Proceedings of the International Conference on Industrial Engineering and Operations Management

Publisher: IEOM Society International, USA DOI: 10.46254/GC03.20250462
Published: February 2, 2026

Integrating Value Stream Mapping, Simulation, and Layout Optimization to Improve Emergency Department Performance in Private Hospitals

Majid M. Aldaihani, Jana Alnasrallah and Shaikha Almutairi
Kuwait University
College of Engineering & Petroleum
Department of Industrial and Management Systems Engineering
P.O. Box 5969 Safat 13060 Kuwait
Email: m.daihani@ku.edu.kw, Janaalnasrallah@gmail.com and Shaikha792002@gmail.com

Abstract

This study addresses operational inefficiencies in the Emergency Department (ED) of a private hospital, focusing on reducing the rate of patients leaving without being seen (LWBS). Value Stream Mapping (VSM) was employed to identify delays and bottlenecks in the patient journey, and a simulation model evaluated potential improvements. Implementing parallel processes, including combined triage with registration and doctor review with payment, reduced total lead time by 14.4%. The Block Diagramming Method (BDM) was applied to optimize the ED layout, repositioning critical rooms and decreasing unnecessary movement by 20%. For long-term improvement, a 1,854 m² ED extension was proposed, with financial feasibility assessed through cost analysis and sensitivity evaluation. The approach provides a practical framework to enhance patient flow, efficiency, and service quality.

Keywords
Emergency Department, value stream mapping, healthcare Engineering, facility layout, Kuwait.

1. Introduction
Emergency Departments (EDs) are critical components of healthcare systems, providing urgent care to patients with varying levels of medical acuity. The efficiency of an ED directly influences patient outcomes, satisfaction, and overall hospital performance. However, many EDs face persistent operational challenges, including long waiting times, overcrowding, and high rates of patients leaving without being seen (LWBS). These issues not only compromise patient safety but also increase the workload and stress on medical staff, leading to suboptimal care delivery. In private hospitals, where patient volumes and service expectations are high, inefficient ED processes can significantly impact both clinical outcomes and operational costs. Traditional approaches to improving patient flow often focus on isolated interventions, such as staffing adjustments or scheduling changes, without addressing systemic bottlenecks in the patient journey. This research is motivated by the need for a holistic, data-driven approach to enhance ED performance. By integrating efficient engineering tools and techniques such as Value Stream Mapping (VSM), simulation modeling, and Block Diagramming Method (BDM), this study aims to identify inefficiencies, optimize patient flow, and improve the overall layout and resource allocation of a private hospital ED. The study demonstrates how combining workflow analysis, process simulation, and facility design can provide practical solutions for reducing lead times, minimizing unnecessary movement, and enhancing service quality.

A substantial body of research has examined healthcare provider behavior through the lens of facility layout analysis. For example, Faber et al. (2023) and Meng, Batt, and Terwiesch (2021) demonstrated that ED layout influences how nurses organize their tasks, showing that distance-based layouts encourage task batching that reduces staff movement but may increase patient waiting times without compromising care quality. Other studies have adopted data-driven approaches to facility layout but have relied primarily on observational and survey-based methods. For instance, Hollingsworth et al. (1998) used direct observation of ED nurses and found that approximately 32% of nursing time was devoted to direct patient care, 47% to indirect care activities, and 21% to non-patient-related tasks, underscoring the importance of efficient layout design for healthcare productivity. Similarly, Tucker (2004) conducted observational studies across multiple hospitals to assess the impact of operational failures on medical staff performance. Within the healthcare architecture literature, hospital facility layout has frequently been evaluated using provider survey data to examine the effects of staff–patient visibility (Bosch et al. 2016) and ward design (Hua et al. 2012) on performance outcomes such as patient satisfaction and quality of service. In addition, Soriano-Meier et al. (2011) highlighted the role of physical layout in supporting lean management initiatives aimed at improving overall ED productivity. On the other hand, simulation-based evaluation is widely used to analyze process complexity in EDs because it can capture the stochastic and dynamic nature of ED operations more effectively than analytical models (Rossetti et al., 1999; Yousefi et al., 2020). Many studies combine simulation with stochastic optimization to assess staffing and scheduling policies, with most focusing on fixed-shift staffing configurations (Ahmed and Alkhamis, 2009; Feng et al., 2017; Ghanes et al., 2015; Guo et al., 2020). For example, stochastic programming and chance-constrained models have been applied to optimize staffing levels while meeting waiting time targets (Ahmed and Alkhamis, 2009; Guo et al., 2017). In contrast, relatively few simulation-based studies consider flexible staffing or scheduling strategies in EDs (Kuo, 2014; Yeh and Lin, 2007).

The literature review reveals a gap in studies that integrate multiple methodologies to jointly address lead time reduction and unnecessary movement. This research aims to bridge that gap by combining workflow analysis, process simulation, and facility design to develop practical solutions that reduce lead times, minimize non-value-added movement, and enhance overall service quality.

2. Background

The private hospital examined in this study operates under a clearly defined hierarchical organizational structure. At the top of the hierarchy is the General Manager, who is responsible for strategic planning, funding allocation, and policy formulation. Reporting directly to the General Manager, the Deputy General Manager oversees all major departments, each of which is further organized into specialized divisions. Among these, the Emergency department has been identified as key focus area for operational and clinical improvement.

During the data collection phase in the ED of the studied private hospital, four key performance metrics were examined and benchmarked against international emergency care standards, as presented in Table 1. These benchmarks, established by organizations such as the World Health Organization (WHO), the International Federation for Emergency Medicine (IFEM), and the Australasian College for Emergency Medicine (ACEM), include the average waiting time prior to triage, the average time from triage to physician assessment for triage levels 3 to 5, the average length of stay (LOS), and the proportion of patients who leave without being seen (LWBS). The LWBS metric represents patients who present to the ED but depart before receiving medical assessment or treatment. The hospital examined in this study exceeds international benchmarks in the first three performance metrics. However, it underperforms with respect to the proportion of LWBS patients, which ranges from approximately 4 to 9 patients per day. International guidelines recommend an LWBS rate of 2% or lower (International Emergency Nursing). Given a daily ED volume of approximately 115 to 218 patients, the corresponding LWBS rate at the studied hospital ranges from 3.5% to 4.1%, exceeding the accepted standard. This elevated rate warrants further investigation and underscores the need for targeted process improvements to reduce patient walkouts. The LWBS rate was calculated using the following equation: LWBS Rate (%) = (Number of LWBS Patients / Total ER Visits) X 100.

Table 1. Comparison of ED Statistics Between the hospital and International Standards

Statistics	Standard	Studied hospital
Average Waiting Time Before Triage (Walk in Patients)	**≤ 15 minutes**	10-15 Minutes
Average Time from Triage to Doctor Examination (level 3 to 5)	Level 3: ≤ **30 min** Level 4**: ≤ 60 min** Level 5**: ≤ 120 min**	15-20 Minutes
Average Length of Stay (level 1 to 5)	**≤ 4 hours**	2-4 Hours
Patient Leaving Without Being Seen Rate	**≤ 2%**	2.6% - 6.9%

A cause-and-effect (fishbone) diagram was developed to identify the key factors contributing to the elevated LWBS rate. As illustrated in Figure 1, six primary cause categories were identified. Among these, three areas were selected for detailed analysis: facility limitations, operational issues along the patient journey, and constraints related to equipment and resources. These areas were prioritized due to their strong potential to improve operational efficiency, patient flow, and resource utilization. Each of these key issues is examined in separate sections of this report, where the underlying challenges are analyzed and corresponding improvement strategies are proposed.

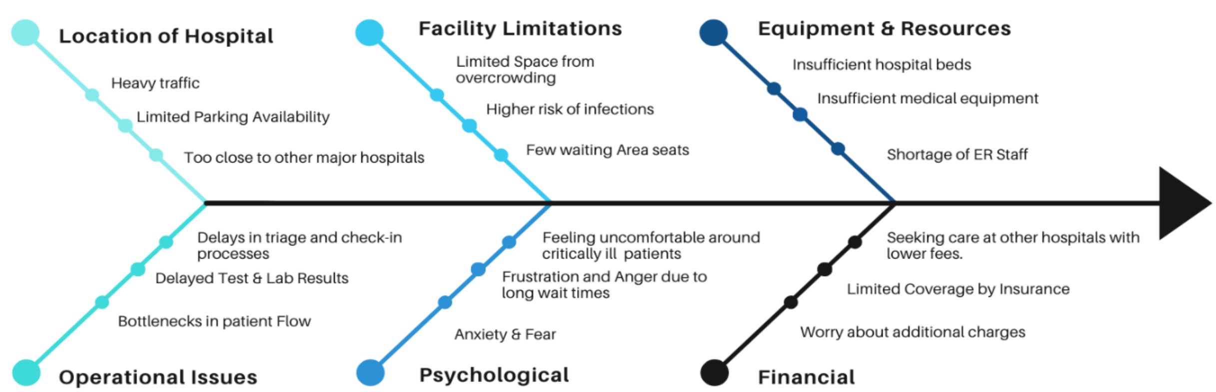

Figure 1. Fishbone Diagram of Factors Contributing to the High LWBS Rate

3. Operational Processes

To analyze patient flow in the Emergency Department, it is first necessary to define patient acuity levels. Upon arrival, patients undergo a triage process in which their condition severity is assessed and prioritized using the Canadian Triage and Acuity Scale (CTAS). This scale classifies patients into five levels, which are Level 1 (resuscitation), which requires immediate medical intervention, Level 2 (Emergent), Level 3 (Urgent), Level 4 (Less Urgent) and Level 5 (non-urgent).The CTAS framework supports clinical decision-making by enabling healthcare staff to rapidly identify patients requiring urgent care versus those who can safely wait. Patients classified as Levels 1 and 2 must receive immediate physician attention, whereas patients in Levels 3 to 5 may experience waiting times when physicians are not immediately available. The flowchart in Figure 2 illustrates the patient journey in the ED.

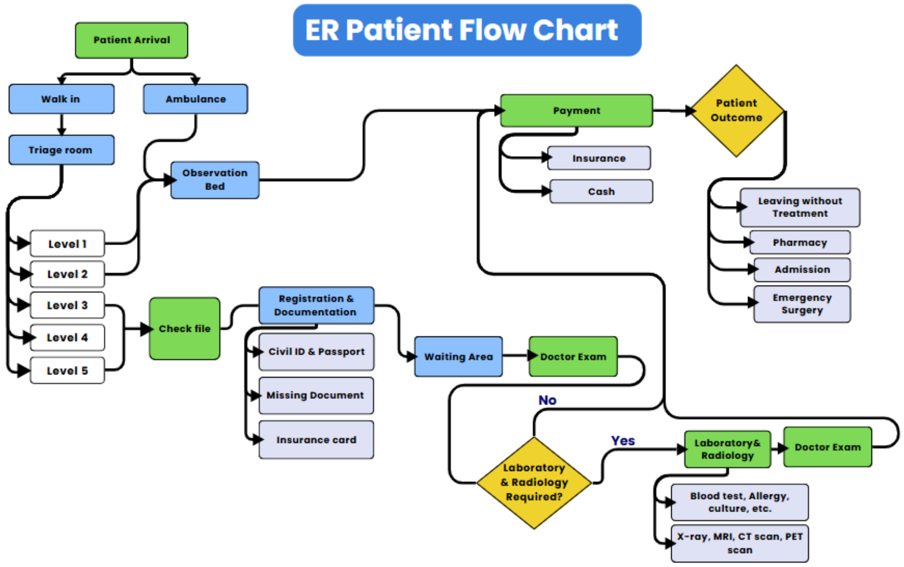

Figure 2. Emergency Patient Flow Chart

The patient journey in the ED, as illustrated in the flowchart, begins with patient arrival, either as a walk-in or via ambulance. All patients initially undergo triage, during which they are assigned a priority level based on the acuity scale. Following triage, patients are either transferred to an observation bed or proceed to the registration and documentation stage, where staff verify required documents such as a civil ID, passport, or insurance card. After registration, patients wait in the designated waiting area until they are examined by a physician. When laboratory or radiology services are required, patients are routed accordingly for diagnostic procedures, such as blood tests or medical imaging, and then return to the physician for results review. Patients subsequently proceed to the payment stage, which may involve insurance processing or cash payment. The patient flow concludes with several possible outcomes, including leaving without treatment, visiting the pharmacy, hospital admission, or emergency surgery. Insights from meetings with ED staff identified several critical stages, highlighted by green boxes in the flowchart, that frequently create bottlenecks in patient movement. These stages form the initial focus of the analysis, with the objective of identifying and addressing inefficiencies in patient flow to enhance both the timeliness and quality of emergency care delivery.

A comparison between international benchmarks and the current performance of the studied hospital further underscores the need to improve internal processes within the ED. The average processing time for non-urgent patients exceeds the standards recommended by the Canadian Triage and Acuity Scale (CTAS). It is found that the studied hospital average is between 2 and 4 hours while it is between 1 and 3 hours in CTAS. This deviation indicates delays in patient flow, particularly for non-urgent cases, which are expected to progress through the system more efficiently.

4. Methodology: Value Stream Map

To better understand and improve patient flow in the Emergency Department, Value Stream Mapping (VSM), an Industrial Engineering tool, was applied. VSM was used to map each step of the patient journey from arrival to departure, enabling a comprehensive visualization of the care process. Although originally developed for lean manufacturing, VSM has been widely adopted in healthcare settings to identify inefficiencies and sources of delay. The method distinguishes between value-added activities, represented by process cycle times, and non–value-added activities, such as waiting times. This distinction allows targeted efforts to reduce overall process time and enhance the continuity and efficiency of patient flow. The Society for Health Systems (SHS) emphasizes the importance of adopting a systems perspective when implementing improvements in EDs. Value Stream Mapping (VSM) is presented as a tool for defining system structure by clearly illustrating how processes flow from one stage to the next, thereby revealing interdependencies, delays, and sources of waste. In contrast, simulation is used to evaluate proposed changes to this structure in a risk-free environment, allowing performance testing without disrupting patients, staff, or hospital operations. Although VSM originated in manufacturing, the article highlights its broad applicability to service systems, including healthcare. Specifically, hospitals can employ VSM to map patient flows, identify operational bottlenecks, and support improvement planning in much the same way manufacturers analyze product flows. As such, VSM, when combined with simulation, serves as a powerful approach for enhancing service performance in emergency departments.

4.1. Stopwatch Study

This study focused specifically on non-urgent patients, who account for approximately 57% of total emergency visits at the studied hospital and are easier to observe without disrupting critical care. To evaluate their journey through the Emergency Department, a stopwatch study was conducted, manually timing each patient as they progressed through seven key processes, from arrival to the final payment stage. Observations were carried out during peak hours to ensure the results reflected high-demand operational conditions. Although the target sample size was 121 patients, only 58 observations were collected due to time constraints. The hospital deploys 2 triage nurses, 4 laboratory staffs, 3 physicians, and 2 cashiers during peak hours to manage non-urgent cases. These staffing levels correspond to the conditions under which the observations were conducted.

4.2. Current Value Stream Map

The current-state VSM, shown in Figure 3, depicts the complete patient journey for non-urgent cases in the ED. The map visually represents each stage, from patient arrival and triage to registration, examination, laboratory testing, physician review, and payment. Processes highlighted in blue indicate the major activities included within the scope of this study, primarily involving direct interactions with non-urgent patients. The VSM facilitated the identification of delays, bottlenecks, and redundant movements in the existing system. Importantly, it distinguished between value-adding and non-value-adding steps, providing a foundation for proposed improvements aimed at reducing patient waiting times and streamlining the overall care experience.

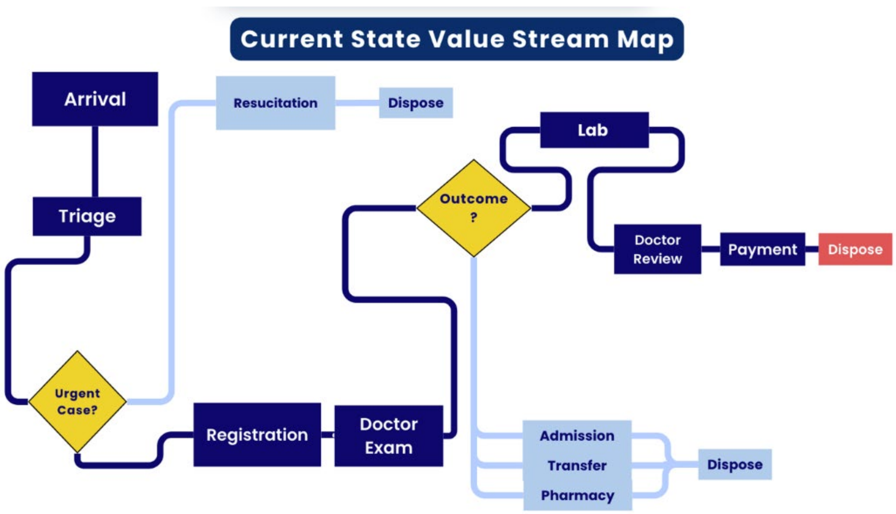

Figure 3. Current State Value Stream Map for Non-Urgent Patients

Table 2 presents the statistical results derived from stopwatch data collected during the VSM study. The average total lead time for non-urgent patient cases was 142.1 minutes, of which 100.6 minutes represented value-added time, indicating periods when patients were actively receiving care. The remaining 41.5 minutes were non-value-added, primarily attributable to delays and waiting between processes. The calculated control limits capture the natural variability in patient flow observed during the study and serve as a critical reference for comparing against the confidence intervals generated by the simulation model to evaluate its accuracy.

Table 2. VSM Time Summary and Control Limits

	Average	Standard Deviation	Lower Control Limit	Upper Control Limit
Total Lead Time	142.1	16.8	137.7	146.4
Value Added Time	100.6	12.8	97.3	103.9
Non -Value Added Time	41.5	12.1	38.3	44.6

4.3. Model Development

To support decision-making and evaluate the impact of proposed improvements, a simulation model of the ED was developed using Arena. This approach enabled testing of different scenarios without disrupting actual operations and facilitated assessment of potential solutions prior to implementation. The current-state simulation model was built using data collected from the VSM study and analyzed with Arena's Input Analyzer, which generated the most appropriate statistical distributions for each process based on real-time observations from the stopwatch study. The modeled processes included Arrival, Triage, Registration, Doctor Examination, Laboratory Testing, Doctor Review, and Payment. These distributions were used to construct a simulation that accurately replicates the flow of non-urgent patients through the ED. Staffing resources in the model were fixed to reflect the actual levels observed during the stopwatch study, ensuring the simulation accurately represents current operational conditions. Patient interarrival times were derived from stopwatch data and incorporated into the model to capture realistic arrival patterns and demand fluctuations. The time between arrival found to be Expo (6.6) minutes.

Triage Time Distribution: Based on the results from the Input Analyzer, the triage process follows a Weibull distribution, expressed as 3 + WEIB (3.87, 1.63). The p-value was greater than 0.05, which indicates the distribution is a good fit for the data. This makes the Weibull distribution suitable for simulating the time between patient arrivals at triage.

Registration Time Distribution: The time for the registration process follows a Beta distribution and expressed as: 2 + 11 × BETA(1.28, 2.26). The p-value was 0.0999, which is greater than 0.05, meaning the distribution is statistically suitable.

Doctor Exam Time Distribution: The Input Analyzer showed that the doctor exam process follows a Triangular distribution, with the expression: TRIA (8, 13, 20). The p-value was 0.615, which is well above 0.05, confirming that the distribution fits the data well. This makes the triangular distribution a suitable and accurate choice for modeling doctor exam times in the simulation.

Lab Time Distribution: The lab process follows a Lognormal distribution, expressed as 7 + LOGN (10.2, 13.5). The p-value was 0.005, which is less than 0.05, indicating that the distribution is not a perfect statistical fit. However, the square error was low at 0.0303, and the visual fit on the histogram shows that the Lognormal distribution still closely represents the actual data. Therefore, it was selected as the best available option for modeling the lab process time in simulation.

Doctor Review Time Distribution: The doctor review process follows a beta distribution, expressed as 2 + 17 × BETA(1.57, 1.92). The p-value was 0.111, which is greater than 0.05, confirming the distribution is statistically suitable.

Payment Time Distribution: The payment process follows a beta distribution, expressed as 3 + 14 × BETA (1.98, 1.86). The p-value was 0.475, which is greater than 0.05, confirming that the distribution is statistically suitable.

4.4. Current Simulation Model

The results of the simulation model are summarized in Table 3. The total lead time for patients was 140 minutes, of which 102 minutes represented value-added time, when patients were actively receiving care, and 38 minutes corresponded to non-value-added time, primarily spent waiting. These findings highlight an imbalance in the process flow, with certain activities creating bottlenecks. To address these inefficiencies, the implementation of parallel processes is proposed. Specifically, Triage and Registration, as well as Doctor Review and Payment, can be reorganized to occur simultaneously. This approach is intended to reduce overall process time and enhance the efficiency of the Emergency Department system. The strategy is informed by Lean thinking, which has been successfully applied in similar healthcare settings. Case studies have shown that combining tasks such as triage and registration, or clinical review and payment, can significantly improve workflow efficiency and reduce delays without increasing resource demands, particularly when linking clinical and administrative steps. The improved simulation model reflects these proven Lean-based strategies by introducing the selected parallel processes, thereby enhancing overall patient flow and system performance.

Table 3. Simulation Results for Total Time and Queuing Delays

Term	Total Lead Time	Value Added Time	Non Value Added Time	Triage Queue	Registration Queue	Doctor Exam Queue	Lab Queue	Doctor Review Queue	Payment Queue
Average (min)	140	102	38	1.17	5.36	7.42	35.1	8.55	5.45

4.5. Model Verification and Validation

To ensure the accuracy and reliability of the simulation model, verification was conducted by examining the logic, process sequence, and resource behavior to confirm that the model accurately represented the intended real-world workflow. This verification process was guided by lean healthcare principles, with a focus on minimizing waste and improving patient flow. Validation was carried out by comparing the simulation outputs against actual system data. Key performance metrics, including average waiting times for each process, were analyzed. To determine whether the simulation model accurately reflects the real system in terms of total lead time, variance testing was first performed, followed by a two-sample t-test to compare the means. A significance level of $\alpha = 0.05$ was used for the test on variances, with the following hypotheses: $H_0\colon {\sigma_{Real\ system}}^2 = {\sigma_{Simulation}}^2$; $H_1\colon {\sigma_{Real\ system}}^2 \neq {\sigma_{Simulation}}^2$

The sample sizes were $n_{(1)simulation} = 50$ and $n_{(2)Real}$=58 with sample variances of ${s_{(1)Simulation}}^2 = 220.97$ and ${s_2}^2 = 295$. The test statistic was calculated as: $F_0 = 220.97 / 295 = 0.748$. Using Excel, the critical values were found to be $F_{0.025,49,57} = 1.716$ and $F_{0.975,49,57} = 0.576$. Since $F_0 = 0.748$ falls between the critical values ($0.576 < 0.748 < 1.716$), the null hypothesis is not rejected. This indicates that the variances are equal at the 95% confidence level. Given the equality of variances, a two-sample t-test assuming equal variances was used to compare the means. The pooled variance was calculated as $sp^2 = 260.86$, and the sample means were $\overline{X_1} = 140.51$ and $\overline{X_2} = 141.9$. With a combined degree of freedom of 106 and a critical value $t_{0.025,106} = 1.982597$, the confidence interval for the difference in means was: $\mu_1 - \mu_2 \in -1.3908 \pm 5.1954 \rightarrow (-7.58622, 4.77271)$. Since zero lies within this interval, it is concluded that there is no statistically significant difference in the mean total lead time between the simulation model and the real system at the 95% confidence level.

4.6. Improved Simulation Model

The improved simulation model was employed to assess the effect of implementing parallel processes on reducing overall ED process time. As shown in Figure 4, two main parallel activities were introduced. First, triage and registration were integrated into a single process, eliminating redundant waiting and streamlining the initial patient handling. Second, doctor review and payment were modeled to occur simultaneously, allowing discharge procedures and administrative tasks to be completed in parallel. In the existing system, distinct roles, such as triage nurses and cashiers, handled administrative tasks like registration and payment. In the enhanced simulation model, these functions were consolidated: nurses took on both triage and registration duties, while doctors managed medical examinations along with administrative responsibilities, including discharge decisions and payment approval. This optimized workflow and improved resource coordination resulted in a 14.4% reduction in total lead time, decreasing from 140 minutes in the current model to approximately 119.9 minutes in the improved model.

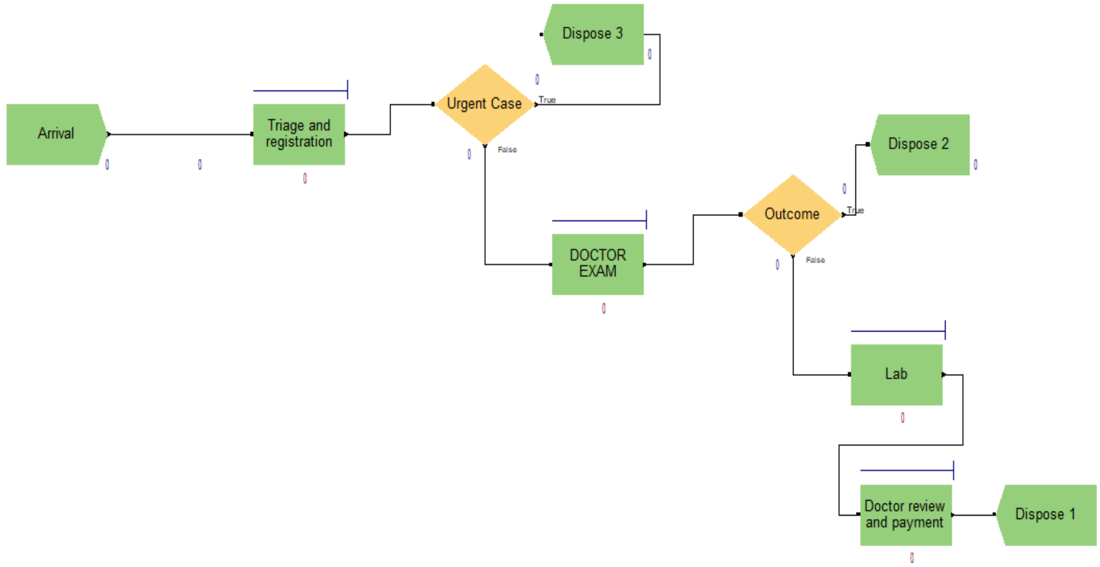

Figure 4. Improved Simulation Model with Parallel Processes

4.7. Validation of Model Improvements

To compare the current simulation model, referred to as the AS-IS model, with the improved simulation model, a test on variances was first conducted. Following this, a two-sample t-test for the means was applied based on the result of the variance test. A significance level of α = 0.05 was used for the test on variances, with the following hypotheses:

$H_0{:}\, \sigma_{AS\ IS\ system}{}^2 = \sigma_{Improved}{}^2;\, H_1{:}\, \sigma_{AS\ IS\ system}{}^2 \neq \sigma_{Improved}{}^2$
The sample sizes were $n_{(1)AS\ IS}$= 50 and $n_{(2)Improved}$= 50, with sample variances of $s_1{}^2$ = =220.97 and $s_2{}^2$ = 165.34. The test statistics were calculated as: F_0 = 220.97 / 165.34 = 1.34.

Using Excel, the critical values were found to be $F_{0.025,49,49}$ = = 1.762 and $F_{0.975,49,49}$= 0.567. Since F_0 = 1.34 falls between the critical values (0.567< 1.34 < 1.762), the null hypothesis is not rejected. This indicates that the variances are equal at the 95% confidence level. Given the equality of variances, a two-sample t-test assuming equal variances was used to compare the means. The pooled variance was calculated as: (sp^2 = 193.11). The sample means were, $\overline{X_1}$ = = 140.5 and $\overline{X_2}$ = 119.90. With a combined degree of freedom of 98 and a critical value $t_{0.025,98}$ = = 1.98, the confidence interval for the difference in means was: $\mu_1 - \mu_2 \in 20.6 \pm 10.7 \rightarrow (9.87, 31.34)$. Since the confidence interval does not include zero and lies entirely above it, it is concluded that the improved simulation model has a statistically significantly lower mean total lead time than the current model at the 95% confidence level.

5. Emergency Floor Layout

The ED floor, shown in Figure 5, is located on the hospital's ground level and features two main entrance and exit points: one providing direct access to the ED and another connecting to the broader hospital. Discussions with ED staff identified two critical areas of concern. First, visibility within critical care areas is limited. Staff noted that the Doctor Exam Room has restricted sightlines to the triage and resuscitation rooms, which are essential for rapid response and continuous monitoring. According to the Facility Guidelines Institute (FGI), the Doctor Exam Room should be positioned closer to both triage and resuscitation areas to ensure quick access and ongoing visual supervision, particularly for high-acuity patients. Additionally, the resuscitation room is recommended to be located near the emergency entrance and exit to allow immediate access upon patient arrival, as supported by FGI and the American College of Emergency Physicians (ACEP) layout guidelines. Second, the current ED layout lacks sufficient capacity to handle patient volume during peak periods. When all ED rooms are occupied, patients are often transferred to the second floor, which is outside the ED, resulting in delays and increased staff movement. To address these issues, solutions will be proposed for both the short and long term. In the short term, the focus will be on optimizing internal layout and functional relationships to improve visibility and workflow in critical care areas. For the long term, an extension assessment will be conducted to expand capacity and accommodate patient demand.

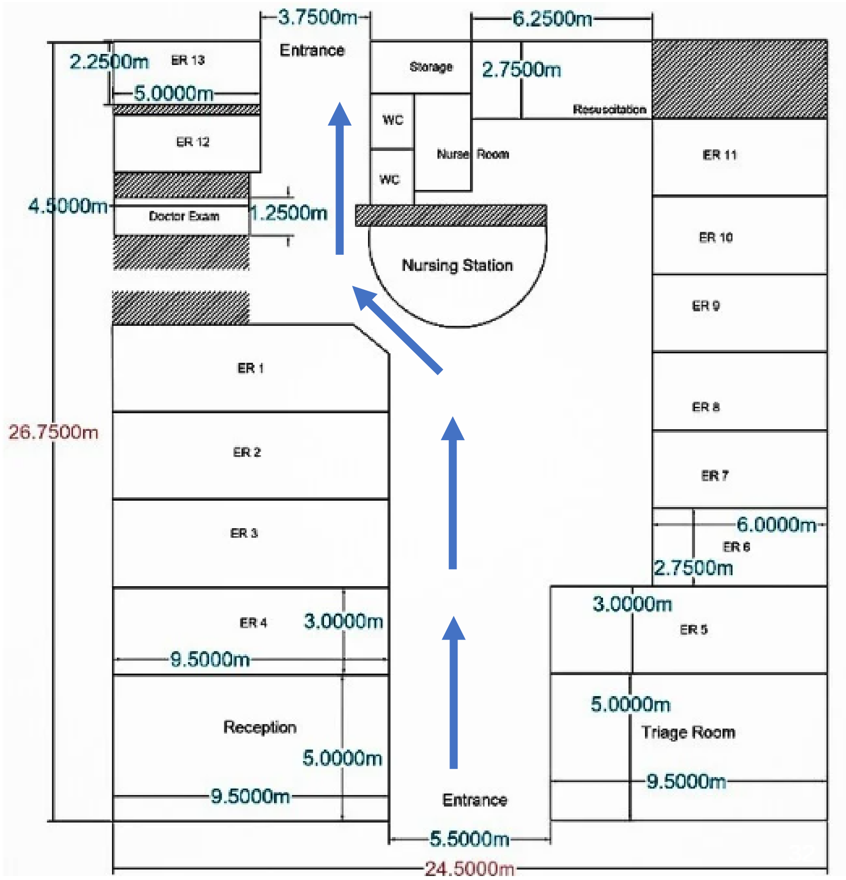

Figure 5. AutoCAD Current Emergency Floor Layout

5.1. Short Term

In the short term, the primary objective is to minimize movement by positioning related rooms closer together, considering the interactions of medical staff, non-medical staff, and patients. Table 4 summarizes several layout methods reviewed to support this goal. Based on the specific requirements of this case, the Block Diagramming Method (BDM) was identified as the most suitable approach. BDM focuses on optimizing the relative positions of rooms rather than altering their sizes or shapes, making it ideal for situations where room dimensions are fixed. The method uses flow data to guide the arrangement of departments while allowing expert judgment to inform the layout decisions. This combination ensures that high-interaction areas, such as the doctor's examination room, triage, and resuscitation rooms, are positioned close to one another in a manner that reflects both actual movement patterns and practical operational experience.

Table 4. Comparison of Layout Design Methods for ED Optimization

Method	Overview	Limitations	ER Room Use
Block Diagramming Method (BDM)	Fixes departments sized based on flow matrix	The layout is manual and must be evaluated using flow and adjacency data	Best for improving room proximity
Relationship Diagramming Method (RDM)	Draws closeness relationships between rooms	Does not account room dimensions	Informative in early phases
Graph Based Method (GBM)	Uses network graphs to optimize paths between departments	Too complex for small changes	Supports flow analysis but lacks room layout details

Quadratic Assignment Problem (QAP)	Use algorithms to assign departments to fixed locations to minimize total cost	often ignores expert layout considerations	Suitable for adjusting a stable ER layout at the final stage

In this analysis, the unit load represents the movement of a single entity between rooms within the Emergency Department. Entities include patients, medical staff, and non-medical staff, encompassing all individuals involved in departmental operations. The average unit load per year was calculated to be 317, as shown in Table 5. This value was derived by averaging the annual number of entities and mapping their movements throughout the ED. The unit load serves as a key input for developing the layout and provides a basis for evaluating the proximity of frequently interacting rooms.

Table 5. Average Daily Entity Load

Entities	Doctors	Patients	Nurses	Medical Staff	Avg Entity Load
Avg Per Day	9	218	81	9	317

Several conditions were taken into account when applying the Block Diagramming Method (BDM). First, room sizes were considered fixed, and ED rooms were grouped into functional zones—for example, Zone 1 includes ER 1 and ER 2. The complete list of rooms reflects both their physical arrangement and functional groupings within the department. In total, 14 rooms were included in the analysis, covering clinical, administrative, and supporting areas such as storage, restrooms, and the nurses' station. These conditions ensure that the layout recommendations generated by BDM are practical, implementable, and consistent with the existing structure and use of the Emergency Department.

A two-step approach was employed to develop the Block Diagramming Method (BDM). First, a percentage matrix was created to represent the proportion of entity movements between each pair of rooms in the Emergency Department. This data, collected by the examined hospital for purposes such as infection control planning, was deemed appropriate for use as the basis for our calculations. Next, a flow matrix was generated by multiplying the percentages in the matrix by the total unit load value, enabling an estimate of the actual number of movements between each room based on annual averages. The resulting aggregate flow matrix served as the foundation for calculating the weighted non-adjacency loads in the block diagram.

5.1.1. Current and Improved ED Layout

The current ED layout was created by placing each room in its actual location and grouping them into zones based on functional use. The total weighted non-adjacency load was calculated at 6,505, as shown in Figure 6 (Left).

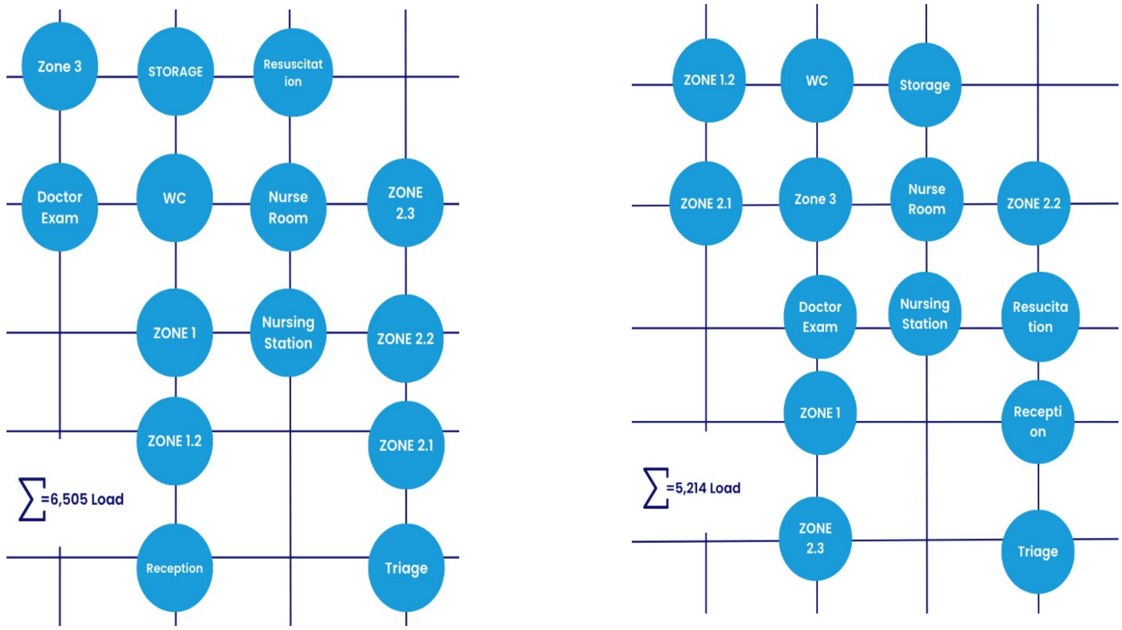

Figure 6. Current ED Layout (Left) and Improved ED Layout (Right) Based on BDM

This metric represents the cumulative movements between rooms that are not directly adjacent. A high non-adjacency load indicates that a substantial portion of movement occurs between distant rooms, resulting in longer walking distances, slower patient flow, and reduced staff efficiency. These findings underscore the need for layout improvements aimed at minimizing non-adjacent interactions by positioning high-traffic rooms closer together. Figure 6 (Right) illustrates the improved ED layout following the application of the BDM Method. Compared to the existing layout, several key modifications were implemented to reduce unnecessary movement and enhance workflow efficiency. The reception area was repositioned closer to the triage room, streamlining the check-in and initial assessment process for patients. Additionally, the resuscitation room was relocated nearer to the entrance, providing faster access for critical cases. These changes reduced the total weighted non-adjacency load, resulting in an approximate 20% improvement in overall movement efficiency throughout the department.

5.2. Long Term Planning

For long-term planning, both international standards and data from other local private hospitals were used as benchmarks to assess whether the hospital's Emergency Department meets capacity requirements. International guidelines, including those from the FGI and AIA, recommend ED areas of 5,500 to 6,500 m² for 200–220 patients per day, corresponding to area-to-patient ratios of 27.3 to 29.5. In contrast, the studied hospital currently has the smallest ratio, just 3.7, even when compared to other private hospitals. These comparisons underscore the undersized nature of the existing ED space relative to patient volume and established benchmarks. The proposed extension involves expanding the current ED within the hospital's existing building. This could be achieved by utilizing vacant or underused adjacent spaces, or through horizontal or vertical construction to increase capacity. The primary objective is to enlarge the functional area of the ED to better accommodate patient demand and enhance workflow efficiency.

Using the average area-to-patient ratio from private hospitals and multiplying it by the hospital's average daily patient volume, the required ED extension area was estimated at approximately 1,852 m². This approach provides a more realistic estimate that reflects local operational conditions, rather than relying solely on international standards, which may not accurately represent the practices of private hospitals in Kuwait. The average construction cost applied in this analysis, 616 KD/m², was derived from recent hospital extension projects in Kuwait. This figure represents the estimated cost to construct one square meter of hospital space, including materials, labor, and associated expenses under local market conditions. By using data from actual local projects, this estimate offers a practical and reliable reference for budgeting and planning should the hospital proceed with the proposed ED extension.To estimate the cost of extending the ED, the Unit Method Estimate was applied, a standard approach in early-stage construction planning. The required extension area was calculated using the average ED area-to-patient ratio of local hospitals (11.504 m² per patient). With the hospital receiving 218 patients per day, the estimated total area needed is 2,507 m². After accounting for the existing ED area of 655 m², the additional space required is approximately 1,854 m². The total initial construction cost (P) was calculated by multiplying the additional area by the average unit construction cost, resulting in an estimated cost of 1,142,230 KD. The salvage value was estimated at 35% of P, reflecting the portion of the facility's value expected to remain at the end of its useful life. This percentage aligns with the International Valuation Standards (IVS), which recommend a depreciation range of 30–40% for durable structures such as hospital buildings.

Following this cost estimation, a capital recovery analysis was performed using sensitivity analysis to assess the impact of different financial scenarios on the hospital's long-term investment. This approach supports the development of a realistic and financially viable plan for the ED extension.

A sensitivity analysis of the capital recovery cost was conducted by evaluating different combinations of interest rates (5%, 10%, and 15%) and facility lifespans (5, 10, and 15 years). This analysis estimates the annual amount the hospital would need to recover if it invests in the proposed ED extension. As shown in Table 6, the annual capital recovery varies depending on financing conditions and the expected useful life of the facility. These results provide the hospital with flexibility in selecting a repayment plan that aligns with its budget and financial strategy, while supporting informed decision-making regarding long-term investment in ED expansion.

Table 6. Capital Recovery Sensitivity Analysis

Interest Rate	5%			10%			15%		
Number of Years	5	10	15	5	10	15	5	10	15
Capital Recovery (KD)	246,443	131,739	94,252	268,892	154,662	119,312	293,258	181,276	149,359

6. Conclusion and Recommendations

At the Emergency Department of the studied private hospital, a cause-and-effect diagram identified six key challenges contributing to the high rate of patients leaving without being seen (LWBS). Three of these challenges—facility limitations, equipment and resource constraints, and operational issues, were prioritized due to their direct impact on patient waiting times and quality of care. Value Stream Mapping was then conducted to identify delays and bottlenecks throughout the patient journey. A simulation model was developed to evaluate proposed improvements, and the implementation of parallel processes, such as combining triage with registration and doctor review with payment, resulted in a 14.4% reduction in total lead time. The Block Diagramming Method was applied to optimize the facility layout by repositioning critical rooms, reducing unnecessary patient movement by 20%. For long-term facility improvement, a 1,854-square-meter extension was proposed based on local and international benchmarks, with its financial feasibility assessed through detailed cost analysis and sensitivity evaluation.

Future research may incorporate demand forecasting and real-time decision support to further reduce LWBS under fluctuating arrival patterns. The simulation model can be extended to include dynamic staffing and flexible scheduling policies. In addition, the impact of digital interventions such as electronic triage and mobile pre-registration can be evaluated. Finally, applying the framework across multiple hospitals would enhance its generalizability and robustness.

References

Ahmed, M.A. and Alkhamis, T.M. Simulation optimization for an emergency department healthcare unit in Kuwait, *European Journal of Operational Research*, vol. 198, no. 3, pp. 936-942, 2009.

Bosch, SJ., Apple, M., Hiltonen, B., Worden, E., Lu, Y., Nanda, U. and Kim, D. To see or not to see: Investigating the links between patient visibility and potential moderators affecting the patient experience, *Journal of Environmental Psychology*, vol. 47, pp. 33–43, 2016.

Faber, J., Coomes, J., Reinemann, M. and Carlson, J.N. Creating a Rapid Assessment Zone with Limited Emergency Department Capacity Decreases Patients Leaving Without Being Seen: A Quality Improvement Initiative, *Journal of Emergency Nursing*, vol. 49, no. 1, pp. 86–98, 2023.

Feng, Y.Y., Wu, I., and Chen T.L. Stochastic resource allocation in emergency departments with a multi-objective simulation optimization algorithm, *Health Care Management Science*, vol. 20, no. 1, pp. 55-75, 2017.

Ghanes, K., Wargon, M., Jouini, O., Jemai, Z., Diakogiannis, A. and Hellmann, R. Simulation-based optimization of staffing levels in an emergency department, *Simulation*, vol. 91, no. 10, pp. 942-95, 2015.
Guo, H., Gu, H., Zhou, Y. and Peng, J. A data-driven multi-fidelity simulation optimization for medical staff configuration at an emergency department in Hong Kong, *Flexible Services and Manufacturing Journal*, vol. 10, pp. 1-25, 2020.
Hollingsworth, JC., Chisholm, CD., Giles, BK., Cordell, WH. and Nelson, DR. How do physicians and nurses spend their time in the emergency department?, *Annals of Emergency Medicine*, vol. 31, no. 1, pp. 87–91, 1998.
Hua, Y., Becker, F., Wurmser, T., Bliss-Holtz, J. and Hedges, C. Effects of nursing unit spatial layout on nursing team communication patterns, quality of care, and patient safety, *Health Environments Research & Design Journal*, vol. 6, no. 1, pp. 8–38, 2012.
Kuo, Y.H. Integrating simulation with simulated annealing for scheduling physicians in an understaffed emergency department, *The Hong Kong Institution of Engineers Transactions*, vol. 21, no. 4, pp. 253-261, 2014.
Meng, L., Batt, R. J. and Terwiesch, C. The Impact of Facility Layout on Service Worker Behavior: An Empirical Study of Nurses in the Emergency Department, *Manufacturing & Service Operations Management*, vol. 23, no. 4, pp. 819-834, 2021.
Rossetti, M.D., Trzcinski, G.F. and Syverud, S.A. Emergency department simulation and determination of optimal attending physician staffing schedules, *Proceedings of the 1999 Winter Simulation Conference*, vol. 2, pp. 1532-1540, 1999.
Soriano-Meier, H., Forrester, PL., Markose, S. and Arturo Garza-Reyes, J. The role of the physical layout in the implementation of lean management initiatives, *International Journal of Lean Six Sigma*, vol. 2, no. 3, pp. 254–269, 2011.
Tucker, AL. The impact of operational failures on hospital nurses and their patients, *Journal of Operations Management*, vol. 22, no. 2, pp, 151–169. 2004.
Yeh, J.Y. and Lin, W. S. Using simulation technique and genetic algorithm to improve the quality care of a hospital emergency department, *Expert Systems with Applications*, vol. 32, no. 4, pp. 1073-1083, 2007.
Yousefi, M., Yousefi, M. and Fogliatto, F.S. Simulation-based optimization methods applied in hospital emergency departments: A systematic review, *Simulation*, vol. 96, no. 10, pp. 791-806, 2020.

Biographies

Majid M. Aldaihani is a Professor in the Department of Industrial and Management Systems Engineering at Kuwait University. He received his BS in Petroleum Engineering from Kuwait University and his MS and PhD in Industrial and Systems Engineering from the University of Southern California. His research interests focus on applied operations research and healthcare quality systems. He is a Certified Educational Institution Auditor, a recipient of Six Sigma Master Black Belt, and a recipient of Kuwait University Award of Excellence in Teaching. He is a member of Institute for Operations Research and Management Science (INFORMS), Institute of Industrial Engineers (IIE) and Kuwait Society for Engineers (KSE).

Jana Alnasrallah received her bachelor's degree from Kuwait University, College of Engineering and Petroleum, majoring in Industrial and Management Systems Engineering. Her research interests focus on healthcare quality systems. She received the Best Senior Design Project Award from the Kuwait Foundation for the Advancement of Sciences (KFAS). Jana is also a member of the Kuwait Society of Engineers.

Shaikha Almutairi received her bachelor's degree from Kuwait University, College of Engineering and Petroleum, majoring in Industrial and Management Systems Engineering. Her research interests focus on healthcare quality systems. She received the Best Senior Design Project Award from the Kuwait Foundation for the Advancement of Sciences (KFAS). Shaikha is also a member of the Kuwait Society of Engineers.