 4 present the simulation results prior to and following the suggested improvements. It illustrates that substantial reductions occurred in all triage classes regarding both the patient count within the system and the duration of stay in the ED. The White, Green, and Yellow classes demonstrated reductions of over 50% in both average system size and time, whereas Red patients, despite being prioritized, saw a 37.9% reduction in average time in the system. Triage performance demonstrated significant improvement.

Table 4. Reductions in patient numbers and length of stay across all triage classes in the ED.

| Class | Metric | | Before | After | Improvement |
|---|---|---|---|---|---|
| White | Number In System | Average | 12.49 | 6.27 | 49.80% |
| | | Maximum | 21.00 | 17.00 | 19.05% |
| | Time In System (hr) | Average | 1.77 | 0.79 | 55.37% |
| | | Maximum | 3.25 | 2.41 | 25.85% |
| Green | Number In System | Average | 4.46 | 1.94 | 56.50% |
| | | Maximum | 10.00 | 6.00 | 40.00% |
| | Time In System (hr) | Average | 1.67 | 0.72 | 56.89% |
| | | Maximum | 2.80 | 1.64 | 41.43% |
| Yellow | Number In System | Average | 2.35 | 1.16 | 50.64% |
| | | Maximum | 10.00 | 4.00 | 60.00% |
| | Time In System (hr) | Average | 1.90 | 0.75 | 60.53% |
| | | Maximum | 2.57 | 1.04 | 59.53% |
| Red | Number In System | Average | 0.33 | 0.25 | 24.24% |
| | | Maximum | 3.00 | 2.00 | 33.33% |
| | Time In System (hr) | Average | 1.61 | 1.00 | 37.89% |
| | | Maximum | 1.92 | 1.82 | 5.21% |

The integration of the Triage Game, Smart Area, Lighting System, and Simulation demonstrates the significant potential of coordinated innovation in ED operations. The integration of patient flow management with specific technological and procedural interventions effectively reduced system bottlenecks and enhanced the efficiency and responsiveness of the care environment. The results demonstrate that simulation-driven insights can inform practical enhancements, effectively connecting operational analysis with real-world application. The framework outlined is adaptable and scalable, providing a model for healthcare facilities aiming to improve efficiency, increase staff satisfaction, and uphold a patient-centered approach. The study emphasizes the effectiveness of integrative strategies in achieving sustainable, system-wide enhancements in complex clinical environments.

## 5. Conclusion

This study systematically examined significant issues in the ED of hospitals, such as extended patient waiting times, variable triage classification, overcrowding, and suboptimal resource utilization. Interventions that integrated DES, the Triage Game, and the Smart Area resulted in significant enhancements: reductions in patient waiting times, improvements in triage accuracy, optimization of resource allocation, and alleviation of staff workload and burnout. Overcrowding and patient experience were improved, resulting in a more organized and patient-centered environment.

The simulation model, which included explicit parameters such as warm-up periods, replication counts, performance measures, and statistical analyses, facilitated a reliable, data-driven assessment of alternative interventions. The potential for exploring dynamic staffing, predictive scheduling, and real-time resource allocation is also present.

Limitations encompass dependence on historical data, oversimplified assumptions in service processes, a narrow focus on the ED, and restricted generalizability to other hospitals. The current study was performed in a big tertiary-care hospital; nevertheless, the suggested combination of simulation, spatial optimization, and digital triage training is fundamentally modular and may be adapted to other healthcare settings. Smaller hospitals may gain advantages from streamlined iterations of the model with reduced resources, while bigger systems can utilize the framework for optimization across several departments. Essential characteristics, like arrival rates, service durations, and resource configurations, can be adjusted to align with local conditions. Subsequent research will concentrate on implementing the model in hospitals with diverse capabilities to enhance its validation regarding adaptability and cost-effectiveness. Future research could mitigate these issues by broadening the simulation through hybrid or agent-based models, incorporating predictive analytics for patient arrivals, and deploying advanced digital solutions, including AI-driven triage and real-time monitoring dashboards, to improve operational efficiency and patient care.

This study illustrates that the integration of simulation with novel operational and technological strategies establishes a scalable framework for enhancing ED performance, staff well-being, and patient outcomes.

## Acknowledgements

We gratefully acknowledge the healthcare professionals and staff from hospitals in Jordan for their participation and insights, which were essential in guiding this project and enhancing patient care and ED efficiency.

## References

Astolfi, R., Lorenzoni, L., and Oderkirk, J. Informing policy makers about future health spending: A comparative analysis of forecasting methods in OECD countries. *Health Policy*, 107(1), 1–10, 2012. https://doi.org/10.1016/j.healthpol.2012.05.001

Elendu, C., Amaechi, D. C., Okatta, A. U., Amaechi, E. C., Elendu, T. C., Ezeh, C. P., and Elendu, I. D. The impact of simulation-based training in medical education: A review. *Medicine*, 103(27), e38813, 2024. https://doi.org/10.1097/MD.0000000000038813

Farrokhnia, N., and Goransson, K. E. Swedish emergency department triage and interventions for improved patient flows: A national update. *Scandinavian Journal of Trauma, Resuscitation and Emergency Medicine*, 19(1), 18, 2011. https://doi.org/10.1186/1757-7241-19-72

Grissinger, M., Gaunt, M. J., and Shilman, A. Allergy-related medication error reports submitted to a large patient safety reporting system. *Patient Safety*, 1(1), 18-27, https://doi.org/10.33940/medical/2019.9.3, 2019.

Gul, M., and Celik, E. An exhaustive review and analysis on applications of statistical forecasting in hospital emergency departments. *Health Systems*, 9(4), 263-284, 2020. https://doi.org/10.1080/20476965.2018.1547348

Hedding, K., Dippenaar, E., and Wallis, L. A descriptive study of demographics, triage allocations and patient outcomes at a private emergency centre in Pretoria, *South African Family Practice*, 63(4), 2021. https://doi.org/10.4102/safp.v63i1.5308

Hitchcock, M., Gillespie, B., Crilly, J., and Chaboyer, W. Triage: An investigation of the process and potential vulnerabilities, *Journal of advanced nursing*, 70(7), 1532-1541, 2014. https://doi.org/10.1111/jan.12304

Johnson, K, D., Punches, B. E., and Smith, C. R. Perceptions of the essential components of triage: a qualitative analysis. *Journal of Emergency Nursing*, 47(1), 192-197, 2021. https://doi.org/10.1016/j.jen.2020.08.009

Johnson, K, D., and Alhaj-Ali, A. Using Simulation to Assess the Impact of Triage Interruptions. *Journal of Emergency Nursing*, 43(5), 435-443, 2017. https://doi.org/ 10.1016/j.jen.2017.04.008

Lamé, G., and Dixon-Woods, M. Using clinical simulation to study how to improve quality and safety in healthcare. *BMJ simulation and technology enhanced learning*, 6(2), 87, 2020. https://doi.org/10.1136/bmjstel-2018-000370

Mandahawi, N., Al-Shihabi, S., Abdallah, A. A., and Alfarah, Y. M. Reducing waiting time at an emergency department using design for Six Sigma and discrete event simulation. *International Journal of Six Sigma and Competitive Advantage*, 6(1-2), 91-104, 2010. https://doi.org/10.1504/IJSSCA.2010.034858

Mandahawi, N., Shurrab, M., Al-Shihabi, S., Abdallah, A. A., and Alfarah, Y. M. Utilizing six sigma to improve the processing time: a simulation study at an emergency department. *Journal of Industrial and Production Engineering*, 34(7), 495-503, 2017. https://doi.org/10.1080/21681015.2017.1367728

O'Connor, E., Gatien, M., Weir, C., and Calder, L. Evaluating the effect of emergency department crowding on triage destination. *International journal of emergency medicine*, 7, 1-7, 2014. https://doi.org/10.1186/1865-1380-7-16

Silva, J, A. D., Emi, A. S., Leão, E. R., Lopes, M. C. B. T., Okuno, M. F. P., and Batista, R. E. A. Emergency Severity Index: accuracy in risk classification. *Einstein (Sao Paulo)*, 15, 421-427, 2017. https://doi.org/10.1590/S1679-45082017AO3964

Taguti, P, daS., Dotti, A. Z., de Araujo, K. P., de Pariz, P. S., Dias, G. F., Kauss, I. A., Grion, C. M., and Cardoso, L. T. The performance of a rapid response team in the management of code yellow events at a university hospital, *Revista Brasileira de terapia intensiva*, 25, 99-105, 2013. https://doi.org/10.5935/0103-507X.20130020

Van der Linden, M, C., Meester, B. E., and van der Linden, N. Emergency department crowding affects triage processes. *International emergency nursing*, 29, 27-31, 2016. https://doi.org/10.1016/j.ienj.2016.02.003

Varndell, W., Hodge, A., and Fry, M. Triage in Australian emergency departments: Results of a New South Wales survey. *Australasian Emergency Care*, 22 (2), 2019. https://doi.org/81–86. 10.1016/j.auec.2019.01.003

Viola, D, C. M., Cordioli, E., Pedrotti, C. H. S., Iervolino, M., Bastos Neto, A. D. S., Almeida, L. R. N. D., and Lottenberg, C. L. Advanced units: quality measures in urgency and emergency care. *Einstein (Sao Paulo)*, 12, 492-498, 2014. https://doi.org/10.1590/S1679-45082014GS2894

World Health Organization. (2022). Global report on diabetes. World Health Organization. https://www.who.int/publications/i/item/9789241565257

Yalçin, G., and Anil, M. Pediatric Disaster Triage System. *Forbes Journal of Medicine*, 3(2), 2022. https://doi.org/10.4274/forbes.galenos.2021.40427

## Biographies

**Mumen Rababah** is an Assistant Professor of Industrial Engineering at The Hashemite University, Jordan. He received his BSc and MSc in Industrial Engineering from Jordan University of Science and Technology, Jordan, and a Ph.D. in Industrial and Systems Engineering from Auburn University, USA. His teaching expertise spans simulation, supply chain management, and data analysis. Mumen's research focuses on logistics, simulation, and AI applications.

**Ayman Al-Hayek** graduated with a Bachelor's degree in Industrial Engineering from the Hashemite University, Jordan.

**Yazan Jaradat** graduated with a Bachelor's degree in Industrial Engineering from the Hashemite University, Jordan.

**Tamara Alnawaiseh** graduated with a Bachelor's degree in Industrial Engineering from the Hashemite University, Jordan.

**Razan Aldowery** graduated with a Bachelor's degree in Industrial Engineering from the Hashemite University, Jordan.