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

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I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged.

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ABSTRAK

Kesesakan Jabatan Kecemasan (*Emergency Department*, ED) merupakan cabaran berterusan yang menyumbang kepada tempoh menunggu yang panjang, peningkatan kos operasi, serta menjejaskan keyakinan awam terhadap sistem penjagaan kesihatan. Walaupun pendekatan *Lean* telah dilaksanakan secara meluas dalam persekitaran ED, kebanyakan penilaian bergantung kepada penggunaan alat *Lean* secara terasing serta perbandingan pra dan pasca pelaksanaan yang ringkas, dengan integrasi penilaian ekonomi yang terhad. Oleh itu, bukti berkaitan dengan model *Lean* yang direka bentuk dan disahkan secara sistematik serta dinilai menggunakan pendekatan kuasi-eksperimen dan analisis kecekapan kos masih terhad. Kajian ini bertujuan untuk mereka bentuk dan membangunkan model berasaskan *Lean* serta menilai kesannya terhadap prestasi operasi dan kecekapan kos di Jabatan Kecemasan sebuah hospital pengajar universiti awam di Malaysia. Berpandukan kerangka Penyelidikan Reka Bentuk dan Pembangunan **(**DDR), kajian ini dilaksanakan dalam tiga fasa: analisis keperluan, reka bentuk dan pembangunan model, serta penilaian. Analisis keperluan berstruktur yang menggabungkan data prestasi, pemetaan aliran kerja, pandangan pihak berkepentingan dan pemerhatian mengenal pasti kekangan kritikal di Zon Hijau. Model *Lean* dibangunkan melalui pemetaan aliran nilai dan pengesahan pakar. Reka bentuk kuasi-eksperimen *Interrupted Time Series* (ITS) menganalisis median harian masa triaj-ke-pendaftaran (TTR), masa ketibaan-ke-konsultasi (ATC), dan tempoh berada di Jabatan Kecemasan (LOS) merentasi dua tempoh pemerhatian enam bulan (n=363 titik masa) menggunakan regresi bersegmen dengan struktur ralat *autoregressive integrated moving average* (ARIMA). Pelaksanaan intervensi menunjukkan pengurangan serta-merta yang signifikan dalam TTR sebanyak 0.95 minit (95% CI –1.36 hingga –0.53; $p<0.001$), manakala ATC dan LOS menurun tetapi tidak signifikan (ATC (–25.37 minit; 95% CI –90.05 hingga 39.32; $p=0.44$) dan LOS (–7.72 minit; 95% CI –19.50 hingga 4.07; $p=0.20$)). Jumlah kos operasi menurun sebanyak 2.63% walaupun jumlah lawatan pesakit meningkat sebanyak 19.5%. Kos per pesakit menurun daripada RM855.10 kepada RM696.56 (–18.5%; $p=0.19$), manakala kos per jam pesakit menurun daripada RM283.16 kepada RM233.80 (–17.4%; $p=0.14$). Dapatan ini membuktikan bahawa intervensi *Lean* yang direka secara sistematik mampu menambahbaik aliran pesakit dan meningkatkan kecekapan kos dalam keadaan permintaan perkhidmatan yang tinggi. Kajian ini turut menyediakan kerangka yang boleh diguna pakai untuk penambahbaikan sistem dalam persekitaran ED yang terhad sumber.

Kata kunci: Pengurusan *Lean*; Jabatan Kecemasan; Kuasi-eksperimen; *Interrupted Time Series*; Penilaian ekonomi

ABSTRACT

Emergency Department (ED) overcrowding remains a persistent challenge, contributing to prolonged waiting times, rising operational costs, and undermining public confidence in healthcare systems. Although Lean has been widely implemented in ED settings, many evaluations rely on isolated tool applications and simple pre–post comparisons, with limited integration of economic evaluation. Evidence on systematically designed, validated Lean models evaluated using quasi-experimental and cost-efficiency approaches remains limited. This study aimed to design and develop a Lean-based model for the emergency department of a public university hospital in Malaysia, and evaluate its impact on operational performance and cost efficiency. Guided by a Design and Development Research (DDR) framework, the study was conducted in three phases: needs analysis, model design and development, and model evaluation. A structured needs analysis combining performance data, workflow mapping, stakeholder input, and observation identified critical bottlenecks within the Green Zone. A Lean-based model was developed through value stream mapping and underwent expert validation. A quasi-experimental Interrupted Time Series (ITS) design analysed daily median triage-to-registration time (TTR), arrival-to-consultation time (ATC), and length of stay (LOS) across two six-month periods (n=363 time points) using segmented regression with autoregressive integrated moving average (ARIMA) error structures. Implementation was associated with a statistically significant immediate reduction in TTR of 0.95 minutes (95% CI –1.36 to –0.53; $p<0.001$). Reductions in ATC (–25.37 minutes; 95% CI –90.05 to 39.32; $p=0.44$) and LOS (–7.72 minutes; 95% CI –19.50 to 4.07; $p=0.20$) were not statistically significant. Total operating costs decreased by 2.63% despite a 19.5% increase in patient volume. Cost per patient declined from RM855.10 to RM696.56 (–18.5%; $p=0.19$), and cost per patient-hour from RM283.16 to RM233.80 (–17.4%; $p=0.14$). These findings provide empirical evidence that a systematically designed Lean intervention can produce measurable front-end flow improvements while enhancing cost efficiency under increased service demand. This study provides a reproducible framework for system-level redesign in resource-constrained ED settings.

Keywords: Lean healthcare; Emergency Department; Quasi-experimental; Interrupted Time Series; Economic evaluation

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LIST OF ABBREVIATIONS

ACF	Autocorrelation function
AMO	Assistant medical officer
AR	Autoregressive
ARIMA	Autoregressive integrated moving average
ATC	Arrival-to-consultation
CI	Confidence interval
CQI	Continuous quality improvement
CTQ	Critical to quality
CVI	Content validity index
DDR	Design and Development Research
DEA	Data envelopment analysis
DEAR	Department of Education and Research
DMAIC	Define, Measure, Analyse, Improve, Control
ED	Emergency department
EDWIN	Emergency Department Work Index
EMR	Electronic medical records
EMTS	Emergency Medicine and Trauma Services
ESI	Emergency Severity Index
FADE	Focus, Analyse, Develop, Execute
FOCUS	Find, Organise, Clarify, Understand, Select
HPIA	Hospital Performance Indicator for Accountability
I-CVI	Item-level content validity index
IHI	Institute for Health Improvement
IIUM	International Islamic University Malaysia
IREC	IIUM Research Ethics Committee
IQR	Interquartile range
ICT	Information and communication technology

IT	Information technology
ITS	Interrupted time series
KPI	Key performance indicators
LOS	Length of stay
LWBS	Left-without-being-seen
MA	Moving average
MOH	Ministry of Health
MREC	Medical Research Ethics Committee
MYR	Malaysian ringgit
NEDOCS	National Emergency Department Overcrowding Scale
NHS	National Health Service
NNVA	Necessary non-value-added
NVA	Non-value-added
PACF	Partial autocorrelation function
PAT	Priority admission triage
PCE	Process cycle efficiency
PDCA	Plan-do-check-act
PDPA	Personal Data Protection Act
PDSA	Plan-do-study-act
PLT	Process length time
PT	Process time
RCA	Root cause analysis
RIE	Rapid improvement events
SASMEC	Sultan Ahmad Shah Medical Centre
S-CVI/Ave	Scale-level content validity index – average method
SD	Standard deviation
SDG	Sustainable Development Goals
SIPOC	Suppliers-Inputs-Process-Outputs-Customer
SMED	Single-minute exchange of die

TAT	Turnaround time
TQM	Total quality management
TTR	Triage-to-registration
UKM	Universiti Kebangsaan Malaysia
UHC	Universal Health Coverage
VA	Value-added
VAS	Value-added service
VOB	Voice of business
VOC	Voice of customer
VSM	Value Stream Map
WT	Waiting time

CHAPTER I

INTRODUCTION

1.1 INTRODUCTION

This chapter introduces the concept of Lean management and its application within healthcare settings, with particular emphasis on its relevance to emergency department (ED) operations. Emergency departments face persistent operational challenges, including increasing patient demand, overcrowding, prolonged waiting times, and inefficiencies in patient flow. These challenges place significant strain on healthcare resources and compromise service quality, patient experience, and operational sustainability.

Lean offers a structured approach to addressing such challenges by focusing on process optimisation, waste reduction, and improvement of workflow efficiency. Its growing adoption in healthcare reflects the need for systematic management approaches capable of enhancing performance in complex, high-demand environments such as the ED.

In this chapter, the background and context for applying Lean in emergency departments are presented, followed by a detailed discussion of the problem statement that motivates the study. The chapter then outlines the research questions, research objectives, and research hypotheses that guide the design, development, and evaluation of the Lean-based intervention examined in this thesis.

1.2 RESEARCH BACKGROUND

Healthcare systems worldwide are facing increasing pressure to deliver high-quality, safe, and efficient care in the context of evolving epidemiological trends, demographic shifts, and constrained resources. Ageing populations, rising prevalence of chronic disease, and growing expectations for timely and patient-centred care have contributed to escalating demand for healthcare services (Khan et al. 2024; Oskvarek et al. 2026; Santos et al. 2026). These pressures are particularly visible within emergency departments (EDs), with recent evidence suggesting that between 30% and 90% of emergency departments worldwide are experiencing persistent overcrowding (Alshiakh et al. 2025; Barrera 2025). In response, healthcare organisations are increasingly required to optimise the use of limited resources, including workforce, physical space, equipment, and diagnostic services, while maintaining timely access to care, patient safety, service quality, and the broader goals of universal health coverage (Kheng Khor et al. 2024; Rosa et al. 2021; Yanful et al. 2023).

The burden of ED overcrowding generates consequences that extend beyond immediate operational pressures, producing ripple effects across patient outcomes, healthcare worker wellbeing, and broader health system performance (Sartini et al. 2022). Overcrowding has been associated with delays in triage, consultation, diagnostics, and time-sensitive interventions, alongside prolonged waiting times, increased emergency department length of stay (LOS), reduced patient satisfaction, staff burnout, and higher healthcare resource utilisation (Ahmed et al. 2025; Alshiakh et al. 2025; Gross et al. 2023; Pearce et al. 2023; Sartini et al. 2022). The literature increasingly conceptualises ED overcrowding as a systems-level phenomenon arising from complex interactions between patient demand, workflow inefficiencies, resource constraints, and downstream access block across the broader healthcare system (Altun & Kudu 2025; Haas & Brundisini 2023; Mohd Nasir et al. 2025; Pearce et al. 2024). Consequently, improving patient flow and operational efficiency has become a major priority within emergency care systems globally.

Within this context, healthcare organisations have adopted continuous quality improvement (CQI) approaches to strengthen healthcare delivery, optimise resource

utilisation, and improve patient outcomes. Such approaches emphasise systematic, data-driven, and iterative improvement of healthcare processes through multidisciplinary engagement, workflow redesign, and performance monitoring to support long-term operational performance, patient flow efficiency, quality of care, and organisational resilience within high-demand healthcare settings (Endalamaw et al. 2024; Mitreska et al. 2025; Pozzan et al. 2025).

Among the various CQI methodologies, Lean management has emerged as one of the most widely implemented approaches for improving operational efficiency, reducing waste, and redesigning patient flow processes across diverse healthcare environments (Codognotto et al. 2025; Nawanir & Fauzi 2025). Lean originated from the Toyota Production System (TPS) that was developed within the Japanese automotive industry as a systematic approach to improving quality, efficiency, and organisational performance through the elimination of waste and optimisation of workflow processes (Womack & Jones 1997). Central to Lean thinking is the reduction of inefficiencies conceptualised through the interconnected principles of *muda* (waste), *mura* (workflow variability), and *muri* (system overburden), all of which contribute to process delays, operational instability, and reduced value creation. Although initially applied within manufacturing, Lean has evolved into a broader organisational philosophy adopted across multiple sectors, including healthcare (Alogla 2025; Lima et al. 2021; Ramori et al. 2021).

The Lean approach finds popular appeal in healthcare as it seeks to redesign clinical practices and resources around simplified, efficient, and value-added care. Within healthcare settings, Lean extends beyond isolated process-improvement tools and emphasises multidisciplinary engagement, frontline problem-solving, workflow redesign, and organisational learning to support sustainable operational improvement (Hammoudeh et al. 2021; Reponen et al. 2021; Rosa et al. 2021). Consequently, Lean has been positioned not only as a technical process-improvement methodology, but also as a systems-oriented approach capable of supporting organisational transformation within complex healthcare environments.

The complexity of ED operations, characterised by multiple parallel workflows, interdependent services, and variability in demand and capacity, represents a particularly relevant context for the application of Lean principles. EDs function as the frontline of hospital care, managing patients with varying levels of acuity under conditions of uncertainty, time pressure, and fluctuating demand, and are often considered as the safety net of the healthcare system (Mostafa & El-Atawi 2024). However, perpetual reports of overcrowding, delayed treatment times, and poor patient satisfaction have strained this safety net to the breaking point, affecting quality and access to care (Souza et al. 2021). Moreover, inefficiencies within the ED can propagate upstream and downstream effects throughout the hospital system, contributing to congestion in inpatient wards, diagnostic services, and ancillary departments (Tiso et al. 2020). In settings where overcrowding results in prolonged waiting times, increased length of stay, and higher rates of patients leaving without being seen, Lean principles have been identified as a potentially effective approach for improving flow and reducing waste related to waiting, transportation, and unnecessary movement (Breen et al. 2020; Holden 2011; Kenny et al. 2024; Thangarajoo 2015).

A growing body of literature has examined the application of Lean as a strategy for improving patient flow, reducing non-value-adding activities, and strengthening throughput efficiency within emergency care settings (Bucci et al. 2016; Dickson et al. 2009; Holden 2011; Sánchez et al. 2018; Souza et al. 2021; Tiso et al. 2020; White et al. 2014). Multiple studies have demonstrated improvements in operational indicators following Lean implementation, particularly in relation to waiting time (Mazzocato et al. 2012), time to physician assessment (Murrell 2011), emergency department length of stay (LOS) (Allaudeen et al. 2017; Dickson et al. 2009; Murrell 2011; Naik et al. 2012; White et al. 2014), patient throughput (Zocchi et al. 2015), and rates of patients leaving without being seen (LWBS) (Murrell 2011). However, in one of the earliest critical reviews of Lean implementation within emergency departments, Holden (2011) highlighted substantial variability in Lean implementation, including differences in the Lean tools applied, organisational engagement, and assessment of its impact. These observations remain important within Lean healthcare literature, particularly as many studies report favourable operational outcomes despite substantial methodological and implementation heterogeneity.

In Malaysia, increasing utilisation of public hospital emergency departments, particularly within tertiary referral and academic medical centres, has intensified concerns regarding overcrowding (Abdul Hamid et al. 2025; Wan Mohd Aminuddin & Ismail 2021). Recent local studies have highlighted prolonged waiting times, staffing pressures, workflow disruption, and increasing operational burden within emergency care settings, particularly in high-volume non-critical care zones managing large numbers of semi-urgent and non-urgent patients (Abdul Hamid et al. 2025; Chau et al. 2024; Krisnan et al. 2025). In parallel with broader healthcare transformation efforts, Lean Healthcare initiatives have been introduced within Malaysian healthcare organisations, particularly through the Ministry of Health (MOH) as part of a national Public Service Delivery Transformation programme aimed at reducing waiting times and managing chronic overcrowding in public hospitals (Anis Shazura et al. 2019). Nevertheless, much of the existing Malaysian Lean Healthcare literature remains centred on fragmented or isolated process-improvement initiatives, with limited evidence regarding comprehensive end-to-end emergency department redesign, structured implementation approaches, and robust longitudinal evaluation of operational and financial outcomes within academic tertiary care settings.

Hence, despite the increasing adoption of Lean within healthcare and emergency care settings, important questions remain regarding how Lean interventions can be effectively implemented and evaluated. Furthermore, although many studies report improvements in operational performance following Lean implementation, comparatively fewer evaluations have employed robust longitudinal approaches capable of accounting for temporal trends, organisational variation, and sustainability of change over time. In addition, financial outcomes remain less consistently evaluated within emergency department Lean studies despite increasing pressure on healthcare systems to optimise resource utilisation alongside operational performance. These limitations create ongoing challenges in understanding the broader organisational and operational impact of Lean implementation within public tertiary emergency care systems.

Accordingly, there is a need to examine Lean implementation within emergency department settings using context-sensitive implementation approaches capable of

integrating the needs of an organisation, operational redesign, and longitudinal outcome evaluation from both operational and financial perspectives. Within the Malaysian context, further evidence is particularly needed regarding the implementation and evaluation of Lean interventions within public university hospital settings, particularly approaches that move beyond isolated process-improvement initiatives towards more integrated end-to-end redesign. The present study, therefore, seeks to develop, implement, and evaluate a Lean-based intervention model within a public university hospital emergency department and evaluate its impact on operational throughput indicators and financial outcomes.

1.3 PROBLEM STATEMENT

Despite growing evidence supporting Lean interventions in emergency care, significant uncertainties remain regarding where Lean interventions should be targeted, how they should be designed, and how their effectiveness should be evaluated. These unresolved issues are particularly relevant within Malaysian public university hospitals and form the basis of the present study.

Emergency departments do not function as homogeneous operational environments. Different ED acuity zones operate through distinct clinical workflows, staffing arrangements, and patient-care processes, resulting in variations in how operational strain and overcrowding manifest across emergency care systems. While high-acuity zones prioritise rapid stabilisation of critically ill patients, non-critical care areas managing large volumes of semi-urgent and non-urgent patients have been shown to experience greater congestion, prolonged waiting times, throughput delays, and workflow bottlenecks (Krisnan et al. 2025).

Consistent with Lean philosophy, effective process redesign should be preceded by systematic identification of operational bottlenecks and workflow inefficiencies within the local care environment (Thangarajoo 2015; Yahata et al. 2025). Despite this principle, Lean healthcare literature frequently reports operational improvements following intervention implementation without clearly describing how priority intervention areas were identified and selected within complex ED workflows (Holden 2011; Kenny et al. 2024; Souza et al. 2021; Tiso et al. 2020). Consequently, uncertainty

remains regarding which areas of emergency department operations experience the greatest operational strain and therefore warrant prioritised process improvement efforts.

A second challenge concerns how Lean principles can be systematically translated into effective interventions within complex emergency department environments. Emergency departments represent particularly challenging settings for process redesign because patient flow is characterised by variable acuity, fluctuating demand, shared resources, multidisciplinary care processes, and interdependencies with diagnostic, inpatient, and support services (Samadbeik et al. 2024; Tiso et al. 2020). Consequently, operational inefficiencies rarely arise from a single bottleneck and often reflect interactions across multiple stages of the patient pathway.

In response to this complexity, Lean healthcare literature has progressively evolved beyond the isolated application of individual process-improvement tools towards broader "Lean Thinking" approaches that emphasise organisational transformation, multidisciplinary engagement, and end-to-end workflow redesign (Talero-Sarmiento et al. 2024). Contemporary Lean interventions increasingly combine multiple complementary tools and redesign strategies to analyse workflows, identify waste, prioritise improvement opportunities, and redesign interconnected care pathways (Breen et al. 2020; Frank & Rader 2023; Hayes et al. 2014; Shortell et al. 2021).

Despite this evolution, the implementation logic underpinning Lean interventions remains insufficiently articulated (Holden 2011; Lima et al. 2021; Mazzocato et al. 2012; Tiso et al. 2021). Existing studies frequently report the use of multiple Lean tools but provide limited explanation regarding how specific tools were selected, adapted, integrated, and sequenced in response to local operational challenges. As a result, while integrated Lean interventions are increasingly reported, limited guidance is available regarding how Lean principles should be systematically translated into context-sensitive intervention models capable of addressing the operational realities of complex emergency department environments.

Within Malaysia, Lean implementation has expanded over the past decade as part of broader healthcare transformation initiatives aimed at improving operational efficiency and service delivery (Lum et al. 2023). However, published studies remain predominantly concentrated within Ministry of Health hospitals and selected private healthcare organisations (Anis Shazura et al. 2019; Lum et al. 2023; Zailani et al. 2020; Noris et al. 2022; Ong et al. 2023; Lum et al. 2024). Furthermore, many local initiatives continue to focus on discrete operational improvements or individual service components rather than integrated end-to-end redesign of patient-care pathways (Abdul Aziz et al. 2022; Abdul Hanif et al. 2023; Beh et al. 2025; Choudhury & Lee 2024; Lee et al. 2025). In particular, evidence regarding Lean implementation within Malaysian public university hospital emergency departments remains comparatively limited. Consequently, uncertainty remains regarding how Lean-based redesign initiatives should be systematically developed and implemented within these complex healthcare settings.

Following the development and implementation of a Lean intervention, an equally important consideration concerns how its effectiveness should be evaluated. Existing Lean healthcare literature consistently reports improvements in operational outcomes following intervention implementation, particularly in relation to waiting time, throughput measures, length of stay, and patient satisfaction (Amorim et al. 2019; Breen et al. 2020; Freitas et al. 2023; Hammer et al. 2022; Haq et al. 2018; Kenny et al. 2024; Stahley et al. 2020; Zocchi et al. 2015). These findings suggest that Lean interventions may contribute positively to patient flow and service efficiency within emergency care environments.

However, methodological limitations remain evident within the existing evidence base. Many studies continue to rely on simple pre-post comparisons, limiting the ability to distinguish intervention effects from underlying temporal trends, seasonal variation, fluctuations in patient demand, or concurrent organisational changes (Mazzocato et al. 2012; Murrell 2011; Naik et al. 2012; White et al. 2014). Consequently, there is limited evidence regarding the magnitude, attribution, and sustainability of reported improvements following Lean implementation. This limitation is particularly important within emergency department settings, where

operational performance indicators are inherently influenced by dynamic and interdependent factors, including patient volume, case mix, staffing availability, bed capacity, and hospital-wide patient flow. Robust longitudinal evaluation approaches are therefore required to better understand whether observed changes represent true intervention effects rather than natural variation within complex healthcare systems.

Beyond operational performance, an additional consideration concerns whether improvements achieved through Lean implementation translate into measurable economic benefits. As Lean is fundamentally concerned with eliminating waste and maximising value (D'Andreamatteo et al. 2015; Rosa et al. 2021; Womack & Jones 1997), improvements in patient flow and operational efficiency should theoretically be accompanied by more efficient utilisation of resources and reduced operational costs. However, economic evaluation has historically been much less developed than operational evaluation in the Lean healthcare literature. Moraros et al. (2016) found that none of the methodologically accepted studies in their review directly evaluated actual financial costs, while a more recent systematic review by Wang et al. (2025) identified cost outcomes in only 17 of 60 included studies. Where economic outcomes were reported, the measures varied considerably, including operating costs, inpatient expenditure per admission and broader organisational financial indicators, limiting comparability and the ability to determine whether operational improvements translate into unit-level resource efficiency (Costa & Godinho Filho 2016; Henrique et al. 2016; Moraros et al. 2016; Wang et al. 2025). Consequently, uncertainty remains regarding the economic implications of Lean implementation, particularly when operational and cost-efficiency outcomes are evaluated together.Furthermore, economic outcomes, when reported, are often inconsistently measured, limiting understanding of the relationship between operational improvement and resource efficiency within healthcare settings (Moraros et al. 2016; Wang et al. 2025).

This limitation is particularly relevant within publicly funded healthcare systems operating under increasing resource constraints, where quality improvement initiatives are expected to demonstrate not only operational benefits but also efficient utilisation of available resources. Within Malaysian healthcare settings, Lean evaluations have largely focused on service delivery and operational performance

indicators, with comparatively limited evidence regarding resource utilisation and operational cost efficiency outcomes (Anis Shazura et al. 2019; Lum et al. 2023; Noris et al. 2022). Consequently, uncertainty remains regarding whether improvements achieved through Lean-based redesign initiatives are accompanied by measurable gains in operational cost efficiency within Malaysian public university hospital emergency departments.

Hence, despite wide application of Lean within healthcare and emergency department settings, several important gaps remain within the existing evidence base. First, there is limited guidance regarding how intervention priorities should be systematically identified within complex and heterogeneous emergency department workflows before redesign efforts are undertaken. Second, existing studies provide insufficient direction on how Lean principles can be translated into integrated, context-sensitive intervention models capable of addressing the operational realities of emergency care environments. Third, despite generally favourable findings, many evaluations continue to rely on relatively simple before-and-after designs, limiting confidence in the magnitude, attribution, and sustainability of reported operational improvements. Finally, while Lean is frequently justified as a strategy for improving efficiency and reducing waste, evidence regarding its impact on operational cost efficiency remains comparatively limited. These unresolved issues are particularly evident within Malaysian public university hospital emergency departments, where evidence on systematic Lean implementation, rigorous evaluation, and cost efficiency remains scarce. Addressing these gaps forms the central focus of the present study.

1.4 RESEARCH JUSTIFICATION

Despite growing interest in Lean management as a strategy for improving emergency department performance, translating Lean principles into effective and sustainable operational improvements remains challenging. There is limited guidance regarding how Lean principles can be systematically translated into context-specific intervention models that address end-to-end emergency department workflows and remain feasible within real-world operational constraints. Methodologically, this study addresses this limitation within the existing Lean healthcare literature by adopting a Design and

Development Research (DDR) approach that documents the complete pathway from needs analysis and problem localisation through intervention design, validation, implementation, and evaluation. By integrating these stages within a single research framework, this study provides a transparent and systematic process for translating Lean principles into a context-sensitive intervention model.

In addition, methodological limitations remain evident in the evaluation of Lean interventions. Although many studies report improvements in waiting time, throughput measures, and length of stay, evaluations frequently rely on simple pre–post comparisons that are unable to adequately account for underlying temporal trends, seasonal variation, or concurrent organisational changes. The present study therefore employs interrupted time series analysis to assess both immediate and sustained changes in operational performance, providing a more robust evaluation of intervention effects within a complex healthcare environment. Such methodological transparency is important for understanding why interventions succeed or fail and for supporting replication across healthcare settings.

In addition to the methodological gaps identified in the literature, the relevance of this study is further supported by broader national and international priorities aimed at strengthening healthcare system performance, service efficiency, and sustainable resource utilisation. The Health Research Priorities for the 12th Malaysia Plan (12MP-HRP) 2021–2025 emphasise the evaluation of healthcare programmes, service delivery processes, and quality improvement initiatives to optimise healthcare performance and resource utilisation. Similarly, the study aligns with Sustainable Development Goal 3 (SDG 3), particularly Target 3.8 on achieving Universal Health Coverage (UHC), which highlights the importance of ensuring access to quality healthcare services through efficient and sustainable health systems. These priorities are further reflected in ongoing efforts by the Ministry of Health Malaysia and the World Health Organization to strengthen service delivery, improve healthcare efficiency, and enhance the responsiveness of health systems in the face of increasing demand and resource constraints.

This study addresses these priorities by evaluating Lean implementation within a public university hospital setting. In addition to evaluating operational performance, the study incorporates an assessment of operational cost efficiency to examine whether Lean interventions are accompanied by more efficient utilisation of healthcare resources. This is particularly relevant within publicly funded healthcare systems, where quality improvement initiatives are expected to demonstrate not only service improvements but also responsible stewardship of limited resources. By evaluating changes in cost per patient and cost per patient-hour alongside operational outcomes, the study contributes evidence regarding the relationship between workflow redesign, resource utilisation, and operational efficiency. Such evidence supports ongoing efforts to strengthen healthcare sustainability and aligns with national and international priorities aimed at improving value in healthcare delivery.

Beyond its relevance to healthcare policy and resource management, the study provides a practical framework for emergency department improvement. By systematically analysing operational challenges, developing a context-sensitive Lean-based model, and evaluating its implementation within a real-world clinical environment, the study offers a structured approach for redesigning patient-flow processes across the emergency department pathway. The practical relevance of this framework is strengthened by its application within a Malaysian public university hospital emergency department, a setting that has received comparatively limited attention within the local Lean healthcare literature and operates within a distinct academic-service environment compared with Ministry of Health hospitals and private healthcare institutions. Although public university hospitals share core public-sector funding and staffing mechanisms with Ministry of Health hospitals, they also carry a dual clinical and educational mandate, serving as training grounds for undergraduate and postgraduate medicine, nursing and allied health programmes. Their workforce includes permanent staff alongside rotating postgraduate trainees, which may influence workflow continuity, team cohesion and the sustainability of service-improvement initiatives. By examining the development, implementation, and evaluation of the model within this academic healthcare environment, the study generates context-specific evidence regarding the application of Lean principles while providing a

transferable framework that may support future emergency department improvement initiatives in similar healthcare settings.

1.5 RESEARCH QUESTIONS

i. Which area(s) within the emergency department experience the greatest operational strain and therefore warrant targeted process improvement?

ii. How can Lean principles be translated into a context-specific Lean-based model for the identified emergency department focus area?

iii. To what extent does the implementation of the Lean-based model affect emergency department operational performance?

iv. What is the impact of the Lean-based model on emergency department operational cost efficiency?

1.6 RESEARCH OBJECTIVES

1.6.1 General objective

To design and develop a Lean-based model for improving emergency department operations, informed by a systematic needs analysis, and evaluate its impact on operational performance and cost efficiency outcomes.

1.6.2 Specific objectives

i. To identify the most appropriate focus area for intervention based on operational performance indicators, patient feedback, and stakeholder input.

ii. To design and develop a Lean-based model tailored to the emergency department Green Zone, informed by findings from the needs analysis.

iii. To evaluate changes in emergency department operational performance following implementation of the Lean-based model, as measured by triage-to-registration time (TTR), arrival-to-consultation time (ATC), and length of stay (LOS).

iv. To estimate changes in cost per patient and cost per patient-hour before and after implementation of the Lean-based model.

1.7 RESEARCH HYPOTHESES

i. Implementation of the Lean-based model is associated with changes in triage-to-registration time.

ii. Implementation of the Lean-based model is associated with changes in arrival-to-consultation time.

iii. Implementation of the Lean-based model is associated with changes in length of stay.

iv. Implementation of the Lean-based model is associated with an operational cost change in the emergency department.

1.8 RESEARCH GAP ANALYSIS

Existing emergency department Lean studies have predominantly focused on evaluating operational outcomes following implementation, with relatively limited attention given to the systematic design and development of context-specific Lean intervention models. Furthermore, economic outcomes remain under-reported compared with traditional operational indicators such as waiting time and length of stay. These gaps highlight the need for research that integrates needs assessment, intervention development, implementation, operational evaluation, and economic assessment within a single methodological framework.

The research gaps identified in the problem statement were mapped to the corresponding research questions, research objectives, and research hypotheses in accordance with the Design and Development Research (DDR) framework. This mapping demonstrates how each phase of the study, from problem identification and localisation, through model design and development, to empirical evaluation, arises from the underlying research problems. The alignment between problem gaps, research questions, objectives, and hypotheses is presented in Table 1.1. This alignment informed the sequential organisation of the study into needs analysis (Phase 1), model

design and development (Phase 2), and model evaluation (Phase 3), as detailed in Chapter 3.

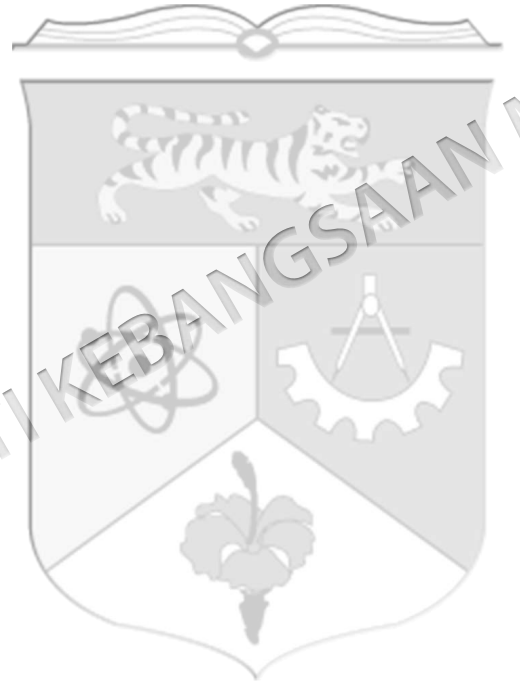

Table 1.1 Alignment of identified problem gaps with research questions, research objectives, and research hypotheses

Problem Statement	Research Question	Research Objective	Research Hypotheses
Uncertainty regarding which areas of emergency department operations experience the greatest operational strain and therefore warrant prioritised process improvement efforts.	Which area(s) within the emergency department experience the greatest operational strain and therefore warrant targeted process improvement?	To identify the most appropriate focus area for intervention based on operational performance indicators, patient feedback, and stakeholder input.	*No hypothesis* (needs analysis)
Limited evidence regarding how Lean principles should be systematically translated into contextually appropriate intervention models within complex emergency department environments.	How can Lean principles be translated into a context-specific Lean-based model for the identified emergency department focus area?	To design and develop a Lean-based model tailored to the emergency department Green Zone, informed by findings from the needs analysis and current-state map.	*No hypothesis* (model design and development)
Limited rigorous evaluation of Lean's impact on emergency department operational performance.	To what extent does the implementation of the Lean-based model affect emergency department operational performance?	To evaluate changes in emergency department operational performance following implementation of the Lean-based model, as measured by triage-to-registration time (TTR), arrival-to-consultation time (ATC), and length of stay (LOS).	**H1:** Implementation of the Lean-based model is associated with changes in triage-to-registration time. **H2:** Implementation of the Lean-based model is associated with changes in arrival-to-consultation time. **H3:** Implementation of the Lean-based model is associated with changes in length of stay.
Insufficient evidence on the economic implications of Lean interventions in emergency department settings.	What is the impact of the Lean-based model on emergency department operational cost efficiency?	To estimate changes in cost per patient and cost per patient-hour before and after implementation of the Lean-based model.	**H4:** Implementation of the Lean-based model is associated with operational cost change in the emergency department.

1.9 CONCLUSION

This chapter has established the foundation for the study by situating the research within the broader context of healthcare system pressures, emergency department overcrowding, and the growing application of Lean management in complex clinical environments. The research background highlighted the relevance of Lean as a process improvement approach in healthcare, while also identifying persistent gaps in the systematic design, implementation, and evaluation of Lean interventions within emergency departments, particularly in public university hospital settings.

The problem statement subsequently identified four interrelated research gaps concerning the prioritisation of intervention areas within emergency department operations, the translation of Lean principles into context-sensitive intervention models, the rigorous evaluation of operational performance outcomes, and the assessment of operational cost efficiency. Collectively, these gaps highlight the need for a structured approach that integrates operational assessment, intervention development, implementation, and evaluation within a single research framework. Accordingly, this study seeks to generate evidence regarding how Lean principles can be systematically applied to improve emergency department performance within a Malaysian public university hospital.

In alignment with this focus, the chapter presented the research questions, objectives, and hypotheses to address the identified gaps. Having established the rationale, scope, and direction of the research, the next chapter reviews the relevant literature on emergency department operations, Lean management, and methodological approaches to evaluating system-level interventions. This review provides the theoretical and empirical grounding necessary to inform the design and development of the Lean-based model and to position the study within the existing body of knowledge.

CHAPTER II

LITERATURE REVIEW

2.1 INTRODUCTION

The increasing demand for timely and high-quality emergency care, coupled with resource constraints, has intensified pressure on emergency departments, where overcrowding remains a persistent challenge. These inefficiencies, often conceptualised through the input–throughput–output model, have significant implications for patient outcomes, operational performance, and healthcare costs. In response, healthcare organisations have adopted Continuous Quality Improvement (CQI) approaches, with Lean management emerging as a key strategy to enhance efficiency and value delivery.

The literature review is organised into three thematic pillars that establish the foundation of the study. The first pillar examines the phenomenon of ED overcrowding, including current patient flow processes, contributing factors, and the consequences of overcrowding across patient, healthcare worker, and organisational levels. The second pillar reviews Continuous Quality Improvement (CQI) approaches and the Lean concept, with particular emphasis on the application of Lean within healthcare settings globally and in Malaysia, including commonly utilised Lean tools and evaluation indicators. The third pillar explores relevant theoretical perspectives underpinning organisational and process change, particularly change management theories relevant to healthcare improvement initiatives.

The synthesis of operational challenges, Lean methodologies, and change management theory culminates in the study's conceptual framework. This model illustrates the critical relationships between Lean interventions, the change process, and

the resulting operational and financial outcomes, serving as the architectural guide for this research.

2.2 EMERGENCY DEPARTMENT OVERCROWDING

2.2.1 Burden of care in emergency departments

Emergency department (ED) overcrowding is one of the most pressing global healthcare challenges, with estimates suggesting that between 30% and 90% of EDs worldwide experience persistent overcrowding (Alshiakh et al. 2025). Rising patient demand, workforce constraints, hospital access block, and prolonged waiting times compromise timely access to care, strain healthcare resources, and affect the ability of healthcare workers to deliver efficient and safe emergency care.

ED overcrowding occurs when the demand for emergency healthcare services exceeds available resources, including physical space, staffing, and diagnostic capacity, resulting in a critical issue that adversely impacts both patient care quality and the overall efficiency of the healthcare system (Ahmed et al. 2025; Altun & Kudu 2025; Barrera 2025; Pearce et al. 2024). This issue has become particularly important in contemporary healthcare systems where EDs function not only as acute care entry points, but also as safety nets for broader healthcare access limitations.

In Malaysia, ED overcrowding has emerged as an increasingly visible public healthcare concern. Public hospitals and academic medical centres continue to experience rising ED utilisation, particularly in densely populated urban centres and tertiary referral hospitals (Abdul Hamid et al. 2025; Chau et al. 2024; Krisnan et al. 2025). Recent national data analysing workload across 137 Ministry of Health (MOH) hospital emergency departments demonstrated substantial disparities in ED strain, with 26% of hospitals exceeding internationally recognised overcrowding thresholds based on patient-to-physician ratios per hour.

In another study, Krisnan et al. (2025) explored healthcare workers' experiences within the green zone of a large public hospital in the Klang Valley and highlighted the operational vulnerability of non-critical care zones managing high volumes of semi-

urgent and non-urgent patients. The study described overcrowding within the green zone as being associated with prolonged waiting times, staffing constraints, inappropriate ED utilisation, workflow disruption, increasing workload pressure, and delays across multiple stages of patient care (Krisnan et al. 2025).

These findings highlight ED overcrowding as a multifaceted healthcare challenge affecting emergency care systems globally and within Malaysia. The persistence of overcrowding despite ongoing efforts to expand capacity and improve access suggests that the phenomenon cannot be attributed to a single cause, but arises from the interaction of multiple operational and system-level factors. Understanding these underlying drivers is essential for identifying appropriate improvement strategies and informing interventions aimed at enhancing patient flow, service efficiency, and overall emergency department performance. The factors contributing to ED overcrowding are discussed in the following subsection.

2.2.2 Factors contributing to emergency department overcrowding

The burden of care associated with ED overcrowding stems from a complex interaction between patient demand, operational processes, resource availability, and patient disposition within emergency care systems. This perspective is reflected in Asplin et al.'s framework (Asplin et al. 2003), which provides a structured approach to understanding the underlying drivers of ED overcrowding through three interconnected components: input, throughput, and output. This framework is depicted in Figure 2.1.

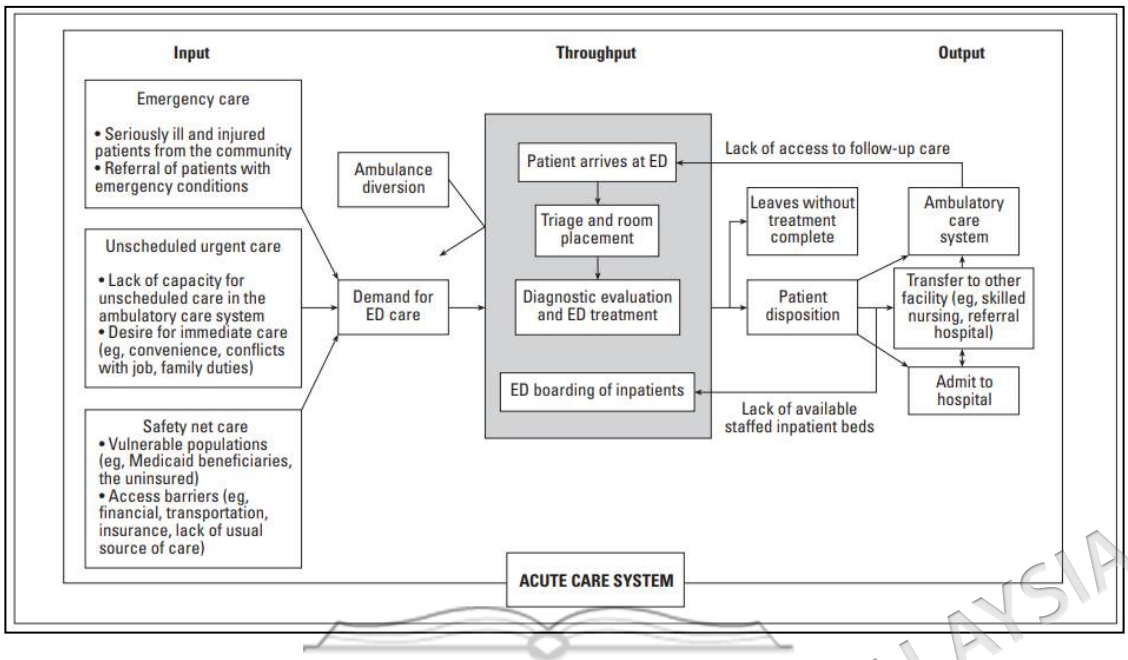

Figure 2.1 The input-throughput-output conceptual model of emergency department crowding

Source: Asplin et al. (2023)

Input factors refer to determinants of demand for emergency department services and influence the volume and characteristics of patients entering the ED. These factors include healthcare system characteristics, such as access to primary care, specialist services, and mental health support, as well as broader population and community influences. Environmental conditions, temporal variations, socioeconomic circumstances, and local population health needs may further affect patterns of ED utilisation and contribute to fluctuations in patient demands.

Throughput factors refer to processes occurring within the emergency department that influence the movement of patients from arrival to disposition. These factors encompass workflow efficiency, staffing capacity, clinical decision-making, diagnostic and treatment processes, and the availability of supporting services. Inefficiencies within any of these processes may create bottlenecks that delay patient progression through the ED. In addition, boarding of admitted patients awaiting inpatient beds can further constrain throughput by reducing the capacity and resources available for ongoing patient care.

Output factors relate to the ability of patients to exit the emergency department and transition to appropriate downstream care settings. These factors are largely influenced by the capacity and responsiveness of the wider healthcare system, including the availability of inpatient beds, transfer facilities, ambulatory services, and community-based care. Constraints within these downstream services may delay patient disposition, contribute to access block and boarding, and generate cascading effects on patient flow throughout the hospital system (Ahmed et al. 2025).

The literature identifies a range of factors contributing to emergency department overcrowding across the input, throughput, and output domains of Asplin's conceptual model. These factors are summarised in Table 2.1.

Table 2.1 Factors contributing to emergency department overcrowding

Component	Factors identified in the literature	Author(s) (Year)
Input	Increasing ED attendance / rising demand	Chrusciel et al. (2026); Haas & Brundisini (2023); Herzog et al. (2025)
	Ageing population and complex comorbidities	Chrusciel et al. (2026); Herzog et al. (2025)
	Limited access to primary care	Altun & Kudu (2025); Haas & Brundisini (2023); Pearce et al. (2023)
	Non-urgent ED utilisation / patient behaviour	Altun & Kudu (2025); Pearce et al. (2023)
	Socioeconomic disparities and access inequalities	Altun & Kudu (2025); Haas & Brundisini (2023)
	Environmental and temporal factors (weather, events, holidays)	Ahmed et al. (2025); Chrusciel et al. (2026)
Throughput	Delays in triage and patient assessment	Kienbacher et al. (2022); Pearce et al. (2023)
	Delays in diagnostics and treatment processes	Altun & Kudu (2025); Herzog et al. (2025); Pearce et al. (2023)
	Staffing constraints and workforce limitations	Herzog et al. (2025); Altun & Kudu (2025)
	Inefficient workflow and care coordination	Altun & Kudu (2025); Haas & Brundisini (2023)
	Patient acuity and case complexity affect processing time	Chrusciel et al. (2026); Herzog et al. (2025)

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Output	Access block/inpatient bed shortages	Haas & Brundisini (2023); Pearce et al. (2023); Sartini et al. (2022)
	Boarding of admitted patients in the ED	Herzog et al. (2025); Pearce et al. (2023); Sartini et al. (2022)
	Delays in discharge processes	Altun & Kudu (2025); Haas & Brundisini (2023)
	Hospital-wide capacity constraints	Haas & Brundisini (2023); Sartini et al. (2022)

2.2.3 Measurement of emergency department overcrowding

Although ED overcrowding arises from the interaction of input, throughput, and output factors, it is most commonly assessed using throughput-related indicators that reflect the efficiency of patient movement through the emergency department (Grant et al. 2020; Haq et al. 2018; Kenny et al. 2024; Youssef et al. 2024). Measures such as waiting time, time to physician assessment, length of stay, and rates of patients leaving without being seen provide observable and quantifiable manifestations of congestion within the ED and are therefore frequently used as operational indicators of overcrowding. These measures are particularly relevant for quality improvement initiatives because they reflect processes that can be monitored and influenced through organisational and workflow redesign (Stahley et al. 2020; Youssef et al. 2024).

Table 2.2 summarises the commonly used measures of ED overcrowding identified in the literature.

Table 2.2 Operational indicators and composite scoring systems used in the literature to quantify emergency department overcrowding

Indicator	Definition
ED occupancy rate	The proportion of occupied ED beds, which is the number of occupied beds divided by the total number of ED beds; is usually expressed as a percentage.
ED Length of Stay (LOS)	The time patients spend in the ED.
ED volume	The total number of patients in the ED during a defined time.

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ED boarding time	The time admitted patients spend in the ED waiting for transport to their assigned hospital bed.
Number of boarders	The number of patients waiting in the ED for a hospital bed.
Waiting room number	The number of patients in the waiting room of an ED.
Emergency Department Work Index (EDWIN)	Based on a formula that aims to measure the ratio of workload to work capacity - $\sum n_i t_i / N_a(B_T - B_A)$, where: • n_i is the number of patients in the ED in the triage category • i, t_i is triage category • N_a is the number of attending physicians on duty • B_T is the number of treatment bays • B_A is the number of admitted patients in the ED The triage category is defined by the Emergency Severity Index (ESI).
National Emergency Department Overcrowding Scale (NEDOCS)	A score based on a formula that requires the following variables: • the number of ED patients, • the number of ED beds, • the number of hospital beds, • the number of ventilators in use in the ED, • the waiting time for the longest admission, the waiting room time of the last patient called to a bed, and • the number of admits in the ED.

These indicators provide measurable representations of the operational burden experienced within overcrowded emergency departments and are widely used to evaluate patient flow performance, throughput efficiency, and service accessibility (Badr et al. 2022; Mohd Nasir et al. 2025). However, evidence from a systematic review by Badr et al. (2022) suggests that while individual indicators provide useful snapshots of ED conditions, no single measure is sufficient to fully represent the complexity of overcrowding. Instead, commonly used indicators tend to reflect specific aspects of ED functioning, such as occupancy and patient volume as proxies for demand, length of stay and waiting time as markers of process efficiency, and boarding-related measures as indicators of downstream capacity limitations (Badr et al. 2022). This observation is particularly important given the multidimensional nature of ED overcrowding, where delays and inefficiencies occurring across different stages of patient flow are often interconnected and cumulative. Thus, comprehensive evaluation of ED operational performance frequently requires the use of multiple complementary indicators capable of capturing different dimensions of patient flow and throughput burden across the emergency care pathway.

Within high-volume public tertiary referral and academic medical centres, these operational pressures are often further amplified by sustained patient demand, workforce limitations, referral complexity, and the competing demands of service delivery and clinical training. As such, the burden of ED overcrowding extends beyond operational inefficiency alone and reflects broader challenges involving healthcare quality, patient safety, workforce wellbeing, and organisational performance. The consequences associated with sustained ED overcrowding are discussed further in the following subsection.

2.2.4 The consequences of emergency department overcrowding

Emergency department overcrowding has implications that extend beyond delays in patient flow and operational performance. A growing body of evidence demonstrates that sustained overcrowding may adversely affect patients, healthcare workers, and the wider healthcare system through its impact on care quality, patient safety, workforce wellbeing, and organisational performance (Alshiakh et al. 2025; Chau et al. 2024; Pearce et al. 2023; Sartini et al. 2022). Within Malaysia, overcrowded conditions in a tertiary academic hospital emergency department were associated with an increase in-hospital mortality among patients with sepsis, highlighting the potential clinical consequences of prolonged congestion even in settings striving to maintain timely care delivery (Chau et al. 2024). These findings suggest that ED overcrowding is not merely an operational concern but a broader healthcare quality and patient safety issue with implications across multiple levels of the healthcare system.

The consequences of ED overcrowding are multifaceted and can be understood across three levels: patient, healthcare worker, and at the institutional/systems level. The specific consequences identified in the literature are synthesised in Table 2.3, organised according to these levels.

Table 2.3 Summary of consequences of emergency department overcrowding across patient, healthcare worker, and institutional levels based on literature synthesis

Level	Main Consequence(s)	Key Findings	Author (Year)
Patient	Care processes and patient safety	Delays in triage (eg. During crowding, target times to triage elapsed more often (49.7% vs 24.9%, $p<0.001$), and more patients were not triaged (2.2% vs 1.6%, $p<0.001$).	Ahmed et al. (2026); Amin & Haswita (2023); Kienbacher et al. (2022); Van der Linden et al. (2016)
		Delays in time-sensitive interventions (ie. analgesia, antibiotic administration, stroke evaluation, trauma care, sepsis management, and diagnostic delays).	Ahmed et al. (2026); Gross et al. (2023); Kienbacher et al. (2022); Sartini et al. (2022)
		Higher hospital-acquired complications.	Ahmed et al. (2026)
		Longer time to treatment.	Alshiakh et al. (2025); Haas & Brundisini (2023); Pearce et al. (2023); Sartini et al. (2022)
	Patient outcome	Prolonged emergency department (ED) and inpatient length of stay (LOS).	Ahmed et al. (2026); Amin & Haswita (2023); Pearce et al. (2023); Van der Linden et al. (2016)
		Increased left without being seen (LWBS).	Alshiakh et al. (2025); Kienbacher et al. (2022); Sartini et al. (2022)
		Reduced patient satisfaction.	Alshiakh et al. (2025); Sartini et al. (2022)
		Higher morbidity and mortality.	Alshiakh et al. (2025); Amin & Haswita (2023); Gross et al. (2023); Pearce et al. (2023); Sartini et al. (2022)
Healthcare worker		Reduced adherence to evidence-based care.	Ahmed et al. (2026); Amin & Haswita (2023)
		Increased workload.	Amin & Haswita (2023)

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	Impacts on employee turnover and well-being; staff burnout.	Gross et al. (2023); Haas & Brundisini (2023); Abdul Hamid et al. (2025)
Institutional / Systems	Higher resource utilisation.	Ahmed et al. (2026); Pearce et al. (2023)
	Reduced surge/disaster response capacity.	Gross et al. (2023)
	Varied access to care.	Abdul Hamid et al. (2025)

At the patient level, overcrowding disrupts care processes, compromises patient safety, and leads to poorer clinical outcomes. Care processes refer to the sequence of clinical and operational activities involved in the delivery of healthcare, including triage, diagnosis, treatment, and patient disposition. In the context of ED overcrowding, disruptions to care processes can be linked directly to patient safety concerns. Long wait times for initial evaluation and treatment can worsen outcomes for time-sensitive conditions such as strokes, myocardial infarction, and sepsis (Chau et al. 2024; Sartini et al. 2022). Furthermore, high patient volume within a high-pressure emergency department setting may lead to medication errors, including errors in dosage, wrong medication administration, and missed dosages (Ahmed et al. 2025; Alshiakh et al. 2025). Delays in triage, assessment, and diagnostic tests are also widely reported, contributing to prolonged waiting times and reduced adherence to recommended care pathways (Kienbacher et al. 2022; Van der Linden et al. 2016). These process inefficiencies compromise patient safety by increasing the risk of delayed diagnosis, missed clinical deterioration, and preventable complications.

These disruptions also translate into adverse patient outcomes, including prolonged ED and inpatient length of stay, increased admission rates, and higher rates of patients leaving without being seen (Ahmed et al. 2025; Sartini et al. 2022). Overcrowding has also been associated with increased morbidity and mortality, although findings on mortality remain inconsistent across studies (Ahmed et al. 2025). Reduced patient satisfaction and poorer care experiences further reflect the cumulative impact of delays and compromised care processes on patients (Sartini et al. 2022).

At the healthcare worker level, ED overcrowding imposes substantial physical, cognitive, and emotional demands on clinical staff, with implications not only for staff well-being but also for the quality and safety of care delivered. Increased patient volumes, prolonged boarding, and persistent time pressure contribute to excessive workload and cognitive burden, particularly in high-acuity environments where rapid decision-making is required (Amin & Haswita 2023). Under overcrowded conditions, healthcare workers are frequently required to manage multiple competing priorities simultaneously, often while caring for patients beyond the intended capacity of the

department. Such conditions can reduce adherence to evidence-based practices and clinical guidelines, as clinicians may adopt abbreviated approaches to care in an effort to manage patient flow (Ahmed et al. 2025; Amin & Haswita 2023).

Sustained exposure to overcrowded and resource-constrained working environments has also been associated with adverse psychological outcomes among healthcare workers. Studies have reported increased levels of occupational stress, emotional exhaustion, fatigue, and burnout among ED staff working in overcrowded departments (Gross et al. 2023; Haas & Brundisini 2023). Burnout, characterised by emotional exhaustion, depersonalisation, and reduced professional accomplishment, may subsequently affect staff morale, job satisfaction, and organisational commitment. In turn, these factors contribute to absenteeism, reduced productivity, and higher employee turnover, further exacerbating existing workforce shortages within emergency care settings (Abdul Hamid et al. 2025; Gross et al. 2023).

At the institutional and health systems level, ED overcrowding reflects broader inefficiencies in healthcare delivery and generates significant operational and financial consequences. Overcrowding is associated with increased healthcare resource utilisation, including greater demand for inpatient beds, diagnostic services, staffing, and ancillary support services (Ahmed et al. 2025; Gross et al. 2023). Prolonged ED length of stay and access block contribute to inefficiencies in bed management and reduce overall hospital throughput, thereby limiting the institution's capacity to respond effectively to surges in patient demand or disaster situations (Gross et al. 2023). In addition, persistent overcrowding may disrupt organisational performance indicators, including waiting time targets, patient flow benchmarks, and quality-of-care metrics, potentially affecting institutional reputation and undermining public confidence in the healthcare system.

Beyond operational inefficiencies, ED overcrowding also has important implications for equity and access to care at the system level. Variability in waiting times and access to timely emergency care may disproportionately affect vulnerable and disadvantaged populations, including older adults, lower socioeconomic groups, and patients with complex healthcare needs (Abdul Hamid et al. 2025; Pearce et al. 2023).

These inequities may arise because overcrowded systems often prioritise immediate clinical urgency over continuity and comprehensiveness of care, creating barriers for patients who already experience structural disadvantages in accessing healthcare services. Furthermore, prolonged overcrowding may contribute to increased healthcare expenditure through avoidable admissions, prolonged hospitalisation, repeated ED visits, and inefficient resource allocation.

These findings demonstrate that the burden of ED overcrowding extends beyond patient-level delays alone and increasingly affects healthcare workers, operational efficiency, and broader healthcare system performance. Importantly, many of these consequences do not occur in isolation but emerge through disruptions occurring across multiple sequential emergency care processes. Delays in registration, triage, consultation, diagnostics, treatment, disposition, and patient transfer may progressively accumulate within the emergency care pathway, amplifying workload pressure, resource strain, communication challenges, and downstream congestion. Consequently, understanding the operational workflow of emergency departments becomes important not only in examining how overcrowding develops, but also in identifying where inefficiencies arise and how patient-flow interventions may be targeted within complex emergency care systems.

2.2.5 Current basic processes in the emergency department

Patients move through the ED in a series of sequential yet interdependent stages, from initial presentation to final disposition. This patient flow typically encompasses triage, clinical assessment, diagnostic evaluation, treatment, and eventual discharge, admission, or transfer. Conceptually, this reflects the throughput component of emergency care, while remaining closely influenced by upstream demand (input) and downstream system capacity (output) (Asplin et al. 2003).

Patients entering the ED are first registered and assessed at the triage counter, where their clinical condition is evaluated to determine the urgency of care. Triage, therefore, functions as a critical gateway into the ED process, shaping patient prioritisation and influencing subsequent waiting times. Following triage, patients undergo clinical evaluation, which includes history taking, physical examination, and

initiation of medical management. Depending on clinical needs, patients may then proceed to diagnostic investigations, including laboratory testing and imaging, which support clinical decision-making.

Subsequently, patients receive definitive treatment and are referred to respective primary teams, depending on their diagnosis, or are placed under observation, often requiring ongoing monitoring and reassessment. A disposition decision is then made, where a patient may be discharged home, admitted for inpatient care, or transferred to another facility. Here, a phenomenon known as “boarding”, where delays occur in securing inpatient beds, can result in prolonged length of stay in the ED, despite a decision to admit (Sartini et al. 2022).

The overall patient flow within the ED, incorporating these stages and transitions, is illustrated in Figure 2.2.

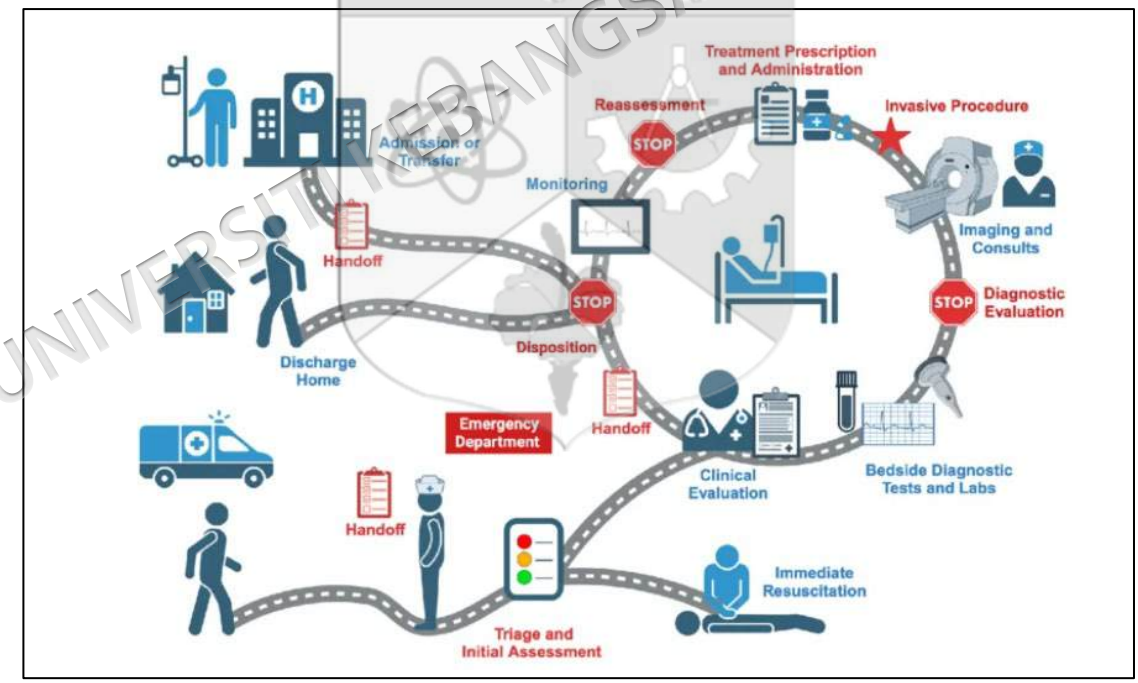

Figure 2.2 Patient flow through the emergency department

Source: Rovati et al. (2025)

As shown in Figure 2.2, patient flow in the ED involves multiple feedback loops. Patients may cycle between assessment, investigation, and treatment before a definitive disposition is reached. In addition, transitions between stages, such as from diagnostic

evaluation to treatment or from disposition decision to physical transfer, represent critical points where delays may occur. These interruptions can lead to prolonged patient stays within the ED and exacerbate overcrowding by constraining throughput and limiting the availability of resources for incoming patients. Consequently, understanding this process is essential for identifying areas of inefficiency and potential targets for process improvement.

2.3 CONTINUOUS QUALITY IMPROVEMENT INITIATIVES

The complexity of emergency department overcrowding and its underlying patient flow challenges has led to the implementation of a wide range of interventions aimed at improving efficiency and quality of care. These interventions span multiple levels of the healthcare system, targeting factors related to demand, internal processes, and patient disposition.

Continuous quality improvement (CQI) has emerged as a key paradigm for addressing healthcare system challenges through structured, data-driven, and iterative approaches to process optimisation. This section reviews the principles and models of CQI in healthcare, followed by a synthesis of CQI initiatives aimed at improving ED patient flow.

2.3.1 Overview of continuous quality improvement initiatives in healthcare

Deficiencies in care quality are rarely attributable to individual performance, but instead to the design and functioning of healthcare systems. As such, Continuous Quality Improvement (CQI) has emerged as a central paradigm in healthcare for analysing and improving care processes. CQI is defined as a systematic, data-driven approach aimed at enhancing healthcare processes, patient safety, and outcomes through ongoing, iterative cycles of evaluation and change (Endalamaw et al. 2024; O'Donnell & Gupta 2023). Unlike traditional quality assurance approaches, which focus on identifying and correcting deviations from predefined standards, CQI adopts a dynamic and proactive orientation that emphasises continuous monitoring and optimisation of processes by embedding improvement within routine practice. This is achieved through iterative cycles that involve identifying performance gaps, implementing targeted interventions,

measuring outcomes using defined indicators, and refining processes based on feedback (O'Donnell & Gupta 2023).

CQI initiatives primarily target processes as the most modifiable component of care delivery and rely on the systematic use of performance indicators to monitor change and guide decision-making. The use of both primary metrics, such as waiting time and ED length of stay, and secondary metrics, such as left without being seen (LWBS) rates, patient satisfaction, and resource utilisation, allows organisations to evaluate intended effects while identifying unintended consequences, thereby reducing the risk of shifting inefficiencies from one part of the system to another (O'Donnell & Gupta 2023). In practice, CQI has been applied across a wide range of healthcare settings, such as reducing readmission rates, standardising care through clinical pathways, and improving medication adherence in chronic patients (Endalamaw et al. 2024).

A range of CQI models have been applied in healthcare, each offering a distinct framework for guiding improvement activities. However, the applicability and effectiveness of a given model may vary depending on the nature of the problem being addressed, as well as the organisational and clinical context (Endalamaw et al. 2024). Some CQI models emphasise process optimisation, aiming to improve the efficiency, flow, and reliability of care delivery, while others are more oriented towards outcome measurement and impact, focusing on achieving measurable improvements in patient safety, satisfaction, or clinical results. These perspectives are interrelated, as improvements in outcomes are often contingent upon effective redesign of underlying care processes. This highlights the need for approaches that not only optimise care processes but also demonstrate measurable improvements in outcomes.

To operationalise such approaches in practice, a range of CQI models and frameworks has been developed to guide the design, implementation, and evaluation of improvement initiatives. These models provide structured pathways for translating CQI principles into actionable strategies within complex healthcare systems. While the literature describes these models individually (Endalamaw et al. 2024), it does not categorise them according to their primary focus or level of application. Therefore, this

review synthesises the models thematically: iterative cyclical models, process-focused methodologies, and organisation-wide frameworks. A summary of the key CQI models and their characteristics is presented in Table 2.4.

Table 2.4 Continuous Quality Improvement (CQI) models

Theme	Model / Framework	Key Components	Application
Iterative Cyclical Models	PDSA (Plan–Do–Study–Act)	An iterative cycle involving problem identification, root cause analysis, solution implementation, evaluation, and standardisation	Incremental, continuous improvement through repeated testing and refinement
	FOCUS–PDCA	Find, Organise, Clarify, Understand, Select + PDCA cycle	Structured process improvement, root cause identification, and continuous quality improvement through team-based problem solving
	FADE Cycle	Focus, Analyse, Develop, Execute	Structured problem-solving using data-driven analysis and implementation
	5C Cyclical Model	Consultation, Collection, Consideration, Collaboration, Celebration	Community-based, participatory improvement with cyclical evaluation
Process-Focused Methodologies	Lean	Waste elimination (e.g., waiting, defects), flow optimisation, value-based care, supported by Kaizen principles	Process efficiency, workflow optimisation, and reduction of non-value-added activities
	Lean Six Sigma (DMAIC)	Define, Measure, Analyse, Improve, Control	Combines process efficiency with variation reduction and quality control
	5S Framework	Sort, Set in order, Shine, Standardise, Sustain	Workplace organisation and standardisation to improve efficiency and reliability
	Kaizen Principles	Continuous, incremental improvement; staff engagement; data-driven change; waste and variability reduction	Culture of continuous improvement embedded in daily processes
Organisation-Wide Frameworks	Total Quality Management (TQM)	Organisation-wide quality focus, leadership engagement, continuous improvement culture	System-level transformation through organisational alignment and culture change

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Breakthrough Series (Institute for Healthcare Improvement (IHI) Model)	Collaborative learning sessions, shared improvement cycles, and cross-site learning	Scaling improvement through structured collaboration and knowledge exchange
Logic Framework	Problem identification, root cause analysis, objective setting, implementation planning	Structured planning and evaluation linking problems to outcomes
Collaborative / Meeting-based Approaches	Structured team processes (goal setting, role assignment, evaluation, feedback cycles)	Team-based coordination and continuous evaluation of improvement activities

Iterative cyclical models, such as the Plan–Do–Study–Act (PDSA) cycle, emphasise incremental testing and continuous refinement through repeated cycles of change. These approaches are particularly suited to localised improvements, where rapid feedback and adaptation are required. In contrast, process-focused methodologies, including Lean and Six Sigma, adopt a more structured approach to improvement. These models focus on enhancing efficiency, reducing variation, and improving flow across interconnected processes, making them especially relevant for complex, high-demand environments. Organisation-wide frameworks, such as Total Quality Management and collaborative improvement models, extend beyond individual processes to address system-level factors, including leadership, organisational culture, and cross-functional coordination.

In the context of emergency departments, where patient flow is dynamic and highly sensitive to system constraints, CQI has been utilised to "fast-track" low acuity patients, decrease wait times, and enhance patient satisfaction. Nevertheless, the application of CQI in this setting has taken diverse forms, with the literature reporting a wide range of interventions targeting different components of the patient flow pathway. This heterogeneity reflects the absence of a unified approach to addressing ED overcrowding and highlights the need to examine how such interventions have been conceptualised and implemented in practice.

2.3.2 Interventions to improve emergency department patient flow

Interventions to improve emergency department patient flow have been widely reported in the literature, reflecting the complexity of overcrowding as a multifactorial systems problem. Existing reviews commonly categorise these interventions according to the stage of the patient journey they target, using the input–throughput–output framework (Haas & Brundisini 2023; Pearce et al. 2024). Others have classified interventions based on their underlying mechanisms, such as human factors, organisational processes, and infrastructure (Samadbeik et al. 2024). While both approaches provide valuable insights, they are rarely integrated within the literature. Therefore, this subsection will synthesise interventions using a combined framework that maps intervention types and

mechanisms onto the input, throughput, and output components of ED patient flow. This approach enables a more comprehensive understanding of how different strategies target specific system constraints, while also highlighting gaps in the current evidence base.

While CQI models can provide a structured approach to improvement, their application in emergency departments may be better understood when situated within the broader system of patient flow. The input–throughput–output framework, therefore, provides a useful lens for examining how CQI-driven interventions are applied in the ED.

a. Input interventions

Interventions addressing input challenges are designed to manage demand for ED services by influencing patient inflow and redirecting care to more appropriate settings. Common strategies include strengthening access to primary healthcare services, implementing triage diversion pathways, and introducing prehospital interventions such as tele-triaging and non-conveyance protocols. These approaches aim to reduce unnecessary ED attendances and improve the alignment between patient needs and care settings (Chua et al. 2025; Santos et al. 2026).

Interventions at this stage are predominantly system-and policy-oriented, often extending beyond the ED to involve community and primary care services. For example, Chan et al. (2015) described the integration of primary care units within or adjacent to EDs, while Jeyaraman et al. (2021), Maninchedda et al. (2023), and Pearce et al. (2024) described enhancing primary care access through the extension of primary care operating hours. Despite their potential to reduce demand pressures, the implementation of input interventions is inherently dependent on system-level factors, including the availability of accessible primary care services, effective integration across care settings, and well-established prehospital triage and referral mechanisms. Consequently, while such strategies address upstream contributors to overcrowding, they are less frequently studied and reported in the literature compared to interventions focused on throughput within the ED (Samadbeik et al. 2024).

b. Throughput interventions

Throughput interventions focus on improving the efficiency of processes within the ED and represent the most extensively studied category of patient flow strategies. These interventions primarily target triage processes, workflow redesign, staffing configurations, and the optimisation of diagnostic and treatment processes.

A major focus of throughput interventions involves optimising triage processes, which function as the initial point of patient contact in the ED. Reported strategies include physician-, nurse-, and team-based triage models, Rapid Assessment Zones, fast-track systems, and advanced triage protocols (Bittencourt et al. 2020; Freitas et al. 2023; Grant et al. 2020; Soster et al. 2022). In physician-led and team-based triage approaches, senior clinicians are positioned at the front end of the ED to initiate early assessment, diagnostic testing, and treatment, thereby reducing delays in clinical decision-making and downstream care processes. Quantitative evidence indicates that physician-led triage interventions have been associated with reductions in ED length of stay (LOS) ranging from 82 minutes to modest increases of 18 minutes (−20.7% to +7.2%), while nurse practitioner- or physician assistant-led triage models demonstrate similarly variable effects, with reported LOS reductions of up to 106 minutes (−22% to +7.3%) (Grant et al. 2020). Team-based triage approaches have shown comparatively more consistent improvements, with LOS reductions ranging from 4 to 34 minutes (8%–16%). Several physician-at-triage interventions have also demonstrated reductions in rates of patients leaving without being seen (LWBS), although findings remain inconsistent across studies (Grant et al. 2020).

Triage-based streaming and fast-track models further seek to improve throughput by directing patients into differentiated care pathways according to acuity or clinical need. These approaches aim to reduce congestion within standard ED workflows by aligning patient complexity with appropriate resources early in the care process. Advanced triage protocols and nurse-initiated investigations facilitate earlier initiation of diagnostic and therapeutic interventions prior to physician review, thereby streamlining workflow processes and accelerating downstream clinical decision-making. Evidence suggests that patient streaming, fast-track systems, and rapid

assessment models are among the more consistently effective throughput interventions, with reported LOS reductions ranging from 9 to 114 minutes (4.0%–47.5%) across studies (Grant et al. 2020; Santos et al. 2026). Similarly, split-flow models and rapid evaluation units have demonstrated LOS reductions ranging from nine to 60 minutes (4.0%–41.6%), highlighting the benefits of aligning patient pathways with resource availability and clinical complexity.

More recently, technology-supported interventions, including electronic triage systems, predictive analytics, and real-time operational dashboards, have been explored to support patient prioritisation, resource allocation, and proactive flow management (Saifullah et al. 2025). Interventions targeting diagnostic workflows, such as point-of-care testing and expedited laboratory processes, have also been implemented to reduce delays associated with investigations and treatment initiation. However, the effectiveness of these approaches remains variable. For example, point-of-care testing interventions have been associated with LOS reductions ranging from 114 minutes to slight increases of 8 minutes (−26.8% to +3.8%), with benefits often confined to specific patient subgroups requiring targeted investigations (Grant et al. 2020). Similarly, workforce-related interventions, including the introduction of nurse practitioners, physician assistants, scribes, and modified staffing configurations, demonstrate inconsistent effects across settings, reflecting variability in organisational context and implementation strategies.

More comprehensive interventions integrating multiple throughput strategies, such as patient streaming, early senior clinician assessment, and workflow redesign, have demonstrated comparatively larger improvements in patient flow outcomes, with reported LOS reductions of up to 114 minutes (1%–41%) (Grant et al. 2020). Nevertheless, these interventions are frequently more resource-intensive and operationally complex, often requiring organisational restructuring, interdepartmental coordination, and additional capacity. Notably, several integrated approaches incorporate elements of process standardisation, workflow optimisation, and waste reduction, reflecting increasing recognition of ED overcrowding as a process and systems management issue rather than solely a capacity problem.

Overall, the literature suggests that throughput interventions can contribute to improvements in ED operational performance, particularly when interventions facilitate earlier clinical assessment, streamlined workflows, and more efficient patient streaming. However, the magnitude and sustainability of these improvements remain highly context-dependent. A recurring finding across studies is that throughput interventions are frequently implemented as discrete operational strategies targeting specific bottlenecks rather than as components of an integrated system-wide redesign. Consequently, improvements in one aspect of patient flow may not be sustained and may inadvertently shift bottlenecks elsewhere within the care pathway. These findings highlight the importance of structured, process-oriented approaches capable of systematically analysing and redesigning interconnected ED workflows.

c. Output interventions

Output interventions address the movement of patients out of the ED and focus on improving discharge processes, inpatient bed availability, and coordination across hospital services. Key strategies include enhanced discharge planning, the establishment of short-stay or observation units, full-capacity protocols, and initiatives aimed at reducing inpatient boarding and facilitating the timely transfer of admitted patients. Unlike throughput interventions, which primarily target processes occurring within the ED itself, output interventions typically require coordination across multiple hospital departments and are more closely linked to hospital-wide capacity management and organisational processes.

A major focus of output interventions involves reducing access block and inpatient boarding, which are recognised contributors to prolonged ED crowding and delays in patient flow. Observation and short-stay units have been implemented to facilitate the management of patients requiring brief monitoring or treatment, thereby reducing unnecessary inpatient admissions and alleviating pressure on ED bed capacity (Pearce et al. 2024). Similarly, enhanced discharge planning initiatives seek to improve inpatient throughput through earlier identification of patients suitable for discharge, multidisciplinary discharge coordination, and improved communication between inpatient and ED teams (Haas & Brundisini 2023). These interventions aim to increase

bed availability and reduce delays in transferring admitted patients from the ED to inpatient wards. System-level interventions such as full-capacity protocols and centralised bed management systems have also been introduced to optimise hospital-wide patient flow and minimise delays associated with inpatient bed allocation (Santos et al. 2026).

While evidence suggests that output-focused interventions can contribute to reductions in ED length of stay, boarding duration, and access block, their implementation is often operationally complex and highly dependent on organisational readiness, leadership support, and cross-departmental coordination (Haas & Brundisini 2023; Pearce et al. 2024). Unlike many throughput-focused initiatives, interventions targeting output processes typically require system-wide organisational change extending beyond the direct control of the ED and are therefore frequently more resource-intensive and politically challenging to implement. Consequently, output interventions are less commonly implemented and evaluated compared with throughput-focused strategies. Nevertheless, the literature increasingly recognises that sustainable improvements in ED overcrowding cannot be achieved through ED-based process optimisation alone, but instead require coordinated approaches that address constraints across the broader hospital system.

d. Synthesis of interventions to improve ED patient flow

Given the diversity of interventions reported in the literature, synthesising strategies according to the stage of patient flow they target provides a useful framework for understanding how overcrowding has been addressed in practice. Existing studies describe interventions targeting patient inflow (input), internal ED processes (throughput), and patient disposition or hospital exit processes (output). However, these interventions differ not only in their operational focus but also in the extent to which they are guided by formal Continuous Quality Improvement (CQI) methodologies. Table 2.5 summarises key interventions reported in the literature according to the input–throughput–output framework, alongside the CQI principles or models underpinning their implementation where specified.

Table 2.5 Interventions to improve emergency department patient flow using the input-throughput-output framework

Patient Flow Doman	Intervention	Description of intervention	CQI Principle	Main Outcome Reported	Author(s) (Year)
Input	Extended primary care access	Expansion of primary care operating hours to reduce non-urgent ED attendances	Not specified	Reduced low-acuity ED presentations	Jeyaraman et al. (2021); Pearce et al. (2024)
	Co-located primary care services	Integration of primary care clinics within or adjacent to EDs	Not specified	Improved diversion of non-emergency cases	Chan et al. (2015)
	Tele-triage / prehospital triage	Remote assessment and referral prior to ED attendance	Not specified	Reduced unnecessary ED utilisation	Santos et al. (2026)
	Non-conveyance protocols	Ambulance services manage selected patients without ED transport	Not specified	Reduced ED demand	Chua et al. (2025)
Throughput	Physician-led triage	Senior physicians positioned at triage to initiate assessment and investigations	Lean	Reduced ED LOS and LWBS	Bittencourt et al. (2020); Grant et al. (2020)
	Team triage	Multidisciplinary triage involving physicians and nurses	Not specified	Improved patient flow and reduced waiting times	Grant et al. (2020)
	Fast-track systems	Separate care pathways for low-acuity patients	Lean	Reduced LOS and overcrowding	Freitas et al. (2023); Jeyaraman et al. (2021)
	Rapid assessment zones	Dedicated areas for early assessment and treatment initiation	Not specified	Reduced waiting time	Grant et al. (2020)
	Advanced triage protocol	Triage staff initiate investigations/treatment before physician review	PDSA	Earlier intervention and shorter LOS	Soster et al. (2022)

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	Nurse-initiated investigations	Nurses authorised to order selected diagnostic tests	Not specified	Faster diagnostic turnaround time	Grant et al. (2020)
	Point-of-care testing	Diagnostic testing conducted within ED for rapid results	Lean Six Sigma	Reduced diagnostic turnaround time, LOS	Grant et al. (2020)
	Patient streaming and split-flow models	Segregation of patients according to acuity or care needs with parallel processing for different patient categories	Lean	Improved throughput efficiency, reduced LOS	Grant et al. (2020); Santos et al. (2026)
	Predictive analytics and real-time dashboards	Digital systems supporting patient flow decisions and resource allocation	Not specified	Improved resource allocation, patient flow monitoring, operational efficiency	Alvee et al. (2024)
	Workforce reconfiguration	Additional physicians, nurse practitioners, scribes, or altered staffing patterns	Not specified	LOS, waiting time, provider productivity, throughput efficiency	Grant et al. (2020)
Output	Observation / short-stay unit	Dedicated units for short-term monitoring and treatment	Not specified	Reduced ED LOS, reduced inpatient admissions, reduced boarding time	Pearce et al. (2024)
	Enhanced discharge planning	Early flagging for patients to be discharged	Not specified	Reduced discharge delays, reduced inpatient LOS, improved patient throughput	Haas & Brundisini (2023)
	Full capacity protocols	Redistribution of admitted patients across inpatient wards during crowding	Not specified	Reduced access block, reduced ED boarding, improved surge capacity	Santos et al. (2026)
	Bed management initiatives	Centralised coordination of inpatient bed allocation and patient transfer	Lean Six Sigma	Reduced boarding time, improved inpatient bed utilisation, reduced ED congestion	Santos et al. (2026)

Overall, the literature demonstrates that interventions to improve ED patient flow are highly heterogeneous and predominantly concentrated within the throughput phase of care. While many interventions have reported improvements in operational indicators such as waiting time, length of stay, boarding duration, and rates of patients leaving without being seen, findings across studies remain variable and strongly influenced by organisational context, implementation strategies, and broader system constraints. Importantly, many interventions are implemented as discrete operational initiatives targeting specific bottlenecks rather than as components of an integrated system-wide redesign. Consequently, improvements achieved in one aspect of patient flow may not be sustained and may inadvertently shift inefficiencies elsewhere within the care pathway.

Furthermore, although several interventions reflect principles consistent with Continuous Quality Improvement (CQI), relatively few studies explicitly report the use of formal CQI methodologies to guide intervention design, implementation, and evaluation. This highlights the need for structured, process-oriented approaches capable of systematically analysing interconnected workflows, reducing inefficiencies, and supporting continuous improvement across the ED patient journey.

Among the various CQI methodologies, Lean has emerged as one of the most widely applied process-focused approaches in healthcare. The following section introduces the Lean concept, then delves into the tools and applications of Lean within healthcare and emergency care settings.

2.4 THE LEAN CONCEPT

Lean is a management philosophy originating from the Toyota Production System (TPS), which was developed within the Japanese automotive industry following the Second World War. Initially conceptualised by Taiichi Ohno and colleagues at Toyota, Lean emerged as a systematic approach to improving productivity, quality, and organisational efficiency through the elimination of waste and the optimisation of process flow (Womack & Jones 1997). Although first applied within manufacturing,

Lean has since evolved into a broader organisational philosophy that has been adopted across multiple industries, including construction, finance, insurance, public administration, and healthcare (Lima et al. 2021).

A central component of Lean philosophy is the systematic identification and reduction of inefficiencies within organisational processes. Within the Toyota Production System, inefficiencies are commonly conceptualised through three interrelated concepts: *muda* (waste), *mura* (unevenness or variability), and *muri* (overburden). *Muda* refers to activities that consume resources without adding value from the customer's perspective, *mura* describes inconsistencies or fluctuations in workflow, while *muri* refers to excessive strain placed on workers, equipment, or systems. Collectively, these conditions contribute to process inefficiency, delays, reduced quality, and operational instability.

The elimination of *muda* has become the most widely recognised aspect of Lean thinking. Ohno originally identified seven forms of waste within organisational processes: transportation, inventory, unnecessary motion, waiting, over-processing, overproduction, and defects, with subsequent adaptations also recognising the underutilisation of human potential as an additional form of waste (Womack & Jones 1997). In service environments, these forms of waste may manifest as delays, duplication of work, excessive movement, process variation, errors, inefficient communication, and underutilisation of staff capabilities. However, Lean extends beyond waste elimination alone, as reducing variability (*mura*) and preventing overburden (*muri*) are equally important for achieving stable, efficient, and sustainable processes.

Womack and Jones (1997) conceptualised an operational framework of Lean thinking through five principles: specifying value, identifying the value stream, creating continuous flow, establishing pull, and pursuing perfection. Value refers to activities or outcomes that directly meet customer needs, whereas the value stream encompasses all processes required to deliver a product or service. Continuous flow seeks to minimise interruptions, delays, and bottlenecks within processes, while pull systems aim to align production or service delivery with actual demand rather than forecasted demand. The

pursuit of perfection reflects Lean's emphasis on continuous improvement and the ongoing elimination of inefficiencies. These principles support the systematic redesign of workflows to improve efficiency, quality, responsiveness, and value creation.

Unlike approaches that rely primarily on episodic quality control or top-down managerial directives, Lean emphasises continuous improvement embedded within everyday work practices. Over time, Lean has evolved beyond a set of operational tools into a broader systems-oriented approach to organisational management. Contemporary literature increasingly describes Lean as an integrated philosophy encompassing organisational culture, leadership, teamwork, continuous learning, and customer-centred process improvement rather than merely a collection of technical methods (Nawanir & Fauzi 2025). Nevertheless, the conceptualisation of Lean remains heterogeneous within the literature, with some authors viewing it primarily as a process improvement methodology, while others regard it as a broader organisational philosophy or umbrella concept encompassing multiple theories and practices (Åhlström et al. 2021).

The adaptability of Lean across different sectors is largely attributable to its process-oriented focus and emphasis on value creation, efficiency, and continuous improvement. In complex service systems characterised by high demand variability, multiple interdependent processes, and constrained resources, Lean provides a structured approach for analysing workflows, reducing inefficiencies, and improving operational performance. These characteristics have contributed to increasing interest in the application of Lean within healthcare settings, particularly in environments such as emergency departments where patient flow, timeliness, and coordination of care are critical determinants of service quality and organisational performance. The following section examines the emergence and application of Lean within healthcare systems.

2.5 LEAN IN HEALTHCARE

The transfer of Lean from manufacturing into healthcare emerged during the late 1990s and early 2000s, driven by increasing pressures on healthcare systems to improve efficiency, quality, patient safety, and cost-effectiveness (Cohen 2018; D'Andreamatteo et al. 2015). Early applications of Lean in healthcare were first reported in the United

Kingdom and the United States, where healthcare institutions and policy bodies began adapting industrial process-improvement methodologies to clinical and administrative settings (Antony et al. 2019). Organisations such as the Institute for Healthcare Improvement (IHI) in the United States and the National Health Service (NHS) Modernisation Agency in the United Kingdom promoted Lean as a means of improving patient flow, reducing inefficiencies, and supporting continuous quality improvement within increasingly resource-constrained health systems (D'Andreamatteo et al. 2015). Early healthcare applications primarily focused on operational and administrative processes, including appointment scheduling, patient discharge, inventory management, and laboratory workflows, before gradually expanding into more complex clinical environments such as surgical services, intensive care units, and emergency departments (Daultani et al. 2015).

2.5.1 Lean applications

Following its introduction into healthcare systems, Lean has been applied across a wide range of clinical and operational settings to improve efficiency, patient flow, quality of care, and resource utilisation. Existing studies report Lean applications in outpatient services, inpatient care, operating theatres, pharmacy services, diagnostic workflows, and emergency departments. However, substantial variation exists in the scope, implementation approaches, and evaluation of Lean interventions across healthcare settings. This subsection reviews Lean applications within healthcare at both the global and Malaysian levels, with particular attention to emergency department patient flow, implementation approaches, and gaps within the current evidence base.

a. Global

Globally, Lean has been increasingly adopted within healthcare systems as a strategy for improving organisational processes and patient flow. The growing body of Lean healthcare literature demonstrates substantial expansion in Lean applications since the early 2000s, particularly within hospital-based settings (Antony et al. 2019; D'Andreamatteo et al. 2015; Lima et al. 2021; Nawanir & Fauzi 2025; Souza et al. 2021; Tlapa et al. 2020). Across the literature, Lean interventions have predominantly focused on reducing delays, eliminating non-value-added activities, streamlining

workflows, and improving operational efficiency within clinical and administrative processes. Reported applications frequently target patient flow challenges, including prolonged waiting times, delays in care processes, overcrowding, and inefficient resource utilisation (Tlapa et al. 2020).

One of the most widely cited examples is the organisation-wide Lean transformation implemented at Virginia Mason Medical Center in the United States. The hospital created the Virginia Mason Production System, a holistic management model that had a strong impact on the quality of the services provided and led to reductions in lead time and decreases in operating costs (Kenny 2010). Similarly, Lean initiatives within the United Kingdom National Health Service (NHS) focused on improving patient flow, reducing waiting times, and redesigning care delivery processes across outpatient, inpatient, and discharge services (Radnor et al. 2012). Beyond organisation-wide transformation efforts, Lean has also been applied within specific healthcare service areas, including perioperative services, outpatient clinics, pharmacy systems, and laboratory workflows (Lima et al. 2021). For example, studies have reported Lean applications in operating theatres to improve theatre turnaround time and scheduling efficiency (Fletcher et al. 2017), while outpatient and ambulatory care studies frequently focused reducing wait times and improving patient throughput (Breen et al. 2020; Kenny et al. 2024; Mazzocato et al. 2012).

These examples illustrate the diversity of Lean applications within healthcare, encompassing both organisation-wide transformation initiatives and targeted service-level improvements across multiple clinical and operational settings. Selected examples of Lean implementation and reported impacts in healthcare organisations are summarised in Table 2.6.

Table 2.6 Examples of Lean implementations in healthcare

Organisation	Methodology	Impact
Scotland Cancer Treatment	Lean	Customer waiting times for first appointment from an average of 23 days to 12 days, and improvements of customer flow time for patients of 48%.

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Royal Bolton Hospital	Bolton Improving Care Systems (Lean)	Direct savings of £3.1m. Death rate for patients fell by a third. The time taken to process important categories of blood fell from 2 days to 2 hours. Average turnaround time in pathology from 24 hours to 2-3 hours.
Nebraska Medical Centre	Lean principles to redesign the work area in the sterile processing centre and in the clinical laboratories	Reduced staff walking by 167 miles a year. Reduced lab space by 825 sq ft and specimen processing turnaround time by 20%. Reduced manpower by 11 Full-Time Equivalents (FTEs), who were redirected to other critical work. Average length of stay decreased from 6.29 days to 5.27 days.
The Pittsburgh General Hospital	Lean techniques	Change to the procedure for intravenous line insertion, giving a 90% drop in the number of infections after just 90 days. Savings of almost $500,000 a year in intensive care unit costs.
Flinders Medical Centre	Lean thinking	20% more work, fewer safety incidents, same budget, same infrastructure, staff and technology.

Within the diversity of healthcare settings in which Lean has been implemented, emergency departments have emerged as one of the most extensively studied environments for Lean application globally (Bittencourt et al. 2020; Bucci et al. 2016; Lima et al. 2021; Manincheddа et al. 2023; Souza et al. 2021; Tiso et al. 2020). This reflects the operational complexity of EDs, where overcrowding, prolonged waiting times, access block, and increasing patient demand create persistent pressures on patient flow and service delivery. Consequently, Lean has been widely adopted within emergency care as a process-oriented improvement approach aimed at identifying inefficiencies, reducing non-value-adding activities, and optimising patient movement across different stages of care.

Across the literature, Lean interventions within EDs have targeted multiple components of the patient journey, including triage processes, patient streaming, rapid assessment pathways, diagnostic workflows, discharge coordination, and transitions between care areas. Implementation strategies frequently involved process mapping, workflow redesign, standardisation of work processes, and multidisciplinary collaboration to improve throughput efficiency and reduce delays in care delivery. While some studies focused on specific operational bottlenecks, others adopted broader department-wide redesign approaches involving multiple stages of patient flow and

coordination across clinical teams. Selected examples of Lean implementation within emergency departments globally are summarised in Table 2.7.

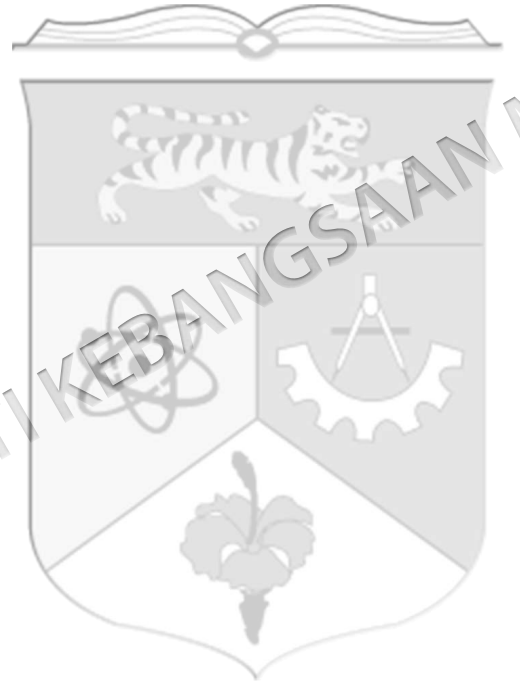

Table 2.7 Examples of Lean implementation in emergency departments

Author(s) (Year)	Country	Study Design	Study Objective	Improvement Process	Outcome
Dickson et al. (2009)	USA	Before-and-after analysis	To evaluate whether the adoption of Lean principles by an Emergency Department (ED) improves the value of emergency care delivered.	Six-step process of Lean education, ED observation, patient flow analysis, process redesign, new process testing, and full implementation.	Patient visits increased by 9.23% in 2006. Despite this increase, LOS decreased slightly and patient satisfaction increased significantly without raising the inflation adjusted cost per patient.
Naik et al. (2012)	USA	Before and after study	To outline a systematic way that Lean principles can be applied across the entire ED patient experience to transform a high-volume ED in a safety net hospital, and review the change in ED performance metrics prior to and after Lean implementation.	Rapid Improvement Events (RIEs)	Median login to disposition time (time from first registration to time of disposition order placement) declined from 4.6 hr (IQR 25%,75%, 4.5–4.9) in period 1 to 4.0 hr (3.7–4.1) in period 2. Median login to triage time (time from first registration to time of triage data entry completion) decrease over the two time periods from 0.6 hr (0.5–0.7) to 0.3 hr (0.2–0.3). Median login to provider time (time from first registration to provider assignment) decreased from 2.1 hr (1.5–2.1) in period 1 to 1.6hr (1.5–1.8) in period 2. Provider productivity (patients per hour) improved by 18.8%.

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White et al. (2014)	USA	Prospective, controlled, before-and-after analysis	To examine the effects of a Lean-based reorganization of Fast Track process flow on length of stay (LOS), percent of patients discharged within one hour, and room use, without added expense.	Reorganization of patient flow through existing rooms, based in systems engineering science and modeling, including queuing theory, demand-capacity matching, and Lean methodologies.	Median LOS among discharged patients was reduced by 15 minutes (158 to 143 min, 95%CI 12 to 19 min, p<0.0001). The number of patients discharged in <1 hr increased by 2.8% (from 6.9% to 9.7%, 95%CI 2.1% to 3.5%, p<0.0001), and median exam room time decreased by 34 minutes (90 to 56 min, 95%CI 31 to 38 min, p<0.0001). In comparison, the control group had no change in LOS (265 to 267 min) or proportion of patients discharged in <1 hr (2.9% to 2.9%), and an increase in exam room time (28 to 36 min, p<0.0001).
Chan et al. (2014)	Hong Kong	Quantitative, pre- and post-Lean design study	To (1) evaluate the current patient flow in emergency department, (2) identify and eliminate the non-value added process, and (3) modify the existing process.	Series of Lean management work, including a structured re-design process, priority admission triage (PAT) program, enhanced communication with medical department, and use of new high sensitivity troponin-T (hsTnT) blood test.	The most time-consuming processes were to wait for an admission bed (38.24 minutes; SD 66.35) and blood testing result (mean 52.73 minutes, SD 24.03). The admission waiting time of emergency medical ward (EMW) was significantly decreased from 54.76 minutes to 24.45 minutes after implementation of PAT program (P<0.05).

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Tejedor-Panchon et al. (2014)	Spain	Quasi-experimental pre-post study	To identify factors that cause delays and to implement Lean methods to reduce overall wait times, including interdepartmental consultations, in a complex tertiary level hospital emergency department.	VSM	Mean (95% CI) time spent in the examining areas by patients with the simplest emergencies was reduced from 80.4 (75.3-85.6) minutes to 61.6 (57.7-65.5) minutes (P<.001). Trauma case times were reduced from 137.8 (130.9-137.6) minutes to 123.8 (119.7-127.8) minutes (P=0.108). Mean (SD) delays until first contact with a physician were also reduced significantly (P<0.001) from 58.0 (6.3) minutes to 49.1 (3.7 minutes). The percentage of patients leaving before seeing a physician also decreased, from 2.8% (0.5%) to 2.0% (0.9%) (P<.001).
Vermeulen et al. (2014)	Canada	Retrospective cohort study with time series analyses of outcomes before and after the program and difference-in-differences analyses	To determine the effects of a process improvement program on ED wait times and quality of care.	Lean improvement opportunities in patient flow from arrival in the ED to discharge from inpatient units.	Decreases were observed in time to physician assessment, left-without-being-seen rates, and 72-hour ED revisit rates

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Beck et al. (2016)	USA	Retrospective before- and after study	To determine if a Lean intervention improved emergency department (ED) throughput and reduced ED boarding by improving patient discharge efficiency from a tertiary care children's hospital.	Team staffing reconfiguration permitted all discharge work to be done at the patient's bedside using a new discharge checklist, afternoon interdisciplinary huddle to work on the following day's discharges	For the general paediatrics service line, the median discharge order entry time decreased from 1:43pm to 11:28am ($p < 0.0001$) and the median time of discharge decreased from 3:25pm to 2:25pm ($p < 0.0001$). The percent of patients discharged before noon increased from 14.0% to 26.0% ($p < 0.0001$). The discharge metrics remained unchanged for the paediatric subspecialty services group. Median ED boarding time decreased by 49 minutes ($p < 0.0001$). As a result, the median time of day admitted patients were discharged from the ED was advanced from 5 PM to 4 PM.
Allaudeen et al. (2017)	USA	Prospective quality improvement initiative	To evaluate a Lean-based initiative to reduce ED LOS for medicine admissions.	Lean-based multidisciplinary initiative beginning with a rapid process improvement workshop to evaluate current processes, identify root causes of delays, and develop countermeasures. Frontline staff developed standard work for each phase of the ED stay. Units developed a daily management system to reinforce, evaluate, and refine standard work.	ED LOS for medicine admissions reduced 26.4%, from 8.7 to 6.4 hours. Difference-in-differences analysis showed that ED LOS for combined medicine and surgical admissions decreased from 6.7 to 6.0 hours (−0.7 hours, $P = .003$) at the intervention site compared with no change (5.6 hours, $P = .2$) at the control sites.

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Hitti et al. (2017)	Lebanon	Before and after study	To assess the impact of a Lean-driven intervention on transportation turnaround time for plain radiography in an ED at a tertiary care center.	VSM, Kaizen, Kanban (the use of informatics to develop pull systems)	Statistically significant decrease in the mean transportation TAT (mean ± SD: 9.87 min ± 15.05 versus 22.89 min ± 22.05, respectively, *p*-value <0.0001). In addition, it was found that 71.6% of patients in the post-intervention had transportation TAT ≤ 10 min, as compared to 32.3% in the pre-intervention period, *p*-value <0.0001, with narrower interquartile ranges in the post-intervention period. Similarly, the "study processing to preliminary report time" and the length of stay were lower in the post-intervention as compared to the pre-intervention, (52.50 min ± 35.43 versus 54.04 min ± 34.72, *p*-value = 0.02 and 3.65 h ± 5.17 versus 4.57 h ± 10.43, $p < 0.0001$, respectively), in spite of an increase in the time it took to release a preliminary report in the post-intervention period.
Elamir (2018)	Kuwait	Quantitative analytical applied research	To propose Lean-based interventions that address the main causes of emergency department overcrowding.	Patient flow improvement project consisting of effective triage using the Canadian Triage and Acuity Scale, fast track services and management of cold cases at primary healthcare centres, and acquisition of a new electronic Health Information System	12% of patients with LOS >6 hours consumed 32.6% of ED design capacity; 56.2% of LOS represented waiting waste, with inpatient bed delays accounting for 52% of wasted time. Findings informed Lean-based interventions targeting patient flow and overcrowding.

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Sánchez et al. (2018)	Spain	Prospective interventional study	To apply Lean thinking in triage acuity level-3 patients in order to improve emergency department (ED) throughput and waiting time.	Lean techniques such as value stream mapping, workplace organization, reduction of wastes and standardization by the frontline staff	Significant reductions in process time of discharged (182 vs 160 min, $P < 0.001$) and transferred to observation (186 vs 176 min, $P < 0.001$) patients, in length of stay (389 vs 329 min, $P < 0.001$), and in waiting time (71 vs 48 min, $P < 0.001$) were achieved after Lean implementation. No significant differences were registered in left without being seen rate (5.23% vs 4.95%), 72-h revisit rate (3.41% vs 3.93%), and mortality rate (0.23% vs 0.15%).
Improta et al. (2018)	Italy	Qualitative analysis to understand process flow; quantitative analysis of waiting time indicators	To apply Lean thinking to the ED with the aim of increasing patient flow, improving processes that contribute to facilitating patient flow through various stages, and eliminating all bottlenecks and activities that generate waste.	Value stream mapping	Positive increase in the performance of the ED, quantified as percentages of hospitalized patients according to triage codes and waiting times.

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Vashi et al. (2019)	USA	Quasi-experimental pre-post study	To (1) describe the extent and depth to which Lean methodologies are used of the use of Lean methodologies to rapidly redesign ED front-end operations that aimed at reducing waiting times to be seen by a provider and (2) evaluate if the intervention achieved its stated aim using quasi-experimental controls and a difference-in-differences approach.	VSM, VSM analysis event, "Door to Door" Rapid Process Improvement Workshop	"Door to Doctor" time at VAPAHCS decreased 12.6 minutes after the intervention, compared to 3.7 minutes in the control sites. Regression-adjusted difference-in-differences estimates for "Door to Doctor" time and "Door to Triage" time showed a significant reduction at VAPAHCS compared with control sites (8.9 minutes and 5.0 minutes, respectively), during the same time period (standard error = 3.5 min; p = 0.01 and standard error = 1.7 min; p = 0.004, respectively). Regression-adjusted difference-in-differences estimates for LWBS rates showed that LWBS did not significantly change at VAPAHCS compared with control sites (0.1% vs. 0.3%, p = 0.8).
Le et al. (2022)	Vietnam	Quantitative study with pre- post- Lean design	To evaluate the current patient flow in EDs, identify and eliminate non-value-added components, and modify the existing process in order to improve waiting times.	VSM, re-design process focusing on prioritising blood tests and ultrasound procedures, streamlining communication with medical departments, using QR codes for healthcare insurance payments, and efficient management of X-ray and CT scan online results	Pre-operative test results (for patients requiring medical procedures/operations) reduced by 33.3% (from 134.4 minutes to 89.4 minutes), vascular interventions by 10.4% (from 54.6 minutes to 48.9 minutes), and admission to other hospital departments by 49.5% (from 118.3 minutes to 59.8 minutes). Satisfaction with ED services rose from 22.9% to 76.5%.

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Kenny et al. (2024)	USA	Retrospective before-and-after analysis	To increase throughput in a fast-track care area without changing staffing in a busy, urban emergency department.	Lean-based throughput model; VSM	Decline in the patient's overall length of stay (-9%, p=0.08), arrival to the room (-10%, p=0.4418), and ED attending to disposition (-9%, p=0.003). Additionally, all aspects of patients leaving prior to treatment completion (against medical advice (-29.4%, p=0.006), elopement (-20.4%, p=0.049), and left without being seen (-5.3%, p=0.11)) declined.

Collectively, the literature demonstrates substantial heterogeneity in how Lean has been operationalised within emergency care settings. While several studies adopted broad department-wide redesign approaches involving multiple stages of the patient journey, others focused on specific operational bottlenecks such as triage flow, radiology turnaround time, fast-track services, or discharge processes. Similarly, implementation strategies varied considerably across settings, ranging from rapid improvement events and workflow restructuring to more comprehensive multidisciplinary transformation initiatives. Despite these differences, a recurring focus across studies was the optimisation of patient flow processes through reduction of delays, streamlining of workflows, and improved coordination of care activities.

However, despite increasing sophistication in Lean implementation approaches, many studies appeared to conceptualise the emergency department as a relatively unified operational environment. Comparatively limited attention was directed towards the variability of patient flow processes across different functional zones, acuity categories, and clinical pathways within the ED itself. Consequently, interventions were frequently implemented at the broader departmental level without detailed differentiation of workflow patterns, operational bottlenecks, and resource requirements across specific patient streams. Given that patient flow processes within emergency departments are heterogeneous, interventions that do not adequately account for these differences may have variable effectiveness across operational areas.

These limitations may be particularly relevant within complex public university hospital settings, where emergency department operations are influenced by multiple interacting clinical, educational, organisational, and resource-related demands. In such settings, patient flow processes may differ substantially across functional areas and levels of patient acuity, requiring more context-sensitive approaches to process improvement. These observations highlight the need for Lean implementation approaches that are informed by detailed process analysis and a clearer understanding of workflow variability across different operational areas within the emergency department.

b. Malaysian scenario

In Malaysia, Lean healthcare has gained increasing prominence over the past decade, particularly following Ministry of Health (MOH) initiatives aimed at strengthening healthcare efficiency, reducing waiting times, and improving service delivery within resource-constrained public health systems. Institutional programmes such as MyLean introduced Lean principles into healthcare organisations and facilitated broader awareness of continuous quality improvement methodologies across Malaysian public hospitals and healthcare services. Concurrently, the Malaysian Lean healthcare literature has expanded to encompass studies examining organisational performance, implementation challenges, sustainability, staff perceptions, operational efficiency, and service-level process improvement (Anuar et al. 2018; Lum et al. 2023; Noris et al. 2022; Ong et al. 2023).

However, compared with the broader international literature, Malaysian Lean healthcare research appears relatively fragmented and remains at a comparatively earlier stage of implementation maturity. While global studies increasingly describe multidisciplinary, end-to-end redesign of patient flow processes across complex healthcare systems and emergency care environments, Malaysian studies more commonly report isolated operational improvement initiatives targeting discrete service bottlenecks.

To better understand the current landscape of Lean implementation within Malaysia, a thematic mapping of the identified literature was conducted. The thematic distribution of studies (Abdul Hamid et al. 2016; Ahmed et al. 2019; Anuar et al. 2017, 2018; Beh et al. 2025; Choudhury & Lee 2024; Lee et al. 2025; Mohamad Jamil et al. 2024; Naufal Adnan et al. 2023; Pan et al. 2023; Saad et al. 2019; Selim Ahmed et al. 2023, 2024; Lum et al. 2024, 2026) according to healthcare setting and implementation depth is illustrated in Figure 2.3.

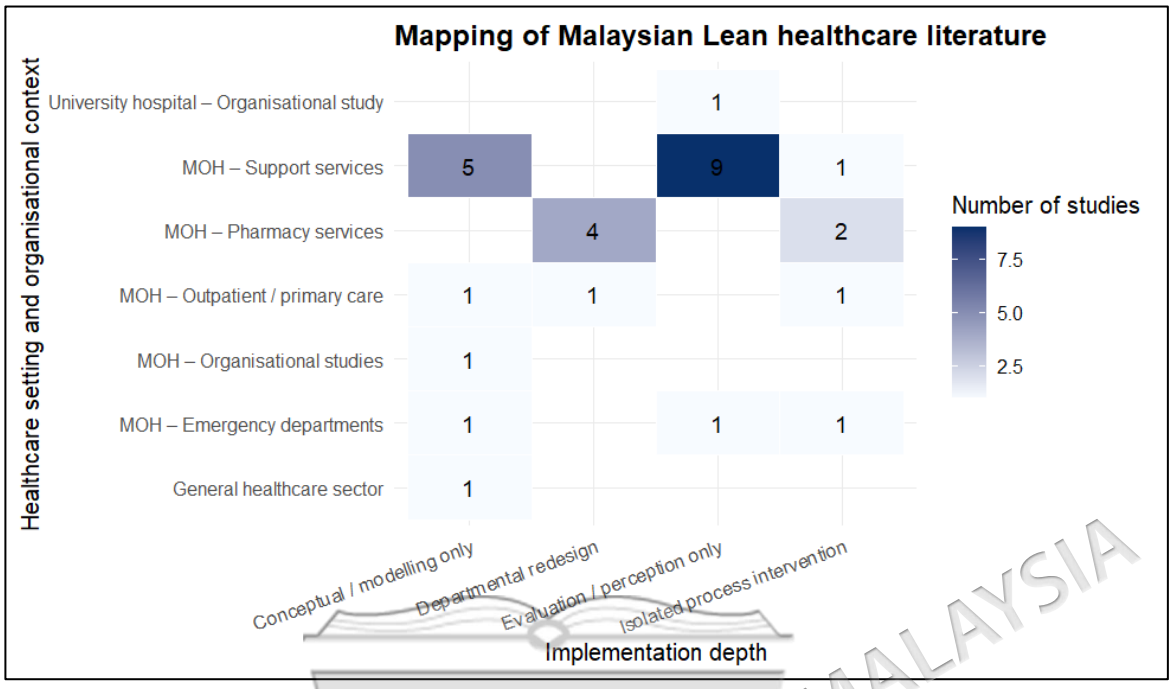

Figure 2.3 Mapping of Malaysian Lean Healthcare literature

The thematic mapping demonstrates that Malaysian Lean healthcare literature is concentrated predominantly within MOH operational settings, particularly pharmacy and support services. There was also a substantial proportion of broader organisation-focused studies examining Lean sustainability (Anuar et al. 2017, 2018; Naufal Adnan et al. 2023; Lum et al. 2024, 2026), implementation readiness (Selim Ahmed et al. 2023, 2024), and staff perceptions (Mohamad Jamil et al. 2024) rather than actual operational redesign processes. Many of these studies were conducted within MOH hospitals (Beh et al. 2025; Choudhury & Lee 2024; Lee et al. 2025; Mohamad Jamil et al. 2024; Pan et al. 2023) or in private hospital settings (Abdul Hamid et al. 2016; Ahmed et al. 2019; Anuar et al. 2017, 2018; Saad et al. 2019; Selim Ahmed et al. 2023). Although these studies provide valuable insights into organisational factors influencing Lean implementation, they offer comparatively limited operational detail regarding how Lean interventions are systematically designed, implemented, and evaluated within complex clinical workflows.

To further examine how Lean principles have been operationalised within Malaysian healthcare settings, the identified studies were reviewed according to healthcare setting, implementation objectives, Lean focus, tools employed, implementation depth, reported outcomes, and relevance to emergency care and

university hospital environments. This synthesis also highlights the extent to which existing studies address end-to-end process redesign and identifies persisting evidence gaps relevant to the present research. The findings are summarised in Table 2.8.

Table 2.8 Characteristics and evidence gaps of Lean Healthcare implementation studies in Malaysia

Author (Year)	Literature Type	Healthcare Setting	Objective	Lean Tools	Implementation Depth	Outcome (if available)	Research Gap
Abdul Aziz et al. (2022)	Case study	Emergency department / interhospital transfer workflow	To analyse the timeliness of step-up care interhospital patient transfer workflow within Hospital Kluster Perak Utara.	Not mentioned	Isolated process intervention	Duration of review time (RTR) accounted for 59.5% of workflow time; multidisciplinary referrals and ED procedures increased patient length of stay and staff length of stay; suggested bypassing ED for selected stable patients.	Focused on interhospital transfer workflow rather than comprehensive ED redesign; limited to one workflow segment; no detailed pre-implementation needs analysis; no zone-specific ED workflow differentiation.

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Abdul Hanif et al. (2023)	Empirical implementation study	Pharmacy service (ambulatory pharmacy)	To improve waiting time and HPIA performance in the ambulatory pharmacy of Hospital Sultan Abdul Halim.	Lean Healthcare; Value Stream Mapping (VSM); Kaizen bursts; Fishbone Diagram; e-VSM	Isolated process intervention	Identified 19 value-added and 29 non-value-added activities pre-intervention; implemented 22 kaizen bursts involving process restructuring, workforce empowerment and equipment enhancement; HPIA improved from 57.12% (August 2022) to 72.26% (December 2022), reaching 80.80% by June 2023; lead times for prescription workflows reduced substantially	Focused on a single operational service area; intervention targeted waiting-time bottlenecks within pharmacy workflow rather than integrated hospital-wide patient flow; limited discussion of broader organisational integration or pre-implementation contextual assessment.

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Abu Bakar et al. (2019)	Case study	Hospital support service / healthcare IT application	To develop a Specimen Labelling System to reduce time taken by medical staff to write patient information on sticker label and to reduce time taken by medical personnel to write specimen details on the specimen delivery.	Agile, PDSA, *Gemba*, analysis of existing workflow	Isolated process intervention	System helps reduce time taken to complete patients details from 45 minutes to 5 minutes; time taken to write and print specimen details in specimen delivery report are reduced from 20 minutes to 3.5 minutes; in Specimen Labelling, task completion time is reduced by 88.9% and in Specimen Dispatch Report, task completion is decreased by 82.5%.	Focused on implementation support rather than comprehensive Lean redesign; limited operational workflow analysis.

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Ahmad et al. (2021)	Case study	Outpatient department	To implement Lean Kaizen techniques towards reducing waiting time at an outpatient department in one of the public healthcare centres in Kedah.	Simulation only using arena simulation software to simulate the modelled process.	Total average processing time for each patient through all the processes reduced by 7.21 minutes (15.20%); can lead to increase in number of patients in and out in daily operations at the outpatient department.	Limited workflow differentiation; simulation-focused operational optimisation within a single service process; no broader organisational or multidisciplinary ED flow redesign; limited contextual needs analysis prior to intervention design.

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Muhammad et al. (2024)	Case study	Outpatient pharmacy	To outline the Lean management approach employed to decrease waiting times at the hospital's outpatient pharmacy and illustrate its effect on patient and employee satisfaction.	VSM, DOWNTIME waste identification, 5 whys, Root Cause Analysis (RCA), Kaizen burst (continuous improvement activities), and prioritization	Unit redesign	standardize the medication dispensing process, streamlined the initial 7 stages identified in VSM to 3 stages after implementing Kaizen bursts. the total number of processes from 13 steps were reduced to 6 steps. Kaizen bursts also optimized workforce allocation, reducing the number of personnel needed from 6 to 1. Significant improvements in medication dispensing process total process times reduced from 7.05 minutes to 4.0 minutes, non-value-added wait times shortened from 69.05 minutes to just 0.9 minutes, and waste effectively eliminated from 30 wastes to just 4. 97% of patients rating the waiting time quality as excellent.	No detailed needs analysis; limited workflow differentiation; focused on operational improvement within a single service area; non-ED setting.

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Jaafar et al. (2024)	Empirical implementation study / case study	Hospital support service (document management)	To analyze the current process of patient document management in healthcare; to develop a model for an improved document management process, and to conceptualize a system model for enhancing healthcare document management.	VSM, "as-is" diagram	Not implemented; only projected results from proposed improvements	Reduces time clinicians spend waiting for patient records; enables real-time, simultaneous access to patient info by multiple HCP, expected that 90–95% will use the system to retrieve patient history information (projected increase in efficiency); potential reduction in LOS (and cost of care) and improved patient satisfaction; improved patient flow.	Focused on narrow administrative workflow; no patient flow redesign; no implementation of intervention.
Wan Muhd Riduan et al. (2024)	Conference abstract	Primary care / fever clinic	To reduce patient lead time at fever tent service.	Kaizen	Isolated process intervention	14 out of 35 (40%) waste identified and eliminated from patient's arrival at fever counter until pharmacy counter; reductions in lead time, distance, steps, waiting time from 150min to 75min (50%), from 320m to 180m (43%), from 680 steps to 270 steps (60%) and from 90min to 38min (57%).	Localised service-level intervention; limited implementation detail.

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Lau et al. (2021)	Quasi-experimental study	Outpatient oncology/radiotherapy clinic	to determine the impact of Lean initiatives on reducing patient waiting times at the oncology outpatient clinic.	VSM, Kaizen, Fishbone diagram	Departmental redesign	Pre-intervention, 48.13% of patients waited >45 mins for consultation. Post-intervention, waiting time significantly lower (z=2.865; p=0.004).	Focused on outpatient operational flow; no broader system integration; limited contextual process differentiation.
Lum et al. (2024)	Qualitative study	MOH hospitals	To explore factors affecting sustainability of Lean within Ministry of Health hospitals.	Lean sustainability framework	Evaluation/perception only	Ten primary themes: 1) fostering Lean expertise through capacity building, 2) Lean implementation approaches and processes, 3) monitoring and evaluation of Lean with performance indicators, 4) encouraging positive behavioural change among HCPs in Lean, 5) disseminating Lean findings, 6) establishing policy for Lean, 7) incentivising Lean practices, 8) leadership in Lean practices, 9) building and strengthening organisational capacity and 10) Lean values	Sustainability-focused rather than implementation-focused; no operational redesign or patient flow analysis.

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Pan et al. (2023)	Case study	Pharmacy service / inpatient discharge medication workflow	To reduce waiting time for receiving discharge medications and to reduce the number of patients waiting at the discharge counter.	VSM, Kaizen burst analysis	Isolated process intervention	Pre-Lean data shows the mean patient waiting time was 16.65 ± 9.40 minutes. The ward pharmacist took 5.25 ± 6.59 minutes to complete an intervention, as compared to 9.61 ± 8.71 minutes at the discharge counter. Post-Lean analysis revealed significant waste elimination with a mean of 6.29 ± 7.15 minutes, approximately 10.36 minutes shorter patient waiting time. To ensure the sustainability of the improvements, regular monitoring of the bedside dispensing targets and continuous monitoring of patient waiting time to ensure seamless intervention, hence reducing patient waiting time.	Narrow service-level intervention; focused on single discharge workflow rather than integrated patient flow redesign.

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Lee et al. (2025)	Quality improvement project	Outpatient pharmacy	To reduce patient waiting time and achieve HPIA target at outpatient pharmacy.	Lean management; Value Stream Mapping (VSM); Spaghetti diagram; Ishikawa diagram; Kaizen bursts	Departmental redesign	Mean prescriptions dispensed within 30 minutes increased to 90.2%; lead time reduced from 75.5 to 45 minutes (without counselling) and from 111.5 to 80 minutes (with counselling); sustained achievement of 95% KPI from March–May 2024.	Focused on pharmacy workflow redesign within a single service area; limited broader organisational integration; no differentiation of patient-flow complexity beyond dispensing workflow.
Beh et al. (2025)	Quality improvement project	Outpatient pharmacy	To improve dispensing efficiency and achieve MOH waiting-time target.	Lean management; Value Stream Mapping (VSM); *Gemba* Walk; Kaizen strategies	Departmental redesign	Prescriptions dispensed within 30 minutes exceeded 95%; waiting time reduced from 29m55s to 18m05s; efficiency improved from 34.24% to 35.80%.	Focused on outpatient pharmacy dispensing process; operational redesign limited to departmental workflow; limited discussion of broader healthcare system integration.

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Choudhury & Lee (2024)	Quality improvement project	Outpatient pharmacy	To increase the percentage of prescriptions dispensed within 30 minutes to 95%, in line with the Ministry of Health (MOH) Core Customer Charter.	Cycle 1 introduced a SMART counter and additional dispensing counter with streamlined workflow; Cycle 2 optimised task distribution, queue categories and colour-coded baskets; and Cycle 3 reorganised the workspace, rationalised quota item management and promoted Value-Added Services (VAS).	Departmental redesign	The percentage of prescriptions dispensed within 30 minutes increased from 62.88% at baseline to 71.16% (Cycle 1), 76.30% (Cycle 2) and 93.87% (Cycle 3), achieving the 95% target in April (96.67%) and May 2023 (95.45%). Average waiting time for 400 prescriptions fell from 140 to 27 minutes, while achievable benefit not achieved (ABNA) decreased from 32.12% to 1.13%. Patient and staff satisfaction for waiting time improved by 59.8% and 66.8%, respectively.	Focused on outpatient pharmacy dispensing process; operational redesign limited to departmental workflow; limited discussion of broader healthcare system integration.

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Tiong et al. (2020)	Retrospective observational study	Public hospital Eds	To assess the efficiency among Lean public emergency departments (ED) through Slack-Based Measure Data Envelopment Analysis (SBM-DEA) and evaluate the impact of Lean on the efficiency in public emergency departments.	NA	Modelling only, no actual intervention	A total of 13 out of 20 public EDs exhibited improvement in arrival to consultant and length of stay upon Lean implementation. However, only 9 out of the 13 public EDs have had an improvement in efficiency score.	Evaluated outcomes of existing Lean initiatives rather than describing detailed implementation processes; limited description of actual workflow redesign or needs assessment.

Among studies reporting actual Lean implementation, the literature appears heavily concentrated within outpatient and pharmacy service settings. Multiple studies described initiatives aimed at reducing outpatient pharmacy waiting time, improving dispensing efficiency, streamlining workflow processes, and eliminating non-value-adding activities through approaches such as value stream mapping, Kaizen activities, process restructuring, and workforce reorganisation (Abdul Hanif et al. 2023; Beh et al. 2025; Choudhury & Lee 2024; Lee et al. 2025). Other implementation studies focused on highly specific operational workflows, including specimen handling activities (Abu Bakar et al. 2017), discharge medication systems, radiotherapy clinic waiting time (Lau et al. 2021), fever clinic lead time (Wan Muhd Riduan et al. 2024), and document management processes (Jaafar et al. 2024). While many of these studies reported improvements in waiting time, turnaround time, and workflow efficiency following Lean implementation, the interventions generally remained localised within individual service areas rather than involving broader multidisciplinary redesign across the patient care continuum.

This pattern contrasts with the broader international Lean healthcare literature, where Lean implementation has progressively evolved towards multidisciplinary and end-to-end redesign of patient flow across complex acute care systems, particularly within emergency departments. Comparatively limited attention has been directed towards understanding how workflow variation, patient complexity, multidisciplinary coordination, and local organisational context influence Lean implementation within emergency care environments.

An additional observation emerging from the thematic mapping is the increasing emphasis on Lean sustainability and organisational performance within the Malaysian literature despite comparatively limited evidence describing rigorous implementation and evaluation of comprehensive Lean interventions themselves. Several studies examined sustainability frameworks, organisational readiness, implementation factors, and staff perceptions of Lean adoption (Adnan et al. 2023; Anuar et al. 2017, 2018; Krishnan et al. 2024; Lum et al. 2024). However, sustainability within Lean systems is inherently dependent on robust implementation processes, context-sensitive redesign,

continuous evaluation, and integration within organisational workflows. The relative scarcity of detailed implementation studies within complex clinical environments therefore raises important questions regarding how Lean interventions are operationalised, embedded, and sustained within Malaysian healthcare settings.

Furthermore, emergency department-related Lean literature within Malaysia remains sparse and fragmented. Existing ED studies were primarily limited to efficiency evaluations (Ahmad et al. 2021), staff perceptions of Lean adoption (Mohamad Jamil et al. 2024), or isolated workflow components such as interhospital transfer processes, rather than comprehensive redesign of ED patient flow systems. Although some studies reported improvements in operational performance indicators following Lean implementation, detailed descriptions of implementation processes, contextual needs assessment, multidisciplinary workflow analysis, and differentiated redesign across ED care zones were often limited. In addition, many implementation studies utilised relatively small-scale pre–post evaluations or observational approaches, with limited longitudinal assessment of sustainability and organisational impact. More rigorous evaluation designs, including interrupted time-series analysis and comprehensive system-level assessment, were largely absent within the identified literature.

This gap is particularly notable within university hospital settings, where healthcare delivery is further shaped by academic, teaching, and training responsibilities in addition to clinical service demands. Among the identified studies, only one study involving a university hospital environment was identified, and this focused primarily on organisational and leadership aspects of Lean rather than describing specific operational Lean implementation within the clinical setting (Ong et al. 2023). Consequently, there remains very limited evidence describing how Lean can be operationalised and evaluated within public university hospital emergency departments characterised by complex multidisciplinary workflows, high patient volumes, and overlapping service and educational functions.

One notable contribution within the Malaysian literature is the Lean Healthcare implementation framework proposed by Noris (2022), which outlined a staged implementation approach involving Lean awareness training, value stream mapping,

Kaizen activities, onsite consultation, implementation monitoring, and performance reporting. The framework, illustrated in Figure 2.4, reflects institutional efforts to operationalise Lean implementation systematically within Malaysian public hospitals and highlights the growing emphasis on organisational readiness and structured Lean deployment.

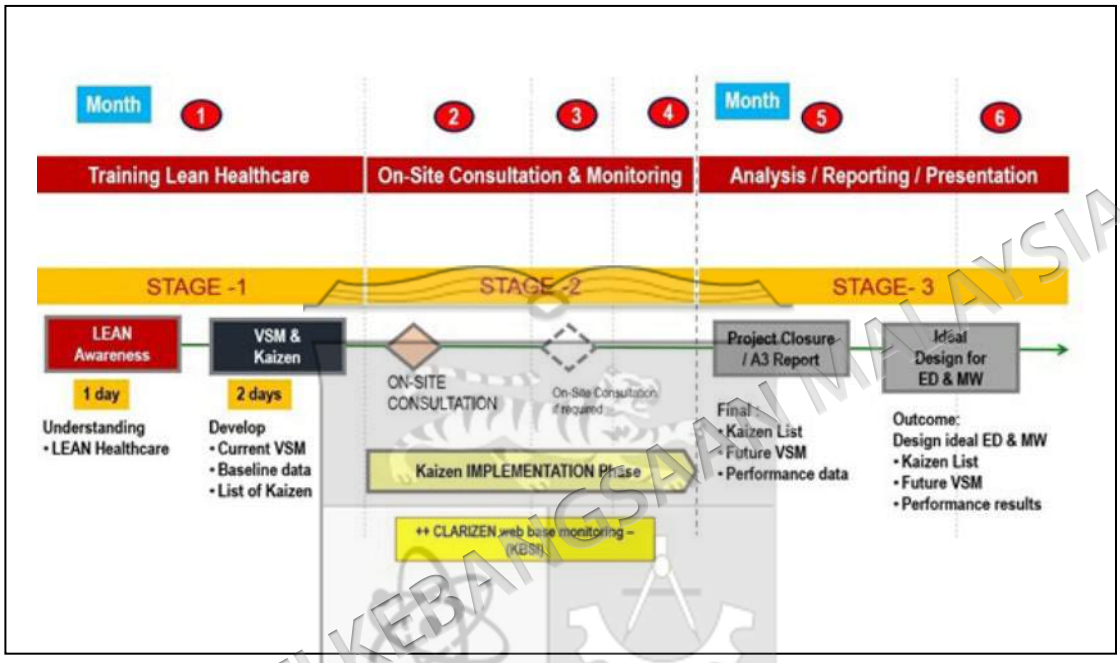

Figure 2.4 Lean Healthcare framework implementation in Ministry of Health (MOH) hospitals

Source: Noris et al. (2022)

However, the framework primarily emphasises general Lean implementation processes and organisational training activities, with limited attention directed towards detailed contextual needs assessment, differentiated workflow analysis, and adaptation to varying operational demands across specific clinical environments such as emergency departments. This observation is particularly relevant within complex healthcare settings where patient flow dynamics, service variability, and multidisciplinary interactions differ substantially across care zones and patient categories.

Nevertheless, the framework provides a useful foundational structure for understanding staged Lean implementation within Malaysian healthcare settings and offers important contextual insights that inform the development of the present study's

conceptual framework. The current study, therefore, seeks to extend these existing approaches by incorporating more detailed process analysis and context-sensitive assessment within the emergency department environment.

Overall, the Malaysian literature suggests that while Lean healthcare has gained increasing institutional and academic attention, existing applications remain predominantly operationally localised and fragmented across service areas. There remains limited evidence describing comprehensive, context-sensitive Lean implementation informed by detailed process analysis and rigorous operational evaluation within complex emergency department environments. These gaps highlight the need for more integrated approaches to Lean implementation within Malaysian public university hospital EDs, particularly approaches that incorporate detailed needs assessment, differentiated workflow analysis, multidisciplinary engagement, and evaluation of both operational and financial outcomes.

2.5.2 Lean tools

Lean implementation within healthcare is supported by a wide range of tools and techniques intended to analyse processes, identify inefficiencies, redesign workflows, and sustain continuous improvement. Across the literature, these tools have been applied within diverse healthcare environments, including emergency departments, outpatient clinics, pharmacy services, perioperative settings, inpatient wards, and administrative systems (Costa & Godinho Filho 2016; D'Andreamatteo et al. 2015; Rotter et al. 2017).

However, there has been substantial variation in how Lean tools are selected, combined, and operationalised across healthcare settings. Increasingly, Lean is understood not as the application of isolated technical instruments, but as a broader implementation system involving process redesign, multidisciplinary collaboration, organisational learning, and continuous improvement activities (Lima et al. 2021; Shortell et al. 2021; Talero-Sarmiento et al. 2024; Tiso et al. 2021). This broader conceptualisation is also reflected within the Malaysian Ministry of Health (MOH) Lean Healthcare programme, which emphasises Lean as both a management philosophy

and organisational improvement system rather than merely a collection of operational tools (Zaiton et al. 2018).

At the same time, the literature suggests that no fixed or universally accepted Lean toolkit exists within healthcare (Hirvelä et al. 2024). Different organisations employ different combinations of tools according to local operational priorities, workflow complexity, organisational readiness, implementation maturity, and service-specific demands. Furthermore, considerable overlap exists between many Lean tools, with several techniques serving complementary or interconnected functions across process assessment, root cause identification, workflow redesign, implementation, and monitoring activities (Costa & Godinho Filho 2016; de Barros et al. 2022; Isfahani et al. 2018; Lima et al. 2021). As a result, Lean implementation within healthcare rarely follows a single standardised sequence, with tools frequently integrated and adapted according to project requirements.

For the purpose of conceptual clarity within healthcare implementation, Lean tools discussed across the literature may be functionally grouped according to their primary role within the implementation process, adapted from existing classifications described by Lima et al. (2021), de Barros et al. (2021), and related healthcare Lean literature. The functional grouping used in the present review is shown in Table 2.9.

Table 2.9 Proposed grouping of Lean tools described in the literature

Functional role	Purpose	Lean tools
Process assessment and workflow visualisation	Understand current-state processes, visualise patient and information flow, identify inefficiencies and bottlenecks	Go to *Gemba*, Process mapping, Process redesign, SIPOC (Suppliers–Inputs–Process–Outputs–Customer), Spaghetti diagram, VSM (Value Stream Mapping), Statistical process control, Wastes analysis, ABC analysis, OEE (Overall Equipment Effectiveness), Simulation/systems approach
Root cause identification and operational analysis	Identify contributors to delays, variation, waste, defects, and operational inefficiencies	Five Whys, Ishikawa diagram (fishbone/cause-and-effect diagram), Risk analysis (Failure Mode and Effect Analysis), Kobetsu, Wastes analysis, Statistical process control, ABC analysis

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Workflow redesign and implementation	Redesign workflows, improve operational flow, reduce waste, standardise work, and support multidisciplinary improvement activities	Continuous flow, Heijunka (levelling), Just-in-Time, Kanban, One-piece-flow/Pull system, Quick changeovers (SMED), Takt time, Work cells, Workload balancing, Kaizen/Rapid Improvement Events, 5S, Jidoka, Poka-yoke (mistake-proofing), Physical work setting redesign, Standardised work, Teamwork, Multidisciplinary task training, Visual management, Daily meetings/rounds, Continuous improvement teams
Prioritisation and decision support	Support prioritisation of interventions, strategic alignment, and improvement planning	Hoshin Kanri, Voice of Business (VOB), Voice of Customer (VOC), Critical to Quality (CTQ), Project management, Theory of Constraints, Lean Six Sigma, SCRUM
Monitoring, evaluation, and sustainability	Monitor implementation progress, evaluate outcomes, sustain improvement, and support continuous organisational learning	PDCA/PDSA, KPI monitoring, A3 reports, Benchmarking, Total Productive Maintenance, Total Quality Management, Lean Six Sigma, Continuous improvement teams

While functional grouping helps provide conceptual clarity regarding the primary operational role of the multitude of Lean tools, the boundaries between categories are not rigid. Many tools perform overlapping functions and are frequently used across multiple stages of implementation. For example, Value Stream Mapping may simultaneously support workflow visualisation, operational diagnosis, redesign planning, and multidisciplinary engagement, and therefore be used in "isolation" (Alogla 2025; Gill 2012; Ingole & Sethia 2015; Jing et al. 2021; Marin-Garcia et al. 2021; Moraes et al. 2023), while monitoring approaches such as key performance indicator (KPI) dashboards and PDCA cycles may function both as evaluation mechanisms and as drivers of continuous improvement (Fonseca & de Medeiros 2026). Consequently, Lean implementation within healthcare often involves flexible integration of complementary tools rather than application of isolated techniques.

One of the clearest patterns emerging from the literature is the central role of process visualisation and workflow analysis within Lean healthcare implementation. Tools such as Value Stream Mapping (VSM), process mapping, SIPOC analysis, spaghetti diagrams, and *Gemba* walks are repeatedly used to make patient movement, delays, duplication, and non-value-adding activities visible within complex healthcare systems (Henrique et al. 2016; Nowak et al. 2017; Zdęba-Mozoła et al. 2023). Within

emergency departments, these tools have been applied to examine triage systems, patient streaming pathways, diagnostic processes, admission delays, discharge workflows, and transitions between care areas (Bal et al. 2017; Dickson et al. 2009; Holden 2011). Cohen (2018) further emphasised that *Gemba* observations and current-state value stream mapping enable improvement teams to "learn to see" operational waste directly within real-world clinical environments, supporting the development of future-state redesign strategies grounded in frontline workflow realities (Cohen 2018). The literature also demonstrates that workflow analysis is frequently accompanied by tools intended to identify the underlying causes of inefficiency and process variation. Fishbone diagrams, Pareto analysis, and the 5 Whys method are commonly used to examine organisational, environmental, staffing, communication, and procedural contributors to delays within healthcare processes (Costa & Godinho Filho 2016; Lima et al. 2021).

Beyond process analysis, many studies describe Lean implementation as an ongoing cycle of workflow redesign and operational adaptation (Flug et al. 2022; Yuliati & Andriani 2021). Within this process, Kaizen represents a central mechanism for continuous improvement by enabling frontline staff and multidisciplinary teams to translate identified workflow problems into practical, incremental changes. Rather than functioning as an isolated tool, Kaizen is commonly embedded within broader Lean activities such as process mapping, Rapid Improvement Events (RIEs), standardisation of work, visual management, workload balancing and 5S, thereby linking problem identification with collaborative redesign and implementation (Abuzied 2022; Mazzocato et al. 2016; Harry et al. 2025). Its emphasis on staff participation is particularly relevant in healthcare, where operational problems are often context-specific and require experiential knowledge from those directly involved in care delivery. However, evidence also suggests that Kaizen activities may be more readily applied to relatively simple operational problems than to complex clinical processes, and that implementation and sustainability can be limited when improvement ideas are not supported by systematic testing, monitoring and objective process data (Mazzocato et al. 2016; Samara & Harry 2025). Within emergency department settings, such redesign initiatives may involve modification of patient streaming pathways, rapid assessment processes, queue management systems, communication structures, and

coordination between different stages of emergency care delivery (Bucci et al. 2016; Holden 2011; Kenny et al. 2024; White et al. 2014).

Recent literature further suggests that Lean redesign efforts increasingly involve broader implementation structures incorporating organisational engagement, implementation facilitation, monitoring systems, and sustainability planning (Hirvelä et al. 2024; Krishnan et al. 2024). Approaches such as Plan–Do–Check–Act (PDCA) or Plan–Do–Study–Act (PDSA) cycles, key performance indicators (KPIs), visual dashboards, audit systems, and implementation monitoring frameworks are frequently used to evaluate implementation progress and sustain operational improvements over time. In Malaysia, the importance of organisational capacity building, Lean champions, leadership engagement, implementation monitoring, and performance evaluation in supporting Lean sustainability is frequently highlighted within MOH hospitals (Lum et al. 2024). The MOH Lean Healthcare Operational Sustainability Guideline further positions Lean tools within a broader PDCA-based implementation cycle involving project initiation, process understanding, redesign, piloting, implementation, monitoring, and sustainability activities (Medical Development Division 2023).

Having established that Lean implementation within healthcare depends less on the isolated application of individual tools and more on complementary approaches integrated according to operational needs, the rationale underlying tool selection and implementation often remains insufficiently articulated. Many studies provide limited explanation regarding how particular tools were chosen, how interventions were adapted to workflow complexity, or how implementation strategies responded to contextual variation within clinical environments. This lack of implementation transparency represents an important limitation within the Lean healthcare literature. As a result, successful outcomes are often reported without a clear understanding of the intervention logic linking identified workflow challenges to the chosen Lean strategies, thereby limiting the reproducibility, transferability, and practical applicability of findings across healthcare settings. Consequently, despite increasing use of integrated Lean approaches, the implementation process itself frequently remains insufficiently theorised and operationally fragmented (Tiso et al. 2021).

This limitation is particularly relevant within emergency departments, where patient flow is dynamic, multidisciplinary, and operationally heterogeneous across different care zones, acuity levels, staffing arrangements, and interdepartmental dependencies. In such environments, the effectiveness of Lean interventions is likely to depend on a detailed understanding of local workflow conditions and the systematic alignment of improvement tools with identified operational needs (Morello et al. 2013; Tiso et al. 2021). However, relatively little guidance exists within the current literature regarding how this alignment should be achieved, highlighting the need for more structured and context-sensitive approaches to Lean intervention design and development.

2.6 INDICATORS FOR LEAN IN HEALTHCARE SETTINGS

Evaluation of Lean implementation within healthcare has evolved considerably over the past two decades. Early Lean healthcare studies primarily focused on operational performance outcomes such as reductions in waiting time, turnaround time, and patient length of stay, particularly within high-volume clinical environments where delays and inefficiencies were most visible (D'Andreamatteo et al. 2015; Souza et al. 2021). Over time, however, the scope of Lean evaluation has broadened substantially to encompass indicators relating to productivity, quality and safety, organisational culture, staff and patient experience, and financial performance (Akmal et al. 2020; Lima et al. 2021; Reponen et al. 2021).

Lean evaluation indicators may be broadly grouped into several domains, including indicators of time and patient flow, efficiency and productivity, quality and safety, satisfaction and organisational culture, and financial or resource utilisation. Time and flow-related measures remain among the most frequently reported outcomes and commonly include waiting time, turnaround time, consultation delays, cycle time, and length of stay (Akmal et al. 2020; Souza et al. 2021). These measures primarily evaluate delays and patient movement across different stages of care delivery. In contrast, operational efficiency indicators focus more broadly on system performance and resource utilisation, including service capacity, workload balancing, process standardisation, and bottleneck management, while quality and safety indicators

evaluate outcomes such as reduction in errors, complaints, and operational defects (Reponen et al. 2021). In parallel, increasing attention has also been directed towards organisational culture, teamwork, staff satisfaction, communication, and patient experience, reflecting the growing recognition that Lean implementation involves both technical and behavioural dimensions of organisational change (Hammoudeh et al. 2021; Tlapa et al. 2020; Tlapa, Franco-Alucano, et al. 2022; Zepeda-Lugo et al. 2020).

More recently, financial and resource-related indicators have emerged with greater prominence within Lean healthcare literature, including assessments of operational costs, resource utilisation, inventory reduction, and organisational efficiency (Narayanan et al. 2022; Sales Coll et al. 2024; Wang et al. 2025). Nevertheless, compared with operational flow indicators, financial evaluation remains comparatively inconsistent and less systematically reported across healthcare Lean studies.

Lima et al. (2021) conducted an aggregated analysis of Lean healthcare outcomes and demonstrated that improvements reported across the literature could be synthesised into several recurring domains involving operational efficiency, quality improvement, organisational performance, and patient-centred outcomes. The common indicators used to evaluate Lean implementation within healthcare settings are summarised in Table 2.10.

Table 2.10 Common indicators used to evaluate Lean implementation in the healthcare setting

Improvement	Indicators
Time gains	Reduction in lead time Reduction of patient waiting time Improvement of cycle time Improvement of hospitalisation time Reduction of waiting lists
Reductions	Reduction of errors Identification and reduction of waste Reduction of stocks Reorganisation of physical space Reduction of costs

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Organizational culture	Improved organisational culture Increased team spirit and communication Employee and supplier satisfaction Improved workload for nurses Reduced overtime
Efficiency & productivity	Efficiency and productivity gains Bottleneck identification Improved patient flow Improved information flow Capacity levelling
Quality & safety	Positive impact on quality and safety indicators Reduced number of complaints Increased customer (patient) satisfaction

Despite the increasing breadth of Lean evaluation domains reported within healthcare literature, operational and patient flow indicators continue to dominate outcome measurement within emergency department settings, where overcrowding, delays in care, and throughput inefficiencies remain major operational concerns. Consequently, Lean emergency department studies have largely focused on evaluating indicators directly related to patient flow performance, particularly waiting time, access to clinical assessment, and emergency department length of stay.

2.6.1 Operational indicators in Lean emergency department studies

Within emergency department settings, Lean evaluation has been dominated by operational indicators that measure delays, throughput, and patient movement across the care pathway. This emphasis is unsurprising, as ED overcrowding is experienced operationally through prolonged waiting, delayed clinical assessment, diagnostic bottlenecks, access block, and extended length of stay. Consequently, Lean ED studies commonly assess time-based indicators such as arrival-to- time to consultation, turnaround time, discharge time, and total ED length of stay. Although these indicators are labelled differently across studies, they generally reflect distinct stages of patient flow: front-end intake, access to clinical assessment, internal throughput, and exit from the ED.

However, the literature also demonstrates considerable heterogeneity in both indicator selection and evaluation methodology. Many studies use simple pre–post comparisons (Mazzocato et al. 2012; Murrell 2011; Naik et al. 2012), while fewer employ stronger quasi-experimental approaches capable of accounting for baseline trends, temporal variation, and secular changes (Sun et al. 2017; Tejedor-Panchon et al. 2014; Van Der Linden et al. 2023; Vashi et al. 2019). This methodological variation is important because reported improvements in waiting time or LOS may reflect the Lean intervention, but may also be influenced by staffing, demand, seasonal variation, policy changes, or concurrent hospital initiatives. Therefore, synthesising operational indicators alongside study methodology is necessary to understand not only what outcomes were measured, but also how robustly Lean effects were evaluated. A summary of the operational indicators and methodologies used to evaluate Lean interventions in emergency departments is presented in Table 2.11.

Table 2.11 Summary of operational indicators and methodologies used for outcome evaluation in Lean emergency department studies

Author(s) (Year)	Methodology	Operational indicator(s) measured	Results
Dickson et al. (2009)	Before-and-after/cross-sectional evaluation	ED LOS, patient volume	LOS reduced across multiple EDs despite increasing patient volume; total LOS decreased by approximately 3% overall, while patient visits increased by 9.23%.
Neimeier et al. (2010)	Before-and-after study	Length of stay	Trauma patient LOS reduced from 10.4 to 8.5 days following Lean implementation.
Ng et al. (2010)	Before-and-after study	Registration-to-physician time, ED LOS, patients leaving without being seen (LWBS), patient satisfaction	Registration-to-physician time decreased from 111 to 78 minutes; LOS for discharged patients reduced from 3.6 to 2.8 hours; LWBS reduced from 7.1% to 4.3%; patient satisfaction improved.
Murrell et al. (2011)	Before-and-after study	ED LOS, arrival-to-physician start time, LWBS	Mean arrival-to-physician start time reduced from 62.2 to 41.9 minutes; LWBS reduced from 4.5% to 1.5%; ED LOS improved after Rapid Triage and Treatment implementation.

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Naik et al. (2012)	Before-and-after study	Median ED patient visits, login-to-triage time, login-to-disposition time, provider productivity	ED patient visits increased by 7.3%; median login-to-disposition time decreased from 4.6 to 4.0 hours; login-to-triage time decreased from 0.6 to 0.3 hours; provider productivity improved by 18.8%.
Mazzocato et al. (2012)	Before-and-after study	Waiting time, lead time	Waiting and lead times improved by 19–24%.
Vermeulen et al. (2014)	Controlled before-and-after study	Median ED LOS, 90th percentile ED LOS, time to physician assessment	Both median and 90th percentile ED LOS and time to physician assessment improved after intervention, although effects varied across sites.
White et al. (2014)	Controlled before-and-after study	Percentage discharged within one hour, exam room time, LOS	Patients discharged within one hour increased by 2.8%; median exam room time decreased by 34 minutes; median LOS for discharged patients reduced by 15 minutes.
Breen et al. (2015)	Before-and-after quality improvement study	Waiting time, LOS, patient throughput	Lean implementation improved patient flow and reduced ED congestion.
El Sayed et al. (2015)	Before-and-after study	Door-to-doctor time, ED LOS	Significant reduction in door-to-doctor time; LOS for discharged patients reduced from 2.6 to 2.0 hours and for admitted patients from 9.0 to 5.5 hours.
Kane et al. (2015)	Before-and-after study	Waiting time, LOS, patient throughput, patient satisfaction	Reduced waiting time and LOS with improvements in throughput and patient satisfaction.
Zocchi et al. (2015)	Multicentre collaborative quality improvement study	Throughput measures, ED LOS	Improvements in ED throughput were observed across participating hospitals.
Beck et al. (2016)	Before-and-after study	Patient discharge time, ED throughput, congestion indicators	Lean intervention improved discharge times and reduced ED congestion.
Allaudeen et al. (2017)	Before-and-after study	ED LOS for medicine admissions	Reduced ED LOS among admitted medicine patients following Lean intervention.
Hitti et al. (2017)	Before-and-after study	Radiology transport turnaround time	Significant reduction in radiology transportation and diagnostic delays.
Falconer et al. (2018)	Quality improvement intervention	Time to triage, timely vital sign assessment	Improved timeliness of triage vital sign completion in lower-acuity patients.

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Elamir et al. (2018)	Before-and-after study	Patient flow indicators, waiting time	Lean concepts improved patient flow processes in the ED.
Vashi et al. (2018)	Before-and-after study	Wait time, LOS	Lean principles reduced waiting times within a Veterans Affairs ED.
Kumar et al. (2019)	Before-and-after quality improvement study	Waiting time to triage	Reduced triage waiting time in a tertiary ED following process redesign.
Shen et al. (2020)	Quality improvement / before-and-after study	Waiting time to triage	Significant improvement in triage waiting time following intervention.
Stahley et al. (2020)	Before-and-after operational intervention	Throughput measures, boarding, ED flow metrics	Bed traffic control and flow redesign improved throughput performance.
Williams et al. (2022)	Quality improvement study	Fast-track patient LOS	Nurse standard work reduced LOS within ED fast-track area.
Hammer et al. (2022)	Hospital-wide flow improvement initiative	ED crowding, boarding, throughput	Enhanced hospital-wide patient flow reduced ED crowding and boarding.
Ravi et al. (2023)	Before-and-after implementation study	ED LOS, patient satisfaction	Integrated consult order reduced LOS and improved user satisfaction.
Payne et al. (2023)	Time-in-motion observational study	Factors contributing to ED LOS	Identified operational contributors to prolonged LOS across ED processes.
Van der Linden et al. (2023)	Interrupted time-series analysis	ED crowding and throughput measures	Process changes demonstrated measurable temporal effects on ED crowding and flow.
Squires et al. (2023)	Simulation/modelling study	ED LOS	Reduction in low-acuity attendance projected to reduce ED LOS.
Hussein et al. (2025)	Before-and-after Lean intervention study	Waiting time, patient satisfaction, staff satisfaction	Lean nursing workflow redesign reduced waiting time and improved satisfaction outcomes.

Lean ED studies consistently prioritise time-based operational indicators, particularly measures related to waiting time, access to clinical assessment, throughput, and emergency department length of stay (LOS). These indicators correspond directly to the core mechanisms through which Lean is expected to improve ED performance, namely reducing non-value-adding delays, streamlining patient movement, improving access to decision-making, and alleviating overcrowding. Across the literature, indicators such as door-to-doctor time, arrival-to-provider time, arrival-to-consultation

time, consultation delay, turnaround time, and LOS are frequently used as proxies for different stages of patient flow within the emergency care pathway. However, despite their conceptual similarities, considerable variation exists in how these indicators are operationally defined and measured across studies, limiting direct comparison between Lean interventions implemented in different settings.

Beyond variation in indicators, substantial methodological heterogeneity also exists within Lean ED evaluation studies. Most studies employ relatively simple before-and-after or retrospective observational designs, with comparatively fewer studies utilising controlled or longitudinal quasi-experimental approaches. Although many studies report improvements following Lean implementation, these designs often inadequately account for underlying temporal trends, seasonal variation, fluctuations in patient volume, staffing changes, organisational restructuring, or concurrent operational initiatives occurring within the ED environment. Consequently, improvements observed following Lean implementation may not necessarily be attributable solely to the intervention itself, but may also reflect broader operational changes occurring over time.

Importantly, comparatively few Lean ED studies have utilised interrupted time series (ITS) analysis despite increasing recognition of ITS as one of the strongest quasi-experimental approaches for evaluating healthcare interventions when randomised designs are not feasible. Unlike simple pre–post comparisons, ITS analysis enables assessment of both immediate and sustained intervention effects while accounting for pre-existing trends and temporal variation within routinely collected operational data (Turner et al. 2020). Given the dynamic and complex nature of emergency department operations, such approaches may provide stronger evidence regarding the true effects of Lean implementation on ED performance.

Collectively, the literature suggests that while operational indicators are central to evaluating Lean within emergency care settings, methodological limitations continue to affect the strength of causal inference across many studies. Furthermore, although waiting time and LOS indicators are commonly reported, fewer studies evaluate operational performance across multiple interconnected stages of ED patient flow. This

is important because delays occurring during early throughput processes may propagate downstream and contribute cumulatively to prolonged LOS and overcrowding. Accordingly, the present study evaluates Lean implementation using operational indicators reflecting distinct but interconnected stages of ED throughput, namely triage-to-registration time (TTR), arrival-to-consultation time (ATC), and emergency department length of stay (LOS). Furthermore, interrupted time series analysis was employed to strengthen causal inference regarding the temporal effects of Lean implementation on ED operational performance.

2.6.2 Economic evaluation of Lean healthcare interventions

Although Lean implementation is frequently associated with improved efficiency and cost reduction within healthcare organisations, financial evaluation remains comparatively underdeveloped relative to operational outcome measurement. Across the literature, Lean interventions are commonly reported to improve resource utilisation, reduce waste, optimise staffing processes, and enhance operational efficiency. However, detailed economic evaluation methods are inconsistently described, and financial outcomes are frequently reported as broad organisational savings rather than structured analyses linked to specific workflow redesign interventions.

Early attempts to evaluate the economic impact of Lean healthcare interventions included the use of activity-based costing and cost–benefit analysis approaches. Dyas et al. (2015), for example, utilised Lean Thinking, Six Sigma, and statistical approaches to develop a simplified activity-based costing model capable of supporting process improvement evaluation within emergency department environments. The study demonstrated the potential utility of operational costing approaches for selecting, prioritising, and validating process improvement initiatives involving multiple clinical workflows and diagnostic pathways.

To further illustrate the diversity of financial evaluation approaches reported within the Lean healthcare literature, Table 2.12 summarises selected studies that have examined economic and financial outcomes associated with Lean implementation.

Table 2.12 Summary of studies reporting financial and economic outcomes associated with Lean implementation in healthcare settings

Author (Year)	Study setting	Methodology	Financial indicator(s)	Key findings
Dickson et al. (2009)	Emergency department	Before-and-after study	Patient volume, direct expense per patient,	Patient volume increased by 9.23%; 9% reduction in direct expense per patient
Dyas et al. (2015)	Emergency department	Activity-based costing / cost–benefit analysis	Process cost analysis	Simplified activity-based costing model supported prioritisation and validation of Lean projects
Sari et al. (2017)	Provincial healthcare system	Economic analysis	Lean implementation cost	Estimated implementation cost between CAD 44–49.6 million
Dobrzykowski & McFadden (2019)	Healthcare organisations	Review	Financial performance indicators	Financial evaluation inconsistently reported across Lean healthcare studies
Narayanan et al. (2020)	Hospital organisations	Quantitative financial performance analysis	Hospital financial performance indicators	Lean implementation was associated with improved hospital financial performance and operational efficiency outcomes.
Hammoudeh et al. (2021)	Healthcare settings	Systematic review	Cost reduction, resource utilisation	Financial outcomes variably defined and measured
Ayaad et al. (2022)	Hospital services	Organisational implementation study	Cost containment, time management, service quality	Lean management improved operational efficiency and supported cost containment initiatives within healthcare services.
Sales Coll et al. (2024)	Surgical process / perioperative services	Economic impact evaluation	Surgical process costs, efficiency outcomes	Lean implementation demonstrated positive economic impact through improved surgical process efficiency and resource utilisation.
Kotte (2025)	Manufacturing / organisational performance context	Financial performance study	Cost reduction strategies, financial performance	Lean implementation associated with improved cost reduction and financial performance strategies, though not healthcare-specific.

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Wang et al. (2025)	Hospitals (systematic review)	Systematic review	Efficiency, quality, cost, satisfaction outcomes	Review reported that Lean implementation was commonly associated with efficiency gains and cost reduction, although costing methodologies varied substantially across studies.

These studies demonstrate growing interest in the economic implications of Lean implementation while also revealing the absence of consistent approaches for measuring and reporting financial outcomes. While many studies report improvements in efficiency, cost containment, or resource utilisation following Lean implementation (Ayaad et al. 2022; Narayanan et al. 2022). Detailed economic evaluation methodologies are inconsistently described and often poorly integrated with operational performance outcomes. Furthermore, financial indicators vary considerably across studies, ranging from broad organisational implementation costs and hospital financial performance measures to more localised indicators such as expense per patient or process-specific costing models. This heterogeneity limits comparability across studies and complicates the interpretation of the true economic impact of Lean interventions within healthcare settings.

An important observation emerging from the literature is that financial evaluation of Lean implementation has largely been conducted at aggregated organisational or programme levels rather than within specific clinical operational environments. Many studies evaluate hospital-wide efficiency gains, organisational cost reduction strategies, or implementation expenditures without directly linking financial outcomes to patient-flow redesign or operational workflow changes occurring within frontline clinical services. Even within studies conducted in emergency department settings, financial analysis remains relatively limited and typically focuses on broad indicators such as overall implementation cost rather than detailed operational costing linked to specific throughput processes.

In addition, methodological approaches used for financial evaluation remain comparatively heterogeneous and underdeveloped relative to operational outcome analysis. Several studies rely on descriptive organisational reporting or broad economic estimates, while relatively few utilise structured costing frameworks capable of evaluating temporal changes in operational resource utilisation following Lean implementation. Although approaches such as activity-based costing have been proposed to support Lean evaluation within emergency department environments (Dyas et al. 2015), no standardised framework for evaluating pre–post operational costs associated with Lean ED implementation was identified within the literature. This limitation is particularly relevant within emergency departments, where resource utilisation is dynamic, multidisciplinary, and operationally interconnected across multiple patient care zones.

Accordingly, the present study incorporates a partial economic evaluation alongside operational outcome assessment to explore the financial implications of Lean implementation within the emergency department setting. Given the complexity of shared resource utilisation across ED workflows, costing was evaluated at the broader departmental level using operational cost-per-hour and cost-per-patient-hour measures rather than being isolated exclusively to individual patient care zones. This approach allows assessment of whether operational improvements following Lean implementation are associated with measurable changes in ED resource utilisation while acknowledging the practical limitations of attributing costs to specific components of patient flow within a complex emergency care environment.

2.7 GAPS IN THE LITERATURE

The preceding review demonstrates that Lean has become a prominent CQI approach in healthcare, particularly because of its ability to address delays, waste, inefficient flow, and resource constraints. The literature demonstrates that Lean has evolved into one of the most widely utilised continuous quality improvement approaches within healthcare, particularly in emergency department settings where operational inefficiencies, prolonged waiting times, overcrowding, and fragmented patient flow remain persistent challenges. Internationally, Lean implementation has increasingly

progressed beyond isolated process improvement activities towards broader multidisciplinary workflow redesign involving integrated use of multiple Lean tools and organisational engagement strategies. Nevertheless, the maturity and depth of this literature remain uneven across settings and contexts.

Within the Malaysian healthcare context, Lean implementation literature remains comparatively limited and concentrated predominantly within Ministry of Health (MOH) hospitals, with many local studies focusing on pharmacy services, outpatient settings, or isolated departmental workflows. Furthermore, several local initiatives remain centred on relatively bounded process modifications or discrete quality improvement activities rather than broader end-to-end organisational redesign involving integrated patient-flow transformation across interconnected emergency care processes. Importantly, Lean implementation within Malaysian public university hospital settings remains particularly underrepresented. Existing studies involving university hospitals have focused on organisational perceptions, leadership dimensions, or conceptual discussions of Lean sustainability rather than detailed operational implementation and evaluation within emergency department environments.

A second gap concerns the implementation logic underlying Lean interventions. While contemporary Lean studies increasingly report the integrated use of multiple Lean tools, studies rarely provide an explicit conceptual or operational rationale explaining how specific tools were selected, sequenced, integrated, or adapted to local workflow complexity. This is particularly relevant within emergency departments, where patient flow involves dynamic interaction between triage systems, consultation processes, diagnostics, admissions, discharge pathways, staffing arrangements, and multidisciplinary coordination. Consequently, although Lean tools are often applied in combination, the implementation process itself frequently remains insufficiently theorised and operationally fragmented.

Methodological limitations also remain prominent within Lean healthcare evaluation studies. Most Lean emergency department studies rely on relatively simple pre–post or retrospective observational designs, with comparatively limited use of robust longitudinal quasi-experimental approaches capable of accounting for temporal

variation, secular trends, seasonal fluctuations, patient volume changes, and concurrent organisational interventions. The limited application of interrupted time-series analysis represents an important methodological gap within the current literature.

Similarly, financial evaluation remains comparatively underdeveloped within Lean emergency department research. While Lean implementation is frequently associated with improved efficiency, cost containment, and resource optimisation, financial outcomes are commonly reported at broad organisational levels or as generalised cost-saving claims rather than detailed operational costing linked directly to patient-flow redesign processes. Few studies integrate operational throughput outcomes with structured economic evaluation, and no consistent emergency department-specific costing framework for Lean implementation was identified within the literature.

Finally, while several studies address selected dimensions of Lean implementation, organisational change, operational redesign, or outcome evaluation, relatively few integrate these components within a single coherent framework. Furthermore, existing literature has focused predominantly on determining whether Lean improves performance, with comparatively less attention directed towards understanding how Lean interventions should be systematically designed, implemented, and evaluated within complex healthcare systems, or why improvements are observed in some operational outcomes but not others. Collectively, these gaps suggest the need for a more integrated and systematically developed Lean implementation model capable of combining organisational change principles, context-sensitive intervention design, multidisciplinary workflow redesign, robust longitudinal evaluation, and operational as well as financial outcome assessment within a university hospital emergency department setting. Such an approach may contribute not only to evaluating Lean effectiveness, but also to advancing understanding of the organisational conditions under which Lean interventions are most likely to succeed.

A summary of selected literature gaps addressed by the present study is presented in Table 2.13.

Table 2.13 Comparative assessment of selected Lean healthcare studies against the dimensions addressed by the present study

Study	ED-focused implementation	Malaysian context	Organisational redesign	Explicit tool integration/ rationale	Change management framework	Robust longitudinal evaluation	Financial evaluation	University hospital setting
Dickson et al. (2009)	✓	✗	✓	✗	✗	✗	Partial	✗
Naik et al. (2012)	✓	✗	✓	Partial	✗	✗	✗	✗
Vermeulen et al. (2014)	✓	✗	✓	✗	✗	Partial	✗	✗
Dyas et al. (2015)	✓	✗	✗	✗	✗	✗	✓	✗
Chan et al. (2014)	✓	✗	Partial	✗	✗	✗	✗	✗
Tiong et al. (2020)	✓	✓	✗	✗	✗	Partial	✗	✗
Harrison et al. (2021)	✗	✗	✗	✗	✓	✗	✗	✗
Noris et al. (2022)	✗	✓	✓	Partial	✓	✗	✗	✗
Lum et al. (2023)	✗	✓	✗	✗	Partial	✗	✗	✗
Present study	✓	✓	✓	✓	✓	✓	✓	✓

Overall, the literature demonstrates that while Lean has become an established CQI approach within healthcare, important conceptual, contextual, and methodological gaps remain within the current evidence base. Existing studies frequently evaluate isolated dimensions of Lean implementation without adequately integrating organisational change processes, context-sensitive tool selection, multidisciplinary workflow redesign, robust longitudinal evaluation, and financial assessment within a single implementation framework. These limitations are particularly evident within Malaysian emergency department literature, where implementation studies remain sparse, and university hospital settings are substantially underrepresented.

The present study addresses these gaps through the systematic design, development and evaluation of a Lean-based intervention model for a public university hospital emergency department. In addition, the study incorporates context-sensitive selection and integration of Lean tools, longitudinal operational evaluation using interrupted time-series analysis, and partial economic evaluation through operational cost analysis. Ultimately, the study seeks to provide a more comprehensive understanding of how Lean implementation may be operationalised, evaluated, and sustained within a complex emergency department environment

2.8 THEORIES RELATED TO LEAN IMPLEMENTATION

The increasing emphasis on healthcare quality, operational efficiency, patient-centredness, safety, and timely access to care has intensified the need for healthcare organisations to continuously adapt and transform their service delivery systems. When successfully implemented, Lean in healthcare has been associated with improvements in patient flow, waiting time, operational efficiency, resource utilisation, quality of care, patient satisfaction, and organisational productivity. Various frameworks have been developed to help organisations implement Lean (AlManei et al. 2018). However, many of these frameworks function primarily as operational roadmaps, prescribing sequences of Lean tools and improvement activities without adequately addressing the complexity of human factors necessary for implementation success. Importantly, the literature increasingly demonstrates that successful Lean implementation extends beyond the

technical application of improvement tools alone and is often accompanied by broader changes in organisational culture, leadership practices, staff engagement, communication, and the way organisations perceive and value work processes. As such, change management, broadly defined as the structured process of facilitating the transition of individuals, teams, or organisations from a current state towards a desired future-state while managing resistance and behavioural challenges associated with change, represents a central foundation underpinning successful Lean implementation within healthcare settings.

The application of change management theories to support implementation and improvement methodologies with healthcare settings has been increasingly explored. Harrison et al. identified twelve formal change management methodologies applied within healthcare contexts, with Kotter's Eight-Step Model and Lewin's Three-Step Model representing the most commonly utilised frameworks (Harrison et al. 2021). In this systematic review of the applications of change management models in healthcare, it was concluded that change management models are often valued because they provide flexible guiding principles capable of supporting organisational change within complex healthcare environments. The review further highlighted that successful healthcare change initiatives frequently involve strong clinician engagement, multidisciplinary participation, collaborative communication, supportive leadership, and enabling organisational culture. AlManei et al. (2018) emphasised that organisational change frameworks differ substantially in their focus, with some models addressing behavioural adaptation at the individual level while others emphasise broader organisational transformation, systems alignment, leadership processes, and institutional culture. Within Lean healthcare implementation, such distinctions are important because Lean interventions frequently extend beyond isolated changes in individual practice and require wider organisational coordination and engagement to sustain improvement efforts.

Given the complexity of Lean implementation within healthcare settings, several change management theories and implementation frameworks are relevant to understanding organisational transformation processes. These theories differ in their conceptualisation of change, primary level of focus, implementation orientation, and

applicability to healthcare improvement initiatives. A comparative overview of change management theories is presented in Table 2.14.

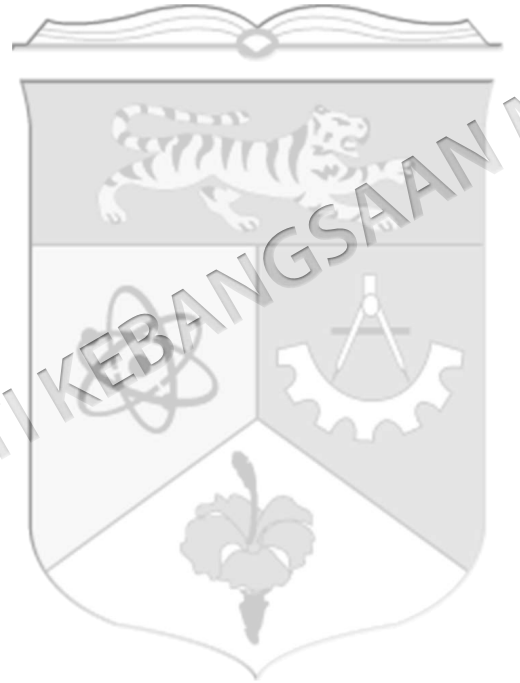

Table 2.14 Change Management Theories

Theory/ framework	Primary level of change	Focus/steps	Strengths	Limitations
Lewin's Three-Step Model	Organisational change	Unfreezing, changing, refreezing	Foundational and conceptually simple; useful for understanding organisational transition	Linear and relatively static, "refreezing" is less compatible with continuously evolving healthcare systems
Kotter's Eight-Step Model	Organisational and behavioural change	Urgency, coalition building, vision, communication, empowerment, short-term wins, institutionalisation	Strong emphasis on leadership, communication, multidisciplinary engagement, sustainability, and organisational culture	Sequential orientation may oversimplify dynamic healthcare environments; resource-intensive
ADKAR Model	Individual behavioural change	Awareness, desire, knowledge, ability, reinforcement	Strong focus on staff readiness, behavioural adaptation, and reinforcement	Less emphasis on organisational redesign and systems-level operational complexity
McKinsey 7S Framework	Organisational and systems change	Alignment of strategy, structure, systems, shared values, style, staff, and skills	Recognises organisational interdependence and systems alignment	Broad and less operationally prescriptive; limited implementation guidance
Normalisation Process Theory (NPT)	Practice integration and sustainability	Embedding new practices into routine work	Strong emphasis on sustainability and integration into clinical practice	Less explicit focus on leadership mobilisation and early implementation processes
Consolidated Framework for Implementation Research (CFIR)	Organisational and implementation context	Intervention characteristics, inner setting, outer setting, process, and individuals	Comprehensive contextual framework for implementation analysis	Complex and primarily diagnostic rather than operational
Theoretical Domains Framework (TDF)	Individual behavioural determinants	Behavioural influences on implementation	Useful for identifying behavioural barriers and enablers	Limited organisational and systems-level orientation

Among the theories reviewed, Kotter's 8-Step Process for Leading Change was considered the most appropriate framework for the present study because it provides a more comprehensive organisational approach to managing complex change within healthcare environments. While Lewin's Three-Step Model remains foundational in organisational change theory, Kotter's framework may be viewed as an extension and operational enhancement of Lewin's broader concepts of unfreezing, change, and refreezing (Kotter 2012). Kotter expanded these broad stages into a more detailed and actionable organisational process involving the creation of urgency, formation of guiding coalitions, development and communication of a shared vision, empowerment of action, generation of short-term wins, consolidation of gains, and anchoring of change within organisational culture (Kotter 2012). In doing so, the framework moves beyond conceptual transition alone and provides clearer guidance regarding how organisational transformation may be operationalised within complex systems.

Importantly, Kotter's model places strong emphasis on leadership engagement, multidisciplinary collaboration, communication, staff empowerment, and sustainability of change, all of which are consistently identified within the Lean healthcare literature as critical determinants of implementation success (Harrison et al. 2021; Kabirinaeini et al. 2023; Tiso et al. 2021). Unlike models focusing predominantly on individual behavioural adaptation, Kotter's framework conceptualises change primarily at the organisational level, recognising that successful transformation requires alignment between leadership structures, organisational culture, operational processes, and frontline engagement. This orientation is particularly relevant within Lean healthcare implementation, where improvements frequently require coordinated change across multiple professional groups, workflows, and operational systems rather than isolated modification of individual behaviours alone.

The strengths of Kotter's model within healthcare settings have been widely discussed in the literature. Harrison et al. (2021) noted that Kotter's framework was among the most frequently utilised change management models in healthcare and was commonly associated with initiatives involving large-scale organisational transformation, multidisciplinary engagement, and implementation of new models of

care. The model's emphasis on creating short-term wins is especially relevant within Lean implementation, where early operational improvements may strengthen staff motivation, reduce resistance to change, and build organisational momentum for sustained improvement efforts. Similarly, the emphasis on anchoring change within organisational culture aligns closely with Lean philosophy, which views continuous improvement not as a one-time intervention, but as an ongoing organisational practice embedded within daily work processes.

Nevertheless, Kotter's framework has also been criticised for presenting change as relatively sequential and linear despite the iterative and dynamic nature of healthcare systems (AlManei et al. 2018). Healthcare organisations, particularly emergency departments, operate within environments characterised by fluctuating demand, operational uncertainty, and continuously evolving priorities. Consequently, implementation processes may not always progress according to clearly defined stages. However, contemporary applications of Kotter's model increasingly recognise the need for flexible adaptation of the framework rather than rigid adherence to stepwise implementation sequences. Harrison et al. (2021) similarly concluded that change management theories are most valuable when used as flexible guiding frameworks capable of supporting implementation within complex healthcare systems rather than as prescriptive formulas for organisational change.

This flexibility is particularly important within the context of the present study. Lean implementation within the study setting involved a complex public university hospital emergency department characterised by multidisciplinary interaction, operational variability, workforce constraints, and longstanding workflow inefficiencies. The implementation process required organisational engagement through Lean Healthcare training, formation of a multidisciplinary Lean team, collaborative workflow mapping and *Gemba* observation, prioritisation of feasible interventions, implementation of operational redesign strategies, and continuous monitoring of outcome indicators. These processes align strongly with Kotter's emphasis on coalition building, communication, empowerment, short-term operational gains, and institutionalisation of change within organisational practice.

Accordingly, Kotter's 8-Step Process for Leading Change was selected as the primary theoretical framework guiding the present study. The framework provides a suitable organisational lens for understanding how Lean implementation may be introduced, operationalised, sustained, and embedded within a complex emergency department environment. Furthermore, its emphasis on leadership engagement, multidisciplinary collaboration, organisational culture, and sustainability aligns closely with both the philosophy of Lean healthcare and the operational realities of implementing change within public hospital systems.

2.9 CONCEPTUAL FRAMEWORK

The present study is guided by a conceptual framework integrating organisational change theory, structured Lean implementation processes, and evaluation of operational and financial outcomes within the emergency department setting. The framework was developed to reflect the multidimensional nature of Lean implementation in healthcare, recognising that successful Lean transformation requires not only the application of technical improvement tools but also organisational readiness, multidisciplinary engagement, implementation structure, and continuous evaluation of outcomes. The conceptual framework therefore synthesises three major components underpinning the study: (i) Kotter's 8-Step Process for Leading Change as the theoretical foundation for organisational change, (ii) the Ministry of Health (MOH) Lean Healthcare implementation framework as the structured implementation process guiding Lean activities, and (iii) the Design and Development Research (DDR) approach framing the overall study phases of needs analysis, design and development, and evaluation.

The theoretical foundation of the framework is based on Kotter's 8-Step Process for Leading Change, which conceptualises organisational change through the creation of urgency, engagement of stakeholders, empowerment of action, generation of short-term wins, and institutionalisation of change within organisational culture (Kotter 1996). As discussed in the preceding section, Kotter's model was selected because it provides a comprehensive organisational framework capable of supporting both behavioural adaptation and operational redesign within complex healthcare environments. The emphasis on leadership engagement, multidisciplinary

collaboration, communication, staff empowerment, and sustainability aligns closely with the operational realities of Lean implementation within emergency departments. Importantly, the model also provides a broader organisational lens through which Lean implementation can be understood not merely as a technical intervention, but as a process of organisational transformation involving multiple professional groups and interconnected workflows.

The second component of the conceptual framework involves the structured Lean Healthcare implementation framework developed for MOH hospitals. The framework operationalises Lean implementation through staged activities involving Lean awareness training, workflow visualisation through value stream mapping (VSM), Kaizen activities, consultation and monitoring processes, implementation of workflow redesign interventions, and project closure activities. While the MOH framework provides practical implementation structure and operational guidance for Lean activities, the present study conceptualises these implementation processes within the broader organisational change principles described by Kotter's model. In this regard, Lean awareness activities correspond to creating readiness and urgency for change, multidisciplinary engagement during VSM and Kaizen phases reflects coalition-building and communication processes, while implementation monitoring and project consolidation align with Kotter's emphasis on sustaining and institutionalising organisational change.

The framework is further situated within the Design and Development Research (DDR) approach guiding the methodological structure of the study. The DDR process involved three broad phases: needs analysis, design and development, and evaluation. The needs analysis phase involved identification of operational inefficiencies, workflow bottlenecks, and contextual factors affecting emergency department performance. This phase informed the subsequent design and development stage, where Lean interventions were collaboratively developed through multidisciplinary engagement, workflow mapping, *Gemba* observation, Kaizen activities, and prioritisation of feasible interventions. Finally, the evaluation phase assessed the effects of the Lean-based intervention model using selected operational and financial outcome indicators.

Within the conceptual framework, the Lean-based intervention model represents the independent variable of the study, while the operational and financial outcomes represent the dependent variables evaluated following implementation. Operational outcomes selected for evaluation included triage-to-registration time (TTR), arrival-to-consultation time (ATC), and emergency department length of stay (LOS), as these indicators reflect distinct but interconnected stages of emergency department patient flow. These indicators were selected based on the preceding literature synthesis demonstrating that time-based operational indicators remain the dominant measures used to evaluate Lean implementation within emergency department settings. In addition, the framework also acknowledges broader Lean outcome domains frequently reported within the literature, including patient safety, patient satisfaction, left-without-being-seen rates, and operational efficiency measures.

Financial evaluation was incorporated through partial economic analysis involving operational cost-per-patient and cost-per-patient-hour indicators at the broader emergency department level. This component reflects the growing recognition within Lean healthcare literature that operational improvements should ideally be examined alongside resource utilisation and financial implications, although formal economic evaluation within Lean emergency department studies remains comparatively underdeveloped.

Figure 2.5 illustrates the conceptual framework of the present study, demonstrating the integration of Kotter's organisational change principles, the MOH Lean Healthcare implementation framework, DDR methodological phases, and evaluation of operational and financial outcomes. Collectively, the framework conceptualises Lean implementation as a structured organisational change process involving iterative interaction between organisational readiness, multidisciplinary engagement, workflow redesign, implementation activities, and outcome evaluation within the emergency department environment.

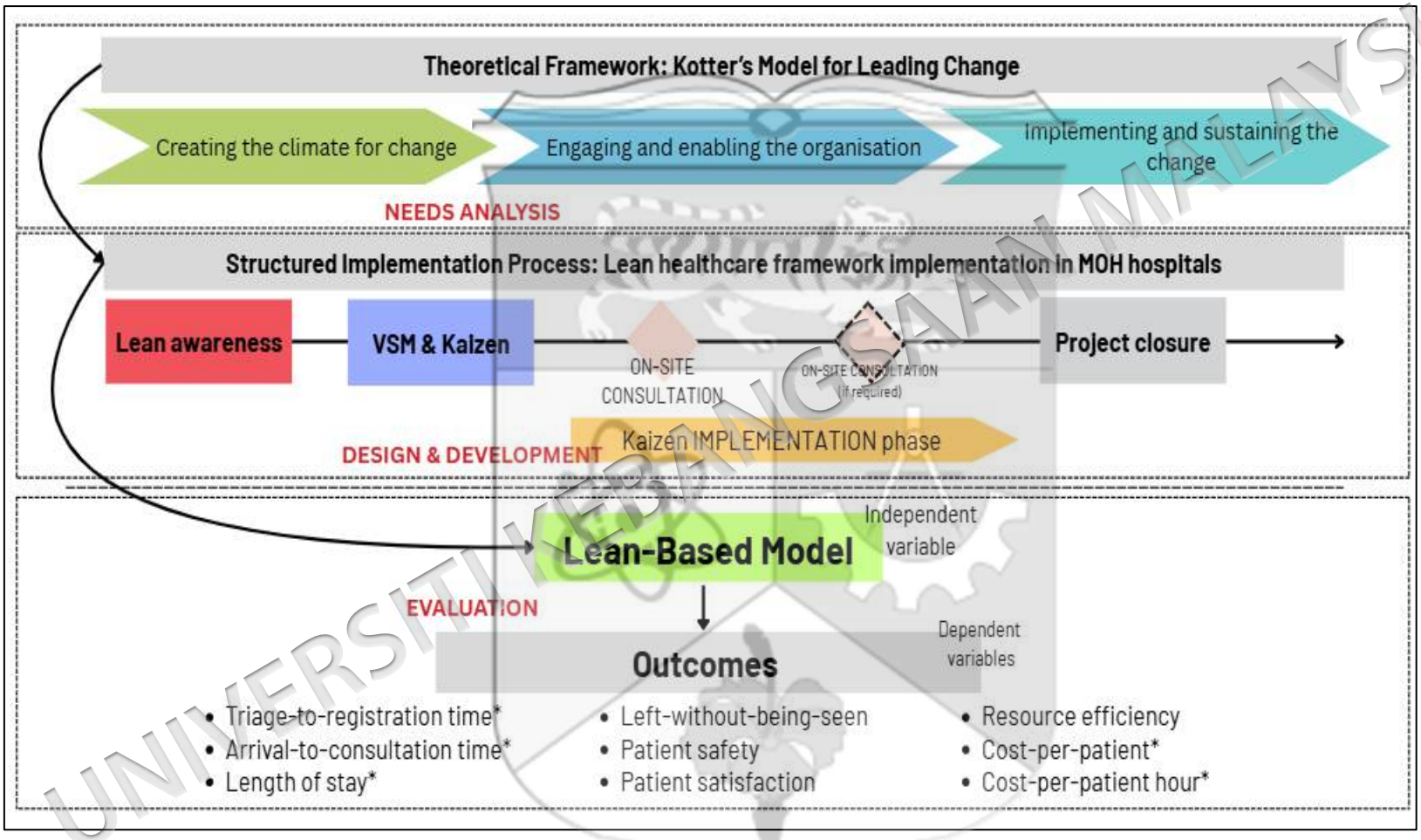

Figure 2.5 Conceptual framework

2.10 CONCLUSION

This chapter critically reviewed the evolution of Lean implementation within healthcare and examined its application within emergency department settings. The review demonstrated that Lean has progressed from a manufacturing-derived improvement philosophy to one of the most widely adopted continuous quality improvement approaches in healthcare, with substantial evidence supporting its potential to improve patient flow, reduce operational inefficiencies, minimise waste, and enhance service delivery. Within emergency departments, Lean interventions have increasingly evolved from isolated process-improvement activities towards more integrated approaches involving multidisciplinary engagement, workflow redesign, and the combined application of multiple Lean tools and techniques.

However, the review also revealed important limitations within the existing evidence base. Although many studies report favourable operational outcomes, considerable variation exists in implementation approaches, outcome measures, and evaluation methods. The rationale underpinning the selection, integration, and adaptation of Lean tools is often insufficiently described, limiting understanding of how Lean interventions should be systematically developed within complex healthcare environments. Furthermore, methodological weaknesses remain common, with many studies relying on simple before–after designs that provide limited evidence regarding attribution and sustainability of observed improvements. Financial evaluation is similarly underdeveloped, with relatively few studies examining whether operational gains translate into measurable improvements in resource utilisation or cost efficiency.

Within the Malaysian context, Lean implementation literature remains comparatively limited, particularly within emergency department settings and public university hospitals. These gaps highlight the need for a more systematic approach to Lean intervention development, implementation, and evaluation that integrates context-sensitive workflow analysis, multidisciplinary stakeholder engagement, robust longitudinal assessment, and consideration of operational cost efficiency. These considerations informed the development of the research framework presented in the next chapter and underpin the methodological approach adopted in the present study.

CHAPTER III

MATERIALS AND METHODS

3.1 INTRODUCTION

This chapter describes the methodological framework employed in the development, implementation, and evaluation of a Lean-based model for improving operational performance in the emergency department. The study adopted the Design and Development Research (DDR) approach, with the methodology organised into three sequential phases: (i) Phase 1 – Needs Analysis, which identified performance gaps and stakeholder requirements; (ii) Phase 2 – Model Design and Development, which involved the design of the Lean-based model; and (iii) Phase 3 – Model Evaluation, which assessed the effects of the intervention using Interrupted Time Series (ITS) analysis and a provider-perspective cost analysis.

3.2 STUDY LOCATION

This study was conducted at a 300-bedded public university hospital located in Kuantan, the capital city of Pahang, on the east coast of Peninsular Malaysia (Figure 3.1). Established in 2016 as the nation's fourth public university hospital, the centre occupies a 27.8-acre site and functions as a tertiary academic medical institution. It provides a comprehensive range of healthcare services encompassing more than 15 clinical specialties and 70 subspecialties, supported by advanced facilities including 20 operating theatres, an intensive care unit, a coronary care unit, paediatric and neonatal intensive care units (PICU and NICU), and an invasive cardiovascular laboratory (ICL).

The hospital is staffed by more than 1,800 employees and approximately 190 clinical specialists across multiple disciplines. As a university teaching hospital, it serves the dual mandate of providing clinical education for undergraduate and

postgraduate medical trainees while functioning as a major referral centre for the East Coast region. Its emergency department is one of the busiest service units, attending to more than 40,000 patients yearly. The combination of high patient throughput, complex case mix, academic training responsibilities, and a rapidly expanding operational environment provided an appropriate and robust context for the present study.

Figure 3.1 Location of Sultan Ahmad Shah Medical Centre IIUM

Source: Google Maps

3.3 STUDY DESIGN AND DURATION

This study employs a design and development research (DDR) framework, a branch of intervention research that focuses on the creation, refinement, and evaluation of models, processes, and tools intended to improve real-world practice. Within the broader field of intervention research, three complementary domains are recognised: Knowledge Development (KD), which generates conceptual or theoretical understanding; Knowledge Utilisation (KU), which focuses on translating existing knowledge into

practice; and Design and Development Research (DDR), which aims to produce new or improved human service technologies through systematic processes of problem analysis, intervention design, development, implementation, and evaluation (Rothman & Thomas 2009).

According to Richey & Klein (2009), DDR is defined as "the systematic study of design, development, and evaluation processes with the aim of establishing an empirical basis for the creation of instructional and non-instructional products and tools and new or enhanced models that govern their development". DDR is characterised by several core features: (i) an initial analysis phase to determine the problem and performance requirements; (ii) the deliberate selection of strategies or design principles aligned with these requirements; (iii) iterative development, refinement, and validation of the resulting model; and (iv) empirical evaluation of outcomes to establish effectiveness (Ellis & Levy 2010; Richey & Klein 2009; Rothman & Thomas 2009).

Consistent with the DDR framework, the present study was organised into three sequential phases that were carried out over an 18-month period from January 2024 to June 2025:

i) Phase 1: Needs analysis (January–June 2024)

ii) Phase 2: Model design and development (July–December 2024)

iii) Phase 3: Model evaluation (January to June 2025)

In Phase 1, a comprehensive needs analysis of the emergency department was conducted to determine the operational gaps requiring intervention. This diagnostic assessment examined multiple data sources, such as daily waiting time records, overcrowding indicators, compliance with set key performance indicators, outpatient feedback, and stakeholder input to characterise the extent and nature of performance problems. This triangulation of evidence provided a clear justification for intervention and identified the Green Zone as the most appropriate site for redesign efforts.

Phase 2 was conducted over a six-month period from July 2024 – December 2024 and consisted of the design, development, and implementation of a Lean-based

model for the Green Zone of the ED. A multidisciplinary Lean team was established, and a two-day Lean Healthcare Workshop was conducted to guide process mapping, bottleneck identification, and workflow redesign. This was followed by an implementation period to allow for full operationalisation of all intervention components. Expert validation using a Content Validity Index (CVI) ensured that the implemented workflow aligned with the intended future-state model prior to evaluation.

In Phase 3, the implemented model was evaluated through two components. First, an Interrupted Time Series (ITS) analysis was applied to assess changes in three operational performance indicators – triage-to-registration time (TTR), arrival-to-consultation time (ATC), and length of stay (LOS) in the ED. The analytical windows for evaluation were defined as January–June 2024 (pre-intervention) and January–June 2025 (post-intervention), ensuring comparisons were made between two equivalent six-month periods that reflected stable pre-intervention operations and fully implemented post-intervention workflows. Secondly, a cost analysis was undertaken to estimate changes in the operational cost of delivering Green Zone services before and after the intervention, using a top-down costing approach. The research framework is illustrated in Figure 3.2.

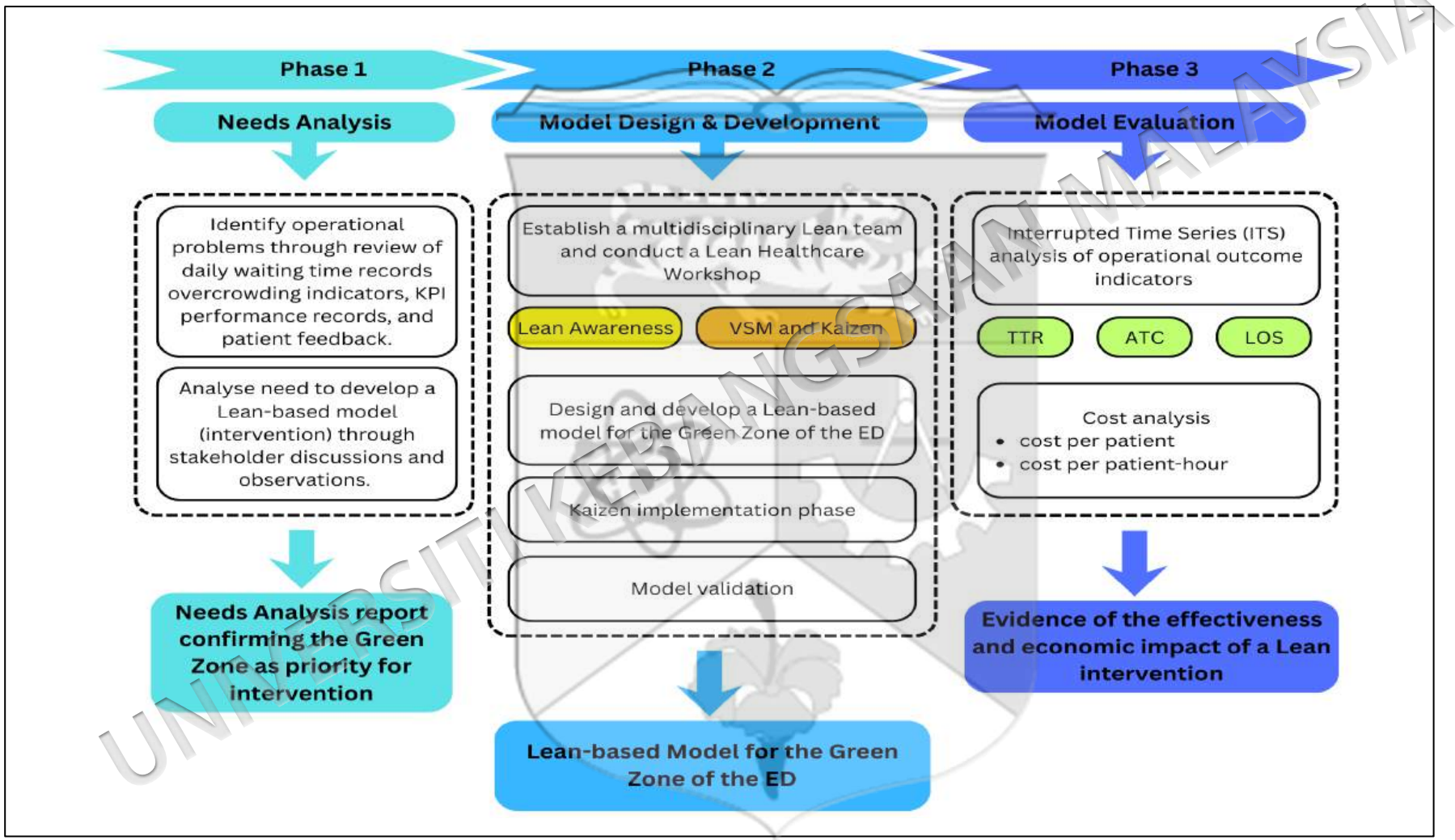

Figure 3.2 Research framework

3.4 PHASE 1: NEEDS ANALYSIS

3.4.1 Purpose of needs analysis

The needs analysis constitutes the diagnostic component of the DDR framework. Within DDR, problem identification is recognised as a necessary first step that guides the subsequent stages of model design, development, and evaluation. This is achieved through a systematic analysis aimed at clarifying the nature of the problem, the performance gaps within the existing system, and the contextual requirements that an intervention must address (Richey & Klein 2009). In this regard, needs assessments are problem-driven inquiries conducted to determine the gap between "what is" and "what should be" in a given system (Thyer 2010).

Two central methodological questions underlie any needs analysis: *who* defines the need, and *how* information about these needs is obtained. Hence, the present needs analysis incorporated the perspectives of those most directly affected by ED system inefficiencies – patients and frontliners, while drawing on multiple complementary data sources, including performance indicators, patient feedback forms, stakeholder input, and direct observation. The primary purpose of this phase was to develop a comprehensive understanding of the operational context of the emergency department, identify existing performance gaps, and determine the functional and structural requirements for developing a Lean-based model.

3.4.2 Study setting

The needs analysis was carried out in the ED of SASMEC IIUM. The ED is organised into three major functional zones that correspond to patient acuity: the Red Zone for critical emergencies requiring immediate resuscitation, the Yellow Zone for semi-critical patients, and the Green Zone for ambulatory, non-critical presentations. The ED workforce comprises emergency physicians, medical officers, assistant medical officers, staff nurses across various grades, medical healthcare assistants, and ancillary support personnel. The floor plan of the ED is depicted in Figure 3.3.

Figure 3.3 Emergency department floor plan

3.4.3 Data sources

The needs analysis drew upon multiple data sources to establish a comprehensive understanding of the operational context, workflow characteristics, performance pressures, and challenges within the emergency department. The following categories of data were used:

i. Administrative and performance monitoring data

This included annual and monthly ED statistics, triage category distributions, patient timestamp records, KPI summaries, and patient feedback reports obtained from the ED medical officer in charge and the IT Department. These datasets provided objective information on service volumes, actual process durations, and performance relative to preset benchmarks.

ii. Patient satisfaction survey data

Patient-reported experience data were obtained from the hospital's routine patient satisfaction survey administered by the Public Relations Unit as part of ongoing service quality monitoring. The survey uses a structured questionnaire with ten items rated on a five-point Likert scale (1 = very poor to 5 = very good), covering domains such as staff behaviour, communication, waiting time, and environmental conditions. Survey responses from patients attending the emergency department Green Zone during the pre-intervention period were extracted for descriptive analysis. As this instrument was part of the hospital's existing service evaluation system, the questionnaire was not developed or validated specifically for this study. Instead, the data were used to provide contextual insight into patient perceptions of service performance and to complement the operational and administrative data used in the needs analysis phase.

iii. Stakeholder input

Perspectives from ED staff were gathered through informal consultations, routine meetings, and field engagement. These inputs provided experiential evidence of workflow challenges, interruptions, resource constraints, and pain points observed during daily operations. Insights from ED staff were reviewed

and grouped into broad operational themes to summarise commonly observed workflow challenges during the needs analysis phase.

iv. Direct observations and contextual documentation

Non-participatory observations of patient flow, patterns of crowding, staff movement, and workspace organisation were conducted during different shifts. Relevant departmental policies and workflow protocols were also reviewed to contextualise operational issues and triangulate findings from quantitative and qualitative sources.

3.4.4 Data collection

Data collection was conducted prospectively between January and June 2024 using an integrated approach combining quantitative data extraction, document review, observational assessment, and stakeholder engagement.

Administrative and KPI data were formally requested and obtained in the form of monthly performance reports and the monthly census of patient attendance records. Timestamp data were obtained from the hospital's IT Department, comprising raw datasets in spreadsheet format, covering all patient encounters recorded in the *iPesakit*® system. Direct observations were carried out on-site across multiple weekdays and weekends to capture typical operational patterns. During these sessions, patient movement, staff allocation, environmental layout, and cross-zone interactions were recorded using field notes. Observations were descriptive rather than evaluative, ensuring minimal disruption to clinical activity. Stakeholder engagement occurred informally through routine discussions, brief interviews, and interactions with various members of the ED staff. Staff were encouraged to describe workflow difficulties, sources of delay, and patient-related challenges they encountered.

3.4.5 Data analysis

Data analysis for Phase 1 utilised an integrative approach combining descriptive quantitative analysis, document review, and structured interpretation of observational and stakeholder-derived information. Administrative datasets and timestamp records

were first examined using descriptive statistics to identify trends in patient volume, waiting times, and performance relative to departmental KPIs. Annual attendance data were analysed to determine longitudinal patterns, while monthly KPI reports were reviewed to evaluate consistency in meeting established benchmarks.

Timestamp data extracted from the *iPesakit*® system were screened for completeness and cleaned to remove incomplete or implausible values. The data were arranged chronologically to allow examination of typical process durations and variability within the clinical workflow. These quantitative analyses were complemented by findings from observational field notes, which provided insight into movement pathways, spatial constraints, cross-zone staff deployment, and task interruptions not visible in administrative data alone.

Stakeholder input was synthesised narratively and used primarily to contextualise quantitative patterns rather than as a separate qualitative dataset. Staff accounts of workflow fragmentation, delays, and operational pressures were compared against trends observed in timestamp data and administrative reports, enabling triangulation across data sources.

The combined analysis allowed for the systematic identification of operational inefficiencies across the emergency department and supported that the Green Zone experienced the highest concentration of workflow bottlenecks and performance challenges. These findings formed the empirical foundation for Phase 2 – model design and development – under the DDR framework.

3.5 PHASE 2: MODEL DESIGN AND DEVELOPMENT

3.5.1 Overview and rationale

Phase 2 of the DDR framework focused on the systematic design and development of a Lean-based Green Zone improvement model. Consistent with DDR principles, model design and development were grounded in: (i) empirical findings generated in Phase 1, (ii) lean healthcare expertise, and (iii) iterative refinement through observation, structured problem analysis, and validation loops. This phase was operationalised

through a two-day Lean Healthcare Workshop, follow-on implementation activities undertaken by a multidisciplinary Lean Improvement Team, and a validation exercise by Lean healthcare experts.

3.5.2 Study participants

A multidisciplinary Lean improvement team was established, consisting of 29 healthcare professionals drawn from both clinical and administrative divisions of the hospital. The team included emergency physicians, medical officers, registered nurses, medical healthcare assistants, pharmacists, radiographers, and medical laboratory technicians, as well as representatives from the Human Resources and General Administration (HRGA) Department, Department of Finance, and Department of Information Technology. Team members were given a mandate by the Hospital Director and provided with a two-day hands-on workshop on Lean healthcare methodology and processes by Lean healthcare experts in the country.

3.5.3 Data collection and study instruments

The following steps from the ten-step implementation framework for Lean thinking transformation of the service redesign (Sales & De Castro 2021) were adapted for this study:

i. Kick-off meeting

An initial meeting was held between the research team, top-level hospital managers, and representatives from the ED. In this first meeting, the scope of the project was agreed on, the expected results were planned, and the strategy moving forward was outlined. A “Lean team” was formed, and all members were given a letter of appointment and Terms of Reference (TOR) from the Hospital Director. The best days and times for the team to be free from their routine for the initial lean training workshop were also decided. This was imperative to ensure that all members were fully available to participate and bring value to the process group.

ii. Team training

A foundational workshop in Lean principles, tools, and methodologies was conducted by certified quality improvement engineers. This two-day on-site workshop served to introduce the Lean team to core concepts such as value, waste, flow, bottleneck identification, and standardisation, and to equip participants with the skills necessary to analyse and redesign healthcare processes. Under guided facilitation, the team constructed the current state Value Stream Map (VSM), identified process inefficiencies and waste points, and generated Kaizen opportunities. These outputs formed the analytical and conceptual foundation for the design and development of the Lean-based model evaluated in this study.

iii. Value stream mapping (VSM)

Value stream mapping (VSM) served as the primary tool for modelling the present Green Zone workflow and identifying opportunities for improvement. VSM was conceived by Rother & Shook (2003) for the industrial environment and has been widely adapted for healthcare due to its ability to visualise patient flow, information flow, and operational dependencies within a single integrated map. VSM differentiates each process step as value-added (VA), non-value-added (NVA) or waste, and necessary non-value-added (NNVA) activities, enabling structured identification of waste and inefficiencies (Khalil & Foo 2024).

Under guided facilitation during the Lean workshop, the multidisciplinary team constructed a current-state VSM that represents the full patient pathway from arrival and triage to registration, consultation, disposition, and eventual exit from the ED. The mapping process allowed the team to visualise interaction points between patients and healthcare personnel, identify delays, rework loops, bottlenecks, and sources of variation, and examine how information moved through administrative and clinical systems (Nazar et al. 2016). Through this exercise, improvement opportunities that could enhance patient flow and increase value from the patient's perspective were systematically identified (Sales & De Castro 2021).

Building on this, the team subsequently developed a future-state VSM, representing the desired Lean workflow with reduced waste, streamlined movement pathways, simplified documentation requirements, and improved coordination across process steps. This future-state map functioned as the conceptual blueprint for the Lean-based model implemented in this study.

iv. Standard zero

Standard zero is the current situation of each healthcare worker's day-to-day, and the existing flow that patients go through in the ED. The team established a "Standard Zero" by documenting every action within the workflow, including its sequence, dependencies and observed variations. This captured the day-to-day operational routines of ED staff, from registration personnel, triage staff, doctors, nurses, and support staff, and clarified role expectations, highlighted variations in practice, and helped identify mismatches between desired and actual workflow execution. This provided a baseline which was essential to ensure that all team members shared a consistent understanding of how work was actually performed, rather than how it was assumed to be performed, and provided a reference point against which the redesigned (future-state) processes could be compared. It also supported the development of more reliable and standardised work routines by identifying where variation led to inefficiency or delay.

v. Cross-process observation

To validate the accuracy of the current-state VSM and standard zero, the Lean team conducted a *Gemba* – a Lean tool defined as "the place where value is created", which was achieved through the following elements: observation (watching people perform the work in-person), location (observing people at the actual location where work is performed), and teaming (interacting with people performing the work) (O'Mahony et al. 2021).

Direct observation, a time motion study, and judgment-based assessments from frontline staff were used to estimate average processing times. These observations were triangulated with timestamp data extracted from the hospital's EMR system (*iPesakit*®), which provided objective measures of throughput such as waiting times and length of stay of patients in the ED.

Following this, the team gathered again to refine the current-state VSM. This ensured that the mapping process reflected actual working conditions.

vi. New standard

Following the finalised current-state VSM, the Lean team proceeded to design the new standard, which represented the redesigned workflow intended to reduce waste, streamline patient flow, and enhance process reliability. As part of the model design and development process, the team generated a series of Kaizen bursts, each capturing a specific source of waste, delay, or inefficiency. These Kaizen bursts functioned as concise improvement ideas, that were then synthesised using an effort-impact matrix to determine feasibility, and were used to inform the configurations of the redesigned workflow.

The team constructed the future-state VSM, which operationalised the new standard. Consistent with Sales & De Castro (2021), the new standard sought to establish an idealised workflow that addressed the inefficiencies identified in the current state and incorporated feasible improvements. In this study, the future-state VSM constituted the Lean-based model to be implemented and evaluated. It served as the operational blueprint for subsequent piloting and validation prior to evaluation in Phase 3.

3.5.4 Data analysis

Data analysis for Phase 2 focused on translating the findings during the Lean Healthcare Workshop into a structured workflow redesign using an integration of Lean tools. The current-state VSM included all observed and reported process steps, waiting times and movement pathways across the Emergency Department workflow in the Green Zone and enabled systematic visual identification of bottlenecks, redundancies, and delays, providing a comprehensive representation of the existing operational system.

Following construction and validation of the current-state map, all identified inefficiencies were converted into specific improvement opportunities and documented as Kaizen bursts, a Japanese word that means “continuous improvement”. Kaizen aims to make small, incremental improvements in processes and systems, leading to significant long-term benefits. The Kaizen process encourages the Lean team to identify

areas for improvement and come up with practical solutions that can be quickly implemented. These solutions were analysed using an effort–impact matrix, in which each proposed change was assessed according to (i) its anticipated effect on patient flow, and (ii) the effort, coordination, or resources required for implementation. This classification enabled the team to prioritise feasible, high-impact modifications while recognising which proposals required additional investment or long-term planning. The prioritised Kaizen and their corresponding classifications were subsequently presented to hospital management for endorsement. Only interventions classified as both high-impact and implementable within existing operational constraints were approved for immediate execution. These selected changes formed the basis of the Lean-based model, representing the intervention that was operationalised during the implementation period and subsequently evaluated in Phase 3.

Following stabilisation of the redesigned workflow, a formal validation exercise was conducted to determine the extent to which each component of the Lean-based model had been implemented as intended. The Content Validity Index (CVI) was used to assess the degree to which the actual workflow observed in the emergency department reflected the specifications outlined in the future-state Value Stream Map. using a 4-point Likert scale (1 = not implemented/not aligned, 2 = partially implemented, 3 = mostly implemented, 4 = fully implemented as intended). A three-member expert panel comprising two quality engineers with certified Lean healthcare expertise and one emergency physician independently reviewed each redesigned process step. Items that received ratings below 3 from any expert were to be accompanied by qualitative comments to allow the Lean team to refine unclear steps and constitute the necessary changes to ensure accurate representation of the intervention.

For each item, an Item-level Content Validity Index (I-CVI) was calculated as:

$$\text{I-CVI} = \frac{\text{Number of experts rating 3 or 4}}{3}$$

An I-CVI ≥ 0.80 was considered evidence of satisfactory implementation alignment (Yusoff 2019).

The scale level content validity index based on the average method (S-CVI/Ave) was then calculated as the average of the item-level CVIs (I-CVI) across all items:

$$\text{S-CVI/Ave} = \frac{\sum \text{I-CVI across all items}}{\text{Number of items}}$$

S-CVI/Ave provides an overall measure of implementation consistency across the full model (Yusoff et al. 2021). An S-CVI/Ave score above 0.90 is considered excellent (Furr 2018).

The resulting high I-CVI and S-CVI/Ave values indicated strong expert agreement regarding the adequacy of implemented interventions, supporting the model's readiness for formal evaluation in Phase 3.

3.6 PHASE 3: MODEL EVALUATION

Data analysis for Phase 3 of the study involved two major components: (i) Interrupted Time Series (ITS) analysis to evaluate the effects of the Lean-based model on operational performance indicators, and (ii) cost analysis comparing pre- and post-intervention expenditure in terms of cost per patient and cost per patient-hour.

3.6.1 Operational outcomes

a. Study design

A quasi-experimental, interrupted time series (ITS) design was employed to evaluate the effects of the Lean-based model on operational performance outcomes in the emergency department. ITS is widely recognised as one of the strongest quasi-experimental approaches for assessing the impact of system-level interventions when randomisation is not feasible (Turner et al. 2020). In a two-period ITS design, observations are modelled across two contiguous temporal segments – before and after

the intervention – allowing the pre-intervention trajectory to serve as a counterfactual (i.e. what would have occurred in the absence of the intervention). This allows for the estimation of both immediate (level) changes and gradual (trend) changes following an intervention (Turner et al. 2020).

The ITS approach was particularly suited to this evaluation because the Lean intervention was implemented at the system level and could not be randomised or compared against an external control group. Meaningful comparison with another hospital's Green Zone was also not feasible, as each institution experiences different patterns of patient volume, case mix, resource constraints, and workflow bottlenecks. These structural and operational differences make external benchmarking unsuitable as a counterfactual. Given these limitations, ITS offered the most rigorous and appropriate method by modelling the expected trajectory of each outcome in the absence of the intervention.

For this study, three daily operational indicators, triage-to-registration time (TTR), arrival-to-consultation time (ATC), and length of stay (LOS) in the emergency department, were collected for two 6-month observational periods: a pre-intervention phase (January–June 2024) and a post-intervention phase (January–June 2025). Between these two observation windows, a six-month implementation and stabilisation period (July–December 2024) was allocated to roll out the Lean-based model, refine workflow changes, and ensure that the redesigned processes were consistently embedded in routine practice.

These indicators were selected because they represent key stages of the emergency department patient pathway and are widely used to evaluate operational efficiency and patient flow in emergency care settings (Lima et al. 2021). Triage-to-registration time reflects the efficiency of early administrative processing following patient arrival, arrival-to-consultation time measures the timeliness of initial physician assessment, and overall length of stay captures the cumulative effect of throughput processes across the entire episode of emergency care. Hence, the use of these indicators provides a comprehensive assessment of both front-end workflow performance and broader operational throughput within the emergency department.

b. Sampling method

A census sampling approach was applied, in which all individual patient encounters managed in the Green Zone were included during both the pre-intervention (January–June 2024) and post-intervention (January–June 2025) observation periods. Census sampling is appropriate when the full population of interest is accessible and ensures complete capture of variation in operational performance without sampling error or selection bias (Daniel 2012).

In this study, each Green Zone encounter constituted an individual data point drawn from *iPesakit*®. All available encounters were retained except those with incomplete timestamps required to compute the operational indicators. This approach parallels the use of individual-level data in registry-based ITS analyses, which include all eligible records after applying minimal exclusion criteria to ensure data quality (Jackson et al. 2024).

For the interrupted time series analysis, each calendar day (12:00 a.m. to 11:59 p.m.) was treated as a single time unit. All patient encounters within this 24-hour window were extracted according to daily operational indicators and sorted in ascending order to derive the daily median. Daily aggregation is consistent with ITS methodology, which requires multiple evenly spaced data points and often uses summary statistics (e.g., rates, means, medians) derived from individual observations to construct population-level time series suitable for modelling pre-intervention trends and post-intervention deviations (Turner et al. 2019).

c. Sampling population

i. Target population

The target population consisted of all patients presenting to emergency departments in Malaysia who were managed within a Green Zone setting.

ii. Study population

The study population comprised all Green Zone patient encounters managed at the emergency department at Sultan Ahmad Shah Medical Centre IIUM (SASMEC IIUM).

iii. Sampling frame

The sampling frame consisted of the complete daily electronic records of all Green Zone patient encounters documented in the hospital's electronic medical record (EMR) system, *iPesakit*®. These records provided the raw time-stamped data required to construct daily operational indicators.

iv. Sampling unit

The sampling unit for the interrupted time series analysis was the daily aggregated operational indicator. Each calendar day (12:00 a.m.–11:59 p.m.) formed one time point in the time series. For each day, all patient encounters within that 24-hour window were sorted, and because the individual-level data were non-normally distributed, the daily median was selected as the time point for each outcome.

d. Sampling criteria

All patient encounters managed in the emergency department Green Zone during the defined pre-intervention (January–June 2024) and post-intervention (January–June 2025) periods were eligible for inclusion. Records were excluded only if key time-stamp fields required to derive the operational indicators were missing, internally inconsistent, or clearly implausible (e.g., negative time intervals or sequences that violated clinical workflow logic). These exclusions were applied solely for data integrity purposes and did not constitute selective sampling. All remaining valid encounters were retained and aggregated for analysis.

i. Inclusion criteria

i. All patient encounters managed in the Green Zone of the emergency department at SASMEC IIUM during the pre-intervention period (January–June 2024), and the post-intervention period (January–June 2025).

ii. Encounters with complete and internally consistent timestamp data required to compute all three operational indicators: triage-to-registration time (TTR), arrival-to-consultation time (ATC), and length of stay (LOS).

ii. Exclusion criteria

i. Cases directed to the Yellow or Red Zone after primary or secondary triage.

ii. Encounters captured during the implementation period (July–December 2024).

e. Study instruments

Data for all operational indicators were extracted from the *iPesakit*® Clinical Information System, the EMR platform used in SASMEC IIUM. Timestamps are generated when clinical or administrative staff enter notes or complete specific tasks in *iPesakit*®, such as documenting triage assessment, completing registration, initiating consultation, placing investigation orders, or finalising discharge. These entries are made as part of routine clinical care and administrative workflow.

For this study, three operational indicators—triage-to-registration time (TTR), arrival-to-consultation time (ATC), and length of stay (LOS)—were derived from the system's time-stamped fields. Daily operational data were obtained through a formal request to the hospital's Information Technology (IT) Department. The IT team extracted the raw timestamp data directly from the *iPesakit*® back-end database and provided them in Excel format, containing all relevant event times for each Green Zone encounter.

f. Sample size

There is currently limited empirical guidance on sample size requirements for ITS analysis (Turner et al. 2019). Estimates of effect size and autocorrelation are key parameters for sample size calculation of ITS series, yet there is little guidance regarding the typical size of these effects that might be seen in ITS of public health interruptions. Recommendations for minimum ITS series length vary widely, ranging from three time points per segment to upwards of 50 time points for models incorporating autoregressive structures (Turner et al. 2020; Zhang et al. 2011). Longer time series enhance the ability to model secular trends, detect intervention effects, and account for autocorrelation or seasonality.

In determining sample adequacy for this study, several methodological considerations were taken into account:

i. the number of pre- and post-intervention time points;
ii. the volume of observations contributing to each time point;
iii. the frequency at which time points are measured;
iv. the timing of the intervention within the series; and
v. the magnitude of the expected effect.

In this study, daily data were used to maximise the number of time points. Each day's data comprised a census of all Green Zone encounters, providing a large number of observations for each time point and improving the stability of daily medians. A total of 182 daily time points were available in the pre-intervention period (January–June 2024, including the leap-year day), which were used to estimate the underlying baseline level and trend and to construct the counterfactual trajectory representing expected performance in the absence of the intervention. An additional 181 daily time points were available in the post-intervention period (January–June 2025), which captured the realised operational performance following full implementation of the Lean-based model.

Cumulatively, 363 daily observations were included in the segmented regression models, which exceeds the minimum recommended thresholds for autoregressive integrated moving average (ARIMA)-based ITS models and provides adequate temporal resolution to estimate level and trend changes while accounting for autocorrelation.

g. Operational definition of the variables

The operational definition of the variables is presented in Table 3.1.

Table 3.1 Operational definition of the variables

Item	Description
Triage-to-Registration Time (TTR)	**Operational definition:** The time interval between a patient's completion of primary triage and completion of the registration process in the Green Zone. This indicator reflects front-end flow efficiency and is sensitive to bottlenecks in administrative and triage documentation processes. Daily median values are used for analysis due to the non-normal distribution of individual patient times. **Calculation**: Registration timestamp – Triage timestamp. **Type**: Continuous. **Measure**: Time in minutes.
Arrival-to-Consultation Time (ATC)	**Operational definition:** The time taken from the patient's arrival at the Emergency Department primary triage station until the patient is first seen by a medical officer in the Green Zone. This measures the timeliness of initial clinical assessment. Daily median values are used for analysis due to non-normal distribution. **Calculation:** Consultation start time – Arrival time at primary triage. **Type**: Continuous. **Measure:** Time in minutes.
Length of Stay (LOS)	**Operational definition:** The total time a patient spends in the Emergency Department Green Zone from arrival until completion of discharge processes (either discharge home or transfer/admission) from the Emergency Department. Daily median values are used for analysis due to non-normal distribution. **Calculation:** Time of ED discharge/transfer – Arrival time at primary triage. **Type:** Continuous. **Measure:** Time in minutes.

h. Data collection

Data collection for the operational outcomes was conducted retrospectively using routinely recorded electronic timestamps extracted from the *iPesakit*® Clinical Information System. All Green Zone patient encounters during the pre-intervention (January–June 2024) and post-intervention (January–June 2025) periods were included.

Because the extracted dataset consisted of raw entries without preprocessing, all operational indicators were computed manually by the researcher using the corresponding timestamp pairs for each encounter. Prior to calculation, the dataset underwent a systematic cleaning procedure to identify and remove implausible records, such as missing timestamps, negative durations, or events documented out of chronological sequence. Following cleaning, the data were organised into daily 24-hour windows (12:00 a.m. to 11:59 p.m.). All encounters within each window were sorted in ascending order. The daily median value was used as the representative time point for each indicator.

i. Data analysis

All data management, statistical analyses, and graphical outputs were conducted using R (ver. 2025.09.2+418) (R Foundation for Statistical Computing, Vienna, Austria). Interrupted time series models were estimated using standard time-series and forecasting packages, and all figures and diagnostic plots were generated within the R environment.

i. Analytical approach

The effects of the Lean-based model on emergency department performance were evaluated using an Interrupted Time Series (ITS) design with segmented regression. ITS is a well-established quasi-experimental approach for evaluating system-level interventions when randomised designs are not feasible, allowing causal inference through comparison of observed post-intervention outcomes with a counterfactual projection based on pre-intervention trends (Turner et al. 2019, 2020).

A single, prespecified intervention point was used throughout the analysis: 1 January 2025, corresponding to the date on which the Lean-based model for the Green Zone was fully implemented and operational. All analyses, therefore, compared outcomes observed after this date with those expected had pre-intervention patterns continued unchanged. Three time-based operational indicators were examined: triage-to-registration time (TTR), arrival-to-consultation time (ATC), and length of stay (LOS). All outcomes were analysed as daily medians due to the non-normal distribution

of individual patient-level times. This approach is consistent with recommended practice in interrupted time series analyses of healthcare process measures, where robust summary statistics are preferred to means in the presence of skewness and outliers (Jackson et al. 2024).

Segmented regression was used to estimate two standard ITS parameters:

i. an immediate level change at the intervention point, and
ii. a change in post-intervention trend relative to the pre-intervention trajectory.

ii. Model specification

For each operational indicator, the ITS model took the form:

$$Y_t = \beta_0 + \beta_1(\text{time}_t) + \beta_2(\text{intervention}_t) + \beta_3(\text{post-trend}_t) + \varepsilon_t$$

where:

- Y_t represents the daily median outcome at time t;
- time_t captures the underlying pre-intervention trend;
- intervention_t is coded 0 before 1 January 2025 and 1 thereafter, estimating the immediate level change (β_2);
- post-trend_t represents time elapsed since the intervention, estimating the slope change (β_3);
- ε_t represents the error term.

iii. Treatment of temporal dependence

While segmented regression provides a flexible framework for estimating level and trend changes in interrupted time series, valid inference depends on appropriate handling of serial autocorrelation in the error structure. Operational time series in the healthcare context commonly exhibit serial autocorrelation and, in some contexts,

seasonal structure. If left unaddressed, this can lead to underestimated standard errors and inflated type I error rates in ITS analyses (Turner et al. 2021; Turner et al. 2019). The temporal dependence was assessed and treated using ARIMA-based error structures within the segmented regression models.

iv. Model adequacy and residual diagnostics

Following identification of outcome-specific ARIMA error structures, model adequacy was formally evaluated to confirm that the selected specifications adequately captured temporal dependence and supported valid statistical inference. Diagnostic checking is a critical component of interrupted time series (ITS) analysis, as inadequately specified error structures can lead to biased standard errors and invalid statistical inference, even when point estimates appear stable (Turner et al. 2019, 2020). Model adequacy was evaluated using residual time-series plots and inspection of residual autocorrelation.

v. Estimation of intervention effects and counterfactual trajectories

Intervention effects were quantified by estimating two key ITS parameters:

- Immediate level change (β_2) – representing the instantaneous shift in the outcome at the defined interruption point (1 January 2025).
- Post-intervention slope change (β_3) – representing the change in trend following the intervention relative to the pre-intervention trajectory.

For each operational outcome—triage-to-registration time (TTR), arrival-to-consultation time (ATC), and length of stay (LOS)—the segmented regression models included an intercept, a continuous time variable representing the underlying pre-intervention trend, a binary intervention indicator coded from 1 January 2025 onwards, and a post-intervention time variable.

Counterfactual trajectories were generated for each operational indicator by projecting the pre-intervention trend forward into the post-intervention period in the absence of the implementation of the Lean-based model. This approach is central to causal interpretation in ITS analysis, as it enables direct comparison between observed

post-intervention outcomes and those expected had pre-intervention patterns continued unchanged (Turner et al. 2019, 2020, 2021).

Daily fitted values from the full ITS models were obtained for the observed series, and counterfactual fitted values were generated from the corresponding reduced models without intervention terms. These fitted and counterfactual series form the basis of the graphical ITS displays presented in Chapter 4, allowing visual assessment of the magnitude, direction, and persistence of intervention effects over time. As recommended by Turner et al. (2020), these plots emphasise both the immediate discontinuity at the intervention point and divergence (or convergence) between observed and counterfactual trajectories during the post-intervention period. Intervention effects were summarised using absolute changes in outcome levels and percentage changes relative to pre-intervention means. Uncertainty around effect estimates was quantified using 95% confidence intervals derived from the fitted regression models.

vi. Sensitivity analyses and robustness checks

Sensitivity analyses were undertaken to evaluate the robustness of the interrupted time series (ITS) findings to alternative modelling assumptions and analytical approaches. Given that ITS estimates can be sensitive to choices regarding error structure, estimation method, and counterfactual construction, the use of complementary analytical strategies is recommended to ensure that substantive conclusions are not artefacts of a single modelling framework (Turner et al. 2020, 2021).

Five classes of ITS models were examined for each outcome:

i. classical segmented regression estimated using ordinary least squares with Newey–West heteroskedasticity- and autocorrelation-consistent standard errors;

ii. generalised least squares (GLS) models with autoregressive correlation structures;

iii. ARIMA regression models with intervention terms specified as external regressors (primary analysis);

iv. exponential smoothing state-space models (ETS/Holt–Winters) used to generate forecast-based counterfactual trajectories; and

v. Bayesian ITS models incorporating uncertainty in level and trend parameters.

Across all sensitivity analyses, the substantive pattern of findings was consistent with the primary ARIMA-based ITS models. Specifically, triage-to-registration time (TTR) demonstrated an immediate reduction following implementation of the Lean-based model, while arrival-to-consultation time (ATC) and length of stay (LOS) did not exhibit statistically reliable changes. Although point estimates and uncertainty intervals varied modestly across modelling frameworks, no alternative specification yielded conclusions that differed in direction or interpretation from the primary analysis.

In accordance with best practice in ITS analysis, the ARIMA regression models were retained as the primary analytical approach due to their transparency, parsimony, and explicit handling of temporal dependence, while alternative models were used to confirm the stability of conclusions rather than to select models based on fit statistics alone (Cryer & Chan 2008; Turner et al. 2020; Wei 2006).

3.6.2 Cost analysis

a. Study design

The cost analysis was conducted as a hospital-based economic evaluation using a provider perspective to estimate the operational cost of delivering Green Zone services in the emergency department before and after the implementation of the Lean-based model. Costs were analysed using a top-down approach. The costing approach used hospital-wide expenditure data, which were apportioned to the emergency department based on standard allocation metrics provided by the Finance Department and the Facilities and Engineering Department.

Two costing windows were analysed: January–June 2024 (pre-intervention) and January–June 2025 (post-intervention). These periods aligned with the operational time series used in the ITS analysis, ensuring that performance and cost outcomes were evaluated over comparable durations. All costs were expressed in Malaysian Ringgit (MYR) for the 2025 financial year. No inflation adjustments were applied because the costing windows spanned equivalent six-month periods in consecutive years.

b. Unit of analysis and classification of cost items

To estimate the resource implications associated with the Lean intervention, all major resources utilised in emergency department operations were identified and valued. Although the intervention was implemented within the Green Zone, resource utilisation within the emergency department is highly integrated, with staffing, consumables, medications, equipment, and support services shared across clinical zones. In accordance with the Emergency Medicine and Trauma Services (EMTS) Policy, the Green Zone manages a heterogeneous patient mix ranging from G1 cases requiring multiple diagnostic and treatment resources to G2 and G3 presentations requiring minimal or no interventions (Ministry of Health Malaysia 2012). However, because operational resources are not routinely allocated or recorded by individual zone, costs could not be reliably attributed exclusively to Green Zone activities. Consequently, the emergency department was defined as the cost centre and unit of analysis for the economic evaluation. This approach was considered more appropriate than attempting to estimate zone-specific costs based on assumptions or indirect allocations that could introduce substantial measurement error.

Cost identification was based on detailed financial records from the Finance Department, procurement summaries from Pharmacy and Supplies, and direct consultations with the Human Resource and General Administration Department and the Facilities and Engineering Department. All cost items were classified into direct medical costs, which were further subdivided into fixed costs, semi-fixed costs, and variable cost categories.

Facility and overhead costs represented fixed costs, including hospital-wide expenditure for utilities (electricity, water, ICT infrastructure), hospital support services

(linen and laundry, biomedical engineering, waste management, security), and hospital insurance premiums. administrative salaries. Because these represent shared hospital resources, they were allocated to the ED proportionate to the physical floor area (square footage) relative to the hospital's total operational area.

Semi-fixed costs comprised labour expenditure, which was calculated based on the actual human resource deployment within the emergency department. Labour cost data were obtained directly from the Human Resources and General Administration Department and included emergency physicians, medical officers, assistant medical officers, staff nurses across various grades, medical healthcare assistants, drivers, and administrative clerical staff supporting ED operations. Because staffing for the Green Zone is drawn from a shared departmental roster, with personnel rotating between the Green, Yellow, and Red Zones, labour expenditure reflects the total cost of staffing the entire emergency department rather than the Green Zone alone. Administrative personnel costs, which are not stationed exclusively in the ED, were apportioned from the hospital-wide human resources budget using standard allocation practices provided by the Finance Department.

Variable direct costs comprised general and specialised clinical consumables as well as medications used in patient care. Expenditure data for these items were obtained from the monthly utilisation reports provided by the Pharmacy Department and the Medical Supplies Unit. Because consumables in the emergency department are procured and stored as a pooled departmental inventory rather than allocated by clinical zone, these costs represent consumption at the department level rather than the Green Zone alone. Medication costs were similarly valued using pharmacy dispensing records, which capture all items issued for emergency department encounters irrespective of zone.

The costing framework, including the classification of cost components and the allocation approach applied to each category, is summarised in Table 3.2.

Table 3.2 Costing framework for the Green Zone of the emergency department

Cost Component	Type	Description
Utilities, facility overhead, support services	Fixed direct cost	Apportioned by floor area
Equipment maintenance	Fixed direct cost	Monthly biomedical servicing cost apportioned by floor area
Administrative overhead	Fixed direct cost	Apportioned by floor area
Labour cost	Semi-fixed direct cost	Salaries & allowances for emergency physicians, medical officers, assistant medical officers, staff nurses across various grades, medical healthcare assistants, drivers, and administrative clerical staff supporting ED operations
Consumables & medications	Variable direct cost	Utilisation-based expenditure on general & specialised consumables and drugs

c. Valuation of cost items

The valuation of cost items was conducted using a top-down approach in which all expenditures attributable to the emergency department were identified from hospital financial records and apportioned according to established allocation rules. More granular approaches, such as Activity-Based Costing (ABC) or Time-Driven Activity-Based Costing (TDABC), could provide closer attribution of resource consumption to individual activities or care processes and may therefore offer greater precision in evaluating the resource implications of Lean workflow redesign. However, implementing these approaches would require detailed mapping of activity pathways, staff time, resource capacity and cost drivers across the Green Zone, which was not feasible within the study period and scope. The top-down approach was therefore selected as a pragmatic and reproducible method for estimating changes in operational unit costs using routinely available financial data.

For fixed costs, total hospital expenditure on utilities, insurance, waste management, linen and laundry services, biomedical engineering support, facility maintenance, and building depreciation was obtained from the Finance Department and the Facilities and Engineering Department. Because these are shared resources supporting all clinical and non-clinical units, fixed costs were apportioned to the emergency department using the square-footage method, whereby each cost item was scaled to the proportion of operational floor area occupied by the ED.

Semi-fixed costs, consisting primarily of labour expenditure, were valued using actual monthly salary statements obtained from the Human Resources and General Administration Department. These records included basic salary and fixed allowances for all cadres rostered to the emergency department. Since staffing for the Green Zone rotates across the whole department, covering the Green, Yellow, and Red Zones, labour costs were valued at the departmental level, reflecting the full cost of maintaining the ED workforce required to deliver Green Zone services. Administrative staff who support ED operations but are not exclusively stationed in the department were costed using standard allocation factors provided by the Finance Department.

Variable direct costs were valued using monthly utilisation and expenditure reports from the Pharmacy Department and Medical Supplies Unit. These records captured the actual quantities and costs of consumables and medications issued to the emergency department during the costing periods. Because consumables are drawn from a pooled ED supply rather than tracked at the zone level, their valuation reflects aggregate ED utilisation.

d. Cost calculations

Following the valuation, all cost components were aggregated to derive the total monthly operating cost of the emergency department. Fixed, semi-fixed, and variable direct costs were summed to produce a comprehensive estimate of monthly expenditure during each costing window. This aggregation involved summing labour costs, direct medical costs, equipment maintenance costs, and apportioned facility and overhead costs, consistent with the provider-perspective and top-down costing framework used in this study. The total monthly cost for month *m* was computed using:

$$\text{TotalCost}_m = \text{LabourCost}_m + \text{DirectMedicalCost}_m + \text{EquipmentCost}_m + \text{Facility/OverheadCost}_m$$

To enable comparison across pre- and post-intervention periods, these totals were converted into two-unit cost metrics: cost per patient and cost per patient-hour.

Cost per patient was calculated by dividing the total monthly operating cost by the total number of Green Zone encounters for that month:

$$\text{Cost per patient} = \frac{\text{Total monthly ED cost}}{\text{Number of Green Zone patient visits for the month}}$$

Cost per patient-hour was calculated to account for both patient volume and the time patients spent in the Green Zone, thereby providing a measure of operational cost efficiency that reflects length of stay. Patient-hours were derived by multiplying the mean monthly length of stay (in hours) by the total number of Green Zone encounters for the corresponding month. The cost per patient-hour was then computed as:

$$\text{Total patient-hours} = \text{Number of patients} \times \frac{\text{mean LOS (minutes)}}{60}$$

$$\text{Cost per patient-hour} = \frac{\text{Total monthly ED cost}}{\text{Total patient-hours for the month}}$$

These calculations were applied identically in the pre- and post-intervention periods, enabling direct comparison of operational cost efficiency following implementation of the Lean-based model. Cost metrics were reported in Malaysian Ringgit (MYR) for each month, and aggregated six-month totals were used to compare overall pre- and post-intervention expenditure.

e. Cost data collection

A data collection tool was created using Microsoft Excel (ver. 2605). Figure 3.4 illustrates the flow of cost data collection, classification, aggregation, and derivation of unit cost measures used in this study. The figure summarises how hospital-wide financial and utilisation data were pooled at the emergency department cost centre, classified into fixed, semi-fixed, and variable cost components, and combined with Green Zone activity data to derive cost per patient and cost per patient-hour.

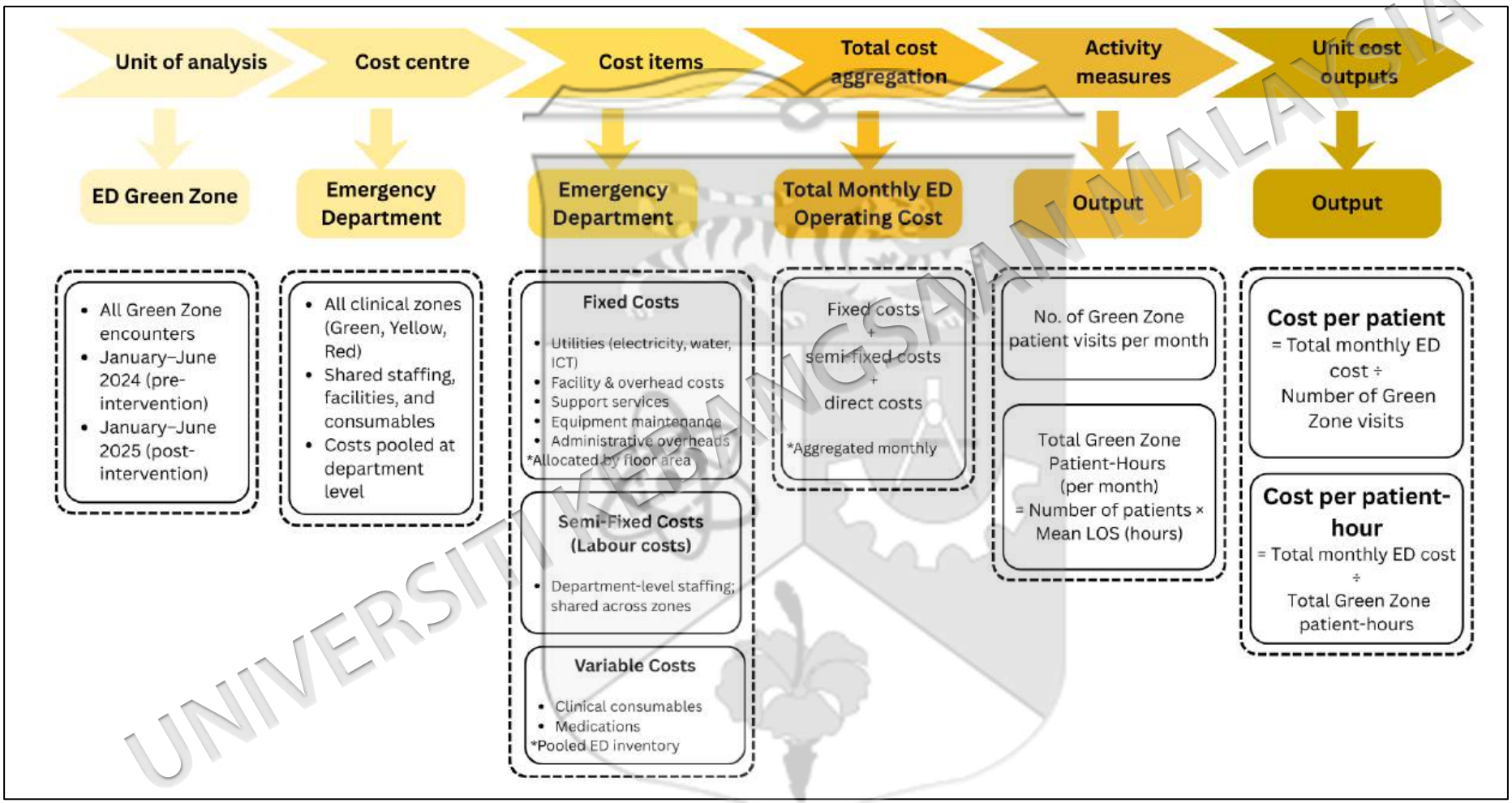

Figure 3.4 Pathway for top-down costing and unit cost estimation for the emergency department Green Zone

3.7 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 Lean workshop and model development activities involved a multidisciplinary Lean team comprising hospital staff from clinical and administrative departments. Emergency department frontliners were actively involved throughout the needs analysis, design, and development, as well as validation phases as part of routine quality improvement initiatives initiated and approved by hospital management. Participation did not require disclosure of personal, sensitive, or identifiable information. Staff contributions were voluntary, undertaken within standard professional roles, and no incentives were provided.

The operational outcome measures used in this research – triage-to-registration time (TTR), arrival-to-consultation time (ATC), and length of stay (LOS) – were derived exclusively from routinely collected, system-generated timestamps within the hospital's electronic medical record system (*iPesakit*®). These data were extracted in aggregate form by the hospital IT Department and did not contain patient names, identification numbers, or other directly identifying information. Only de-identified datasets were provided to the researcher. No direct patient contact was involved, and no identifiable clinical information was accessed, in line with the Malaysian Personal Data Protection Act (PDPA) 2010.

All datasets were stored on password-protected institutional computers and encrypted external drives accessible only to the research team. Raw timestamps and

cost records remained within hospital servers, in compliance with hospital data governance policies. Outputs used in the thesis and publications were presented only in aggregated or summarised form. No information that could allow identification of individual patients, staff members, or financial details linked to specific personnel was reported.

The study posed minimal risk to patients and staff, as it relied on existing operational data and involved no modification to treatment pathways beyond routine quality improvement activities approved by hospital management. Anticipated benefits included improved understanding of emergency department operational performance, enhanced patient flow, and potential improvements in cost efficiency, consistent with institutional objectives to strengthen service delivery.

The researcher did not hold any administrative or supervisory authority over emergency department staff and had no financial interest in any component of the intervention. Payment made to external Lean experts for the workshop was handled entirely by the hospital through established standard operating procedures (SOP). The analysis was conducted independently, and findings were reported objectively without influence from hospital administration.

Ethical approval letters and institutional permission are provided in the appendix.

3.8 CONCLUSION

This chapter has outlined the methodological framework underpinning the design, development, implementation, and evaluation of the Lean-based model for improving emergency department operations in the Green Zone. Guided by the Design and Development Research (DDR) approach, the study followed a structured sequence comprising a needs analysis, model development, and model evaluation. The methods incorporated both qualitative and quantitative elements, including stakeholder engagement, value stream mapping, Lean workshop facilitation, content validation, interrupted time series analysis, and a provider-perspective partial economic evaluation.

The sources of data, sampling procedures, measurement of operational outcomes, and analytical strategies were presented in detail to ensure transparency and reproducibility. Evaluation of the Lean-based model was conducted using a prespecified interrupted time series design with segmented regression, enabling estimation of immediate and sustained changes in operational performance relative to counterfactual projections derived from pre-intervention trends. Temporal dependence was addressed through diagnostic-led ARIMA error structures, and model adequacy was confirmed through residual diagnostics and formal tests for autocorrelation. The costing methodology used a top-down approach to derive the cost per patient and cost per patient-hour in the Green Zone. Ethical considerations were addressed to ensure the responsible handling of operational and financial data throughout the research process.

Overall, the methodological approach adopted in this study provided a systematic framework for identifying operational challenges, developing and validating a context-sensitive Lean-based model, and evaluating its effects following implementation within the emergency department Green Zone. By integrating needs analysis, model design, development, and validation, and interrupted time series analysis, and economic evaluation within a single research framework, the study enabled comprehensive examination of both operational performance and cost efficiency outcomes. The next chapter presents the findings arising from each stage of the research process, beginning with the needs analysis and model development phases, followed by the evaluation of operational and economic outcomes following implementation of the Lean-based model.

CHAPTER IV

RESULTS

4.1 INTRODUCTION

This chapter presents the findings of the study in accordance with the three phases of the Design and Development Research (DDR) framework: (1) needs analysis, (2) model design and development, and validation, and (3) model evaluation. The results are arranged sequentially based on the study design to ensure a logical flow and clarity in alignment with the research objectives.

4.2 PHASE 1: NEEDS ANALYSIS

4.2.1 Operational context and problem localisation within the emergency department

The needs analysis established that operational pressures within the emergency department were not evenly distributed across clinical zones. While the ED functions as an integrated system comprising the Red, Yellow, and Green Zones, findings consistently indicated that the Green Zone experienced the greatest concentration of workflow inefficiencies and performance strain.

Analysis of administrative data demonstrated that patient demand within the emergency department increased substantially over time, with the Green Zone accounting for the largest and fastest-growing share of patient volume. Figure 4.1 presents annual patient attendance by zone between 2016 and 2023.

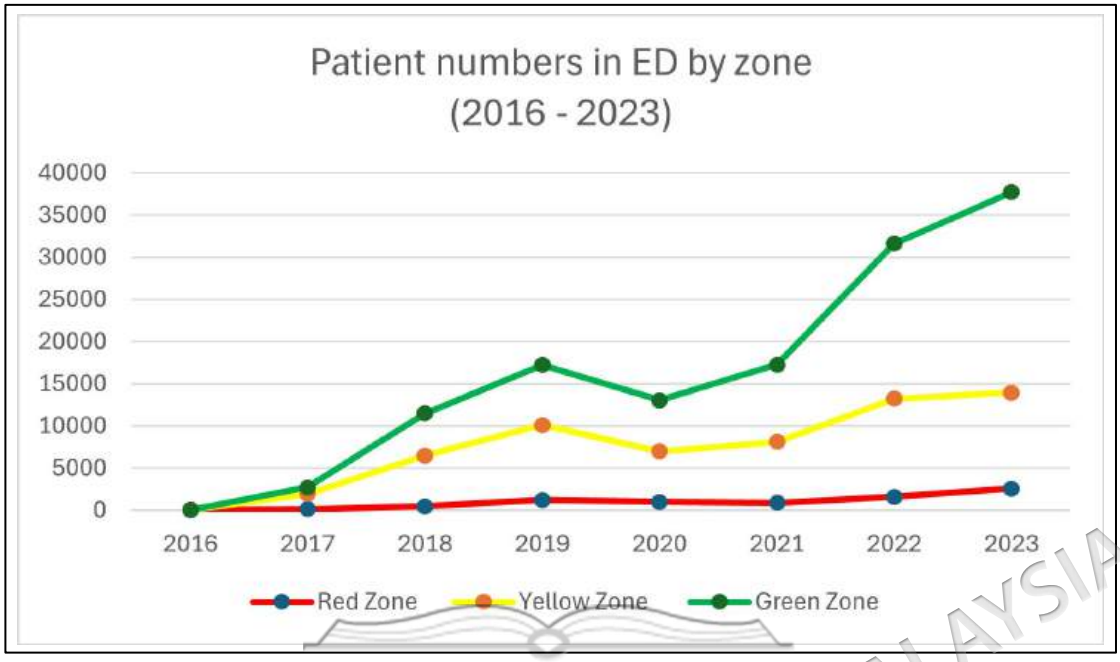

Figure 4.1 Annual emergency department patient volume by clinical zone at SASMEC IIUM, 2016–2023

Figure 4.1 shows that while all zones experienced growth, the increase was most pronounced in the Green Zone. Green Zone attendance rose steadily from 2016 to 2019, declined temporarily in 2020 in line with reduced healthcare utilisation during the COVID-19 pandemic, and rebounded sharply thereafter. By 2022, Green Zone patient volume had increased markedly, and by 2023 reached approximately 40,900 visits, substantially exceeding volumes observed in the Yellow and Red Zones.

The operational implications of this demand distribution are significant. Despite managing lower-acuity cases, the Green Zone bears the greatest absolute workload within the ED and functions as the primary interface between patients and the department. Observations conducted during the needs analysis further indicated that staffing patterns and physical resources had not expanded proportionately with the increase in Green Zone attendance. The Green Zone is staffed by a rotating team of medical officers, assistant medical officers, staff nurses, and medical health assistants. However, during periods of high acuity, cross-zone staff redeployment further constrains Green Zone capacity, contributing to congestion and prolonged waiting times.

Patient volume trends and observed operational conditions indicate that the Green Zone represents the principal pressure point within the emergency department system, providing a strong empirical basis for focusing subsequent process improvement efforts on this zone.

4.2.2 Baseline performance indicators

Baseline performance analysis was conducted to quantify existing delays and operational inefficiencies in the Green Zone prior to model development. Daily timestamp data and monthly performance reports from the 2024 pre-intervention period demonstrated prolonged waiting times across key stages of the patient journey. Analysis of patient-level data revealed a median triage-to registration (TTR) time of 6 minutes (IQR: 5), a mean arrival-to-consultation (ATC) time of 61.49 minutes (SD $\pm$ 41.97 minutes) and a mean length of stay (LOS) in the ED of 181.19 minutes (SD $\pm$ 129.99 minutes). The baseline performance is shown in Table 4.1.

Table 4.1 Baseline performance of key operational indicators in the Green Zone of the emergency department

Performance indicator	Baseline, in minutes (mean $\pm$ SD)
TTR	6.00 (5.00) *
ATC	61.49 $\pm$ 41.97
LOS	181.19 $\pm$ 129.99

*TTR is presented as median (IQR) due to non-normal distribution

Prior to this study, formal performance monitoring within the emergency department focused exclusively on a single key performance indicator: the percentage of G1 patients seen within 90 minutes. According to the Ministry of Health Emergency Medicine and Trauma Services Policy (2012), G1 patients represent low-acuity cases that require multiple diagnostic or treatment resources.

Figure 4.2 presents monthly performance against the emergency department's official Green Zone G1 KPI. Across the months shown, the majority of G1 patients were managed within the stipulated timeframe. However, the figure also demonstrates notable month-to-month variation, with a consistent subset of G1 patients exceeding the 90-minute threshold. Although smaller in absolute number, these exceedances occurred

every month. More importantly, this KPI fails to capture G2 and G3 patients, who constitute a substantial proportion of Green Zone attendances. As a result, waiting times and delays experienced by the majority of Green Zone patients are not systematically measured or reported within the current performance framework.

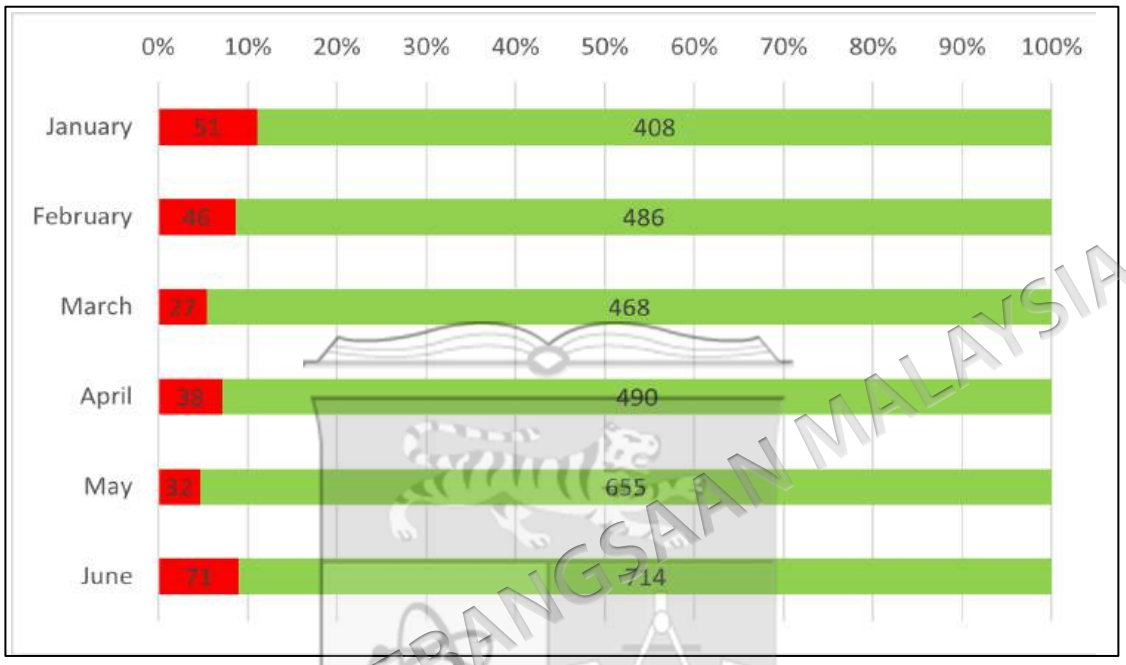

Figure 4.2 Monthly proportion of Green Zone G1 patients seen within and beyond 90 minutes at SASMEC IIUM

In addition to administrative performance indicators, patient-reported experience data provided further insight into baseline service performance in the Green Zone. Patient feedback was routinely collected using a standardised 5-point Likert scale questionnaire (1 = very poor to 5 = very good). The questionnaire evaluated ten dimensions of outpatient service quality, including staff professionalism and communication, waiting times for treatment and ancillary services, appointment scheduling, patient privacy, waiting area comfort, and overall satisfaction with care. Baseline patient satisfaction results are summarised in Table 4.2.

Table 4.2 Summary of patient satisfaction survey results for Green Zone outpatient services (pre-intervention)

	Item	Very Poor	Poor	Average	Good	Very Good	Mean ± SD
1.	Our employees are friendly, polite and helpful.	8	2	5	5	7	3.03 ± 1.60
2.	Our employees are knowledgeable and professional in executing tasks.	9	0	4	7	7	3.11 ± 1.65
3.	Waiting time to receive treatment is acceptable.	10	2	3	8	6	2.93 ± 1.62
4.	Waiting time for billing is acceptable.	4	2	5	8	8	3.52 ± 1.40
5.	Waiting time to get medication is acceptable.	5	1	3	10	8	3.56± 1.45
6.	The doctor gives a clear explanation and communication.	7	3	3	6	8	3.19 ± 1.62
7.	Our employees are concerned about patient's *aurat* and policy.	5	0	4	11	7	3.56± 1.40
8.	Scheduled appointment is satisfactory.	5	0	4	10	8	3.60 ± 1.42
9.	The waiting area is comfortable.	6	2	4	9	7	3.32 ± 1.49
10.	Received satisfactory outpatient treatment.	12	0	2	6	7	2.85 ± 1.77

Overall, mean satisfaction scores ranged from 2.85 to 3.60. The lowest-rated items were overall satisfaction with outpatient treatment (mean = 2.85 ± 1.77) and waiting time to receive treatment (mean = 2.93 ± 1.62). Moderate ratings were observed for staff friendliness and helpfulness (mean = 3.03 ± 1.60), staff professionalism (mean = 3.11 ± 1.65), doctor communication (mean = 3.19 ± 1.62), and waiting area comfort (mean = 3.32 ± 1.49). The highest-rated items were appointment services (mean = 3.60 ± 1.42), waiting time to obtain medication (mean = 3.56 ± 1.45), respect for patient privacy and aurat (mean = 3.56 ± 1.40), and waiting time for billing (mean = 3.52 ± 1.40). Notably, waiting time to receive treatment received a substantially lower rating than waiting times associated with billing and medication services.

4.2.3 Stakeholder-identified needs

Findings from administrative data, performance indicators, and patient feedback were further contextualised through input from emergency department stakeholders. These

stakeholders comprised emergency department frontliners, including emergency physicians, medical officers, assistant medical officers, staff nurses, and medical healthcare assistants, as well as selected administrative and support personnel involved in daily ED operations. Stakeholder insights were gathered informally through routine discussions, observational engagement during clinical shifts, and interactions occurring as part of normal operational activities. Recurring operational issues identified by stakeholders were grouped into four broad themes:

i. workflow congestion and waiting times
ii. fragmented movement pathways
iii. cross-zone staffing redeployment
iv. workflow interruptions and coordination challenges

A summary of the stakeholder-identified issues together with illustrative quotations is presented in Table 4.3.

Table 4.3 Summary of stakeholder-identified operational challenges within the Green Zone

Theme	Subtheme	Operational Implications	Illustrative Quotation
Workflow congestion and waiting times	Peak-period congestion	High patient influx during specific hours contributes to congestion and prolonged waiting times within the Green Zone.	"During peak hours, especially after 5 pm, the Green Zone becomes very crowded, and patients have to wait a long time to be seen."
	Limited consultation capacity	Insufficient clinician availability during high-demand periods reduces consultation capacity and contributes to delays.	"The Green Zone only has one doctor, especially after 10 pm."
Fragmented movement pathways	Multiple care transition points	Patient care requires movement across physically separated locations, increasing travel time and workflow complexity.	"Radiology is so far for the patients to go to."
	Inefficient physical layout	Spatial separation of services and inadequate wayfinding contribute to workflow inefficiencies and delays.	"Patients get lost finding (Secondary) Triage because there are no signs."
Cross-zone staffing redeployment	Staff reallocation during surge periods	Green Zone personnel are periodically redeployed to support higher-acuity zones, reducing available workforce capacity.	"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 of documentation activities interrupts clinical workflow and increases administrative burden.	"We have to document the same thing multiple times, on the nursing census, and again in iPesakit."
	Delays in referral response	Delayed attendance by primary teams prolongs patient waiting time and disposition processes.	"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	Absence of automated notification systems may delay review of completed laboratory investigations.	"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."

Collectively, stakeholder feedback highlighted several operational challenges affecting patient flow within the Green Zone. Congestion during peak attendance periods, limited consultation capacity, fragmented patient movement pathways, staff redeployment, and workflow interruptions were repeatedly identified as contributing to delays in patient progression through the department. These findings complemented the administrative performance indicators and patient feedback data by providing operational insights into the processes perceived by frontline staff to contribute to inefficiencies within the Green Zone.

4.2.4 Synthesis of the needs analysis

In this study, findings from multiple data sources converged to demonstrate a clear and consistent pattern of operational inefficiency concentrated within the emergency department Green Zone.

Administrative data showed that patient demand has increased substantially over time, with the Green Zone accounting for the largest and fastest-growing share of emergency department attendances. Baseline performance indicators further revealed prolonged and highly variable waiting times across key stages of the Green Zone patient journey, particularly between arrival and initial medical assessment. While formal performance monitoring focused narrowly on the proportion of G1 patients seen within 90 minutes, this indicator captured only a subset of Green Zone encounters and failed to reflect delays experienced by the majority of patients categorised as G2 and G3. Patient feedback data reinforced these findings by demonstrating that dissatisfaction was primarily associated with waiting time to receive treatment, rather than downstream processes such as billing or medication dispensing.

Stakeholder observations from emergency department frontliners provided additional contextual validation of these quantitative findings. Staff consistently identified congestion, fragmented movement pathways, cross-zone staffing redeployment, and interruptions to workflow as routine challenges affecting Green Zone operations.

The convergence of administrative data, performance indicators, patient feedback, and stakeholder observations established a clearly defined problem profile characterised by high demand, prolonged waiting times, and inefficiencies in the Green Zone care process. Within the DDR framework, this synthesis defined both the need for intervention and the functional requirements that the intervention must fulfil. These findings provided a strong empirical and theoretical justification for proceeding to Phase 2 of the study, which focused on the design and development of a Lean-based model tailored to the operational realities of the emergency department Green Zone.

4.3 PHASE 2: MODEL DESIGN AND DEVELOPMENT

4.3.1 Preparation and Lean team formation

Following the needs analysis, a structured model design and development process was initiated in accordance with the DDR framework. An initial kick-off meeting was convened with the top management of the hospital and emergency department representatives to confirm the project scope, objectives, and expectations for the improvement initiative. During this meeting, members of the multidisciplinary Lean improvement team were identified and formally appointed. The final team comprised emergency physicians, medical officers, nurses, medical assistants, allied health personnel (including pharmacists, radiographers, and laboratory personnel), and administrative representatives from support functions such as finance, quality management, information technology, and human resources.

In total, 29 participants were involved in the Lean training workshop and model development process, representing multiple clinical and administrative units within the hospital. The distribution of participants by professional role is summarised in Table 4.4.

Table 4.4 Distribution of Lean improvement team members by professional role

Professional category	Frequency (n = 29)	Percentage (%)
Physicians (Specialists and medical officers)	11	37.9
Nursing personnel (Matrons, sisters, staff nurses)	6	20.7

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Administrative / management (finance, human resources, IT)	4	13.8
Assistant medical officers	3	10.3
Allied health professionals (pharmacy, radiology, pathology)	3	10.3
Public health	2	6.9

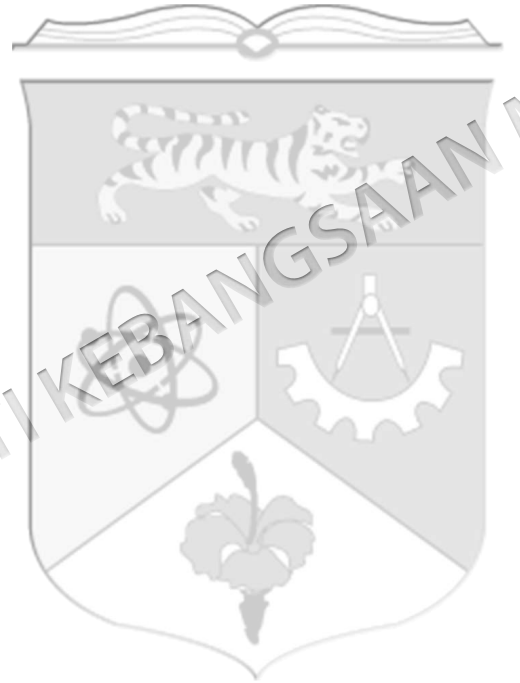
4.3.2 Lean workshop for model development

A two-day Lean Healthcare Workshop served as the central mechanism for developing the intervention model. The workshop was conducted on-site by quality engineers who are certified Lean experts and was attended by all members of the multidisciplinary Lean improvement team. The workshop provided a conceptual understanding of Lean principles among participants and provided a structured environment for collaboratively analysing, redesigning, and optimising the Green Zone workflow. Introductory sessions covered key concepts such as value and waste, flow efficiency, bottleneck identification, and the role of standardisation in healthcare processes. These concepts were reinforced through interactive simulation activities and ensured that staff with varying levels of familiarity with Lean methodology could actively participate in the model development process.

The team proceeded to map the existing Green Zone patient journey from arrival to disposition. Using real-time input from process owners and guided facilitation, participants constructed the current-state Value Stream Map (VSM). Following the creation of the initial current-state map, the team conducted a *Gemba* walk to validate the accuracy of the mapped workflow. During this on-site observation session, team members shadowed patient movement, assessed real-time task sequences, and examined environmental and spatial constraints affecting flow. Upon returning to the workshop room, the team incorporated these findings into the current-state VSM.

The current-state Value Stream Map (Figure 4.3) depicts the end-to-end patient journey through the Green Zone, beginning from primary triage and concluding with patient disposition (discharged home or transferred to the ward). The map integrates

process times (PT), waiting times (WT), resource utilisation (number and type of staff at each step), handovers, investigations, and administrative tasks. A total of 21 discrete process steps were identified along the longest patient route. Overall, the analysis revealed 96 minutes of value-added (VA) time and 303.3 minutes of non-value-added (NVA) time, with a resulting process length time (PLT) of 6.7 hours and process cycle efficiency (PCE) of 24%. This distribution shows that only one-quarter of the patient's time in the Green Zone contributes directly to clinical assessment or treatment (value-added time), whereas the majority is spent on waiting, repetition, or movement between stations.



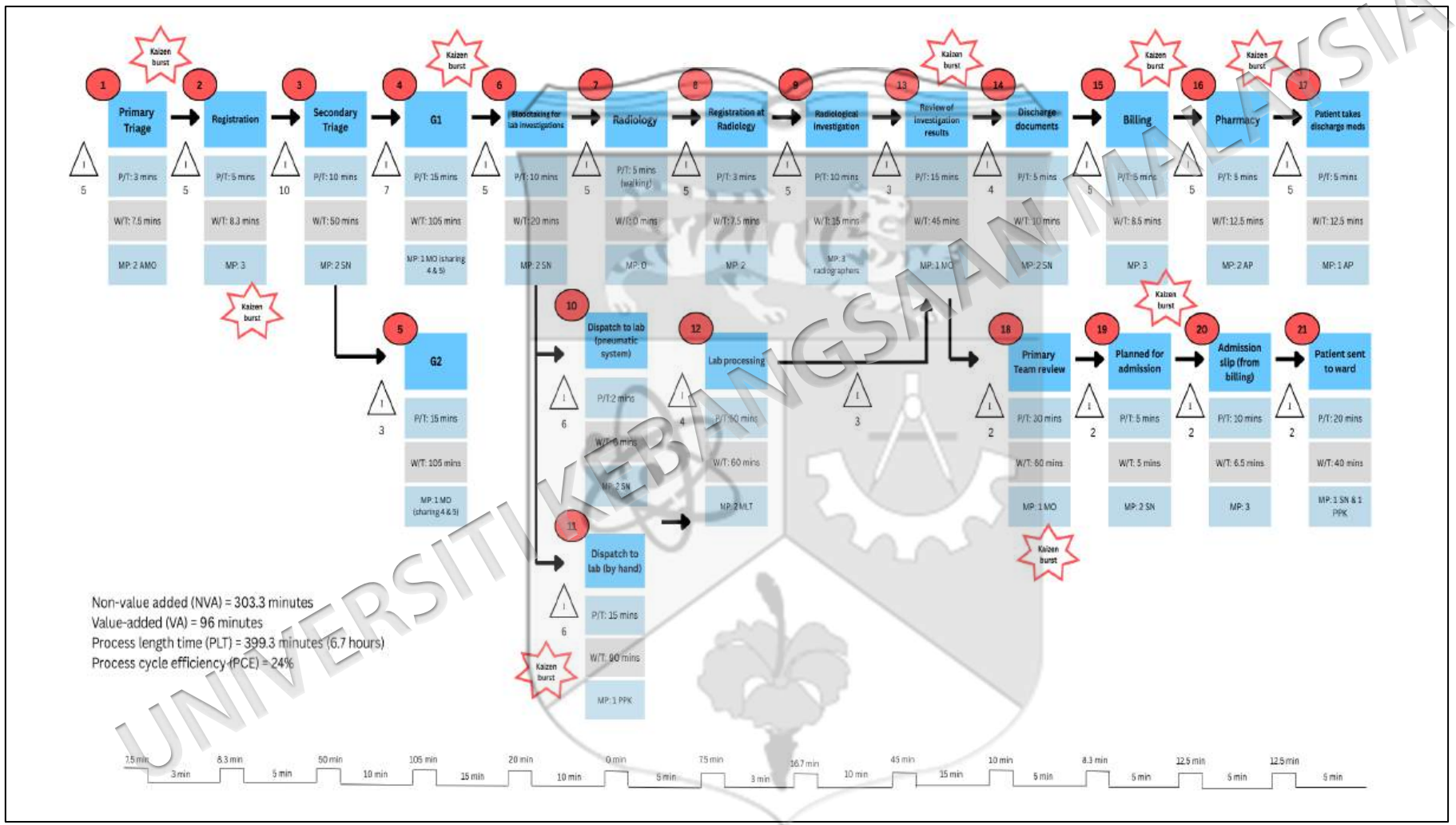


Figure 4.3 Current-state Value Stream Map

4.3.3 Analysis of the Current-state Value Stream Map

The validated current-state VSM revealed several critical inefficiencies within the Green Zone workflow. Registration and triage activities contributed non-value-added (NVA) time due to duplicated data entry across separate systems and the continued reliance on manual forms. Investigation-related steps showed prolonged and variable waiting times, particularly laboratory processing (Step 12, WT = 60–90 minutes) and radiology registration and sequencing (Steps 8–9, WT = 15–45 minutes). The coexistence of both pneumatic tube dispatch (Step 10) and manual specimen transport (Step 11) further indicated inconsistent practices and avoidable delays.

Spatial inefficiencies were also evident. Multiple steps required staff or patients to traverse physically distant points within the department, particularly between consultation areas, radiology, billing, and pharmacy. These movement pathways added time without contributing clinical value. These inefficiencies resulted in a long process length time (PLT) of 6.7 hours and a low process cycle efficiency (PCE) of 24%. By consolidating these delay points, the current state VSM provided a comprehensive diagnosis of operational shortcomings and formed the foundation for generating Kaizen opportunities and developing the future-state workflow.

4.3.4 Generation and prioritisation of Kaizen opportunities

Using the current-state VSM, the Lean improvement team engaged in a structured process to identify and prioritise opportunities for improvement within the Green Zone workflow. Sources of waste, delay, and process variation were identified through facilitated brainstorming and synthesised into Kaizen bursts, which were used to denote continuous improvement opportunities at specific points along the process flow.

Each Kaizen burst was accompanied by one or more proposed countermeasures corresponding to potential actions to improve flow and reduce inefficiencies at that location. In total, nine Kaizen bursts were identified across key process locations in the Green Zone. Several of these improvement opportunities generated multiple proposed solutions, reflecting the multifactorial nature of workflow inefficiencies at a single point

in the process. Table 4.5 summarises the identified Kaizen bursts and their associated proposed improvement actions.

Table 4.5 Kaizen improvement opportunities and associated 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 team leader medical officer
Registration	Delay in registration process due to ambiguity in individual function 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 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 staff oversees the procedure room in a single shift.	Additional manpower for procedure room (AMO).

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Radiology	The x-ray machine in the ED is not used due to insufficient manpower after office hours	Additional manpower (x-ray 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 that 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

The initial map proposes a large number of opportunities for improvement. Therefore, it was important to be able to divide them according to the impact they have on the process and in relation to the effort required to implement the solutions. The proposed Kaizen were evaluated using an effort–impact matrix to determine their feasibility and potential contribution to performance improvement. Each opportunity was assessed in terms of anticipated effect on patient flow and the relative effort, resources, or coordination required for implementation. This process allowed the team to categorise proposed improvements into high-impact, low-effort solutions and high-impact, high-effort initiatives. Figure 4.4 presents the prioritised Kaizen opportunities.

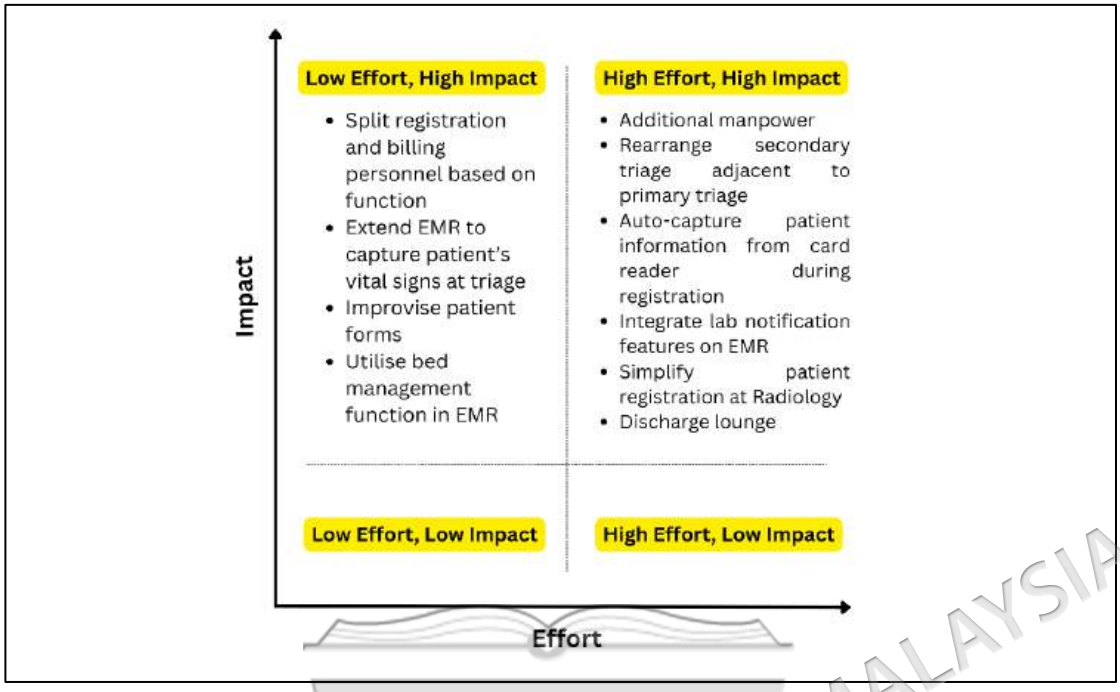

Figure 4.4 Effort-impact matrix of prioritised countermeasures

4.3.5 Future-state Value Stream Map

High-impact but high-effort initiatives, such as increasing manpower or undertaking major physical redesign of the Green Zone, were recognised as potentially transformative but were not considered feasible within the study period due to administrative processes and budgetary considerations. In contrast, several workflow-enhancing initiatives, particularly those related to optimisation of existing electronic medical record (EMR) functions, were identified as feasible within current operational constraints.

Alongside potential EMR-related modifications, a number of high-impact, low-effort improvement opportunities were identified, including simplification of registration steps and optimisation of patient movement pathways. These initiatives did not require additional staffing, major capital investment, or structural renovation and were therefore considered achievable within existing resources. The interventions that could be realistically executed within existing constraints formed the Lean-based model evaluated in this study. The feasible and implementable components were then used to develop a future-state Value Stream Map (VSM) to represent the optimised workflow for the Green Zone (Figure 4.5).

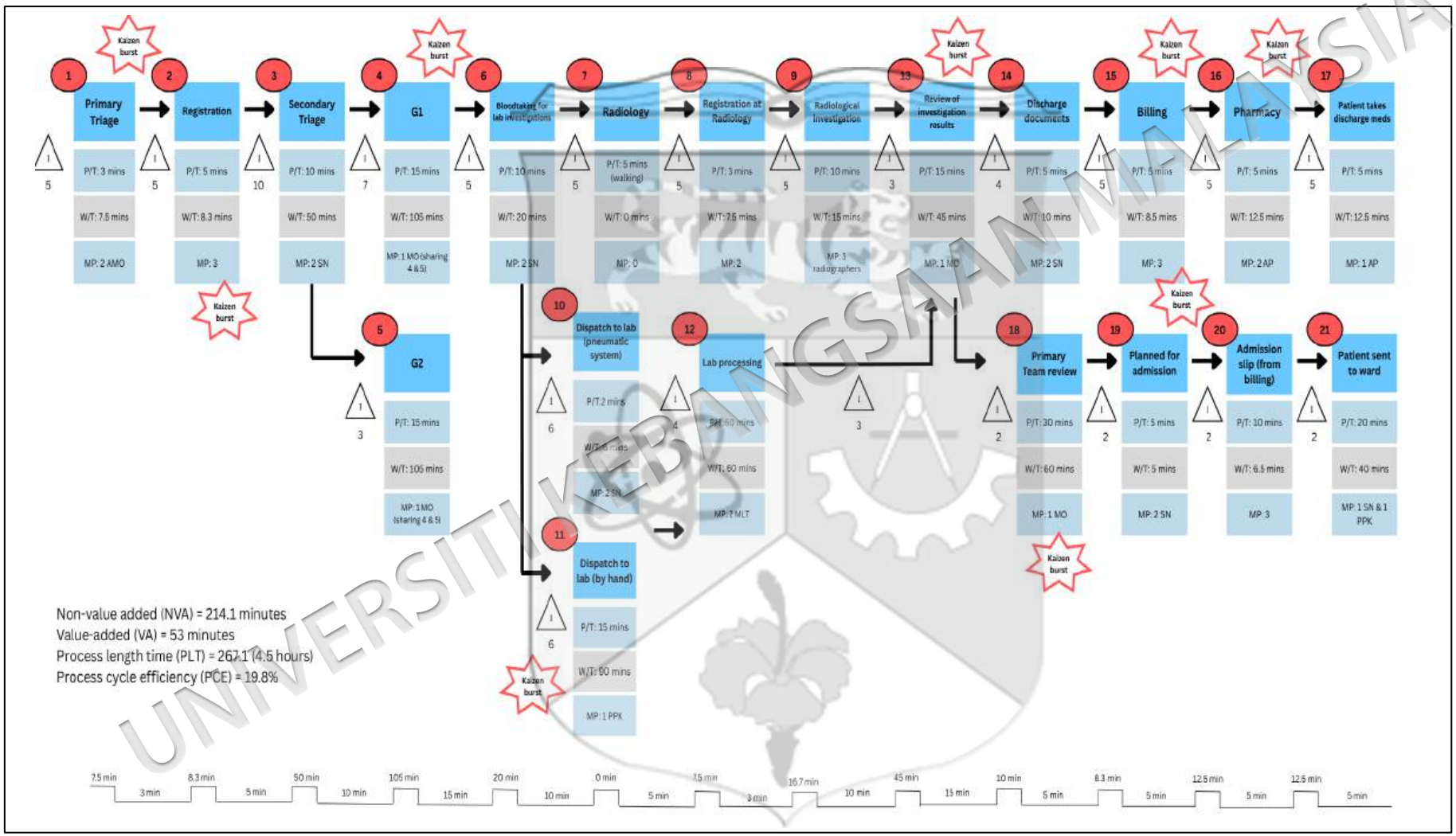

Figure 4.5 Future-state Value Stream Map

Registration and triage steps were consolidated through clearer sequencing and improved EMR documentation fields, reducing non-value-added time at the front end of the patient journey. Movement pathways were reorganised to minimise avoidable transport between consultation rooms, radiology, and pharmacy, supported by improved signage and clearer task ownership. Investigation processes were redesigned through enhanced visibility of pending results within the EMR interface. These changes reduced variation in waiting times and improved the predictability of downstream tasks.

In the future-state design, value-added time decreased from 96.0 to 53.0 minutes (44.8%), while non-value-added time decreased from 303.3 to 214.1 minutes (29.4%) and total process lead time decreased from 399.3 to 267.1 minutes (33.1%). Although the projected Process Cycle Efficiency (PCE) decreased from 24.0% in the current-state map to 19.8% in the future-state map, this should not be interpreted as deterioration in overall process performance. PCE represents the proportion of total process lead time classified as value-added from the patient perspective. In healthcare, however, the patient journey also contains necessary non-value-added (NNVA) activities that do not directly add value from the patient's perspective but are required for safe, appropriate, or organisationally necessary care and therefore cannot always be eliminated. As value-added time decreased proportionally more than the overall process lead time, the calculated PCE consequently declined. Therefore, the reduction in PCE reflects the mathematical composition of the redesigned pathway rather than an increase in waiting or process inefficiency.

The configuration of the future-state VSM represents the intended operational performance of the Green Zone following implementation of the Lean-based model.

4.3.6 Model implementation and validation

Following the development of the future-state workflow, a six-month implementation period (July–December 2024) was allocated to operationalise all components of the Lean-based model. During this period, the hospital Lean team systematically introduced each intervention in accordance with the redesigned process sequence. Implementation

progress was monitored through regular meetings, direct observation, and workflow walkthroughs to ensure that changes were applied consistently and integrated into daily practice. By the end of the implementation window, all interventions identified as feasible during the prioritisation process had been enacted.

To ensure that the model was implemented as intended, a formal model validation exercise was undertaken. Validation followed a content validity approach. Three domain experts, consisting of two certified Lean practitioners and an emergency physician, evaluated the intervention model through a checklist covering every step of the redesigned workflow. Each item represents a redesigned process step, with ratings reflecting the degree to which actual implementation matched the intended future-state intervention. A summary of checklist items, expert ratings, and corresponding CVI values is presented in Table 4.6.

Table 4.6 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

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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**

All redesigned workflow steps achieved an item-level Content Validity Index (I-CVI) of 1.00, indicating complete agreement among expert reviewers that each process element was implemented at least mostly as intended (rating ≥3). The scale-level Content Validity Index/Average was 1.00, showing excellent overall alignment between the intended future-state Lean intervention and its operational implementation in the Green Zone. These findings support the suitability of the model's evaluation in Phase 3 of the study.

4.4 PHASE 3: MODEL EVALUATION

The final phase of the study evaluated the effects of the Lean-based model on operational and economic outcomes in the emergency department. Consistent with the objectives of the intervention, three time-based performance indicators were examined: triage-to-registration time (TTR), arrival-to-consultation time (ATC), and length of stay (LOS) in the Green Zone. Changes in these outcomes were assessed using an interrupted time series (ITS) approach, enabling examination of both immediate and sustained

effects of the intervention. In addition to workflow performance, a partial economic evaluation was conducted to determine whether the intervention influenced operational efficiency from a cost perspective. This analysis focused on the cost per patient and cost per patient-hour in the Green Zone before and after Lean implementation.

4.4.1 Interrupted time series analysis

a. Autocorrelation diagnostics and ARIMA model specifications

Prior to examination of autocorrelation structures, the outcome series were assessed for stationarity in mean to determine whether differencing was required. Stationarity plots are shown for the pre-intervention period only. Visual inspection of the pre-intervention series indicated stable mean behaviour for all outcomes, supporting the use of ARMA-type error structures without differencing. These plots are presented in Figure 4.6 - Figure 4.8.

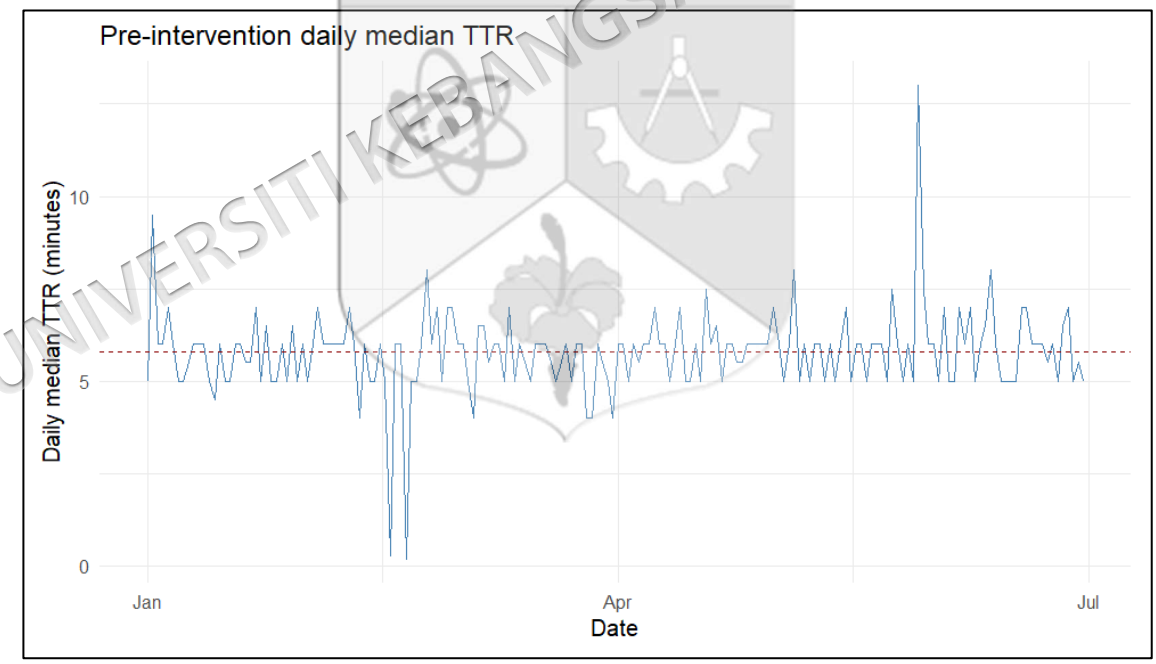

Figure 4.6 Daily median triage-to-registration time (TTR) in the emergency department Green Zone over the study period, showing stable mean behaviour prior to intervention

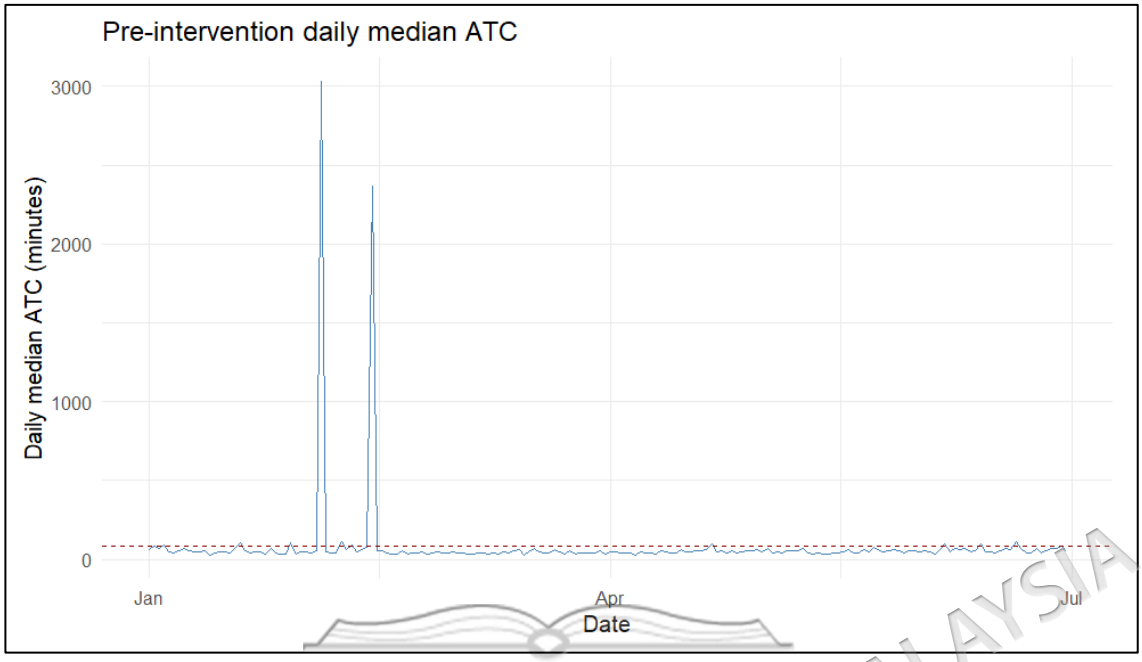

Figure 4.7 Daily median arrival-to-consultation time (ATC) in the emergency department Green Zone over the study period, illustrating variability around a stable mean

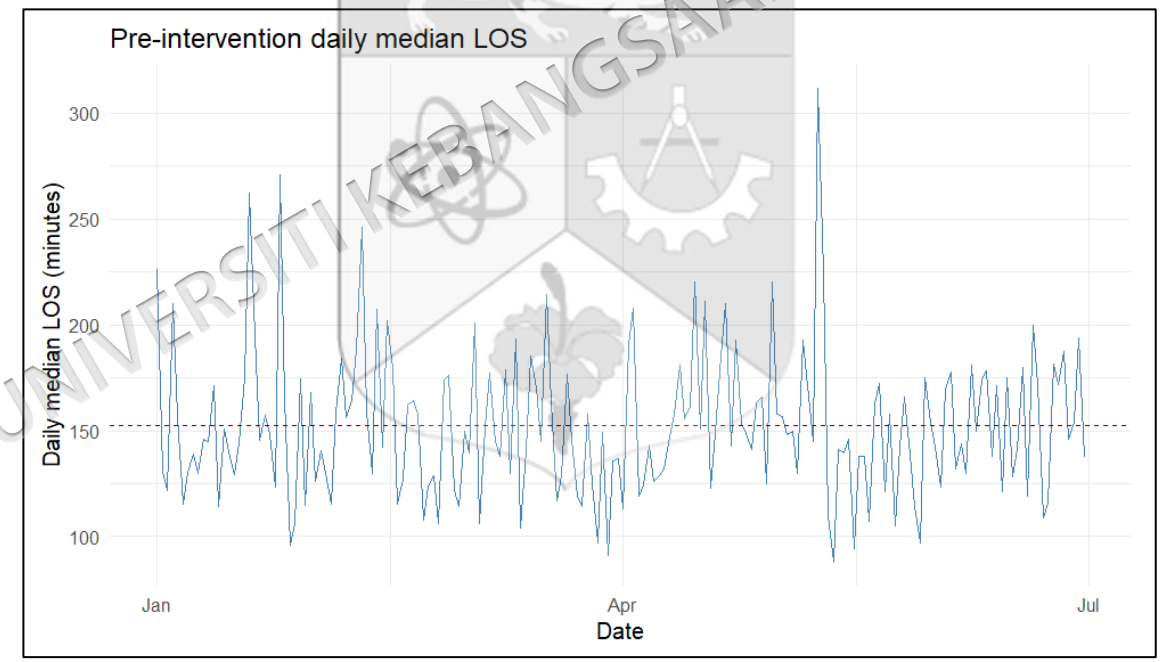

Figure 4.8 Daily median length of stay (LOS) in the emergency department Green Zone over the study period, demonstrating the absence of systematic drift in the pre-intervention period

On this basis, no non-seasonal or seasonal differencing was required, and the differencing parameter was set to zero (d = 0) for all models. Subsequent modelling therefore proceeded within the ARIMA framework with d = 0, such that the fitted models correspond to ARMA-type processes.

Autocorrelation and potential seasonal patterns were then assessed using visual inspection of the Autocorrelation Function (ACF) and Partial Autocorrelation Function (PACF) plots of the pre-intervention series. These diagnostics informed the identification of appropriate ARIMA error structures and the evaluation of whether seasonal components were warranted. Assessment focused on detecting (i) short-term persistence across adjacent lags and (ii) systematic peaks at seasonal lags, such as day-of-week effects, consistent with established time-series modelling principles (Wei 2006). ACF and PACF plots for triage-to-registration time (TTR), arrival-to-consultation time (ATC), and length of stay (LOS) are presented in Figure 4.9 - Figure 4.14.

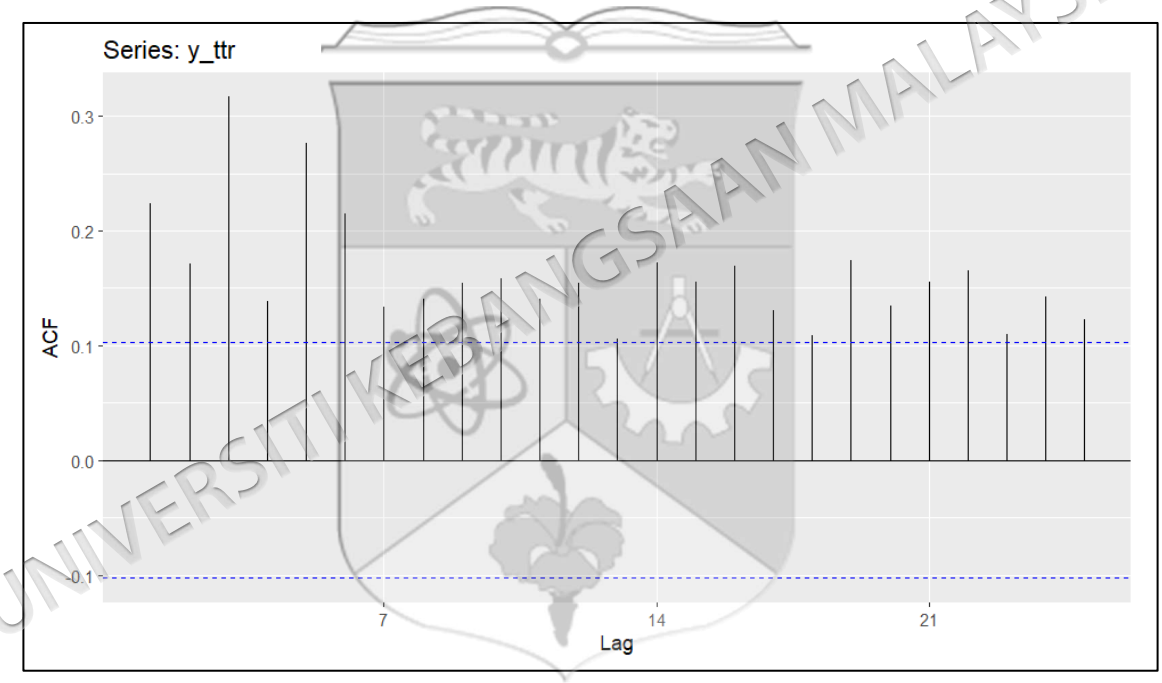

Figure 4.9 ACF plot for TTR

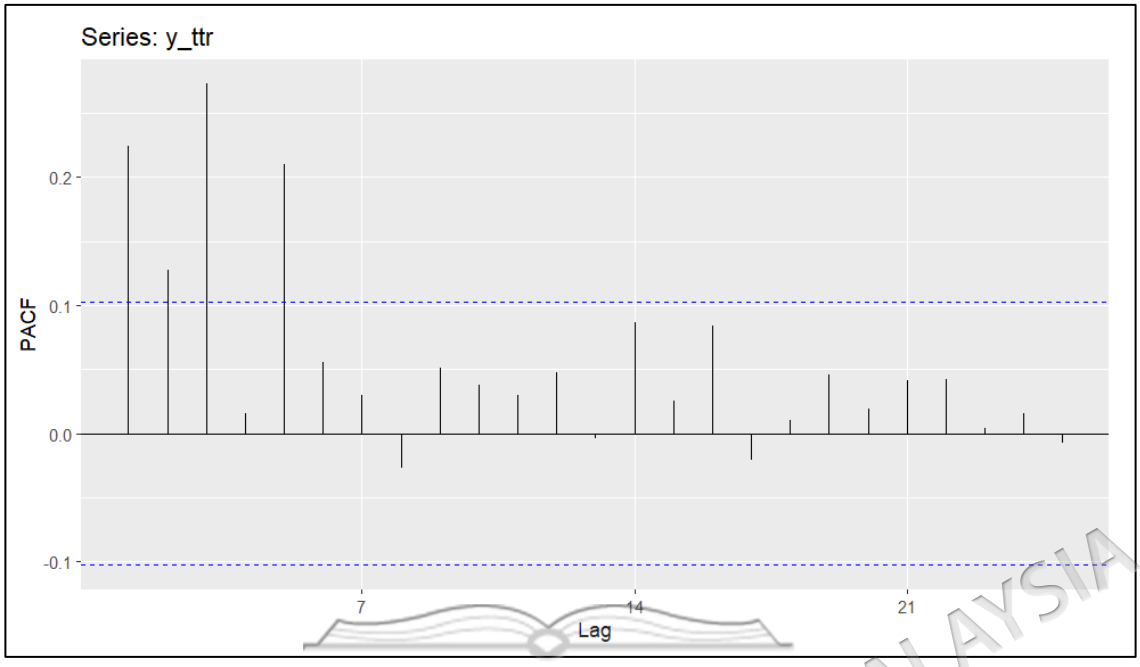

Figure 4.10 PACF plot for TTR

For triage-to-registration time (TTR), inspection of the ACF plot (Figure 4.9) shows an autoregressive process that tails off slowly rather than cutting off at a specific lag. The gradual decay supports the presence of non-seasonal autoregressive dependence. The PACF plot for TTR (Figure 4.10) shows partial autocorrelation at the first several lags, most prominently within lags 1 through 5. The PACF cuts off after lag 5, consistent with a finite-order autoregressive process, and therefore supports modelling TTR using an ARIMA (5,0,0) error structure.

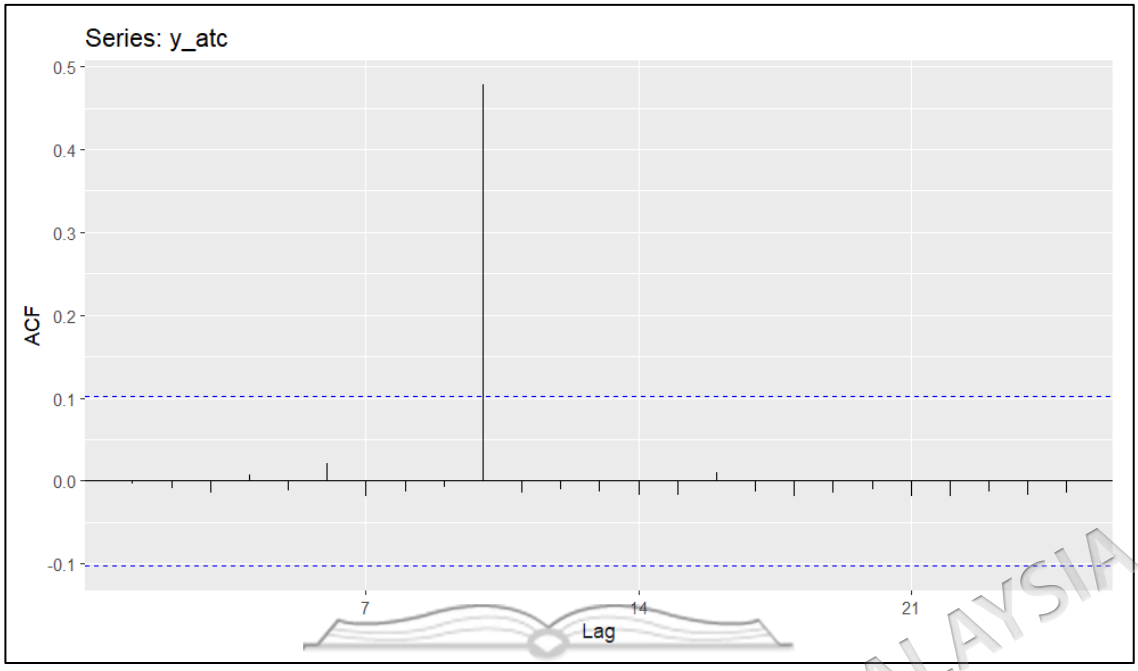

Figure 4.11 ACF plot for ATC

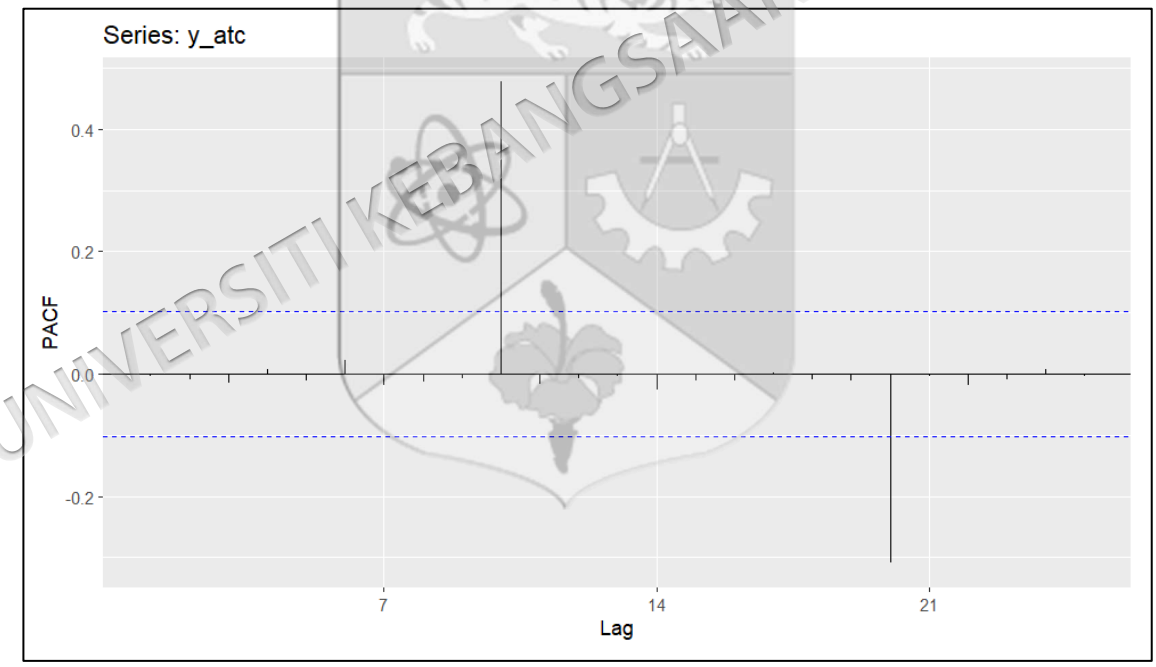

Figure 4.12 PACF plot for ATC

In contrast to TTR, both ATC and LOS exhibited no sustained autocorrelation once intervention terms were included, and were therefore appropriately modelled using ARIMA (0,0,0) error structures.

For arrival-to-consultation time (ATC), the ACF plot (Figure 4.11) is largely flat, with a single isolated spike at lag 7 and no evidence of tailing-off behaviour. The PACF plot (Figure 4.12) shows no clear cutoff pattern, with only isolated spikes present. This diagnostic pattern indicates the absence of sustained autoregressive or moving-average structure. Accordingly, ATC was modelled using an ARIMA (0,0,0) specification, which is equivalent to segmented regression with independent errors.

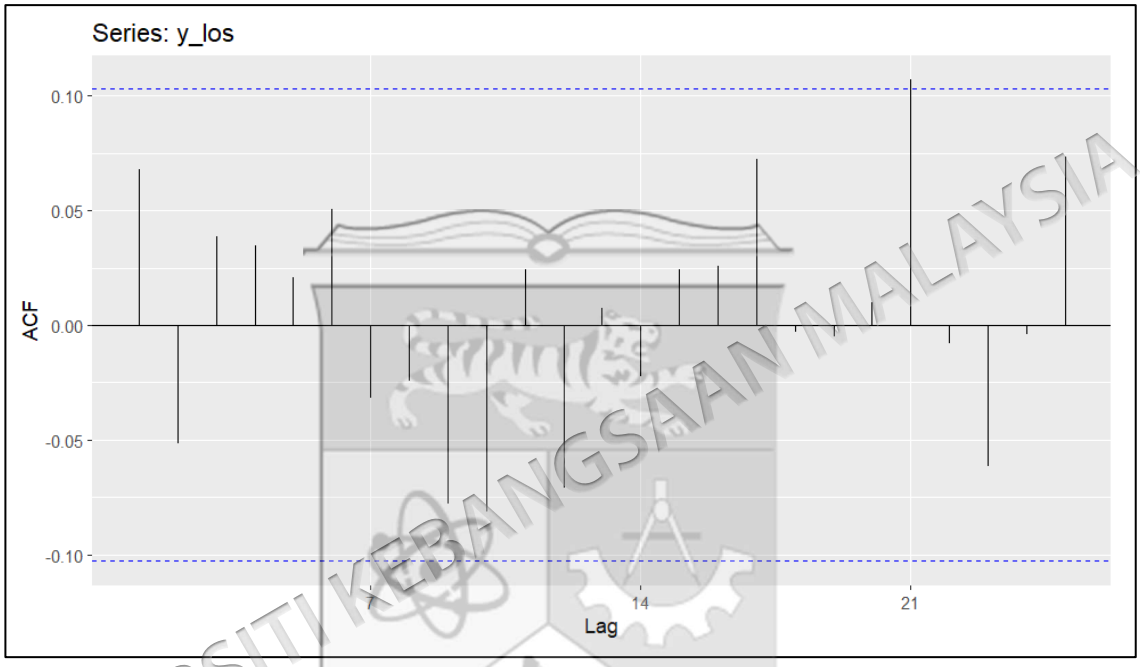

Figure 4.13 ACF plot for LOS

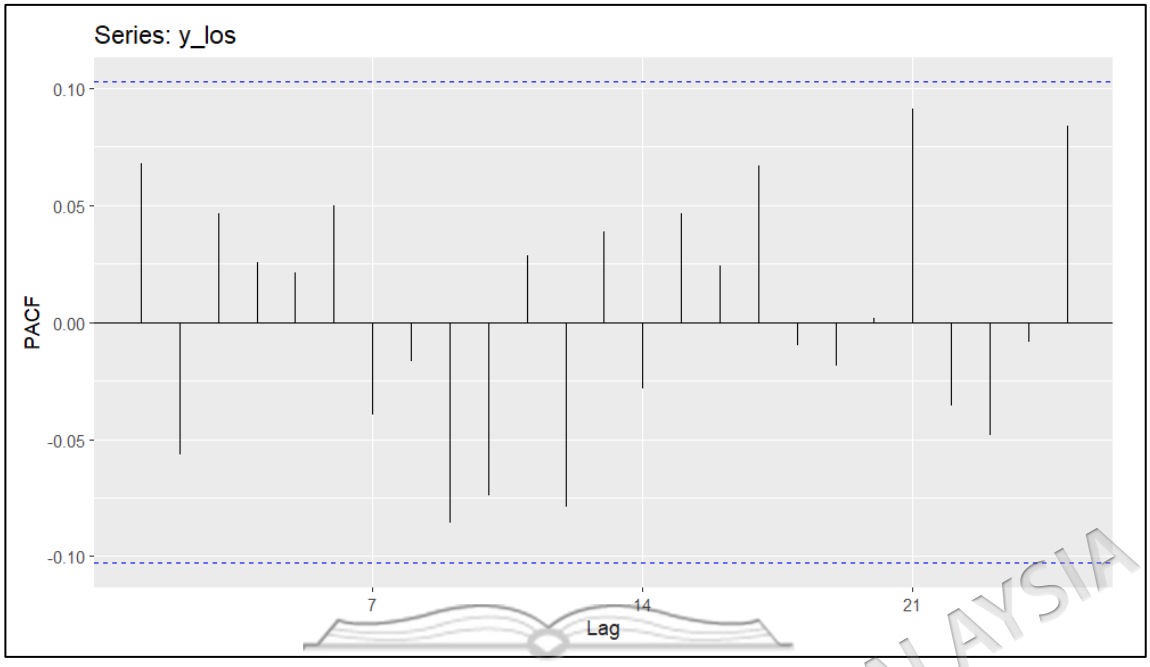

Figure 4.14 PACF plot for LOS

For length of stay (LOS), the ACF plot (Figure 4.13) shows small, irregular autocorrelation values without gradual decay, while the PACF plot (Figure 4.14) shows no cut-off or systematic structure. These diagnostics indicate no meaningful temporal dependence beyond random day-to-day variation. LOS was therefore modelled using an ARIMA (0,0,0) error structure.

A summary of the ACF and PACF diagnostic patterns and their corresponding ARIMA/ARMA model implications for all three operational outcomes is provided in Table 4.7.

Table 4.7 Summary of autocorrelation diagnostics and corresponding ARIMA model specifications for emergency department operational outcomes

Outcome	ACF pattern	PACF pattern	Final model (ARIMA framework)
Triage-to-registration time (TTR)	Tails off gradually across short lags	Cuts off after lag 5	ARIMA (5,0,0) (ARMA with 5 AR terms)
Arrival-to-consultation time (ATC)	Flat overall with one isolated spike	No cut-off; isolated spikes only	ARIMA (0,0,0) (independent errors)
Length of stay (LOS)	Small, irregular values; no tailing-off	No cut-off; random pattern	ARIMA (0,0,0) (independent errors)

b. Model adequacy and residual diagnostics

Residual diagnostic plots for the final models fitted to triage-to-registration time (TTR), arrival-to-consultation time (ATC), and length of stay (LOS) are presented in Figure 4.15 - Figure 4.17. Across all outcomes, residual time series and autocorrelation plots showed residuals fluctuating around zero with no coherent autoregressive or moving-average structure.

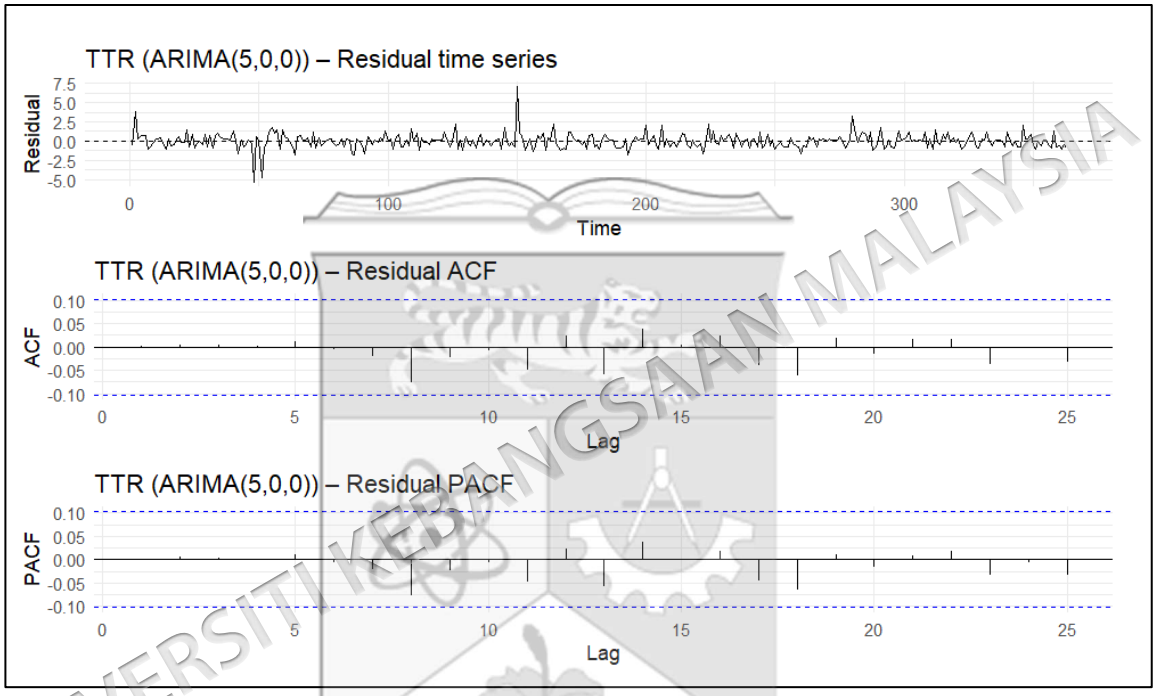

Figure 4.15 Residual diagnostic plots for TTR

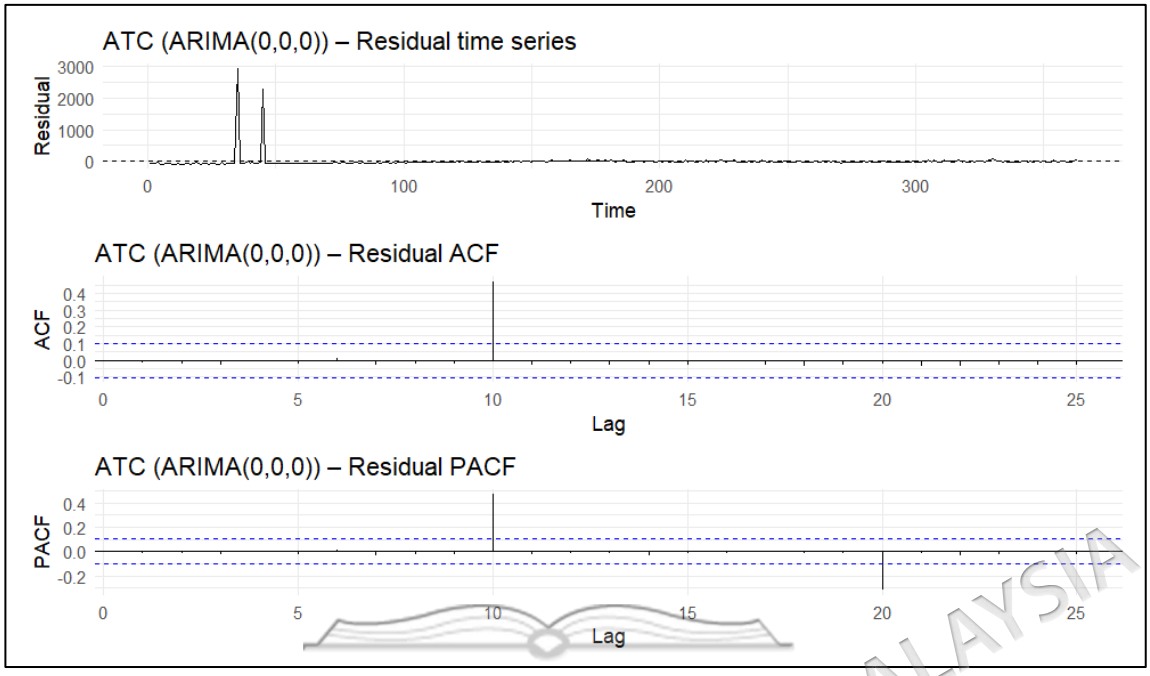

Figure 4.16 Residual diagnostic plots for ATC

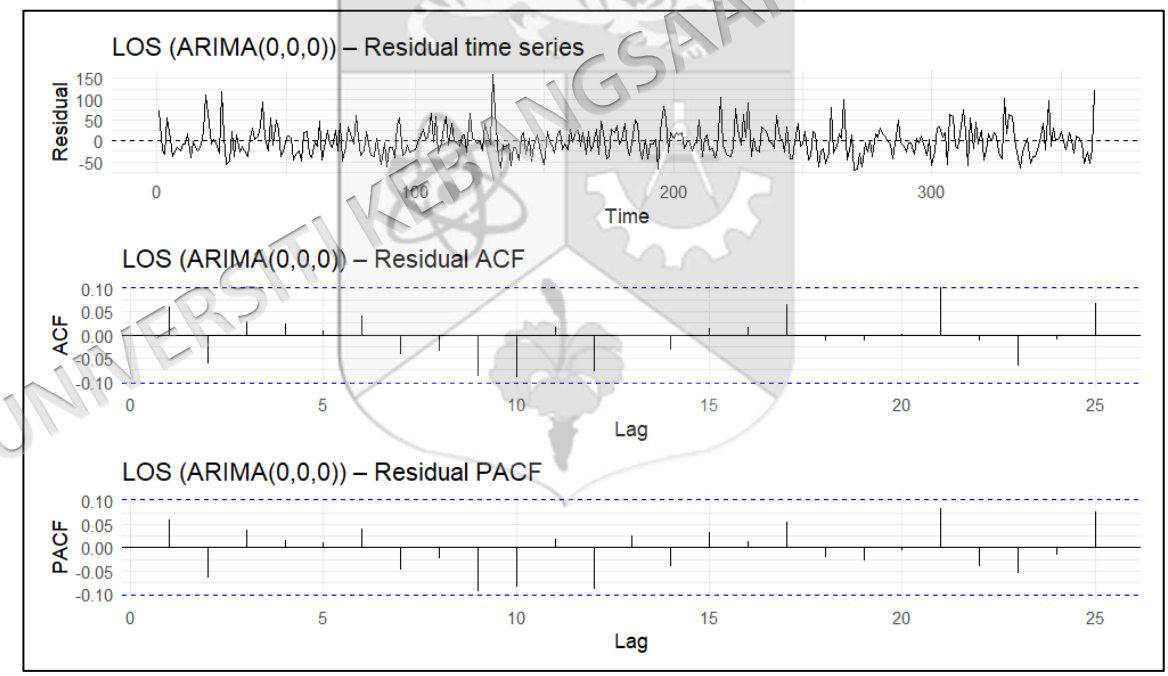

Figure 4.17 Residual diagnostic plots for LOS

Formal tests for remaining serial dependence were conducted to complement the visual diagnostics and the results are summarised in Table 4.8.

Table 4.8 Ljung–Box tests for residual autocorrelation in the final interrupted time series models

Outcome	Ljung–Box χ^2	df	p-value
TTR	8.11	20	0.990
ATC	87.63	20	**< 0.001**
LOS	15.90	20	0.720

TTR, triage-to-registration time; ATC, arrival-to-consultation time; LOS, length of stay; df, degrees of freedom.

For TTR and LOS, Ljung–Box tests provided no evidence of residual autocorrelation, supporting the adequacy of the selected error structures. For arrival-to-consultation time (ATC), the Ljung–Box test indicated residual autocorrelation despite the absence of a clear autoregressive or moving-average structure in the residual ACF and PACF plots. Given the high variability and heteroskedastic nature of ATC, this result was interpreted as reflecting irregular day-to-day fluctuations rather than a stable temporal dependence. In the absence of diagnostic support for a specific autoregressive or moving-average process, no additional AR or MA terms were introduced.

c. Triage-to-registration (TTR) time

Interrupted time series analysis for TTR was conducted using a regression model with ARIMA (5,0,0) errors, incorporating an intercept, an intervention indicator (from 1 January 2025 onwards), and a post-intervention time variable. The final model, therefore, accounted for short-term autocorrelation up to lag 5 while estimating the immediate and trend effects of the Lean intervention.

Figure 4.18 shows the interrupted time series for daily median triage-to-registration time (TTR) in the Green Zone, together with the fitted segmented trend and the counterfactual trajectory had the Lean intervention not been implemented. In the pre-intervention period (January–June 2024), observed TTR fluctuated around a stable mean of approximately 5.8 minutes, with no clear underlying upward or downward trend. At the interruption point (1 January 2025), the fitted trend shows an immediate downward shift in TTR.

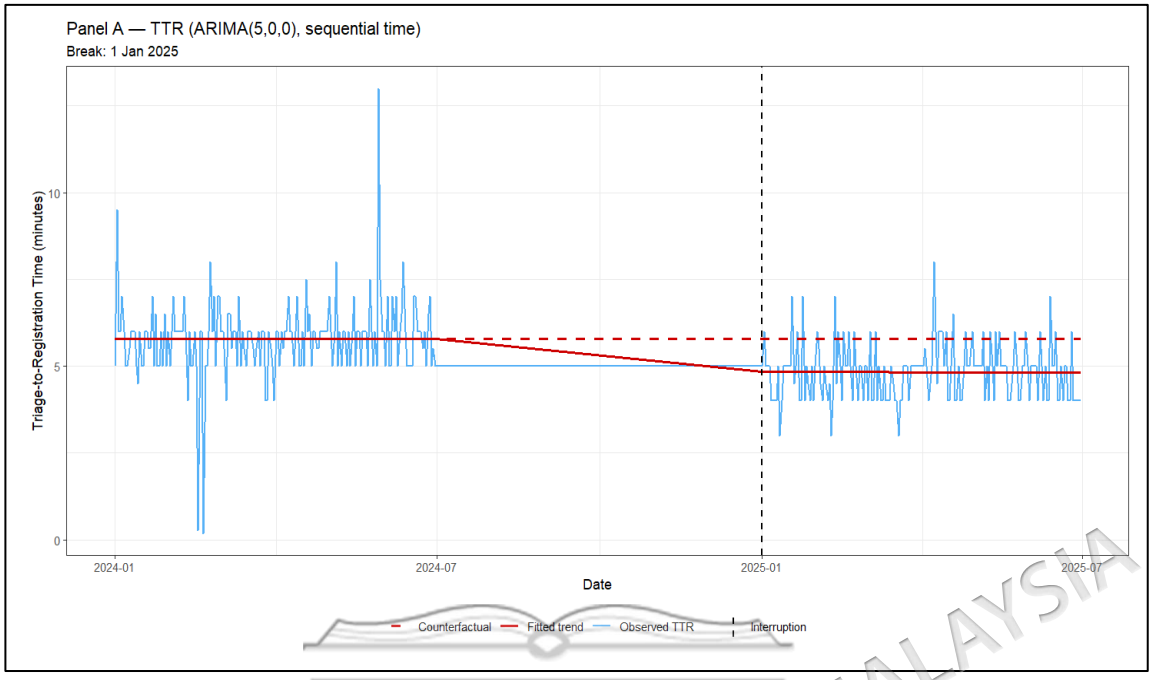

Figure 4.18 Interrupted time series of daily median triage-to-registration time (TTR) in the emergency department Green Zone

As summarised in Table 4.9, the pre-intervention mean TTR was 5.8 minutes, compared with an estimated mean of 4.8 minutes immediately after implementation of the Lean-based Green Zone Improvement Model. This corresponds to an absolute level reduction of 0.95 minutes (95% CI –1.36 to –0.53, $p < 0.001$), or a 16.3% decrease relative to the pre-intervention mean (95% CI –23.6% to –9.1%). The post-intervention trend was approximately flat, indicating that the reduction in TTR was achieved rapidly at the point of implementation and maintained over the subsequent six months.

Table 4.9 ITS estimates in triage-to-registration time (TTR) following implementation of the Lean-based model

	Pre-intervention mean	Post-intervention mean	Level change (95% CI)	% change (95% CI)	p-value
Estimate	5.79	4.84	-0.945 (-1.363 - -0.527)	-16.337 (-23.567 - -9.108)	**<0.001**

d. Arrival-to-consultation (ATC) time

Interrupted time series analysis for ATC was performed using a regression model with ARIMA (0,0,0) errors, indicating no detectable autocorrelation structure after including

the intervention terms. The final model included an intercept, an intervention indicator (from 1 January 2025 onward), and a post-intervention time variable.

Figure 4.19 displays the daily ATC data, together with the fitted segmented regression line and the counterfactual trend. For visual clarity, extreme ATC values were winsorised at the 1st and 99th percentiles, although all analyses were conducted using the original, non-winsorised data.

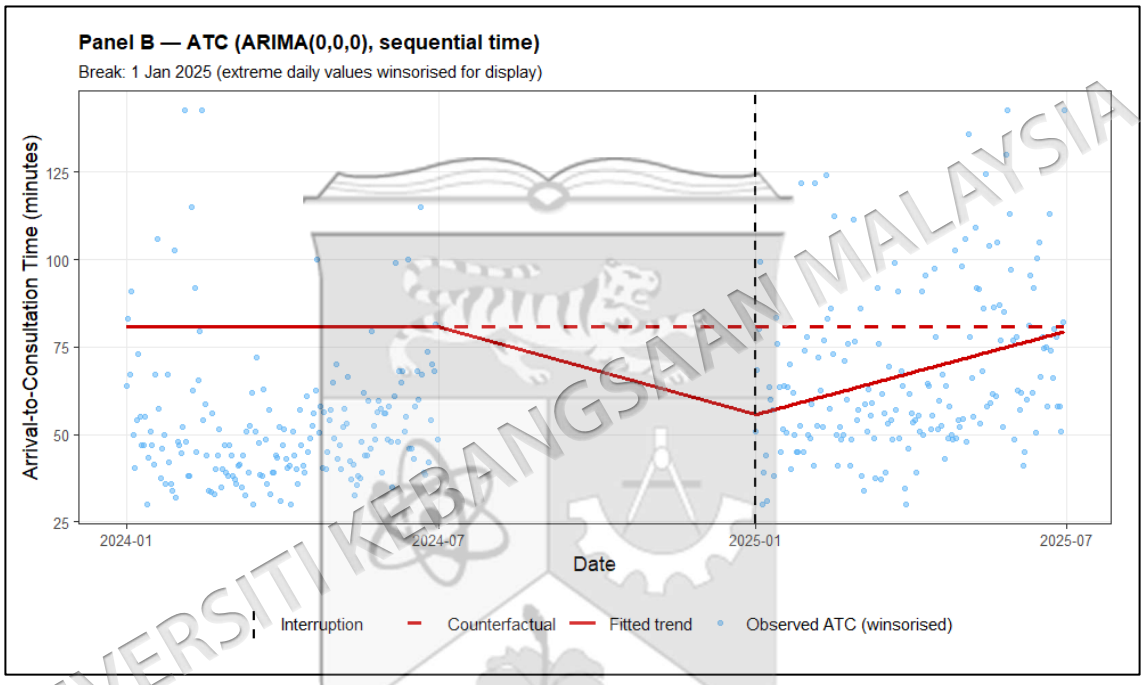

Figure 4.19 Interrupted time series of daily median arrival-to-consultation time (ATC) in the emergency department Green Zone

In the pre-intervention period (January–June 2024), ATC showed substantial day-to-day variability, with values scattered widely between 40 and 120 minutes. The fitted counterfactual line reflects this by remaining approximately flat at the estimated pre-intervention mean of 80.8 minutes. At the interruption point (1 January 2025), the model estimated an immediate level decrease of –25.36 minutes. Although the magnitude of this reduction is numerically large, the 95% confidence interval was wide (–90.0 to +39.3 minutes), and the change did not reach statistical significance ($p = 0.44$), as summarised in Table 4.10.

The post-intervention trend coefficient indicated a small positive slope (0.13 minutes per day), but again, this estimate was not statistically significant. By June 2025, the fitted trend had re-approached the counterfactual line, reflecting the high variability and the absence of a sustained directional change in the post-intervention period. These results show that while an apparent reduction in ATC was observed at the point of implementation of the Lean-based model, the effect was not statistically significant, and ATC remained highly variable before and after the intervention.

Table 4.10 ITS estimates in arrival-to-consultation time (ATC) following implementation of the Lean-based model

	Pre-intervention mean	Post-intervention mean	Level change (95% CI)	% change (95% CI)	p-value
Estimate	80.83	55.47	-25.365 (-90.049 - 39.319)	-31.38 (-111.40-48.67)	0.442

e. Length of stay (LOS) in the Emergency Department

Interrupted time series analysis for Length of Stay (LOS) in the Green Zone was conducted using a regression model with ARIMA (0,0,0) errors. Although exploratory visual inspection suggested possible weekly fluctuations, formal diagnostics found no evidence that seasonal terms improved model fit. The non-seasonal ARIMA specification was therefore retained. The final model included an intercept, an intervention indicator beginning 1 January 2025, and a post-intervention time term.

Figure 4.20 presents the LOS time series together with the fitted segmented regression trend and the counterfactual trajectory assuming no intervention.

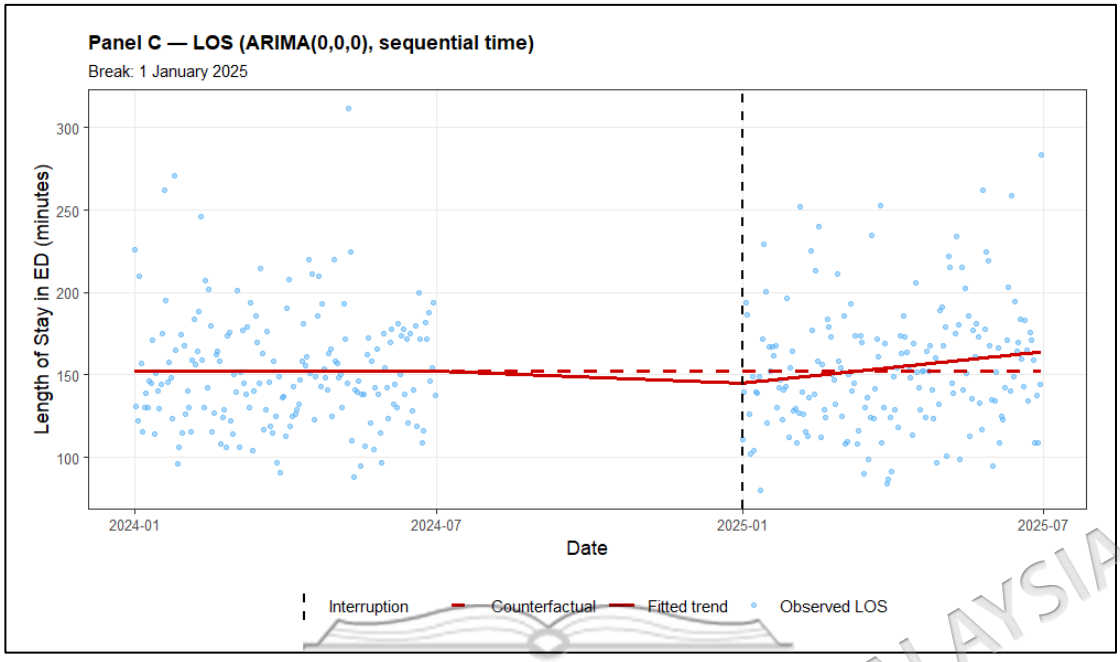

Figure 4.20 Interrupted time series of daily median length of stay (LOS) in the emergency department Green Zone

In the pre-intervention period (January–June 2024), LOS exhibited considerable day-to-day variability, ranging broadly across the 120–200-minute interval, consistent with the high residual variance observed in the model. The counterfactual trend, which represents the expected LOS in the absence of intervention, remained nearly flat at the estimated pre-intervention mean of approximately 152.6 minutes. At the interruption point (1 January 2025), the fitted model estimates an immediate reduction in LOS of 7.7 minutes (95% CI: –19.5 to +4.1 minutes; p = 0.20). The summary of ITS estimates for LOS in the ED are shown in Table 4.11.

While the direction of change favoured improvement, the effect was not statistically significant. Unlike the immediate level change, the post-intervention slope was slightly positive (+0.11 minutes per day), indicating a gradual upward drift in LOS during the six-month follow-up period. As a result, by June 2025, the fitted LOS line converged back toward the counterfactual trajectory, suggesting that any early gains were not sustained over time.

Table 4.11 ITS estimates in length of stay (LOS) following implementation of the Lean-based model

	Pre-intervention mean	Post-intervention mean	Level change (95% CI)	% change (95% CI)	p-value
Estimate	152.60	144.88	-7.72 (-19.50 - 4.07)	-5.06 (-12.77 - 2.67)	0.200

f. Summary of interrupted time series analysis results

Interrupted time series modelling was conducted for three operational outcomes – triage-to-registration time (TTR), arrival-to-consultation time (ATC), and length of stay (LOS) – using segmented regression with ARIMA error structures selected based on autocorrelation diagnostics. Each model included an intercept, an intervention indicator beginning 1 January 2025, and a post-intervention slope term.

For triage-to-registration time (TTR), the ARIMA (5,0,0) model estimated a clear immediate reduction in the level at the intervention point that was statistically significant. For arrival-to-consultation time (ATC), the ARIMA (0,0,0) model estimated a reduction at the intervention point, but the change could not be distinguished from normal variability. Post-intervention values closely followed the counterfactual, showing no measurable improvement in ATC. Finally, for length of stay (LOS), the ARIMA (0,0,0) model estimated a small reduction in LOS immediately after the intervention, but this change was not significant, and daily values remained highly variable. The post-intervention trajectory was close to the counterfactual, indicating no statistically clear change in LOS.

Overall, only TTR demonstrated measurable improvement according to the ITS model following the Lean-based intervention, while ATC and LOS did not exhibit statistically reliable changes during the post-intervention period. The full model coefficients, confidence intervals, and associated p-values are summarised in Table 4.12.

Table 4.12 Summary of ITS estimates for key Green Zone operational indicators before and after implementation of the Lean-based model.

Outcome	Pre-intervention mean	Post-intervention mean	Level change (95% CI)	% change (95% CI)	p-value
TTR	5.79	4.84	-0.95 (-1.36 - -0.53)	-16.34 (-23.57 - -9.11)	**<0.001**
ATC	80.83	55.47	-25.365 (-90.049 - 39.319)	-31.38 (-111.40-48.67)	0.442
LOS	152.60	144.88	-7.72 (-19.50 - 4.07)	-5.06 (-12.77 - 2.67)	0.20

4.4.2 Cost analysis

This section presents the results of the partial economic evaluation comparing the cost of operating the Green Zone before and after implementation of the Lean-based model. Costs were analysed from the hospital provider perspective using a top-down approach. Costs are reported for the six-month pre-intervention period (January–June 2024) and the six-month post-intervention period (January–June 2025).

a. Total cost and service volume

Table 4.13 summarises the total operating cost and service volume between the pre-intervention and post-intervention periods. Total Green Zone operating expenditure decreased slightly from RM 5,670,993.49 in the pre-intervention period to RM 5,521,630.21 post-intervention, representing a 2.63% reduction. During this time, total patient visits increased from 6,632 to 7,927, a 19.53% increase in throughput. Total accumulated patient-hours rose by 17.89% from 20,027.65 to 23,616.64 hours. The difference in average monthly operating expenditure was RM 24,893.88, corresponding to an annualised reduction of RM 298,726.56.

Table 4.13 Summary of total costs, service volume, and average monthly operating costs for the emergency department Green Zone before and after implementation of the Lean-based model

Metric	Pre-Lean	Post-Lean	% change
Total cost (RM)	5,670,993.49	5,521,630.21	-2.63

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Total patients	6,632	7,927	+19.53
Total patient-hours	20,027.65	23,616.64	+17.89
Average monthly cost (RM)	945,165.58	920,271.70	-2.63

Costs are reported in Malaysian Ringgit (RM). Pre-Lean period: January–June 2024; Post-Lean period: January–June 2025. Percentage change reflects the relative difference between periods.

b. Cost per patient and cost per patient-hour

Substantial reductions in unit cost were observed following Lean implementation Table 4.13. The cost per patient decreased from RM 855.10 to RM 696.56, a reduction of RM 158.54 (–18.54%). Similarly, the cost per patient-hour decreased from RM 283.16 to RM 233.80, a reduction of RM 49.36 (–17.43%).

Table 4.14 Comparison of unit cost metrics (cost per patient and cost per patient-hour) in the emergency department Green Zone before and after implementation of the Lean-based model.

Metric	Pre-Lean	Post-Lean	Absolute Change	% Change	p-value
Cost per patient (RM)	855.10	696.56	–158.54	–18.54%	0.19
Cost per patient-hour (RM)	283.16	233.80	–49.36	–17.43%	0.14

Costs are reported in Malaysian Ringgit (RM). Pre-Lean period: January–June 2024; Post-Lean period: January–June 2025. Absolute and percentage changes are calculated relative to the pre-Lean period.

4.5 SUMMARY OF RESULTS

The results of the study are summarised according to the research objectives in Table 4.15. Collectively, the findings demonstrate the identification of a priority intervention area within the emergency department, the development and validation of a context-specific Lean-based model, and favourable changes in operational and cost-related indicators following implementation. The most notable improvement was observed for triage-to-registration time, while reductions in arrival-to-consultation time, length of stay, cost per patient, and cost per patient-hour were not significant.

Table 4.15 Summary of key findings according to research objectives

Research Objective	Key Findings	Evidence
RO1: To identify the most appropriate focus area for intervention based on operational performance indicators, patient feedback, and stakeholder input.	The Green Zone was identified as the priority area for intervention due to high patient volume, prolonged waiting times, lower patient satisfaction regarding waiting time to treatment, and recurring workflow challenges identified by stakeholders.	• Green Zone attendances increased to approximately 40,900 visits in 2023. • Baseline performance indicators demonstrated delays in TTR, ATC, and LOS. • Patient satisfaction ratings were lowest for waiting time to receive treatment. • Stakeholders identified congestion, fragmented patient movement, staffing redeployment, and workflow interruptions.
RO2: To design and develop a Lean-based model tailored to the Emergency Department Green Zone.	A context-specific Lean-based model was developed using an integration of Lean tools, including multidisciplinary engagement, Value Stream Mapping, *Gemba*, and *Kaizen*. The model was validated to ensure that implementation was aligned with the intended intervention design.	• Lean team comprised 29 multidisciplinary stakeholders. • Current-state VSM identified 21 process steps and a process cycle efficiency of 24%. • Nine Kaizen opportunities were prioritised. • Future-state VSM projected reduction in total process time from 6.7 hours to 4.5 hours. • Content validity assessment demonstrated excellent agreement (I-CVI = 1.00; S-CVI/Ave = 1.00).
RO3: To evaluate the effects of the Lean-based model on operational performance.	Implementation was associated with a statistically significant reduction observed for triage-to-registration time (TTR), while changes in arrival-to-consultation (ATC) and length of stay (LOS) were not statistically significant.	TTR decreased from 5.79 to 4.84 minutes (−16.34%, $p < 0.001$). ATC decreased from 80.83 to 55.47 minutes (−31.38%, $p = 0.442$). LOS decreased from 152.60 to 144.88 minutes (−5.06%, $p = 0.200$).
RO4: To estimate changes in operational cost efficiency following implementation of the Lean-based model.	Cost efficiency improved following the implementation, but were not statistically significant.	Cost per patient decreased from RM855.10 to RM696.56 (−18.54%, $p = 0.19$). Cost per patient-hour decreased from RM283.16 to RM233.80 (−17.43%, $p = 0.14$).

4.6 CONCLUSION

This chapter presented the empirical findings of the study across the three phases of the Design and Development Research (DDR) framework: needs analysis, model design and development, and model evaluation. The needs analysis identified the emergency department Green Zone as the primary operational pressure point within the department, characterised by increasing patient demand, prolonged waiting times, and inefficiencies in the patient care pathway. These findings provided the empirical foundation for the development of a Lean-based intervention model tailored to the operational realities of the study setting.

Through a structured Lean workshop, multidisciplinary collaboration, and Value Stream Mapping, a future-state workflow model was developed and implemented to address the identified inefficiencies. Validation by Lean experts and an emergency physician confirmed that the redesigned workflow was implemented in accordance with the intended Lean model within the Green Zone setting.

Evaluation using interrupted time series analysis demonstrated a statistically significant reduction in triage-to-registration time. In contrast, arrival-to-consultation time and overall length of stay showed no statistically significant changes during the evaluation period. A cost analysis further indicated improvements in operational cost efficiency, with reductions observed in cost per patient and cost per patient-hour alongside increased patient throughput.

The next chapter interprets these findings in relation to existing literature on Lean healthcare implementation, emergency department operations, and healthcare process improvement, with particular attention to understanding the factors that may explain the observed pattern of outcomes.

CHAPTER V

DISCUSSION

5.1 INTRODUCTION

This study aimed to identify priority areas for improvement within a public university hospital emergency department, design and develop a context-sensitive Lean-based model, and evaluate its effects on operational performance and cost efficiency. Using a Design and Development Research (DDR) framework, the study combined systematic needs assessment, Lean intervention design and development, implementation, and evaluation within a single research framework.

The findings from the needs analysis confirmed that the Green Zone represented a major operational pressure point within the emergency department, characterised by high patient volume, workflow inefficiencies, prolonged waiting times, and patient dissatisfaction related to service delays. In response, a Lean-based model was developed through the integration of multiple Lean tools and techniques. The resulting model was subsequently implemented within the Green Zone and validated to ensure consistency between the intended intervention design and its implementation

Evaluation of the intervention produced mixed but important findings. The Lean-based model was associated with a statistically significant and sustained reduction in triage-to-registration time, indicating improved efficiency in front-end patient processing. Although arrival-to-consultation time and length of stay showed reductions following implementation, these improvements were not statistically significant and were not sustained over time. From an economic perspective, operational cost efficiency improved, with reductions observed in both cost per patient and cost per patient-hour despite increasing patient volume during the post-implementation period.

These findings suggest that the intervention was effective in improving selected operational processes and resource utilisation, while its influence on broader throughput outcomes was more limited.

This chapter interprets these findings in relation to existing literature on Lean healthcare implementation, emergency department operations, and healthcare process improvement. Particular attention is given to understanding why the intervention produced differing effects across operational outcomes and what these findings reveal about the opportunities and limitations of Lean implementation within complex emergency care environments.

5.2 SYSTEMATIC NEEDS ANALYSIS AS A FOUNDATION FOR LEAN INTERVENTION DESIGN

A key finding of this study was the identification of the Green Zone as the most appropriate target for Lean intervention within the emergency department. This conclusion emerged from a structured needs analysis that integrated administrative utilisation data, operational performance indicators, patient-reported experience measures, stakeholder perspectives, and direct observation of clinical workflows. These data sources converged on a consistent pattern of operational strain within the Green Zone.

The prioritisation of the Green Zone is consistent with previous evidence suggesting that lower-acuity emergency care pathways frequently experience substantial operational strain despite managing clinically less urgent patients. In a Malaysian university hospital, Mohd Yusoff et al. (2018) reported that prolonged waiting times, overcrowding, staffing shortages, and consultation bottlenecks within the Green Zone contributed to difficulties in achieving established targets. Similarly, Ibrahim et al. (2023) observed that approximately 80% of emergency department attendances were managed within the Green Zone, resulting in a mismatch between patient demand and available resources that contributed to overcrowding and treatment delays. Comparable findings were also reported by Krisnan et al. (2025), who described Green Zone overcrowding as being characterised by prolonged waiting times, workflow inefficiencies, staffing shortages, investigation delays, and increasing workload

pressures among healthcare workers. These studies suggest that although lower-acuity patients generally require less intensive clinical management, the large volume of attendances within these care streams often creates significant operational pressure and congestion.

The findings may be further understood through the nature of patient flow within lower-acuity pathways. Unlike higher-acuity zones, Green Zones frequently manage a continuous influx of semi-urgent and non-urgent patients throughout the day. Amorim et al. (2019) and Falconer et al. (2018) demonstrated that lower-acuity patients arrived substantially more frequently than higher-acuity groups, creating sustained pressure on consultation capacity and increasing the risk of queue formation; and were more likely to experience prolonged waiting and delays in clinical assessment. These observations in global ED overcrowding literature help explain why the Green Zone emerged as the principal area of concern in the present study.

The diagnostic profile identified in this study is consistent with Asplin et al.'s (2003) conceptualisation of emergency department crowding as the product of interactions between input, throughput, and output factors. While rising patient demand undoubtedly contributed to increasing pressure on the emergency department, the triangulated findings suggest that the dominant constraint within the study setting was located within the throughput domain. Fragmented movement pathways, duplicated documentation processes, interruptions to clinical workflow, delays in reviewing investigation results, and staffing disruptions arising from cross-zone redeployment were repeatedly identified as contributors to inefficiency. These findings indicate that delays were not solely a consequence of increasing attendance volume but were also amplified by operational processes occurring within the department itself. Delays occurring during triage, registration, consultation, and investigation stages may subsequently propagate throughout the patient journey, resulting in cumulative waiting times and reduced throughput efficiency (Maninchedda et al. 2023; Samadbeik et al. 2024; Youssef et al. 2024).

The patient experience findings further reinforce this interpretation. Evidence indicates that waiting time and timeliness of clinical assessment are among the strongest

determinants of patient satisfaction within emergency departments, particularly among lower-acuity patients whose care pathways frequently involve extended waiting before physician review (Janerka et al. 2024). In the present study, dissatisfaction was concentrated around waiting time to receive treatment, corresponding closely with the operational bottlenecks identified through administrative data and stakeholder feedback. Furthermore, routine performance monitoring relied primarily on the "G1 seen within 90 minutes" indicator, which reflected only a subset of Green Zone encounters and provided limited visibility of delays experienced by the larger G2 and G3 patient populations. The integration of multiple data sources, therefore, provided a more comprehensive understanding of operational performance than reliance on a single service indicator alone (Mostafa & El-Atawi 2024).

An important observation arising from these findings is that emergency departments should not be viewed as homogeneous operational systems when planning process improvement initiatives. Although many Lean emergency department studies acknowledge variation in patient acuity and care pathways, intervention design is frequently undertaken at the level of the emergency department as a whole or within pre-selected operational processes (Abdul Aziz et al. 2022; Abeidi et al. 2018; Dickson et al. 2009; Meidawati & Arini 2024; Tejedor-Panchon et al. 2014; Vashi et al. 2019). For example, Dickson et al. (2009) employed workflow analysis, process mapping, and value stream mapping to redesign emergency department operations, but provided limited explanation regarding how the intervention focus was initially selected. As patient streams differ substantially in terms of acuity, clinical objectives, staffing requirements, workflow complexity, and service demand, operational strain may not be distributed evenly across all areas of the department. This highlights the importance of structured needs assessment integrating administrative utilisation data, operational performance indicators, patient experience measures, stakeholder perspectives, and direct observation prior to intervention development. This approach provided an explicit and evidence-based rationale for prioritising the Green Zone and reduced uncertainty regarding where Lean redesign efforts should be directed within a complex and heterogeneous emergency department environment.

The findings of the needs analysis also have important implications for the selection of an appropriate improvement strategy (Phillips et al. 2015). Lean management emphasises the systematic identification and elimination of non-value-adding activities, reduction of process variation, and optimisation of workflow through redesign of care processes (Brancalion et al. 2024). Given that the principal constraints identified in this study were located within the throughput domain and were largely attributable to workflow inefficiencies, Lean represented an appropriate improvement approach for addressing the operational challenges observed within the Green Zone. The needs analysis, therefore, provided not only a justification for where intervention should occur, but also a rationale for why Lean-based process redesign was an appropriate strategy for addressing the identified problems.

5.3 DESIGN AND DEVELOPMENT OF THE LEAN-BASED INTERVENTION

The design and development phase revealed substantial inefficiencies within the existing Green Zone workflow and provided important insights into the operational factors contributing to delays in patient flow. The current-state Value Stream Map (VSM) identified 21 discrete process steps between patient arrival and disposition, with a process cycle efficiency of only 24%. Although direct clinical care accounted for 96 minutes of the patient journey, substantially more time was consumed by non-value-added activities, resulting in a total process length time of approximately 6.7 hours. More importantly, the identified inefficiencies were dispersed across multiple stages of care, including registration processes, patient movement, investigation workflows, communication pathways, and information management. These findings suggest that delays within the Green Zone were systemic in nature, arising from the cumulative effects of multiple interconnected workflow constraints rather than a single operational bottleneck.

This pattern is consistent with previous Lean analyses of emergency department operations (Dickson et al. 2009; Hammoudeh et al. 2021; Naik et al. 2012; Shakoor et al. 2019; Vermeulen et al. 2014). Dickson et al. (2009) identified delays associated with registration and front-end patient processing, while White et al. (2014) reported inefficiencies related to diagnostic and consultation processes that contributed to

prolonged patient throughput times. Bucci et al. (2016) further highlighted communication gaps, coordination challenges, and unnecessary patient movement as important sources of workflow inefficiency. The similarities between these findings and those observed in the present study suggest that delays within emergency departments commonly arise from interconnected operational processes spanning multiple stages of the patient journey. Consequently, meaningful improvements in patient flow are unlikely to be achieved through isolated process modifications alone and instead require an integrated intervention of the wider care pathway.

Internationally, Lean implementation has progressively evolved beyond the application of individual process-improvement tools towards broader "Lean Thinking" approaches that emphasise multidisciplinary engagement, end-to-end workflow redesign, and system-wide improvement (Alogla 2025; Talero-Sarmiento et al. 2024). Contemporary Lean interventions increasingly combine multiple "Lean tools" to analyse workflows, identify waste, prioritise improvement opportunities, and redesign care pathways (Isfahani et al. 2019; Lima et al. 2021; Souza et al. 2021; Tiso et al. 2020). This approach reflects the growing maturity of Lean implementation internationally, where improvement efforts increasingly emphasise end-to-end redesign of patient-care pathways rather than the isolated application of individual Lean techniques (Breen et al. 2020; Frank & Rader 2023; Hayes et al. 2014; Shortell et al. 2018).

In this regard, a considerable number of Lean intervention studies have utilised Value Stream Mapping to provide a visual representation of the entire patient journey and distinguish between value-added and non-value-added activities (Bal et al. 2017; Henrique et al. 2016). This is often complemented by direct workplace observation (*Gemba*) to validate mapped processes and identify workflow deviations and Kaizen activities to generate and prioritise practical solutions targeting identified sources of waste (Kabirinaeini et al. 2023; Mazzocato et al. 2012; Tiso et al. 2021). The involvement of multiple disciplines within a hospital "Lean team" further strengthens Lean interventions in clinical settings, with previous studies reporting that Lean initiatives are more likely to achieve sustainable improvements when frontline staff and supporting departments are actively involved in identifying workflow problems and

developing solutions (Mazzocato et al. 2012; Shortell et al. 2018). In this study, the intervention was designed through the involvement of 29 hospital personnel representing the Emergency Department, pharmacy, radiology, pathology, information technology, finance, human resources, and administrative units. These complementary approaches enable Lean interventions to move beyond isolated process fixes towards coordinated redesign of interconnected workflows, thereby supporting more sustainable improvements in patient flow and operational performance.

In contrast, the Malaysian Lean healthcare literature remains comparatively concentrated on discrete quality improvement initiatives targeting specific departments, operational problems, or service components, with fewer examples of integrated redesign efforts involving the coordinated application of multiple Lean tools across an entire patient pathway (Beh et al. 2025; Choudhury & Lee 2024; Lau et al. 2021; Lee et al. 2025; Pan et al. 2023; Wan Muhd Riduan et al. 2024). The present study, therefore, extends the Malaysian Lean healthcare literature by demonstrating how Lean principles can be systematically translated into a context-specific intervention model through the integration of multidisciplinary engagement, Value Stream Mapping, *Gemba* observation, Kaizen-based problem identification, and structured prioritisation of improvement opportunities. Importantly, these tools were not applied independently but were used iteratively to diagnose workflow constraints, validate findings, prioritise interventions, and redesign the Green Zone patient pathway. This addresses a limitation frequently identified within the Lean healthcare literature, where the rationale underpinning the selection, adaptation, and integration of Lean tools is often insufficiently articulated (Lima et al. 2021; Tiso et al. 2021). By explicitly documenting this process, the present study provides a more transparent and reproducible framework for translating Lean principles into operational redesign within complex emergency department environments.

Following identification of the improvement opportunities, the multidisciplinary team employed an effort–impact matrix to prioritise interventions that were both operationally feasible and likely to produce meaningful improvements in patient flow. This approach reflects Lean implementation principles that emphasise incremental but achievable workflow modifications rather than large-scale

organisational restructuring (Tiso et al. 2021). While Lean healthcare studies frequently describe the use of Value Stream Mapping, Kaizen activities, and stakeholder engagement to identify improvement opportunities, the process by which proposed interventions are subsequently prioritised and selected is often less clearly articulated (Brancalion et al. 2024; Lima et al. 2021). The use of an effort–impact matrix in the present study, therefore, provided a transparent and systematic mechanism for translating identified workflow problems into a practical intervention strategy. Importantly, this prioritisation process ensured that the final Lean-based model was not simply a collection of proposed improvements but a coordinated set of changes aligned with local resource availability, operational constraints, and anticipated impact on patient flow.

Finally, content validation demonstrated complete agreement that the implemented workflow accurately reflected the intended intervention design, with all items achieving an I-CVI of 1.00 and an overall S-CVI/Ave of 1.00. While Lean healthcare studies commonly describe iterative improvement approaches such as Kaizen events and Plan–Do–Check–Act (PDCA) cycles, relatively few explicitly report formal assessment of intervention fidelity prior to outcome evaluation. Consequently, it is often unclear whether the operational changes evaluated fully correspond to the intervention originally designed. In the present study, content validation provided an additional layer of methodological assurance by confirming that the redesigned workflow was implemented as intended before its effects were assessed.

Collectively, these findings suggest that the design and development phase successfully translated the needs analysis findings into a coherent, context-sensitive Lean-based model through the integrated application of multiple Lean tools, including Value Stream Mapping, *Gemba* observation, multidisciplinary stakeholder engagement, Kaizen-based problem identification, and structured intervention prioritisation. This integrated approach reflects the growing maturity of Lean implementation internationally and addresses a gap in the Malaysian literature, where Lean initiatives have more commonly been reported as discrete quality improvement activities rather than coordinated end-to-end workflow redesign. The resulting intervention provides a transparent and reproducible framework for operational

redesign that may be transferable to other emergency department settings facing similar throughput-related challenges.

5.4 OPERATIONAL PERFORMANCE OUTCOMES OF THE LEAN INTERVENTION

The operational impact of the Lean-based intervention was evaluated using three key emergency department performance indicators: triage-to-registration time (TTR), arrival-to-consultation time (ATC), and emergency department length of stay (LOS). These indicators capture different stages of the ED patient pathway and are widely used in the literature to assess the efficiency of patient flow and the effectiveness of process improvement initiatives (Ibrahim et al. 2023; Lima et al. 2021; Noris et al. 2022; Yuzeng & Hui 2020). In particular, measures related to early patient processing, such as triage and registration times, and arrival-to-consultation times, are frequently used to evaluate Lean interventions because they reflect the efficiency of front-end workflows where operational bottlenecks often arise. In contrast, broader indicators such as total length of stay reflect downstream throughput and system-level constraints that may be influenced by factors beyond the immediate control of the emergency department (Tlapa et al. 2020; Zepeda-Lugo et al. 2020).

To evaluate changes in these operational indicators over time, this study employed a quasi-experimental interrupted time series (ITS) design. ITS analysis is widely recognised as one of the most robust quasi-experimental approaches for assessing the impact of health service interventions implemented at a defined time point, particularly when randomised experimental designs are not feasible (Turner et al. 2021; Turner et al. 2020). By examining changes in both the level and trend of performance indicators before and after implementation, ITS allows for a more reliable assessment of intervention effects while accounting for underlying temporal trends in service utilisation and operational performance.

5.4.1 Triage-to-registration time

The Lean intervention was associated with a statistically significant and sustained reduction in triage-to-registration time (TTR), indicating improved efficiency in the

earliest administrative stage of the Green Zone patient pathway. In the study setting, patients first underwent primary triage before proceeding to the registration counter and subsequently to secondary triage for clinical assessment. Inefficiencies in the registration process created delays in completing the early administrative stage of patient processing. Prior to the intervention, three front-counter stations performed both billing and registration functions, which frequently resulted in registration activities being delayed when counters were occupied with billing-related tasks. In addition, patient demographic information was entered manually into the electronic medical record system during registration, further prolonging processing time. These operational constraints contributed to delays in completing the transition from triage to registration, thereby extending triage-to-registration time (TTR).

The Lean-based redesign, therefore, focused on improving the efficiency of the registration workflow. Billing and registration functions were separated so that designated counters remained consistently available for patient registration. In addition, enhancements were introduced to the electronic medical record system to enable automated capture of patient demographic information through identification card scanning, eliminating the need for manual data entry during registration. These changes reduced administrative bottlenecks and improved the efficiency of early patient processing, contributing to the observed reduction in TTR.

The improvement in TTR observed in this study is consistent with previous research demonstrating that early patient processing stages are particularly responsive to operational redesign. Lean-based interventions in emergency departments have frequently reported improvements in triage and registration waiting times following efforts to streamline front-end administrative workflows and eliminate redundant processing steps (Isfahani et al. 2019; Shakoor et al. 2019; Tlapa et al. 2022). Yuzeng & Hui (2020) reported reduction in waiting time to triage from 18 minutes to 13 minutes following a series of Plan–Do–Study–Act cycles that introduced revised triage procedures, additional triage nurse roles, and adjustments to manpower allocation. Kumar et al. (2019) similarly, used process flow diagrams and fishbone analysis to identify various causes for long triage waiting times, and change ideas were tested using the iterative plan–do–study–act cycles (PDSAs) to reduce triage waiting time in a

tertiary hospital emergency department. Change ideas were focused on improving the knowledge and skills of staff posted in triage and reducing turnover of triage staff. Another study reported significant reductions in door-to-vital-signs time following the introduction of parallel workflow processes and modifications to departmental layout (Falconer et al. 2018), highlighting how delays in early patient assessment can often be addressed through relatively simple operational changes.

More recently, digital innovations have also been explored to improve early-stage patient processing. For example, Arora & Taylor (2026) examined the use of tele triage models capable of predicting patient risk at the point of registration, enabling earlier prioritisation of care before formal clinical triage occurs. Although such approaches remain relatively experimental compared with established workflow redesign strategies, they illustrate the growing range of operational and technological solutions being explored to address delays in early emergency department processing.

At the same time, evidence suggests that triage performance is influenced not only by workflow organisation but also by broader operational conditions within the emergency department. Observational studies have demonstrated that increasing emergency department crowding is associated with longer waiting times to triage and reduced compliance with recommended triage time targets (Kienbacher et al. 2022; Van der Linden & Van der Linden 2019). Factors such as ambulance arrivals, urgent caseload, and temporal variations in patient volume have also been identified as important determinants of delays in early patient processing (Kienbacher et al. 2022). These findings indicate that while process redesign can substantially improve administrative efficiency, triage performance may still be affected by fluctuations in demand and available staffing capacity.

In a broader context, the statistically significant reduction in TTR suggests that the intervention was particularly effective because it targeted workflow activities that were largely within the direct control of emergency department personnel. The redesigned registration process addressed administrative bottlenecks identified during the design and development phase, including overlapping front-counter functions and manual registration procedures, thereby improving the efficiency of early patient

processing without requiring substantial additional resources. Consequently, the benefits of Lean redesign were more readily translated into measurable performance improvements. This finding extends existing Lean healthcare literature by suggesting that the effectiveness of Lean interventions may be influenced by the degree of organisational control over the targeted process. Where bottlenecks arise from locally managed workflow activities, Lean principles may facilitate relatively rapid gains in efficiency, whereas processes dependent on wider organisational structures may be less responsive to local workflow redesign alone. The findings therefore support a more nuanced understanding of Lean implementation in emergency care settings, where intervention success may depend not only on the quality of redesign but also on the organisational location of the bottleneck itself.

5.4.2 Arrival-to-consultation time

In contrast to the significant improvement observed in triage-to-registration time, the Lean intervention did not produce a statistically significant or sustained reduction in arrival-to-consultation time (ATC). Although a modest decline was observed immediately following implementation, this improvement was not maintained over time. This finding suggests that while the Lean-based model effectively addressed administrative inefficiencies in the early stages of patient processing, its influence on the timeliness of physician consultation was more limited.

Existing literature suggests that waiting time to physician consultation is often influenced by operational factors that extend beyond administrative workflow alone. In many emergency department settings, consultation waiting time is primarily determined by the balance between patient demand and available clinical staffing capacity (Hussein et al. 2025; Patil 2024). Even when front-end administrative processes become more efficient, patients may still experience delays before clinical assessment if physician workload increases or if patient arrivals exceed available consultation capacity. In the present study, the Lean intervention improved early administrative flow by streamlining registration processes; however, the rate at which patients could proceed to physician consultation remained dependent on the number of available clinicians and the overall clinical workload within the Green Zone.

Evidence from Lean research further highlights the sensitivity of consultation waiting times to demand–capacity dynamics within emergency department systems (Van Der Linden et al. 2023; Grot et al. 2023; Hussein et al. 2025; Pierce et al. 2023; Simpson et al. 2022). Simulation studies demonstrate that even small variations in patient arrival patterns or consultation duration can generate disproportionately large increases in waiting times due to queueing effects in healthcare service systems (Grot et al. 2023). Another study examining emergency nursing workflows similarly reported that delays in clinical assessment frequently arise from factors such as staffing shortages, incomplete triage processes, and the absence of structured care pathways (Hussein et al. 2025). These findings highlight how improvements in early administrative workflow may not necessarily translate into reductions in consultation waiting time when consultation capacity remains constrained.

These demand–capacity dynamics are particularly relevant in the context of the present study, which focused specifically on the Green Zone of the emergency department where lower-acuity patients are managed. Research examining emergency department attendance patterns has consistently shown that a substantial proportion of ED presentations involve non-urgent or lower-acuity conditions, which can increase overall consultation workload and contribute to longer waiting times before physician assessment (Simpson et al. 2022; Squires et al. 2023). In such settings, high volumes of lower-acuity attendances may generate extended consultation queues even when individual cases require relatively brief clinical assessments. Studies investigating emergency department crowding similarly emphasise that fluctuations in patient volume, admission patterns, and external system pressures can significantly influence throughput indicators such as consultation waiting time and overall department congestion (Van Der Linden et al. 2023).

However, the absence of a statistically significant improvement in ATC observed in the present study contrasts with several Lean interventions that reported reductions in waiting time to physician assessment following workflow redesign (de Barros et al. 2022; Pierce et al. 2023). For example, a Lean Six Sigma redesign of a trauma referral pathway achieved a 34% reduction in patient waiting time alongside a 51% reduction in administrative process steps (Pierce et al. 2023). de Barros et al.

(2022) similarly showed that eliminating non-value-added activities and improving coordination between administrative and clinical processes can enhance the timeliness of clinical review in emergency department settings, while Ravi et al. (2023) reported reductions in emergency department length of stay following implementation of an electronic consultation order system that expedited specialist review. Similarly, Kenny et al. (2024) introduced workflow redesign involving patient assessment and movement between treatment areas, contributing to improvements in throughput performance.

The present study similarly adopted an end-to-end redesign approach, addressing multiple workflow constraints across the Green Zone patient pathway, including registration processes, patient movement, investigation workflows, communication pathways, and information management. However, despite these broader redesign efforts, the most substantial improvements were observed in the early stages of patient processing, while consultation waiting time remained influenced by factors extending beyond the redesigned workflow. In a high-volume public university hospital setting, consultation timeliness may be affected by fluctuating patient demand, teaching responsibilities, consultation workload, and competing clinical priorities.

Nevertheless, the timeliness of physician consultation remains a critical dimension of emergency department performance. Prolonged waiting times prior to clinical assessment have been associated with delayed treatment, poorer clinical outcomes, and reduced patient satisfaction (Alhabib et al. 2024), highlighting that arrival-to-consultation time represents not only an operational throughput indicator but also an important component of patient-centred emergency care. The absence of a statistically significant reduction in ATC therefore provides important insight into the conditions under which Lean interventions are most effective. Although the present study implemented an end-to-end redesign of the Green Zone patient pathway, consultation waiting times remained influenced by factors extending beyond workflow design alone, including demand–capacity dynamics and competing organisational priorities. This finding suggests that delays driven by broader capacity constraints may require complementary organisational strategies, including workforce planning and service capacity management, in addition to Lean-based process improvement.

5.4.3 Length of stay in the Emergency Department

Unlike many published Lean emergency department interventions that report significant reductions in length of stay (LOS), the present study did not demonstrate a statistically significant or sustained improvement in overall LOS. Although a modest reduction was observed following implementation, this effect was not maintained over time. Given that LOS is one of the most frequently evaluated outcome measures in Lean emergency department studies (Isfahani et al. 2019; Lima et al. 2021), this finding warrants careful consideration regarding the conditions under which Lean interventions are able to influence broader patient throughput outcomes.

Length of stay is a composite operational indicator that reflects the cumulative effect of multiple stages of the emergency care pathway, including triage, clinical assessment, diagnostic investigations, specialist consultation, treatment decisions, and patient disposition (Hussein et al. 2025). Unlike early administrative processes, many of these activities depend on coordination across various clinical departments. Studies examining emergency department workflows have consistently identified delays in diagnostic imaging, specialist consultation, admission procedures, and inpatient bed allocation as major contributors to prolonged LOS (Hammer et al. 2022; Lokesh et al. 2020; Payne et al. 2023; Verbano & Crema 2019; White et al. 2015). Consultation processes alone may account for a substantial proportion of overall patient stay, as demonstrated in a prospective cohort study of tertiary emergency departments, which showed that consultation-related activities contributed approximately one-third to more than half of total LOS (Brick et al. 2014). Consequently, improvements achieved in one segment of the patient journey may not necessarily translate into measurable reductions in overall LOS when downstream constraints remain unchanged.

At the same time, substantial evidence demonstrates that Lean and Lean Six Sigma interventions can successfully reduce LOS when redesign efforts target multiple stages of the patient pathway. Reviews of Lean applications in emergency care report that LOS reductions are commonly observed when interventions address broader patient-flow and coordination processes rather than isolated workflow activities (Tiso et al. 2021). For example, Furterer (2018) applied a Lean Six Sigma DMAIC framework

combined with Value Stream Mapping to redesign triage processes, establish fast-track pathways, and improve coordination with diagnostic services, resulting in reductions in overall LOS. Similarly, Al-Munayes et al. (2018) targeted delays in diagnostic testing, discharge processes, and communication with inpatient services, while B. Kenny et al. (2024) redesigned patient assessment workflows and movement between treatment areas, both reporting improvements in patient throughput and LOS. Ravi et al. (2023) further demonstrated that redesign of consultation processes through an integrated electronic consultation order system reduced consultation initiation time and was associated with shorter emergency department stays. In another study, the implementation of standardised nursing workflows in an emergency department fast-track area reduced average LOS from 205 minutes to approximately 150 minutes by eliminating variability in nursing task sequences and reducing delays associated with support activities (Williams et al. 2022).

A notable feature of many studies reporting significant reductions in LOS is that their interventions directly addressed bottlenecks occurring later in the patient journey, including diagnostic workflows, consultation processes, discharge planning, and coordination with inpatient services. Although the present study similarly adopted an end-to-end redesign approach, several constraints identified during the design and development phase remained dependent on departments and processes operating beyond the immediate control of the Green Zone. These included delays associated with referral responses, investigation processing, specialist review, and wider hospital patient flow. Consequently, improvements achieved within the redesigned workflow may have been diluted by downstream constraints that remained unchanged following implementation.

The absence of a statistically significant reduction in LOS observed in the present study provides important insight into the limitations of local workflow redesign as a strategy for improving emergency department performance. This finding challenges the assumption that Lean redesign alone is sufficient to produce substantial reductions in all emergency department performance indicators. Rather, the results suggest that Lean may be most effective when bottlenecks arise from locally managed workflow inefficiencies but may have more limited influence when delays are driven

by wider organisational or hospital-wide constraints. From this perspective, the absence of a significant LOS reduction should not necessarily be interpreted as intervention failure. Instead, it highlights an important distinction between process-level and system-level outcomes within Lean Healthcare implementation. The findings therefore suggest that improvements in emergency department length of stay may require hospital-wide coordination strategies in addition to local process redesign initiatives when seeking to achieve sustained improvements in patient flow.

5.5 ECONOMIC IMPLICATIONS OF THE LEAN INTERVENTION

The findings of the present study indicate that implementation of the Lean-based model was associated with improvements in operational cost efficiency within the emergency department Green Zone. Specifically, cost per patient decreased from RM855.10 to RM696.56, representing a reduction of 18.54%, while cost per patient-hour decreased from RM283.16 to RM233.80, representing a reduction of 17.43%. These improvements, while not statistically significant, occurred despite an increase in patient volume during the post-implementation period, suggesting that the emergency department was able to accommodate a greater number of patients while utilising available resources more efficiently.

An important observation is that improvements in operational cost efficiency were achieved despite the absence of statistically significant reductions in arrival-to-consultation time and length of stay. This suggests that the economic benefits of Lean may not be entirely dependent on improvements in conventional throughput indicators. Rather, Lean may generate value through more efficient utilisation of existing resources, reduction of administrative waste, improved workflow coordination, and enhanced organisational productivity. In the present study, the intervention produced a statistically significant reduction in triage-to-registration time by streamlining registration processes and reducing administrative inefficiencies. Although improvements in downstream indicators were not sustained, these front-end gains may nevertheless have reduced administrative burden, improved utilisation of staff time, and increased the department's ability to manage growing patient demand without proportional increases in operating expenditure. From this perspective, the findings

suggest that Lean interventions may contribute to economic sustainability even when broader system-level constraints limit improvements in downstream operational outcomes.

From a Lean management perspective, these findings are consistent with the fundamental principle of maximising value while minimising waste (Womack & Jones 1997). Lean interventions seek to improve workflow efficiency through the elimination of non-value-adding activities, reduction of unnecessary delays, and optimisation of resource utilisation. Previous studies have similarly reported that financial benefits associated with Lean implementation frequently arise through improvements in workflow efficiency and throughput. For example, Narayanan et al. (2022) reported improvements in hospital financial performance following Lean implementation that were largely attributed to enhanced operational flow and increased patient throughput. Similarly, Sales Coll et al. (2024) found that Lean-based redesign of surgical services improved patient flow, logistics coordination, scheduling systems, and information management, generating substantial operational savings while simultaneously increasing service capacity. Collectively, these findings suggest that Lean interventions may improve economic performance through mechanisms extending beyond direct cost reduction, including improved productivity, increased throughput capacity, and more efficient utilisation of existing organisational resources.

However, the magnitude and nature of economic benefits reported across Lean studies appear to vary according to the healthcare setting in which they are implemented. Studies demonstrating substantial financial gains are frequently conducted in relatively structured environments such as surgical services, where workflows are more predictable, and resource utilisation can be standardised more readily (Sales Coll et al. 2024; Sales & De Castro 2021). In contrast, emergency departments operate under conditions of greater uncertainty, characterised by fluctuating patient volumes, unpredictable case complexity, time-sensitive decision-making, and the need to maintain surge capacity. Consequently, economic improvements within emergency care settings may be more modest and may arise primarily through enhanced operational efficiency rather than reductions in expenditure. The findings of the present study, therefore, suggest that Lean may

contribute to economic sustainability in emergency departments by enabling existing resources to accommodate increasing demand more efficiently rather than by generating substantial cost savings alone.

These findings are particularly relevant within publicly funded healthcare systems operating under increasing demand and resource constraints. Healthcare organisations are increasingly expected to improve service delivery while maintaining financial sustainability and efficient utilisation of available resources. The ability to improve operational efficiency while managing higher patient volumes is therefore an important organisational outcome. Within the context of Malaysian public healthcare, where emergency departments frequently experience overcrowding, workforce pressures, and constrained resources, workflow redesign may provide a practical alternative to resource expansion strategies such as increasing staffing levels or physical infrastructure, both of which require substantial financial investment. The findings therefore support the potential role of Lean as a strategy for improving organisational productivity and resource utilisation within resource-constrained healthcare environments.

Despite growing interest in Lean implementation within healthcare, rigorous economic evaluation remains relatively uncommon. A systematic review by Tlapa et al. (2022) examining Lean, Six Sigma, and simulation-based healthcare interventions reported that most studies focused on operational outcomes such as waiting time, turnaround time, and patient flow, while comparatively few incorporated detailed economic analyses. Similarly, Wang et al. (2025) observed that cost-related indicators were among the least frequently reported outcomes in hospital Lean studies. One explanation for this gap is the methodological complexity of capturing the full economic implications of process-improvement initiatives. In addition to measuring operational outcomes, economic evaluations must also account for implementation costs associated with staff training, workflow analysis, organisational change management, and information technology modifications. Dyas et al. (2015), therefore, emphasised the importance of process-improvement costing frameworks capable of capturing both the costs of inefficiencies and the resources required to implement improvement initiatives. The present study contributes to this relatively underdeveloped area of Lean healthcare

research by incorporating operational cost indicators alongside traditional performance measures, thereby providing additional evidence regarding the economic implications of Lean implementation in emergency department settings.

Nevertheless, the economic findings should be interpreted within the scope of the evaluation undertaken. The analysis adopted a provider-perspective approach and focused primarily on operational cost indicators, namely cost per patient and cost per patient-hour. Broader economic outcomes, such as cost-effectiveness or cost-benefit analysis, were beyond the scope of the study. Consequently, while the findings provide evidence of improved operational cost efficiency, they do not represent a comprehensive economic evaluation of the intervention. Future research should therefore incorporate implementation costs, longer-term sustainability assessments, and formal economic evaluation methods to provide a more comprehensive understanding of the financial implications of Lean-based interventions in emergency care settings.

5.6 TOWARDS A ZONE OF CONTROL PERSPECTIVE ON LEAN IMPLEMENTATION IN EMERGENCY DEPARTMENTS

An important observation emerging from the present study is that the effects of the Lean-based model were not uniform across all outcomes. While triage-to-registration time demonstrated a statistically significant and sustained improvement, arrival-to-consultation time and length of stay did not show significant reductions. At the same time, improvements were observed in operational cost efficiency. This mixed pattern of findings provides an opportunity to move beyond the question of whether Lean works towards a more important question: under what conditions does Lean work most effectively within complex emergency department environments?

One possible explanation relates to the degree of operational control that healthcare teams possess over the targeted process. The triage-to-registration process is largely managed within the emergency department and involves workflow activities that are directly amenable to local redesign, including registration procedures, queue management, information flow, and staff allocation. Consequently, process improvements introduced through Lean redesign could be implemented and sustained with relatively few dependencies on external departments. In contrast, arrival-to-

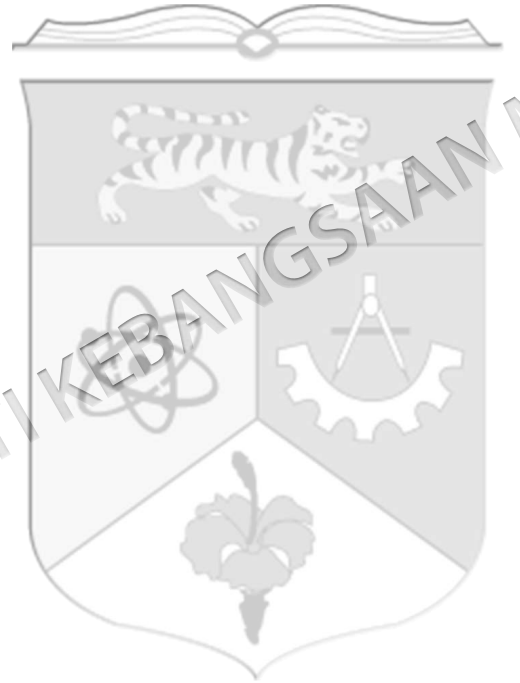
consultation time and length of stay are influenced by a broader network of interdependent processes involving physician availability, diagnostic services, specialist referrals, admission procedures, and hospital-wide patient flow. Although these processes can be influenced by emergency department staff, they cannot be controlled entirely within the department itself.

Based on these findings, the present study proposes a Zone of Control perspective on Lean implementation in emergency departments, illustrated in Figure 5.1. This perspective suggests that Lean interventions are likely to produce the greatest impact when applied to operational processes that are largely under the control of the implementing team. As targeted outcomes become increasingly dependent on shared resources, external departments, or hospital-wide constraints, the impact of local Lean redesign may become progressively attenuated. In this framework, processes such as registration, triage workflow, patient routing, and documentation flow may be viewed as high-control processes, whereas consultation pathways, diagnostic investigations, and referral processes represent shared-control processes. Outcomes such as admission delays, boarding time, inpatient bed allocation, and hospital throughput may be considered low-control processes because they depend heavily on factors beyond the immediate influence of the emergency department.

This perspective may help explain the variability observed across the Lean healthcare literature. Studies reporting substantial improvements often target bottlenecks that are operationally bounded and amenable to direct redesign, whereas interventions addressing broader throughput outcomes frequently encounter organisational constraints extending beyond the scope of local workflow improvement. The findings of the present study, therefore, suggest that the effectiveness of Lean interventions may depend not only on the quality of redesign activities but also on the organisational location of the bottleneck being addressed.

From a practical perspective, this framework has implications for future Lean implementation efforts. Rather than assuming that all emergency department performance indicators are equally responsive to workflow redesign, improvement teams should consider the degree of control they possess over targeted processes when

selecting intervention priorities and establishing performance expectations. Such an approach may support more realistic goal setting, better alignment between interventions and organisational constraints, and more effective allocation of quality improvement resources.



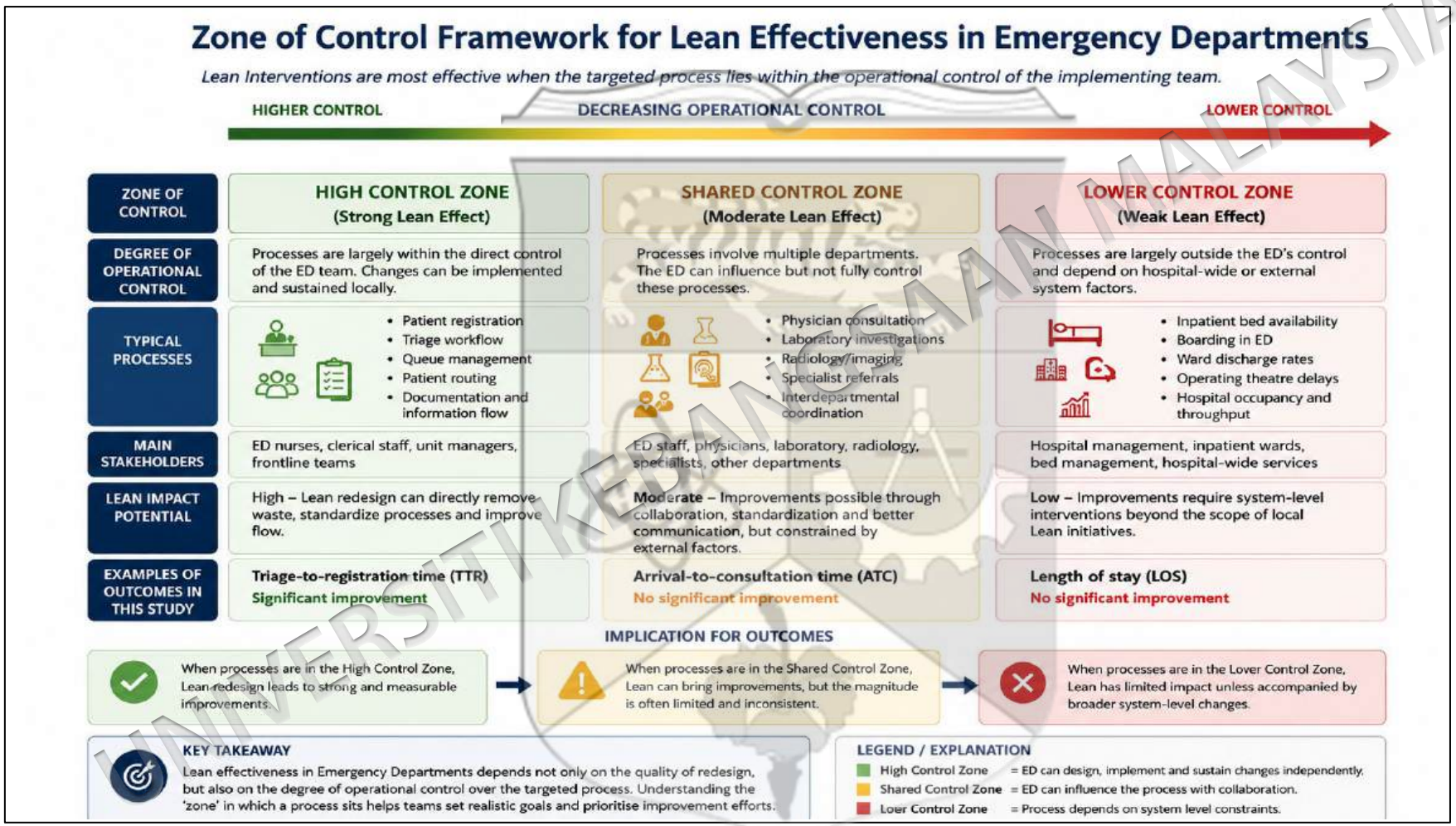


Figure 5.1 Proposed Zone of Control model explaining variation in Lean intervention effectiveness within emergency departments

5.7 STRENGTHS AND LIMITATIONS

This study has several methodological and practical strengths that contribute to the robustness of its findings. First, the study adopted a Design and Development Research (DDR) framework to guide the development of the Lean-based model. This framework ensured that the intervention was informed by a comprehensive needs analysis, grounded in a detailed understanding of operational constraints within the Green Zone patient pathway, and systematically developed through the application of multiple Lean techniques. The resulting Lean-based model was also validated by subject matter experts prior to the evaluation phase. This structured approach to intervention development addresses a recognised limitation in the Lean healthcare literature, where improvement initiatives are frequently implemented as isolated applications of Lean tools without an explicit framework guiding the systematic design, implementation, and evaluation of interventions within complex healthcare environments.

Second, the evaluation of the Lean-based model employed a quasi-experimental interrupted time series (ITS) design, which is widely regarded as one of the strongest observational approaches for assessing the impact of health service interventions implemented at a defined point in time. By analysing both level and trend changes in operational indicators before and after implementation, the ITS approach enabled a more reliable assessment of intervention effects while accounting for underlying temporal trends in emergency department utilisation and performance. This design also addresses a common limitation in the Lean healthcare literature, where many interventions are reported as quality improvement projects relying on simple pre–post comparisons that may overestimate intervention effects. In addition, the selection of operational indicators in this study allowed for a more comprehensive evaluation of the intervention's impact across different stages of the patient pathway. Indicators such as triage-to-registration time and arrival-to-consultation time captured the efficiency of front-end administrative workflows, while overall emergency department length of stay reflected broader throughput dynamics within the emergency care system. By combining a longitudinal ITS evaluation with performance indicators representing both early and downstream stages of patient flow, the study provides a more nuanced

understanding of how Lean-based process redesign influences different components of emergency department throughput.

Third, the study extends the evaluation of Lean interventions beyond operational performance by incorporating a partial economic assessment of the intervention. While many Lean healthcare studies focus primarily on process indicators we examined both operational and financial outcomes, enabling a broader assessment of the intervention's impact. This dual evaluation provides empirical insight into how Lean-based process redesign may influence not only service performance but also cost containment within resource-constrained healthcare environments.

Despite these strengths, several limitations should be acknowledged. First, the study was conducted within a single emergency department setting, focusing specifically on the Green Zone pathway for lower-acuity patients. While this allowed for detailed analysis of local workflow processes, the generalisability of the findings to other emergency departments, and within different zones, may be limited by differences in organisational structure, patient case-mix, staffing models, and physical layout. Emergency departments operate within highly context-dependent environments, and Lean interventions often require adaptation to local operational conditions.

Limitations should also be acknowledged regarding the economic evaluation conducted in this study. The analysis adopted a top-down approach to costing, relying on aggregate expenditure rather than detailed process-level costing. While this approach allowed for an overall assessment of cost efficiency at the departmental level, it did not incorporate activity-based costing methods that allocate resource costs to specific activities within the patient care pathway. This may have enabled more precise estimation of the costs associated with the Lean intervention. In addition, the cost analysis was conducted at the level of the entire emergency department, as financial records were not disaggregated by treatment zones. Consequently, the evaluation included resource utilisation across the Green, Yellow, and Red Zones rather than isolating costs specific to the Green Zone pathway targeted by the intervention. Given that the Green Zone primarily manages lower-acuity cases that typically require fewer clinical resources, this aggregation may dilute the ability to detect more precise cost

changes associated with the redesigned workflow. Future research may therefore benefit from incorporating activity-based costing approaches and zone-specific financial data, which would allow a more detailed assessment of how Lean-based process redesign influences resource consumption within specific segments of the emergency department.

5.8 CONCLUSION

This chapter interpreted the findings of the study in relation to existing literature on Lean implementation in the emergency department. The results demonstrated that a systematic needs analysis successfully identified the Green Zone as a priority area for intervention and provided a robust foundation for the development of a context-specific Lean-based model. Through the integration of multidisciplinary stakeholder engagement, Value Stream Mapping, *Gemba* observation, Kaizen-based problem identification, and structured intervention prioritisation, the study demonstrated how Lean principles can be translated into an end-to-end workflow redesign approach within a complex emergency department environment.

Implementation of the Lean-based model was associated with a statistically significant and sustained improvement in triage-to-registration time, together with improvements in operational cost efficiency. In contrast, arrival-to-consultation time and length of stay did not demonstrate sustained improvements. This highlights the varying responsiveness of emergency department processes to workflow redesign, and suggests that Lean interventions are most effective when bottlenecks arise from operational processes that are largely under the control of the implementing team, whereas outcomes influenced by interdepartmental coordination, diagnostic services, specialist referrals, and wider hospital capacity constraints may require broader organisational and system-level interventions. This observation informed the development of a proposed Zone of Control perspective on Lean implementation, offering a potential explanation for the variability in outcomes reported across the Lean healthcare literature.

Additionally, the findings indicate that economic benefits can be achieved even when improvements in broader throughput measures are constrained by factors

extending beyond the immediate intervention environment. This suggests that the value of Lean in emergency department settings may lie not only in reducing waiting times, but also in improving resource utilisation and organisational efficiency under conditions of increasing service demand.

The findings extend current understanding of Lean implementation within emergency departments by demonstrating that successful operational redesign depends not only on the systematic design and development of a Lean intervention, but also on the alignment between intervention strategies and the organisational location of targeted bottlenecks. The chapter, therefore, reinforces the importance of context-sensitive approaches to quality improvement and provides a foundation for considering the theoretical, practical, and policy implications of the study presented in the subsequent chapter.

CHAPTER VI

CONCLUSION

6.1 INTRODUCTION

This chapter presents the overall conclusions of the study and synthesises the key findings in relation to the study objectives. The study was undertaken to design, develop, and evaluate a Lean-based model to improve operational performance and cost efficiency within the Green Zone of the emergency department of a public university hospital. Guided by the Design and Development Research (DDR) framework, the study integrated needs analysis, intervention design and development, implementation, and evaluation to address operational challenges affecting patient flow and resource utilisation within the emergency department.

Beyond evaluating the effectiveness of the Lean-based model, this study sought to generate a deeper understanding of how Lean interventions function within complex emergency department workflows. The mixed pattern of findings observed across operational outcomes suggests that Lean-based redesign may have differing effects depending on the characteristics of the processes being targeted. Accordingly, this chapter summarises the principal findings of the study, highlights its theoretical, methodological, and practical contributions, discusses implications for public health policy and practice, and outlines recommendations for future research. The chapter concludes by reflecting on the significance of the study for future Lean implementation within emergency departments and other complex, resource-constrained healthcare settings.

6.2 SUMMARY OF FINDINGS

This study was conducted to design, develop, and evaluate a Lean-based model to improve operational performance and cost efficiency within the Green Zone of the emergency department of a public university hospital. The findings are summarised according to the study objectives.

6.2.1 Research Objective 1: To identify the most appropriate focus area for intervention

The needs analysis identified the Green Zone as the most appropriate area for intervention. Administrative data demonstrated that the Green Zone accounted for the largest proportion of emergency department attendances and experienced substantial growth in patient volume over time. Baseline performance indicators revealed delays across multiple stages of the patient journey, including triage-to-registration time, arrival-to-consultation time, and length of stay. Patient satisfaction findings showed that waiting time to receive treatment was among the lowest-rated service domains, while stakeholder engagement identified recurrent issues related to workflow congestion, fragmented patient movement pathways, cross-zone staffing redeployment, and workflow interruptions. Collectively, these findings indicated that the Green Zone represented a key operational pressure point within the emergency department and provided a strong rationale for Lean workflow redesign.

6.2.2 Research Objective 2: To design and develop a Lean-based model to improve operational performance within the Green Zone

A context-specific Lean-based model was developed using an integration of Lean tools and techniques within a Design and Development Research framework. The model was developed through the collaborative efforts of a multidisciplinary Lean team, involving representatives from clinical, allied health, administrative, and support services. Current-state Value Stream Mapping identified 21 process steps and demonstrated substantial workflow inefficiencies, with a process cycle efficiency of 24%. Nine Kaizen improvement opportunities were subsequently identified and prioritised using an effort–impact matrix. Feasible improvement initiatives were incorporated into a future-state Value Stream Map that projected a reduction in process length time from approximately 6.7 hours to 4.5 hours. Content validation demonstrated excellent

agreement that the implemented workflow accurately reflected the intended intervention design (I-CVI = 1.00; S-CVI/Ave = 1.00).

6.2.3 Research Objective 3: To evaluate the effects of the Lean-based model on operational performance

Interrupted time series analysis demonstrated a statistically significant reduction in triage-to-registration time, which decreased from 5.79 minutes to 4.84 minutes, representing a reduction of 16.34% ($p < 0.001$). Arrival-to-consultation time decreased from 80.83 minutes to 55.47 minutes, while length of stay decreased from 152.60 minutes to 144.88 minutes. However, these reductions were not statistically significant and were not sustained over time. The findings indicate that the intervention was most effective in improving early-stage administrative processes within the Green Zone patient pathway.

6.2.4 Research Objective 4: To estimate changes in operational cost efficiency following implementation of the Lean-based model

The economic evaluation demonstrated improvements in operational cost efficiency following implementation of the Lean-based model. Cost per patient decreased from RM855.10 to RM696.56, representing a reduction of 18.54%, while cost per patient-hour decreased from RM283.16 to RM233.80, representing a reduction of 17.43%. These improvements were observed despite increasing patient volume during the post-implementation period, suggesting more efficient utilisation of available resources following workflow redesign.

6.3 RESEARCH CONTRIBUTIONS

While the findings summarised above provide evidence regarding the development, implementation, and evaluation of the Lean-based model, the significance of the study extends beyond its empirical results. The study contributes to the existing body of knowledge through theoretical, methodological, and practical advances that enhance understanding of Lean implementation within emergency department settings.

6.3.1 Theoretical contributions

This study contributes to the growing body of knowledge on Lean implementation in healthcare by extending understanding beyond whether Lean interventions improve performance to examining how and where Lean interventions are most likely to be effective within complex emergency department systems.

First, the study contributes to the Lean healthcare literature by demonstrating the value of systematic needs analysis as a precursor to intervention design. Existing Lean studies frequently focus on the implementation and evaluation of process-improvement initiatives, often assuming that the target area for improvement has already been identified. In contrast, the present study employed a structured needs analysis incorporating administrative data, operational performance indicators, patient experience data, and stakeholder perspectives to identify the Green Zone as the most appropriate focus area for intervention. This approach highlights the importance of aligning Lean implementation with context-specific operational priorities and contributes to a more evidence-informed approach to intervention selection.

Second, the study contributes to the current understanding of Lean implementation by demonstrating that operational improvements may not occur uniformly across different performance outcomes. While implementation of the Lean-based model was associated with a statistically significant improvement in triage-to-registration time and improvements in operational cost efficiency, arrival-to-consultation time and emergency department length of stay did not demonstrate sustained statistically significant reductions. These findings challenge an implicit assumption within parts of the Lean healthcare literature that improvements in local workflow efficiency will necessarily translate into improvements across broader throughput outcomes. Instead, the findings suggest that different emergency department performance indicators may vary in their responsiveness to Lean-based workflow redesign.

Building on this observation, the study proposes a Zone of Control perspective on Lean implementation within emergency departments. The proposed perspective suggests that the effectiveness of Lean interventions may be influenced by the degree

of operational control that implementing teams possess over the targeted process. Processes that are largely controlled within the emergency department, such as registration workflows, patient routing, queue management, and administrative processes, may be more amenable to Lean redesign and therefore more likely to demonstrate measurable improvements. In contrast, outcomes that depend on interdepartmental coordination, diagnostic services, specialist referrals, admission processes, or hospital-wide capacity constraints may be less responsive to local workflow redesign alone. While this perspective requires further empirical evaluation, it offers a potential explanation for the mixed findings observed in the present study and for the variability reported across previous Lean healthcare studies.

The proposed Zone of Control perspective represents the principal theoretical contribution of the study. Rather than viewing Lean as a universally effective solution for all operational challenges, the findings suggest that the impact of Lean may depend on the organisational location of the bottleneck being targeted. This shifts attention from the question of whether Lean works to the more nuanced question of under what conditions Lean is most likely to be effective. Such a perspective may assist researchers and practitioners in developing more realistic expectations regarding the outcomes of Lean implementation and in selecting intervention targets that are aligned with the degree of influence available to the implementing team.

These contributions extend current understanding of Lean implementation within emergency departments by highlighting the importance of context, process characteristics, and organisational boundaries in shaping intervention outcomes. Future researchers may build on these findings by testing the proposed Zone of Control perspective across different hospital settings, clinical environments, and healthcare systems to further refine understanding of the mechanisms through which Lean interventions influence operational performance.

6.3.2 Methodological contributions

This study contributes methodologically to the Lean healthcare literature by demonstrating a systematic and theory-informed approach to the design, development, implementation, and evaluation of a Lean intervention within an emergency department

setting. While Lean has been widely applied in healthcare, previous reviews have highlighted considerable variability in intervention design, implementation processes, and evaluation methods, limiting the reproducibility and comparability of findings across studies. The present study addresses several of these methodological limitations.

First, the study demonstrates the application of the Design and Development Research (DDR) framework as a structured methodology for developing a context-specific Lean intervention. Although Lean studies frequently describe the use of individual process improvement tools, fewer studies explicitly document the process through which needs are identified, interventions are designed, and implementation strategies are developed. By integrating needs analysis, intervention development, model validation, implementation, and evaluation within a single framework, the study provides a transparent and systematic approach to Lean intervention development. This contributes a methodological pathway that may be replicated or adapted by future researchers undertaking healthcare quality improvement initiatives.

Second, the study adopted a comprehensive needs assessment approach that integrated multiple sources of evidence, including administrative data, operational performance indicators, patient experience data, and stakeholder perspectives. Rather than relying solely on operational metrics or management priorities, the intervention target was identified through triangulation of quantitative and qualitative information. This approach strengthened the contextual relevance of the intervention and ensured that the selected improvement priorities reflected both organisational performance needs and frontline operational realities. The study therefore demonstrates the value of combining multiple data sources during the diagnostic phase of healthcare improvement initiatives.

Third, the study contributes methodologically through the systematic integration of multiple Lean tools within a coherent intervention-development process. The Lean intervention was developed through the collaboration of a multidisciplinary “Lean team”, while Value Stream Mapping served as the primary workflow analysis tool. This was complemented by *Gemba* observation, Kaizen-based problem identification, and structured prioritisation using an effort–impact matrix. Importantly, these tools were not

applied as isolated improvement techniques but were used iteratively to diagnose workflow inefficiencies, validate findings, prioritise interventions, and redesign the patient pathway. This provides a more transparent account of how Lean tools can be integrated to support end-to-end workflow redesign within complex healthcare environments.

Fourth, the study contributes to the evaluation of Lean interventions by employing interrupted time series analysis to assess operational outcomes following implementation. Reviews of Lean healthcare research have frequently noted reliance on simple before-and-after comparisons, which may overestimate intervention effects and inadequately account for underlying temporal trends. By using interrupted time series analysis, the present study was able to evaluate both immediate and sustained changes in performance indicators while accounting for pre-existing trends over time. This strengthens the methodological rigour of the evaluation and provides a more robust assessment of intervention effectiveness.

Finally, the study contributes to the relatively limited body of research incorporating economic evaluation into Lean healthcare studies. In addition to operational performance outcomes, the study assessed changes in cost per patient and cost per patient-hour, thereby extending evaluation beyond traditional workflow indicators. Although the economic evaluation was partial in nature, it provides an example of how operational and economic outcomes may be examined concurrently when evaluating healthcare improvement interventions.

6.3.3 Practical contributions

The study makes several practical contributions to emergency department management and healthcare quality improvement practice. Beyond demonstrating the effectiveness of a Lean-based model within a single emergency department setting, the study provides a structured and transferable approach for identifying, prioritising, and addressing operational inefficiencies in complex healthcare environments.

The study contributes a practical framework for Lean intervention development that integrates needs assessment, design and development, validation, and evaluation.

Although the specific workflow redesign implemented in the present study was tailored to local operational needs, the underlying intervention-development process is potentially transferable across healthcare settings. The framework developed in this study, therefore, provides healthcare managers and improvement teams with a practical prototype structured process for Lean implementation that may support wider adoption of structured process improvement initiatives within Malaysian healthcare services.

Second, the findings demonstrate that meaningful operational and economic improvements can be achieved without substantial expansion of staffing, infrastructure, or financial resources. The observed improvements in triage-to-registration time and operational cost efficiency suggest that workflow redesign may provide a feasible strategy for enhancing service performance within resource-constrained healthcare environments. This is particularly relevant for public healthcare organisations facing increasing demand, workforce pressures, and fiscal constraints.

The findings also highlight the importance of aligning improvement strategies with the nature of the targeted operational problem. The differential effects observed across operational outcomes suggest that healthcare managers should carefully consider the degree of influence they possess over a given process when selecting intervention priorities and establishing performance expectations. This insight may assist practitioners in directing improvement efforts towards areas most likely to benefit from workflow redesign while recognising the limitations of local interventions in addressing wider organisational constraints.

6.4 RECOMMENDATIONS FOR PUBLIC HEALTH POLICY AND PRACTICE

The findings of this study suggest that healthcare organisations should adopt a more systematic approach when implementing Lean-based improvement initiatives. Rather than introducing Lean tools as isolated quality improvement activities, healthcare managers should first undertake structured needs assessments that incorporate multiple sources of evidence, including operational performance data, patient experience measures, and stakeholder perspectives. The present study demonstrated that such an approach enabled the identification of the Green Zone as the most appropriate target for intervention and ensured that improvement efforts were aligned with locally relevant

operational challenges. Similar approaches may help healthcare organisations direct limited resources towards areas where process redesign is most likely to yield meaningful improvements.

The findings also highlight the importance of multidisciplinary engagement and end-to-end workflow analysis in healthcare improvement initiatives. Operational inefficiencies within emergency departments frequently arise from interconnected processes involving clinical, administrative, and support services rather than from isolated activities. Consequently, improvement efforts should extend beyond individual performance indicators and instead examine the entire patient journey. The integration of Value Stream Mapping, *Gemba* observation, Kaizen-based problem identification, and stakeholder engagement in the present study provides a practical example of how healthcare organisations may systematically identify and address workflow inefficiencies. Wider adoption of such integrated approaches may strengthen the effectiveness and sustainability of future quality improvement initiatives.

An important implication of the study is that improvement strategies should be aligned with the organisational location of the targeted bottleneck. The findings demonstrated that processes largely under the control of the implementing team were more responsive to workflow redesign than outcomes influenced by broader organisational and hospital-wide factors. Healthcare managers and policymakers should therefore recognise that not all operational performance indicators are equally amenable to local process improvement efforts. While Lean-based redesign may be effective in addressing workflow inefficiencies within departmental control, improvements in outcomes influenced by diagnostic services, specialist consultations, admission processes, and inpatient capacity may require coordinated action across multiple departments and levels of the healthcare system. Future quality improvement programmes should therefore be designed with consideration of both local workflow factors and wider organisational constraints.

Finally, the study highlights the potential value of Lean methodologies as a strategy for improving both operational performance and resource utilisation within resource-constrained healthcare settings. The improvements in operational cost

efficiency observed following implementation suggest that meaningful gains may be achieved without substantial expansion of staffing or infrastructure. This is particularly relevant within public healthcare systems facing increasing service demand and fiscal constraints. The Lean-based model developed in this study may therefore serve as a useful prototype for emergency department process improvement in Malaysian healthcare settings. Although individual workflow modifications should be adapted to local operational contexts, the structured intervention-development process demonstrated in this study offers a practical framework that may support wider implementation of Lean principles within emergency departments and other complex healthcare environments.

6.5 RECOMMENDATIONS FOR FUTURE STUDIES

The findings of this study identify several important avenues for future research that may further advance understanding of Lean implementation within emergency department settings and healthcare systems more broadly.

First, future studies should seek to strengthen causal inference regarding the effectiveness of Lean interventions through the use of comparative implementation designs. Although interrupted time series analysis is recognised as one of the strongest quasi-experimental approaches for evaluating organisational interventions implemented at a single site, future evaluations could incorporate comparison hospitals, multiple emergency departments, controlled interrupted time series designs, or stepped-wedge implementation approaches. Such designs would enable researchers to better distinguish intervention effects from secular trends and external influences. However, future multi-site studies should also recognise that emergency departments operate within highly heterogeneous organisational environments. Differences in patient volume, case mix, staffing models, physical infrastructure, information systems, and organisational culture may substantially influence implementation processes and outcomes. Consequently, future research should not assume direct comparability between institutions but should explicitly examine how contextual characteristics shape the effectiveness of Lean interventions across different settings.

Second, future research should further investigate the proposed Zone of Control perspective introduced in this thesis. The mixed pattern of findings observed in the present study suggests that Lean interventions may have differing effects depending on the degree of operational control that implementing teams possess over the targeted process. While this perspective offers a potential explanation for the significant improvement observed in triage-to-registration time compared with the more limited effects on arrival-to-consultation time and length of stay, it remains a conceptual proposition requiring empirical validation. Future studies should therefore explore whether outcomes located within high-control, shared-control, and low-control operational domains demonstrate systematically different responses to Lean-based redesign. Such work may contribute to a more refined theoretical understanding of how Lean functions within complex healthcare systems and help explain the variability in outcomes reported across the broader Lean healthcare literature.

Third, future research should incorporate more comprehensive economic evaluation methodologies. While the present study demonstrated improvements in operational cost efficiency, the analysis was limited to provider-level operational cost indicators and did not include implementation costs, return on investment, cost-effectiveness analyses, or longer-term assessments of financial sustainability. Future studies should adopt more comprehensive economic evaluation frameworks capable of examining both the resources required to implement Lean interventions and the economic value generated through operational improvements. Such evidence would strengthen decision-making regarding the allocation of healthcare resources and the wider adoption of Lean methodologies within healthcare systems.

Finally, future research should examine implementation processes and sustainability outcomes following Lean implementation. Factors such as leadership support, staff engagement, organisational readiness, and implementation fidelity may influence the long-term success of healthcare improvement initiatives. Longitudinal and implementation-focused studies examining these factors would contribute valuable knowledge regarding how Lean interventions can be embedded, sustained, and scaled within complex healthcare environments.

6.6 CONCLUSION

This study demonstrates that the value of Lean implementation in emergency departments extends beyond improving individual performance indicators. Through the systematic identification of operational needs, the development of a context-specific Lean-based model, and the evaluation of its operational and economic effects, the study provides evidence that Lean can improve efficiency and resource utilisation within complex healthcare environments. More importantly, the findings show that the effects of Lean are not uniform across all aspects of emergency department performance. While substantial improvements were achieved in processes that were largely within the operational control of the implementing team, outcomes influenced by broader organisational and system-level factors proved less responsive to local workflow redesign.

This observation represents an important contribution to the understanding of Lean implementation in healthcare. The findings suggest that a more meaningful question is under what circumstances Lean works, for whom, and on which processes. The study, therefore, challenges the assumption that Lean should be viewed as a universal solution to emergency department overcrowding. Rather, its effectiveness appears to depend on the nature of the operational constraints being addressed. The proposed Zone of Control perspective provides a conceptual lens through which future researchers and practitioners may better understand the variability in Lean outcomes reported across healthcare settings.

Ultimately, this thesis argues that successful Lean implementation depends not only on the application of improvement tools but also on the alignment between the intervention and the nature of the problem being addressed. As healthcare systems continue to face increasing demand, resource constraints, and growing expectations for service quality, future improvement efforts should move beyond adopting Lean as a set of techniques and instead embrace Lean as a strategic, context-sensitive approach to healthcare system redesign. By demonstrating how operational bottlenecks can be systematically identified, prioritised, and addressed, this study contributes both

practical guidance for healthcare organisations and new insight into how Lean functions within complex emergency department systems.

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APPENDIX A

UKM ETHICS APPROVAL

UNIVERSITI KEBANGSAAN MALAYSIA
The National University of Malaysia

SEKRETARIAT ETIKA PENYELIDIKAN UKM • *UKM RESEARCH ETHICS COMMITTEE*

Reference : UKM PPI/111/8/JEP-2024-331
Date : 20 May 2024

Professor Dr. Mohd. Rizal Hj. Abdul Manaf
Department of Public Health Medicine
Faculty of Medicine UKM

Dear Professor/Datuk/Dato'/Datin/Sir/Madam,

ETHICAL APPROVAL TO CONDUCT RESEARCH IN THE NATIONAL UNIVERSITY OF MALAYSIA

Research title	:	Development And Evaluation Of A Lean-Based Model For The Emergency Department Of A Public University Hospital In Malaysia
Ethics Ref. No.	:	JEP-2024-331
Approval period	:	16 May 2024 – 15 May 2027
Study Site	:	Sultan Ahmad Shah Medical Centre @IIUM (SASMEC @IIUM)
Sample Size	:	135 Subjects

With reference to the above.

2. The Research Ethics Committee, The National University of Malaysia (RECUKM) has provided ethical approval for above study. Please be reminded permission from the Deputy Dean of research of the faculty or Director of Institute/Centre and all relevant heads of departments / units where the study will be carried out must be obtained prior to the study. You are required to follow and comply with their decision and all other relevant regulations.

3. Please note that the investigator's responsibility is to ensure that:

i. All Adverse Events should be reported to RECUKM as soon as possible.
ii. Progress report should be submitted every **6 Months**.
iii. All changes / amendments to the study documents / study sites / study team must be notified to the RECUKM. All changes must be approved by RECUKM before continuation of the study.
iv. Application for renewal of the approval has to be submitted to RECUKM within one month (1 month) prior to the expiry of ethical approval.
v. Final Report should be provided to RECUKM when the project is complete.
vi. Please take note that all records and data are to be kept strictly CONFIDENTIAL and can only be used for the purpose of this study. All precautions are to be taken to maintain data confidentiality.

Required forms can be obtained from the The Research Ethics Committee, The National University of Malaysia (RECUKM) website: **https://www.ukm.my/jepukm**

Thank you.

Sekretariat Etika Penyelidikan Universiti Kebangsaan Malaysia
Tingkat 1, Blok Klinikal, Hospital Canselor Tuanku Muhriz,Pusat Perubatan UKM, Jalan Yaacob Latif, Bandar Tun Razak, 56000 Cheras Kuala Lumpur.
Telefon: +603-9145 5046 / 5048
Email: jepukm@ukm.edu.my Web: https://www.ukm.my/jepukm/

ILMU, MUTU DAN BUDI

UNIVERSITI KEBANGSAAN MALAYSIA
The National University of Malaysia

SEKRETARIAT ETIKA PENYELIDIKAN UKM • *UKM RESEARCH ETHICS COMMITTEE*

Yours sincerely,

PROFESOR DR MOHD SHAHRIR MOHAMED SAID
Chairman
Research Ethics Committee
The National University Of Malaysia

c.c.
- **Director**
  Hospital Canselor Tuanku Muhriz
  UKM Medical Centre
- **Deputy Dean (Research & Innovation)**
  Faculty of Medicine UKM
- **Head of Department Public Health Medicine**
  Faculty of Medicine UKM
- **Professor Dr. Azmawati Mohammed Nawi**
- **Dr. Dina Syazana Ho Imran Ho (P137722 – DrPH Candidate)**
  Department of Public Health Medicine
  Faculty of Medicine UKM
- **Asst. Prof.** Dr. **Mohd. Helmie Ismail**
  Kulliyyah of Medicine, IIUM
- **Ts. Dr. Mohd Amran Mohd Daril,**
- **Ir. Ts. Dr. Mohamad Ikbar Abdul Wahab**
- **Ts. Dr. Mazlan Awang**
- **Ts. Dr. Fairui Anwar Abu Bakar**
- **Assoc. Prof. Ts. Dr. Ishamuddin Mustapha**
  Quality Engineering Section, UniKL MITEC
- Approval letter File 2024

APPENDIX B

IIUM ETHICS APPROVAL

Our Ref : IIUM/504/14/11/2/IREC 2024-263
Date : 26 Jul 2024

Prof. Dr. Mohd Rizal bin Abdul Manaf (Principal Investigator)
Public Health Medicine
Faculty of Medicine
Universiti Kebangsaan Malaysia

Dear Prof. Dr.,

The IIUM Research Ethics Committee (IREC) has reviewed your study protocol as mentioned below:-

ID NO.	:	**IREC 2024-263**
RESEARCH TITLE	:	**Development and Evaluation of a Lean-Based Model for the Emergency Department of a Public University Hospital in Malaysia**
REGISTRATION DATE	:	**12 Jul 2024**
CO-INVESTIGATOR	:	**Prof. Dr. Azmawati Mohammed Nawi** **Asst. Prof. Dr. Mohd. Helmie bin Ismail**
STUDENT	:	**Dr. Dina Syazana Ho binti Imran Ho (Postgraduate Student)**
STUDY SITE	:	**Sultan Ahmad Shah Medical Centre (SASMEC) @IIUM**
SAMPLE SIZE	:	**20 in-depth interviews and 95 participants (healthcare workers) for the questionnaire**
ETHICAL EXPIRY DATE	:	**26 July 2025**

The IIUM Research Ethics Committee (IREC) operates in accordance with the Declaration of Helsinki, International Conference of Harmonization Good Clinical Practice Guidelines (ICH-GCP), Malaysia Good Clinical Practice Guidelines and Council for International Organizations of Medical Sciences (CIOMS) International Ethical Guidelines

The following documents have been received and reviewed to the above study: -

1. Study Proposal/Protocol: Version 1, dated 06 May 2024
2. Informed Consent Form (ICF) –
   i. Information Sheet (English) – Version 1, dated 06 May 2024
   ii. Consent Form (English) - Version 1, dated 06 May 2024
   iii. Information Sheet (Malay) – Version 1, dated 06 May 2024
   iv. Consent Form (Malay) -Version 1, dated 06 May 2024
3. Questionnaire - Version 1, dated 06 May 2024
4. Approval Letter from UKM Research Ethics Committee
5. Principal Investigator's CV

Research Management Centre
International Islamic University Malaysia, Jalan Gombak, 53100 Kuala Lumpur
Telephone: (+603) 6421 5802 / 5010 | Fax: (+603) 6421 4862
Email: rmcentre@iium.edu.my | Website: https://www.iium.edu.my/centre/rmc

Decision by IIUM Research Ethics Committee (IREC):

(√) Approved
( ) Disapproved **Date of Approval: 26 July 2024**

The investigator(s) are required to:

a) submit the 'Continuing Review Form' 30 days before EXPIRY DATE to renew Ethical Approval.
b) notify IREC of any change in protocol and obtaining further ethical approval as appropriate.
c) report any adverse incident during study to IREC even if the incident is not directly related to the study.
d) report to the IREC within 72 hours for all internal SAEs (occurring in IIUM PI site).
e) report in a prompt manner if the information impacts the continued ethical acceptability
of the trial for external SAEs (occurring in participants at other sites).
f) report any major protocol deviation that occurs within 5 working days.
g) complete and submit the End of Project Report Form to the IREC Secretariat's Office.
h) All records and data subjects are CONFIDENTIAL and used only for the purposes of this study and all issues and procedures on data confidentiality must be observed.

Yours sincerely,

PROF. DR. NASSER MUHAMMAD AMJAD
Chairman
IIUM Research Ethics Committee (IREC)

DISCLAIMER: The approval letter only covers the ethical aspect of your study only. Any other permission/approval to use any facilities, data or human resource should fall under applicant's responsibility.

APPENDIX C

SASMEC IIUM INSTITUTIONAL APPROVAL

الجامعة الإسلامية العالمية ماليزيا
INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA
Garden of Knowledge and Virtue

LEADING THE WAY
KHALIFAH · AMANAH · IDRA' · RAHMATAN LIL-'ALAMIN
LEADING THE WORLD

INTERNATIONAL MULTI-AWARD WINNING INSTITUTION FOR SUSTAINABILITY

SULTAN AHMAD SHAH MEDICAL CENTRE @IIUM

Ref : IIUM/413/013/14/11/1/IIR25-43
Date : 08 July 2025

Dr. Dina Syazana Ho Imran Ho
Clinical Management Unit
Sultan Ahmad Shah Medical Centre
International Islamic University Malaysia

السلام عليكم ورحمة الله وبركاته,

Dear Dr. Dina Syazana,

APPROVAL TO CONDUCT RESEARCH AT SULTAN AHMAD SHAH MEDICAL CENTRE @IIUM

May this letter reach you while you are in the best of health and well-being by the grace of Allah SWT.

Referring to the above matter, we are glad to inform you that your application to conduct research at Sultan Ahmad Shah Medical Centre @IIUM has been approved.

The details of the research are as follows:

Name of Applicant	:	Dr. Dina Syazana Ho Imran Ho
Research Title	:	Development and Evaluation of a Lean-Based Model for the Emergency Department of a Public University Hospital in Malaysia
Site(s) of Research	:	Department of Emergency Medicine
Duration of Research	:	08/07/2025 – 26/07/2025
Approval No.	:	IIR25-43

It is our hope that your research project will be able to contribute meaningfully to the ummah and the community.

If you have any inquiries, please do not hesitate to contact:
1) Sr. Roswati Binti Nawi (09-591 2510 | roswatinawi@iium.edu.my)
2) Sr. Khairunnissa' Binti Imran (09-5912500 ext. 1078 | nissaa@iium.edu.my)
3) Sr. Nur Awatif Najwa binti Azhar (09-5912500 ext 1192 | swatifnajwa@iium.edu.my)

Thank You. والسلام

ASSOC. PROF. DR. NURIASMINE AIDA JAMANI
Head
Department of Education and Research
Sultan Ahmad Shah Medical Centre @IIUM
International Islamic University Malaysia

Sultan Ahmad Shah Medical Centre @IIUM (SASMEC @IIUM)
Jalan Sultan Ahmad Shah, Bandar Indera Mahkota, 25200 Kuantan, Pahang Darul Makmur

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Website: https://sasmec.iium.edu.my

cc:

1. Prof. Dato' Dr. Mohamed Saufi Awang
   Hospital Director
   Sultan Ahmad Shah Medical Centre @IIUM
   International Islamic University Malaysia

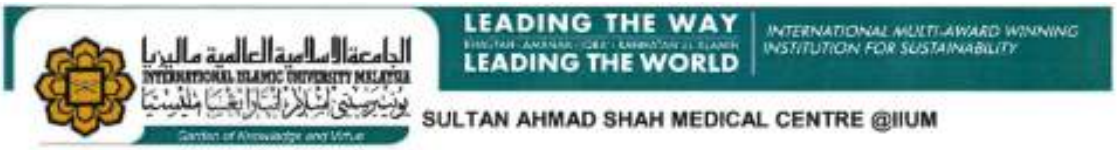
2. Assoc. Prof. Dr. Ahmad Marzuki Omar
   Director Clinical
   Sultan Ahmad Shah Medical Centre @IIUM
   International Islamic University Malaysia

3. Asst. Prof. Dr. Mohd Helmie Mohd Ismail
   Head, Department of Emergency Medicine
   Sultan Ahmad Shah Medical Centre @IIUM
   International Islamic University Malaysia

NAJ/ton/fnn

APPENDIX D

INVITATION TO PARTICIPANTS OF LEAN TRAINING WORKSHOP



Ref. No.: IIUM/413/045/17/13/2
Date: 22nd August 2024

AS PER ATTACHED

Dear Prof. / Assoc. Prof. / Asst. Prof. / Dr. / Br. / Sr.,

RE: INVITATION TO PARTICIPATE IN THE LEAN TRAINING WORKSHOP

I am pleased to extend an invitation to you to participate in the upcoming **Lean Training Workshop** organized by the Clinical Management Unit, Sultan Ahmad Shah Medical Centre @IIUM (SASMEC @IIUM). This workshop is a critical initiative aimed at enhancing our operational efficiency, improving patient care quality, and fostering a culture of continuous improvement within our organization.

The details of the workshop are as follows:
Date : 28 – 29 August 2024 (Wednesday - Thursday)
Time : 8.30 a.m. – 5.00 p.m.
Venue : Seminar Rooms 3&4, Level 4, SASMEC @IIUM

The Lean Training Workshop is designed to provide you with the necessary skills and knowledge to apply Lean Management principles effectively in your daily work. Through interactive sessions, practical exercises, and discussions, you will learn how to identify and eliminate waste, optimize processes, and contribute to the overall improvement of our healthcare services.

Your participation in this workshop is vital to the success of our Lean initiatives, and we believe that the knowledge and skills you will gain will be invaluable in driving continuous improvement across your department. This workshop also offers a unique opportunity to collaborate with colleagues from various departments, share insights, and develop strategies that will benefit SASMEC @IIUM.

Kindly confirm your attendance by **26th August 2024 12:00pm (Monday)** by replying to this email. Your prompt response will allow us to finalize the necessary arrangements.

We are confident that this workshop will be a rewarding experience, and we look forward to your active participation.

Yours sincerely,

DR. MOHAMAD FADHI BIN AZMI
Coordinator
Clinical Management Unit
Sultan Ahmad Shah Medical Centre @IIUM

Sultan Ahmad Shah Medical Centre @IIUM (SASMEC @IIUM)
Jalan Sultan Ahmad Shah, Bandar Indera Mahkota, 25200 Kuantan, Pahang Darul Makmur
Tel: (+609) 591 2500 | Email: prosasmec@iium.edu.my
Website: https://sasmec.iium.edu.my/

List of Participants

Lean Training Workshop

28 – 29 August 2024

No.	Name	Designation	Department / Unit
1.	Asst. Prof. Dr. Edre bin Mohammad Aidid	Public Health Medicine Specialist	Kulliyyah of Medicine
2.	Dr. Luqman Al Bashir bin Mohammed Fauzi	Trainee Lecturer	Kulliyyah of Medicine
3.	Dr. Mohamad Fadhi bin Azmi	Medical Officer	CMU
4.	Dr. Ashraf Syakir bin Zaharaimi	Medical Officer	
5.	Dr. Nor Alyaa binti Mohd Zamnuri	Medical Officer	
6.	Dr. Mohamed Asri bin Mohamed Zaini	Medical Officer	
7.	Asst. Prof. Dr. Mohd Helmie bin Ismail	Head of Department	ED
8.	Asst. Prof. Dr. Aida Nur Sharini binti Mohd Shah	Specialist	
9.	Dr. Muhammad Aizat bin Muhammad Ali	Medical Officer	
10.	Dr. Nur Atiqah binti Mohamed	Medical Officer	
11.	Mohd Zulkifli bin Abd Rahman	Chief AMO	
12.	Mohd Akhyar bin Khazizi	AMO	
13.	Marwan bin Sapian	AMO	
14.	Mohd Fikri Dinie bin Baharudin	Staff Nurse	
15.	Nur Zaharatul Zahirah binti Norazman	Head Nurse	
16.	Mohd Azrin Azly bin Abu Hassan	Head Nurse	
17.	Matron Norhayati binti Mohamed	Matron	
18.	Asst. Prof. Dr. Mohd Fahmi Bin Abd Aziz	General Surgery	Primary team
19.	Dr. Muhamad Syafiz bin Ahmad Ismani	Orthopaedic	
20.	Dr. Ahmad Zulhazwan Bin Ahmad Kasim	Internal Medicine	
21.	Matron Azniwani binti Yusoff	Matron	Nursing
22.	Matron Shahiera Naziera binti Othman	Matron	
23.	Mery Hu Wei Ying	Pharmacist	Pharmacy
24.	Mohamad Tarmizi bin Omar	Radiographer	Radiology
25.	Nurwahida Atira Nordin	Science Officer	Pathology
26.	Mohamad Syaheir bin Azizan	Accountant	Finance
27.	Nur Shahira binti Zulzambi	Administrative officer	Quality
28	Nor Haziah binti Abdul Aziz	IT officer	IT
29	Sr. Asmawati binti Che Ismail	Deputy Director	HR

Attachment 1

Tentative Programme
Lean Training Workshop
SASMEC @IIUM

28-29th August 2024

Time	Programme	Remarks
Day 1: Lean Awareness **28th August 2024**		
0830 – 0900	Registration Breakfast	CMU
0900 – 0905	**Arrival of invited speakers** - Ts. Dr. Mohd Amran bin Daril - Ts. Ir. Dr. Mohammad Ikbar Abdul Wahab - Dr. Farah **Arrival of guests of honour** - YBhg. Prof. Dato' Dr. Mohamed Saufi Awang (Hospital Director) - YBhg. Prof. Dr. Zamzuri Zakaria (Director Clinical) - YBhg. Dr. Siti Zainab Tauhid (Director Administration)	
0905 – 0910	Do'a recitation	Dr. Syakir
0910-0915	Welcome remark by Hospital Director	Prof. Dato' Dr. Mohamed Saufi Awang
0915 – 0930	Briefing and Introductory of Lean Training Workshop	Dr. Dina Syazana Ho
0930 – 1030	Opening lecture by UniKL	Dr. Amran
1030 – 1100	**BREAK**	
1100 – 1300	Lecture	Dr. Ikbar
1300 – 1400	**Lunch & Zohor prayers**	
1400 – 1500	Lecture	Dr. Farah
1500 – 1700	Group discussion & knowledge transfer session	Dr. Amran Dr. Ikbar Dr. Farah
1700	**END OF DAY 1**	

Day 2: Discussion & Consultation 29th August 2024		
0830 – 0900	Registration Breakfast	
0900 – 1100	Group discussion & presentations	Facilitated by Dr. Amran & Dr. Farah
1100 – 1130	**BREAK**	
1130 – 1300	Gemba	**ED SASMEC @IIUM**
1300 – 1400	**Lunch & Zohor prayers**	
1400 – 1700	Discussion Implementation plan	Dr. Amran Dr. Ikbar Dr. Farah
1700	**END OF DAY 2**	

APPENDIX E

FRONT PAGE OF THESIS-RELATED MANUSCRIPT

Malaysian Journal of Public Health Medicine 2026, Vol. 26 (1): 134 - 148

ORIGINAL ARTICLE

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

Dina Syazana Ho Imran Ho[1], Azmawati Mohammed Nawi[1], Rosnah Sutan[1], Mohd Amran Mohd Daril[2], Mohamad Ikbar Abdul Wahab[2], Nur Farah Hafizah Mukhtar[2], Mohd Helmie Ismail[3], and Mohd Rizal Abdul Manaf[1]

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[2]Quality Engineering Section, Universiti Kuala Lumpur Cawangan Malaysian Institute of Industrial Technology (UniKL - MITEC), Persiaran Sinaran Ilmu, Bandar Seri Alam, 81750 Masai, Johor, Malaysia.
[3]Department of Emergency Medicine, Kulliyyah of Medicine, International Islamic University Malaysia, Jalan Sultan Ahmad Shah, Bandar Indera Mahkota, 25200 Kuantan, Pahang, 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

APPENDIX F

CERTIFICATE OF ORAL PRESENTATION AT THE 2ND INTERNATIONAL LEAN HEALTHCARE CONFERENCE 2025

MEDICAL DEVELOPMENT SOCIETY
REVIVE.RECHARGE.REGAIN

KEMENTERIAN KESIHATAN MALAYSIA

UniKL UNIVERSITI KUALA LUMPUR

CERTIFICATE
OF ACHIEVEMENT

THIS CERTIFICATION IS AWARDED TO

DR. DINA SYAZANA HO IMRAN HO, PROF. DR. AZMAWATI MOHAMMED NAWI, PROF. DR. ROSNAH SUTAN, ASSOC. PROF. IR. TS. DR. MOHD AMRAN MOHD DARIL, ASSOC. PROF. IR. TS. DR. MOHAMAD IKBAR ABDUL WAHAB, TS. DR. NUR FARAH HAFIZAH MUKHTAR, PROF. DR. MOHD RIZAL ABDUL MANAF, DR. MOHD HELMIE ISMAIL

AS THE RECEIVER OF

SILVER AWARD

FOR THE ORAL PRESENTATION TITLED

APPLYING VALUE STREAM MAPPING TO IMPROVE DELIVERY OF PATIENT CARE IN THE EMERGENCY DEPARTMENT OF A PUBLIC UNIVERSITY HOSPITAL

AT

2ND INTERNATIONAL LEAN HEALTHCARE CONFERENCE
BERTAM RESORT,PENANG
12-13 AUGUST 2025

TS DR MAZLAN BIN MD ZAHID
DEAN/HEAD OF CAMPUS
UNIVERSITI KUALA LUMPUR
MALAYSIAN INSTITUTE OF
INDUSTRIAL TECHNOLOGY

DR MOHD FEROUS BIN ALIAS
PRESIDENT
MEDICAL DEVELOPMENT SOCIETY
(MEDEV)

APPENDIX G

APPROVAL TO WRITE IN ENGLISH

UNIVERSITI KEBANGSAAN MALAYSIA
The National University of Malaysia

SEKRETARIAT PENGAJIAN SISWAZAH • SECRETARIAT OF POSTGRADUATE STUDIES
FAKULTI PERUBATAN • FACULTY OF MEDICINE

Rujukan : UKM FPR SPS.600-6/6/2
Tarikh : 18 Julai 2024

Dr. Dina Syazana Ho Binti Imran Ho (P137722)
Program Ijazah Doktor Kesihatan Masyarakat
Jabatan Perubatan Kesihatan Awam
Fakulti Perubatan UKM

YBrs. Dr.,

KEPUTUSAN PERMOHONAN MENULIS TESIS DALAM BAHASA INGGERIS

Dengan segala hormatnya perkara di atas adalah dirujuk.

2. Sukacita dimaklumkan bahawa Mesyuarat Jawatankuasa Pengajian Siswazah Ke-282 bertarikh 01 Julai 2024 telah **MELULUSKAN** permohonan YBrs. Dr. untuk menulis tesis dalam Bahasa Inggeris bagi program Doktor Kesihatan Masyarakat kerana mengikut penetapan oleh pihak penaja biasiswa daripada Sultan Ahmad Shah Medical Centre (SASMEC) IIUM, Universiti Islam Antabangsa Malaysia (UIAM)

Sekian, terima kasih.

Yang benar,

NUR AMIRA SYIFA' AZLI
Penolong Pendaftar
Sekretariat Pengajian Siswazah
Fakulti Perubatan UKM

s.k - **Ketua**
Jabatan Perubatan Kesihatan Awam
Fakulti Perubatan UKM

- **Penyelaras**
Program Doktor Kesihatan Masyarakat
Jabatan Perubatan Kesihatan Awam
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  Jabatan Perubatan Kesihatan Awam
  Fakulti Perubatan UKM