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ORIGINAL ARTICLE

DESIGN AND DEVELOPMENT OF A LEAN-BASED MODEL FOR THE EMERGENCY DEPARTMENT GREEN ZONE OF A PUBLIC UNIVERSITY HOSPITAL IN MALAYSIA

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ABSTRACT

Emergency Departments (EDs) operate under sustained pressure from increasing patient demand, overcrowding, and workflow inefficiencies. Although Lean principles have been widely adopted in healthcare to address these challenges, there remains limited documentation of systematic processes for designing and developing Lean-based intervention models in complex clinical environments. This study aimed to systematically design and develop a Lean-based model for the green zone of a public university hospital Emergency Department using a Design and Development Research (DDR) framework. This study comprised three phases: (i) needs analysis, (ii) model design and development, and (iii) model validation. A multidisciplinary Lean team conducted Value Stream Mapping (VSM) and Gemba to identify workflow inefficiencies and non-value-added activities. Improvement opportunities were prioritised using an effort–impact matrix to ensure feasibility within existing resource constraints. The prioritised components were integrated into a future-state workflow, constituting the Lean-based model, which was subsequently implemented at a pilot level within the department. Future-state VSM analysis projected a reduction in overall process length time from 6.7 hours to 4.5 hours, corresponding to an estimated 29% improvement in patient waiting time. Expert validation demonstrated strong agreement regarding the clarity, feasibility, and operational alignment of model components. This study provides a structured and reproducible pathway for the development and preliminary implementation of Lean-based interventions in Emergency Department setting, contributing methodological guidance for systematic healthcare process redesign in resource-constrained environments.

***Keywords**: Emergency Department; Green Zone; Lean Model; Workflow Improvement; Patient Waiting Time; Healthcare Quality Improvement*

INTRODUCTION

Emergency Departments (EDs) serve as critical access points within healthcare systems, managing high-acuity and time-sensitive conditions [1]. Over the past decade, rising patient volumes, increasing case complexity, bed shortages, and workforce constraints have contributed to persistent ED overcrowding worldwide [2,3]. Overcrowding, defined as the mismatch between service demand and available resources, has been associated with prolonged waiting times, delayed decision-making, reduced quality of care, and adverse patient outcomes [4-6].

In Malaysia, rising Emergency Department attendance and increasing service demand in Ministry of Health (MOH) hospitals have intensified concerns regarding overcrowding and operational strain [7]. A recent national analysis of 137 MOH hospitals reported substantial workload disparities, with approximately 26% of hospitals exceeding the overcrowding threshold based on patient-to-physician ratios. These pressures are further compounded by demographic, geographic, and socioeconomic factors, particularly in rural and non-specialist hospitals, highlighting systemic challenges in ensuring equitable access to emergency care [8]. In addition, university hospitals often experience further operational complexity due to their dual roles in service delivery and clinical training. The presence of trainees, supervisory requirements, and a broader case mix may contribute to increased process variability and longer decision-making pathways, thereby amplifying workflow inefficiencies within already strained Emergency Department systems [9].

Emergency Departments are typically organised into acuity-based zones, including red, yellow, and green zones. The Green Zone manages ambulatory, lower-acuity patients and is often characterised by

high patient volume, rapid turnover, and significant variability in waiting times, making it a critical target for workflow optimisation [10]. From an operational perspective, ED overcrowding is commonly conceptualised using the input–throughput–output model [11], where throughput inefficiencies (those occurring within the internal care processes of the ED), represent the most immediate and modifiable drivers of patient flow delays. While input factors (e.g., rising patient demand) and output constraints (e.g., inpatient bed shortages) are often system-level challenges, throughput processes fall directly within the operational domain of the ED and are therefore more amenable to targeted redesign interventions.

Previous studies have consistently identified key throughput bottlenecks, including delays in triage processes, prolonged waiting time for diagnostic investigations, inefficient consultation workflows, and duplication of documentation [12–14]. Additional constraints such as staff shortages, limited coordination between clinical teams, and delayed laboratory and radiology turnaround times further exacerbate internal process delays, contributing to prolonged length of stay and reduced flow efficiency [14]. Hence, addressing workflow inefficiencies within EDs remains a strategic priority for healthcare systems seeking to improve quality, safety, and operational sustainability.

Lean methodology has been widely adopted in healthcare as a systems-based approach to improving efficiency through the identification and elimination of non–value-added activities [15,16]. Lean was originally developed as part of the Toyota Production System (TPS) and emphasizes waste reduction, standardisation, and continuous improvement to enhance value for the customer [17-19]. In healthcare settings, Lean applications have been associated with improvements in patient flow, reductions in waiting times, and enhanced resource utilisation [20-23]. Among Lean implementation tools, Value Stream Mapping (VSM) is widely used to visualise workflow processes, distinguish value-added from non–value-added activities, and construct future-state redesign [24-29]. In Emergency Department settings, VSM has been applied to identify bottlenecks and support process improvement initiatives [24,28,30].

However, despite the extensive application of Lean methodologies in Emergency Departments, the existing literature predominantly focuses on post-implementation outcomes, such as reductions in waiting time or length of stay, with limited attention to the methodological processes through which Lean interventions are systematically designed, prioritised, and validated prior to implementation [31,32]. In particular, there is a lack of transparent and reproducible frameworks detailing how improvement components are derived from empirical workflow analysis and translated into operational models under real-world constraints. This limits the replicability, transferability, and scalability of Lean interventions across different healthcare settings. Furthermore, while Value Stream Mapping is frequently used as a diagnostic and redesign tool, its application is often reported in isolation, without integration into a structured methodological framework that guides the full intervention development process. As a result, decision-making processes such as prioritisation of interventions, feasibility assessment, and validation are often insufficiently described.

There is a need for structured methodological approaches that can systematically guide the design, development, and validation of Lean-based interventions prior to effectiveness evaluation. Such approaches should integrate empirical workflow analysis, feasibility considerations, and stakeholder input to ensure that redesigned processes are both operationally viable and contextually appropriate within complex healthcare environments. Accordingly, this study aimed to systematically design and develop a Lean-based Model for the Green Zone of a public university hospital's Emergency Department using a Design and Development Research framework. Specifically, the study sought to (i) conduct a structured analysis of existing workflow processes, (ii) identify and prioritise inefficiencies through Value Stream Mapping and feasibility assessment, and (iii) construct and validate a future-state Lean model aligned with operational constraints and stakeholder consensus.

METHODOLOGY

Study design and setting

This study employed a Design and Development Research (DDR) framework to systematically design and develop a Lean-based Model for the Green Zone of a public university hospital Emergency Department (ED). The study comprised three sequential phases: (i) Phase 1 – contextual needs analysis, (ii) Phase 2 – model design and development, and (iii) Phase 3 – model validation. DDR was chosen because it provides a structured, phase-based approach that supports the development of contextually relevant interventions through iterative processes of needs analysis, model design, and validation prior to effectiveness evaluation [33]. The study was conducted in the Emergency Department of a 300-bed public university hospital in Malaysia between January and December 2024. The hospital is a tertiary academic medical centre providing over 70 subspecialty

services and managing approximately 200,000 outpatient visits annually.

Phase 1: Needs analysis

Phase 1 involved a structured needs analysis to identify operational inefficiencies, workflow bottlenecks, and contextual constraints within the Emergency Department (ED) to inform model development. Multiple data sources were used, including administrative performance data, patient waiting time records, key performance indicators (KPIs), patient feedback, and stakeholder input.

Administrative and timestamp data extracted from the hospital's electronic medical record system were analysed descriptively to identify patterns in waiting time, and service delays. Non-participatory observations of patient flow and staff activities were conducted over a one-month period, including weekdays and weekends, to capture typical operational patterns. In total, ten observational sessions were conducted across different shifts (morning, evening, and night shifts) to ensure representation of peak and non-peak service periods. Observations focused on patient movement, staff allocation, workflow interruptions, and environmental constraints. Existing workflow protocols and documentation systems were reviewed to identify discrepancies between intended and actual practice. Stakeholder perspectives were also obtained through informal consultations and field-based discussions conducted during routine clinical operations. These engagements were not structured as formal interviews or focus groups but were integrated into daily workflow interactions to minimise disruption and capture real-time experiential insights. Participants included physicians, nurses, assistant medical officers, and support staff. Inputs were synthesised thematically to identify commonly reported workflow bottlenecks and operational challenges.

Observational findings and stakeholder input were synthesised and triangulated with quantitative trends to construct a comprehensive representation of existing workflow inefficiencies. This assessment identified the Green Zone as the priority area for structured process redesign and provided the empirical foundation for subsequent model development in Phase 2.

Phase 2: Model design and development

Phase 2 was conducted between July and December 2024 and involved the design and pilot implementation of a Lean-based model for the Green Zone. A multidisciplinary hospital Lean team was established, comprising 30 healthcare professionals, including emergency physicians, medical officers, nurses, assistant medical officers, pharmacists, radiographers, laboratory personnel, and administrative staff (human resources, finance, IT, registration, and billing). The team underwent a structured, intensive three-day Lean Healthcare workshop facilitated by certified Lean practitioners. The workshop combined lecture-based instructional sessions with hands-on application, and covered core Lean principles and tools, including value identification, waste elimination, workflow standardisation, Value Stream Mapping (VSM), Gemba observation, and Kaizen-based continuous improvement. Participants were actively engaged in mapping the current-state workflow, identifying bottlenecks, and generating improvement opportunities through guided exercises.

Value Stream Mapping (VSM) was used as the primary tool to analyse the existing workflow. The multidisciplinary team developed a current-state VSM representing the full patient journey from arrival to discharge. Each process step was categorised as value-added (VA) or non–value-added (NVA), enabling systematic identification of bottlenecks, redundancies, and delays. To ensure accuracy, the mapping process was supported by Gemba observations, time-based assessments, and triangulation with timestamp data obtained from the electronic medical record system.

Identified inefficiencies were translated into structured improvement opportunities, documented as Kaizen bursts representing targeted process improvements. While a single discrete Kaizen event was not conducted, the workshop incorporated core Kaizen principles of continuous, team-based problem solving and iterative improvement. Kaizen bursts were evaluated using an effort–impact matrix, in which each proposed change was assessed based on expected impact on patient flow and feasibility within existing operational constraints. High-impact, feasible interventions were prioritised and incorporated into a future-state VSM representing the redesigned workflow. This future-state model formed the Lean-based intervention that was subsequently pilot implemented within the Emergency Department to allow operational testing and refinement.

Phase 3: Model validation

Following pilot implementation of the redesigned workflow, a validation exercise was conducted after four months to assess the extent to which the implemented processes aligned with the designed model. A three-member expert panel comprising two certified Lean practitioners and one Emergency Physician independently evaluated each component of the redesigned workflow using a 4-point Likert scale for relevance (1 = not relevant to 4 = highly relevant). Experts were selected based on

predefined criteria, including formal certification or training in Lean healthcare methodologies and at least five years of experience in healthcare quality improvement or Emergency Department operations. Content Validity Index (CVI) was used to quantify agreement, with item-level CVI (I-CVI) and scale-level CVI (S-CVI/Ave) calculated. An I-CVI ≥ 0.80 and S-CVI/Ave ≥ 0.90 were considered indicative of satisfactory and excellent agreement, respectively [34]. Qualitative feedback from experts was also reviewed and used to refine workflow components where necessary.

Ethical considerations

This study was conducted in accordance with established ethical principles governing research involving human participants, including the Declaration of Helsinki, the Malaysian Good Clinical Practice Guidelines, and the institutional requirements of the International Islamic University Malaysia (IIUM) and Sultan Ahmad Shah Medical Centre IIUM (SASMEC IIUM). Ethical approval was obtained from the IIUM Research Ethics Committee (IREC) (registration no.: IREC-2024-263) and the Universiti Kebangsaan Malaysia Medical Research Ethics Committee (UKM MREC) (registration no.: JEP-2024-331). Institutional approval was granted by the Department of Education and Research (DEAR), SASMEC IIUM (registration no.: IIR25-43).

The study involved workflow analysis and systems redesign within the Emergency Department and did not include direct patient recruitment or intervention. Administrative and electronic medical record (EMR) timestamp data were analysed in aggregate form for operational assessment purposes without extraction of identifiable patient information. Participation of healthcare personnel in Lean design activities was conducted under formal institutional mandate as part of a structured quality improvement initiative.

RESULTS

Phase 1: Needs analysis

Baseline performance analysis was conducted to quantify existing delays and operational inefficiencies in the Green Zone prior to model development. Analysis of patient-level timestamp data from the 2024 pre-intervention period demonstrated prolonged waiting times across key stages of the patient journey. The median triage-to-registration (TTR) time was 6 minutes (IQR: 5). Delays were more pronounced in downstream processes, with a mean arrival-to-consultation (ATC) time of 61.49 minutes (SD ± 41.97) and a mean length of stay (LOS) of 181.19 minutes (SD ± 129.99). A summary of baseline performance indicators is presented in Table 1.

Table 1: Baseline performance of key operational indicators in the Green Zone of the ED

Performance indicator	Baseline (in minutes)
TTR[a]	6 (IQR: 5)
ATC[b]	61.49 ± 41.97
LOS[b]	181.19 ± 129.99

TTR: Triage-to-registration; ATC: Arrival-to-consultation; LOS: Length of stay, [a]Median (IQR), [b]Mean (± SD)

Direct observational assessment identified spatial separation between primary and secondary triage, duplication of documentation processes, role ambiguity between registration and billing functions, and intermittent bottlenecks in the procedure room and radiology pathways. Thematic analysis of stakeholder input identified several key operational challenges contributing to workflow inefficiencies in the Emergency Department (ED) Green Zone. Four major themes emerged: (i) workflow congestion and waiting times, (ii) fragmented movement pathways, (iii) cross-zone staffing redeployment, and (iv) workflow interruptions and coordination challenges. Representative quotes illustrating these themes are presented in Table 2. Triangulation of administrative data, observational findings, and stakeholder input during the needs analysis identified the Green Zone as the most feasible and impactful target for structured workflow redesign. These findings informed model design and development in Phase 2.

Table 2: Thematic analysis of stakeholder perspectives on workflow inefficiencies in the Emergency Department Green Zone

Theme	Subtheme	Description	Quotes
Workflow congestion and waiting times	Peak-period congestion	High patient influx during specific hours leads to overcrowding, particularly in the Green Zone	"During peak hours, especially after 5pm, the Green Zone becomes very crowded, and patients have to wait a long time to be seen"
	Limited consultation capacity	Insufficient number of available clinicians during high-demand periods contributes to delays	"The Green Zone only has one doctor, especially after 10pm"
Fragmented movement pathways	Multiple care transition points	Patients and staff must move across several physically separated areas (triage, consultation, investigations, administration)	"Radiology is so far for the patients to go to"
	Inefficient physical layout	Spatial separation of services contributes to delays and workflow inefficiencies	"Patients get lost finding (Secondary) Triage because there are no signs.."
Cross-zone staffing redeployment	Staff reallocation during surge	Green Zone staff are redeployed to higher-acuity zones during peak demand	"When the red or yellow zone is busy, we are pulled from the Green Zone to help there."
Workflow interruptions and coordination challenges	Repeated documentation requirements	Duplication in documentation processes interrupts clinical workflow	"We have to document the same thing multiple times, on the nursing census, and again in iPesakit."
	Delays in referral response	Waiting for primary teams to attend referrals contributes to prolonged patient stays	"There is a memo that patients need to be seen by the Primary Team within a certain duration.. but most of the time, that doesn't happen"
	Delays in reviewing blood investigations	Availability of lab results in the system is not alerted on the EMR system	"There is no alert button that tells me the patient's blood investigations are ready.. If I forget because I am seeing other patients, the patient ends up having to wait for very long"

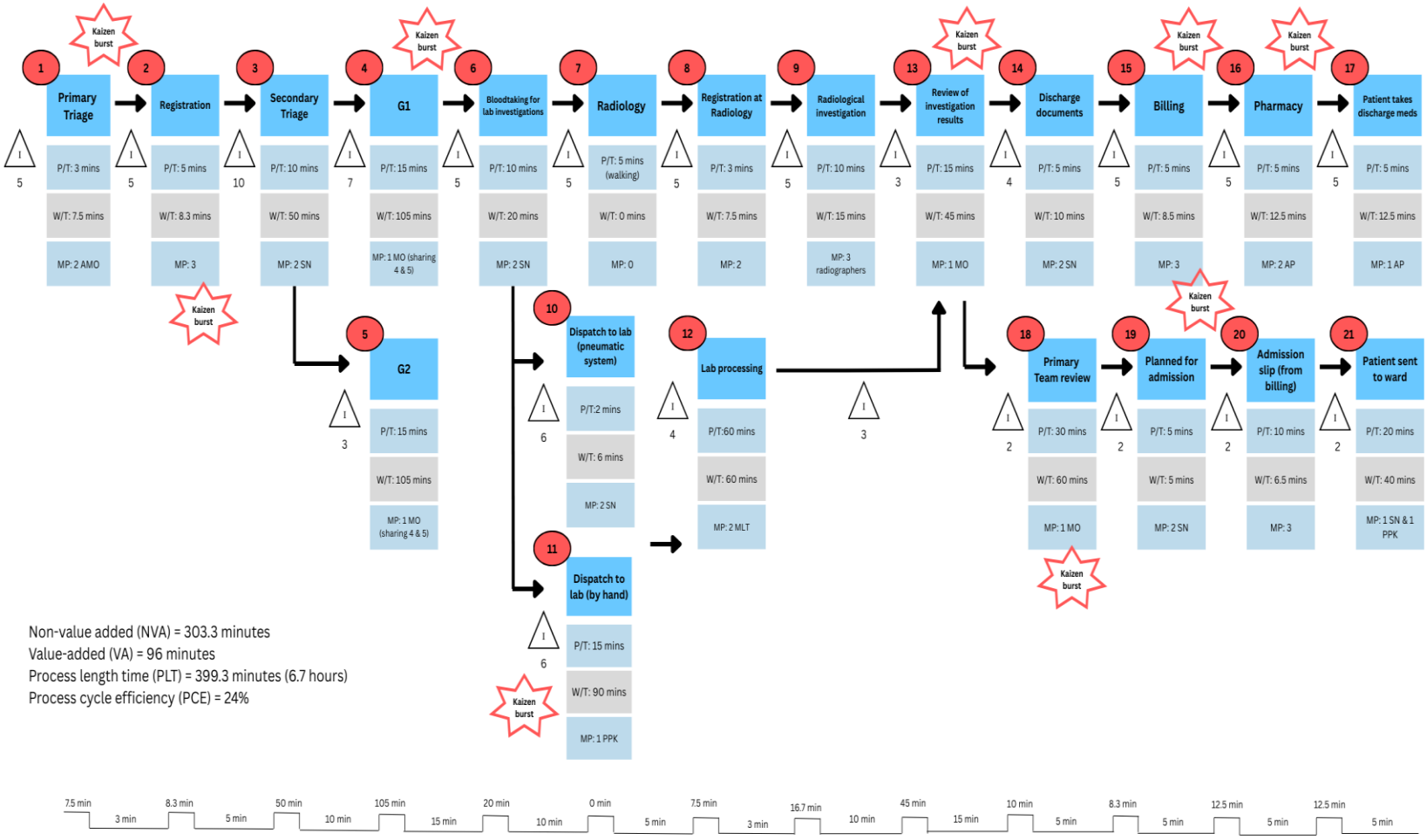

Figure 1: Current-state Value Stream Map (VSM)

Phase 2: Model design and development

A current-state Value Stream Map (VSM) was constructed to represent the complete Green Zone patient journey from arrival to final disposition (Figure 1). Analysis of the mapped workflow demonstrated that value-added activities constituted a relatively small proportion of total process time, while non–value-added waiting intervals accounted for the majority of overall delay. The current-state VSM revealed multiple transition inefficiencies, including physical separation between primary and secondary triage stations resulting in avoidable patient movement and handover delays, overlapping registration and billing roles, repetitive documentation processes, delayed laboratory and radiology result notifications, and manpower constraints during high-volume shifts. These inefficiencies formed the empirical basis for structured improvement generation. Under current-state conditions, the calculated process length time (PLT) was 6.7 hours, with a process cycle efficiency of 24%. Following validation of the current-state map through cross-process observation and stakeholder review, identified inefficiencies were translated into structured improvement proposals (kaizen opportunities). These were categorised according to process location, as shown in Table 1.

Table 1: Kaizen improvement opportunities and proposed countermeasures across the Green Zone workflow

Location	Identified problem	Proposed Kaizen
Primary triage	Potential for prolonged waiting time due to insufficient manpower or improper triage	Gatekeeper role for the team leader, medical officer
Registration	Delay in the registration process due to ambiguity in the individual functions of registration and billing staff.	Split counter for incoming registration and outgoing billing (prioritize to be based on function; back-up when needed).
	Registration information has to be manually entered, leading to lengthy registration processes.	Auto-capture information from the card reader.
Secondary triage	Primary and secondary triage were located far from each other, leading to delays in accurate triaging and difficulties for both patients and healthcare workers.	Arrange secondary triage to be adjacent to primary triage.
	Nursing staff at secondary triage document both on paper and in the EMR due to problems with the EMR system.	Remove manual census; extend from EMR.
Consultation room	Patients have to walk a distance from the waiting area to the consultation room, potentially leading to delays.	Pit stop outside the consultation room to allow patients who will be called next to wait outside of the consultation room.
	The attending doctor fills out multiple forms to indicate what procedures the patient requires next.	Amend and improve on the existing form to integrate all clinical, laboratory, and radiological procedures.
	The attending doctor needs to review multiple investigations for patients. Lack of real-time notification results in delays.	Integrate real-time lab notifications into the EMR.
	Patient waiting time is significantly increased during high patient volume as only one or two doctors is working in the Green Zone in a single shift.	Additional manpower (doctor).
Procedure room	Patient waiting time is significantly increased during high patient volume, as only one staff member oversees the procedure room in a single shift.	Additional manpower for the procedure room (AMO).
Radiology	The X-ray machine in the ED is not used	Additional manpower (x-ray

	due to insufficient manpower after office hours	technician) to allow full utilization of the x-ray machine in ED and prevent patients and porters from having to go to the Radiology Department for x-rays.
	Complex and dual registration of patients from the ED at the Radiology Counter increases waiting time.	Simplify and automate patient registration in the EMR system.
Admission	Patients who require admission are often stranded in the ED when wards are full, or patients have been discharged from the ward but are still using the bed because they have not gone home.	Bed Management Unit / Bed Watcher, Discharge lounge

Improvement proposals were subsequently evaluated using an effort–impact matrix to determine implementation feasibility relative to anticipated operational benefit. The resulting prioritisation matrix is presented in Figure 2. manpower, financial, and regulatory constraints.

Interventions classified as high-impact and feasible within existing resource limitations and within the study duration were prioritised as immediate redesign components to be included in the Lean-based model.

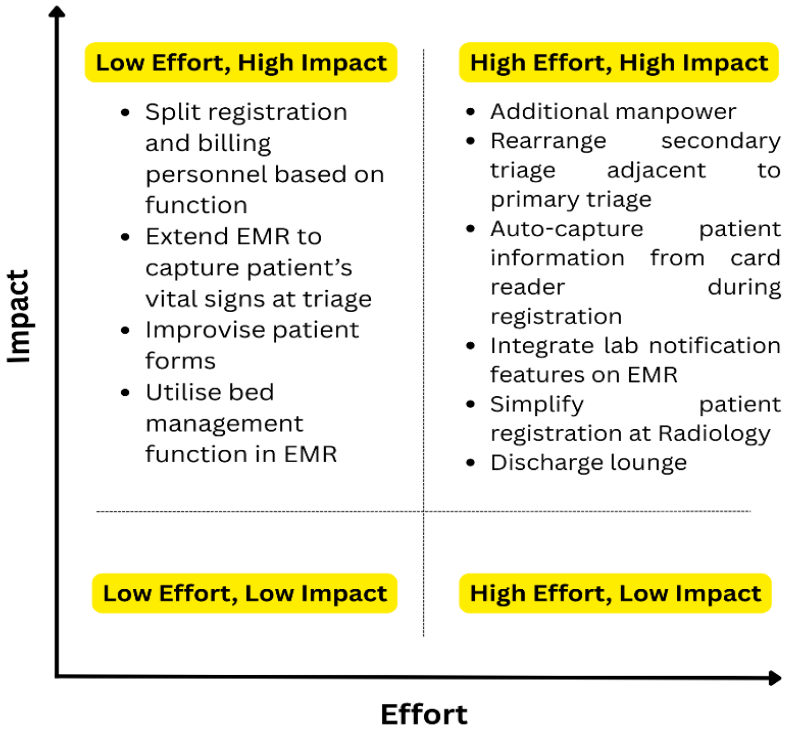

Figure 2: Effort-impact matrix of prioritised countermeasures

A future-state Value Stream Map was then constructed to operationalise the prioritised redesign components, constituting the Lean-based Green Zone Model. Under the future-state configuration, projected process length time was reduced to 4.5 hours.

The redesigned workflow emphasised standardisation, elimination of duplication, and clearer delineation of professional roles. The future-state VSM (Figure 3) illustrates the changes incorporated into the final model.

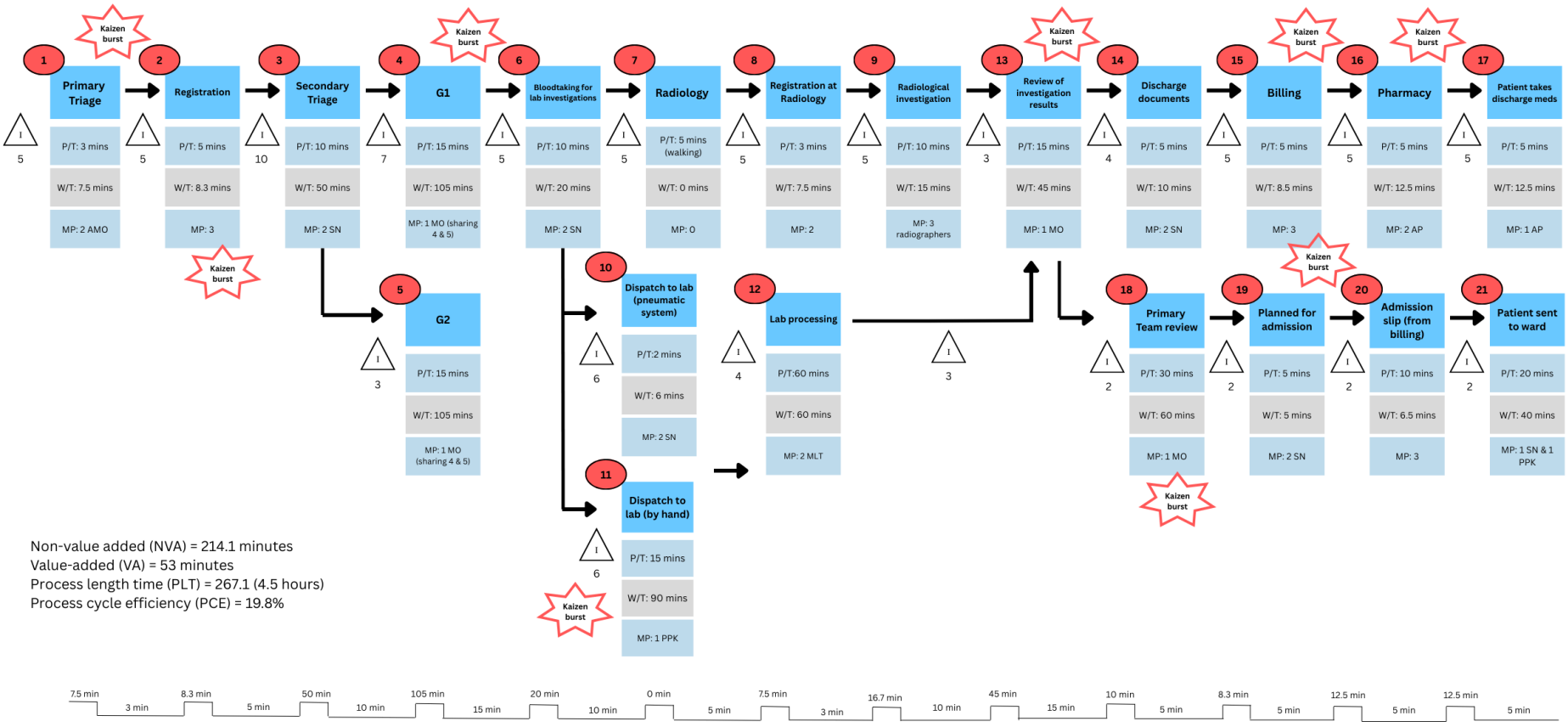

Figure 3: Future-state Value Stream Map (VSM)

Phase 3: Model validation

All model components achieved strong expert agreement. Item-level Content Validity Index (I-CVI) scores met or exceeded the predefined threshold of 0.80 across all domains of the Lean-Based Green Zone Model. The overall Scale-level Content Validity Index (S-CVI/Ave) exceeded 0.90, indicating high consensus regarding clarity, feasibility, and operational alignment. Expert feedback obtained during the four-month post-implementation review supported the practical integration of the redesigned workflow within routine operations. Minor refinements were made to selected documentation and communication processes based on panel recommendations. These findings support the internal coherence and contextual suitability of the model prior to formal effectiveness evaluation.

Table 2: Content validity assessment of redesigned Green Zone workflow components

Item	Process step	Expert 1	Expert 2	Expert 3	I-CVI
1.	A designated gatekeeper medical officer (team leader) oversees triage flow, supports triage decisions, and intervenes during periods of congestion to prevent unnecessary delays.	3	3	3	1.0
2.	Patients proceed to a dedicated registration counter, functionally separated from billing activities.	4	4	4	1.0
3.	Patient demographic information is auto-captured using a card reader, reducing manual data entry and registration time.	4	4	4	1.0
4.	Vital signs and triage information at Secondary Triage are recorded directly into the EMR, with manual census documentation eliminated.	4	4	4	1.0
5.	A designated “pit stop” area outside consultation rooms allows patients who will be called next to wait nearby, reducing idle movement and missed calls	4	3	3	1.0
6.	The attending doctor conducts a consultation using a single integrated clinical form that combines documentation for clinical assessment, laboratory tests, and radiological investigations, which replaces multiple separate forms and repeated documentation.	4	4	4	1.0
7.	Real-time laboratory notification features alert clinicians when results are available, reducing review delays	4	4	4	1.0
8.	Patient registration for radiology is simplified and automated within the EMR, eliminating duplicate registration steps at the radiology counter.	4	4	4	1.0
9.	Patients proceed to a dedicated billing counter, separate from incoming registration, reducing cross-traffic and waiting time.	4	4	4	1.0
10.	Patients requiring admission are coordinated through the Bed Watcher system, which is updated in real-time.	3	3	3	1.0
S-CVI Average					**1.0**

DISCUSSION

This study describes the systematic design and development of a Lean-based model for the Green Zone of the Emergency Department (ED) using a Design and Development Research (DDR) framework. The findings highlight that workflow inefficiencies within the Green Zone are primarily driven by throughput-related bottlenecks, including delays in consultation, fragmented patient movement pathways, and workflow interruptions due to coordination challenges. By organising the redesign process into sequential phases of needs analysis, model development, and expert validation, this study contributes a transparent and replicable pathway for Lean-based ED intervention design. The baseline analysis demonstrated substantial variability in arrival-to-consultation time (ATC) and length of stay (LOS), reflecting inconsistent workflow efficiency across patient encounters. Similar patterns have been reported in previous Lean-based ED studies, where high variability in process times was associated with inefficient resource utilisation and lack of standardised workflows [35,36]. Thematic findings from stakeholder perspectives further reinforced these observations, highlighting peak-period congestion, staff redeployment, and fragmented service pathways as major contributors to delays.

These inefficiencies must be understood within the structural organisation of Emergency Departments, which are typically divided into acuity-based zones (Red, Yellow, and Green), each characterised by distinct clinical urgency, diagnostic intensity, and workflow architecture. High-acuity zones often involve time-critical interventions and multidisciplinary coordination, whereas the Green Zone manages ambulatory, lower-acuity patients with higher throughput demands and greater exposure to process variability. Consequently, the nature and distribution of workflow inefficiencies differ across zones, with lower-acuity pathways often more susceptible to delays arising from process fragmentation and coordination gaps. Rather than applying Lean uniformly across the entire ED, the DDR-guided needs analysis enabled identification of the sub-system with the greatest operational inefficiency burden. Empirical assessment of process lead times and non–value-added intervals demonstrated that the Green Zone exhibited substantial variability and delay. This targeted, zone-specific redesign aligns with the principle that Lean interventions should be value-stream specific and context-sensitive rather than uniform application across heterogeneous care pathways [5,37].

In response to these identified inefficiencies, the Lean-based model developed in this study was designed to directly address workflow constraints through standardisation of processes, elimination of non–value-added activities, and improved coordination across care steps. Value Stream Mapping (VSM) served as a foundational design instrument in this study, consistent with the structured methodology described by Rother and Shook [38]. VSM provides a systematic framework for visualising end-to-end workflows, identifying bottlenecks, and guiding the development of future-state configurations. The present study operationalised these steps within the Green Zone context. The current-state map integrated EMR timestamp data and Gemba observations to empirically quantify delays and workflow fragmentation specific to ambulatory patient flow. Kaizen improvement opportunities were subjected to structured prioritisation using an effort–impact matrix, which formalised decision-making during model construction. This approach ensured that selected countermeasures were not only theoretically beneficial but feasible within existing manpower, financial, and organisational constraints. The prioritised interventions were subsequently translated into a future-state map, which functioned as the operational specification of the Lean-based model. While studies describing Lean application in EDs frequently report the use of Value Stream Mapping [24,28–30,39], the detailed description of how future-state configurations are derived and prioritised under real-world constraints is less commonly described [36,40,41]. By integrating structured prioritisation with contextual feasibility considerations, this study contributes to methodological transparency in Lean-based intervention design.

The projected reduction in process length time (PLT) from 6.7 hours to 4.5 hours, corresponding to an estimated 29% improvement, is supported by the systematic elimination of non–value-added activities and restructuring of workflow sequences within the future-state VSM. These improvements were derived from empirically quantified delays identified in the current-state mapping, including waiting intervals, redundant movements, and process fragmentation, and recalculated based on optimised patient flow pathways under the redesigned model. Similar magnitudes of improvement have been reported in Lean-based ED interventions involving workflow standardisation and bottleneck reduction [15,42–45]. However, it is important to emphasise that the estimates in this study are based on model-based projections rather than measured post-implementation outcomes. As such, the projected improvements represent the expected impact of the redesigned workflow under optimal operational conditions and should be interpreted as indicative rather than definitive.

The final phase of the DDR framework involved post-implementation expert validation. Validation conducted after pilot implementation allowed assessment of the model under routine operational conditions. As effective redesign requires not only the application of Lean tools but also alignment with organisational context and workflow realities, expert consensus regarding the clarity, feasibility, and operational coherence of the redesigned model is essential prior to formal effectiveness evaluation [37,41].

A key contribution of this study lies in addressing a critical gap in the existing literature on Lean applications in Emergency Departments, namely, the absence of structured and reproducible development pathways for intervention design. Previous studies have reported improvements in waiting times and operational performance following Lean implementation [40–42,46,47], yet the processes through which interventions are systematically developed are often insufficiently described. By applying a DDR framework, this study provides a structured, transparent, and replicable approach to Lean-based ED redesign.

Limitations

Several limitations should be acknowledged. First, the Lean-based model was implemented at a pilot level within a single-centre setting, which may limit the generalisability of findings to other Emergency Departments with different organisational structures and resource constraints. Second, the projected improvements in process performance were derived from future-state VSM analysis rather than empirical post-implementation evaluation, and therefore may not fully reflect actual operational conditions. Third, stakeholder input was obtained through informal consultations rather than structured qualitative interviews, which may limit the depth of qualitative insights. Finally, the expert validation process involved a small panel, although acceptable within methodological recommendations for Content Validity Index (CVI) studies.

Future research should focus on full-scale implementation and rigorous evaluation of the model's impact on patient flow, clinical outcomes, and operational efficiency using robust quantitative study designs. Further research may also include multi-centre studies to assess the transferability and scalability of the DDR-guided Lean development approach across diverse healthcare settings.

CONCLUSION

This study demonstrates that Lean-based Emergency Department redesign can be systematically developed and validated using a Design and Development Research (DDR) framework. By structuring the redesign process into sequential phases of needs analysis, model design and development, and expert validation, the study provides a transparent and replicable pathway for Lean intervention development in complex clinical environments, particularly in ED settings. The findings highlight that throughput inefficiencies within the Green Zone, particularly delays in consultation, fragmented patient movement, and workflow interruptions, can be addressed through targeted, zone-specific redesign rather than uniform, system-wide interventions. The pilot implementation of the Lean-based model and its alignment with expert validation suggest that the redesigned workflow is both operationally feasible and contextually appropriate within existing resource constraints. From a practical perspective, this study offers actionable guidance for healthcare administrators and Emergency Department managers seeking to improve patient flow in high-volume, resource-limited settings. The structured use of Value Stream Mapping combined with feasibility-based prioritisation provides a scalable approach for identifying inefficiencies and implementing targeted improvements without requiring extensive additional resources. However, the projected improvements in process performance are based on future-state modelling and have not yet been confirmed through formal effectiveness evaluation. Further research is required to assess actual operational impacts of the Lean-based model following full-scale implementation. Overall, this study contributes a methodologically grounded and practically applicable framework for Lean-based Emergency Department redesign, supporting more systematic and context-specific approaches to healthcare process improvement in resource-constrained healthcare systems.

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Competing interests

The authors declare no competing interests.

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