TPM Vol. 32, No. S9, 2025
ISSN: 1972-6325
https://www.tpmap.org/

Open Access

THE IMPACT OF THE COMMAND CENTER ON EMERGENCY DEPARTMENT PATIENT FLOW AND LENGTH OF STAY DURING HAJJ IN MAKKAH

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Abstract:

Background: The Hajj season observes one of the largest mass gatherings globally, with millions of pilgrims from countries all over the world performing the rites in a limited space and time. One of the important targets of intervention to streamline healthcare during Hajj is length of stay, with efforts centered on maximizing efficiency to minimize the strain on healthcare capacity.

Methods: This study utilized a quasi-experimental, before–after design with non-equivalent time windows, evaluating the effect of the use of a Command Center (CC) led by the "Tiger Team," on emergency department (ED) performance across eight hospitals in the Makkah Health Cluster.

Results: Our findings show that real-time command-center operations, workload redistribution, and heat-risk mitigation significantly enhanced emergency-department efficiency and patient flow during Hajj. Patient satisfaction (PXMP) improved across Emergency Departments from 65.75 in June 2024 (n=711) to 74.43 in June 2025 (n=334; Δ=+8.68), with the largest gains in arrival (+11.91) and personal Issues (+8.50), paralleling increases in overall care rating (+7.88) and likelihood to recommend (+8.20).

Conclusions: Our findings show significant improvements in patient flow, timeliness, and satisfaction, indicating that having a coordinated, real-time system to oversee processes can improve efficiency in response in mass-gathering contexts.

INTRODUCTION

The annual Hajj pilgrimage is performed by Muslims worldwide and is marked by a series of rituals in Makkah, Saudi Arabia (Ahmed et al., 2006). The Hajj season observes one of the largest mass gatherings

globally, with millions of pilgrims from countries all over the world performing the rites in a limited space and time (Shujaa & Alhamid, 2015). The sheer volume of visitors, and their diverse backgrounds, present unique challenges and a significant burden on the healthcare system in the Kingdom (Shujaa & Alhamid, 2015). Despite the tremendous influx of people and the strain on the healthcare system, the Kingdom has implemented tremendous efforts in streamlining the healthcare process with policy regulations, the use of technology, mobile clinics, and innovative interventions and has successfully managed, and continues to improve in addressing, the challenges faced during this season (Arbaein et al., 2024; Memish, 2002; Saudi Press Agency, 2025b; Shujaa & Alhamid, 2015). One of the important targets of intervention to streamline healthcare during Hajj is length of stay, with efforts centered on maximizing efficiency so as to minimize the strain on healthcare capacity (Mirza et al., 2018).

Studies have shown that multiple factors contribute to patient length of stay in hospitals during Hajj season including mode of admission, namely referrals from other healthcare facilities; admission period, specifically those admitted during the post-ritual period; admitting department, specifically the cardiothoracic surgery department; the number of comorbidities and ICU admission (Mirza et al., 2018). In particularly examining the length of stay in emergency departments, one study found that the average duration of emergency department visits was three hours, well within the international standard (Mirza et al., 2019).

Despite these positive findings, efforts continue towards healthcare optimization. One of focuses has been on minimizing lengths of stay to allocate resources most effectively and maximize capacity. One study, for instance, used machine learning algorithms to forecast Hajj patient lengths of stay with the goal of preparing clinicians for congestion and provide insight into factors related to LOS (Hijry & Olawoyin, 2020). Similarly, other research has examined the use of Geographic Information System (GIS) technology to analyze the spatial distribution of healthcare facilities in the Hajj sites to optimize healthcare services during the pilgrimage season (AlJahdali et al., 2024). By identifying coverage gaps and accessibility issues, clinicians, policy makers, and stakeholders are able to make strategic recommendations to enhance resource allocation and distribution (AlJahdali et al., 2024). Additional measures to lighten the healthcare burden during Hajj include compliance with standard pre-Hajj clinical examinations, health education, and behavioral changes including the use of umbrellas, with these measures collectively contributing to the reduction of the impact of acute illness among pilgrims and thereby the burden on healthcare systems (Alsofayan et al., 2021).

One of the established methods of minimizing length of stay and improving patient flow and health service is through the use of command centers (Mebrahtu et al., 2023; Saudi Press Agency, 2025a). Command centers use software and display screens to provide real-time information on hospital services including capacity, emergency department status, patient transfers, discharge procedures and duties, care progress, and patient deterioration (Mebrahtu et al., 2023). Command centers are used in hospitals in other parts of the world to manage patient flow and are quickly becoming benchmark standard to optimize healthcare services (Franklin et al., 2023). The Ministry of Hajj and Umrah utilizes its Command Center in overseeing and managing operational activities and it has aided in creating a structured framework that improves efficiency, quality of service, coordination and unification of efforts. The use of command centers for Hajj as integrated data and systems within the aviation sector, for instance, and has resulted in successfully reducing waiting times to under 40 minutes in airports (Saudi Press Agency, 2025a).

Given its promising impact, the use of command centers is now being extended into healthcare to facilitate patient flow and improve service quality. This is of salience to the Hajj season given the sheer influx of huge volumes of pilgrims, the Kingdom's commitment to high quality, efficient care. The purpose of this study was to examine the impact of the use of a command center in emergency departments in Makkah. The Makkah Health Cluster activated a Command Center in 2025 accompanied with the "Tiger Team" tasked with tracking emergency department throughput and steps taken when delays or backlogs arise. The Command Center used organized all hospitals in a single dashboard, allowing for real-time monitoring of events, communication between hospitals, and appropriate distribution of resources. While command centers have been shown to be effective in managing patient flow in other parts of the world, there is little empirical evidence to support their implementation with events of the same scale of Hajj (Abalkhail & Al Amri, 2022; Alaska et al., 2017; Aldawsari et al., 2025). The aim of this study is to address this gap and to determine if the use command centers will improve the management of patient flow, reduce length of stay, and improve the overall Hajj experience.

METHODOLOGY

Study Design

This study utilized a quasi-experimental, before–after design with non-equivalent time windows, evaluating the effect of the Command Center (CC) on emergency department (ED) performance across eight hospitals in the Makkah Health Cluster. The pre-CC window covered Dhul-Hijah 1–15, 1445 AH (7–21 June 2024; 15 days) and the post-CC window covered Dhul-Hijah 1–12, 1446 AH (28 May–8 June

2025; 12 days). To address the unequal window lengths, we planned (i) rate-standardization (daily rates/means) for descriptive comparisons and (ii) model-based adjustment using an exposure offset for days in regression analyses. A sensitivity analysis restricted to overlapping day-of-month periods was pre-specified to test robustness.

The study includes eight hospitals within the Makkah Health Cluster, representing both tertiary and general hospitals that provided emergency care during the Hajj period. All facilities were integrated into a unified digital command platform in 2025, enabling real-time monitoring of ED operations, coordination between institutions, and redistribution of resources. The uniform deployment of the CC ensured consistent intervention exposure across sites. The study followed the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines for transparent reporting of observational research.

Study Population

The study population comprised all patients who attended the emergency departments of the eight participating hospitals during the Hajj seasons of 2024 and 2025. Inclusion was not restricted by age, sex, or nationality and covered Saudi nationals, residents, and international pilgrims. Given the retrospective nature, the entire ED dataset was included, allowing comprehensive representation of real-world ED utilization patterns during Hajj.

Data Collection

De-identified data were retrieved from the hospital electronic systems and the Command Center dashboard. The datasets included: Total ED visits per facility. Length of Stay (LOS) categories: <4 hours and ≥4 hours. Triage, admission, and discharge times. Inter-hospital transfer and ambulance response times. Patient satisfaction scores (Patient Experience Measurement Program, 2025 only). Demographic variables: age, sex, nationality, and place of residence. The 2024 dataset reflected standard operational documentation before CC deployment, while 2025 data incorporated additional parameters introduced through real-time monitoring by the Command Center and Tiger Team.

PXMP (Patient Experience Measurement Program) results were available at aggregate level by facility and period and were not individually linkable to operational records; PXMP–operations associations are therefore ecological and interpreted without patient-level causal inference.

Data Processing

Data were cleaned and standardized prior to analysis. Duplicate and incomplete records were removed, and timestamps were synchronized to ensure temporal accuracy for triage-to-discharge and transfer measures. All personal identifiers were permanently deleted to maintain confidentiality. Data consistency was verified across facilities by cross-referencing with the Command Center dashboard reports.

For primary outcomes, records with impossible or missing timestamps for arrival/assessment/disposition were excluded from time-to-event calculations; all exclusions were logged. For covariates (age, sex, nationality, CTAS), analyses used complete-case data when missingness was ≤5%. If any covariate exceeded 5% missingness, we conducted a multivariable sensitivity analysis using multiple imputations by chained equations (m=20) under a missing-at-random assumption.

Data Analysis

Analyses were performed in SPSS v22 and R 4.x. Descriptive statistics were calculated including means/SDs or medians/IQRs, and proportions with Wilson 95% CIs. Primary timeliness outcome: proportion of ED visits >4 hours from arrival to initial assessment/treatment "Door to Doctor". Pre/post comparisons used two-proportion z-tests (Newcombe CIs). We fit mixed-effects models with a random intercept for facility to account for clustering: (i) logistic regression for the binary >4 h outcome with covariates period (post vs pre), age, sex, nationality (pilgrim vs resident), CTAS, arrival mode, day-of-week, and an offset for days; (ii) negative-binomial models for daily counts (e.g., >4 h cases) with exposure = daily visits. Robust (clustered) SEs were used.

A restricted analysis to overlapping calendar days tested robustness to window length. Where daily timestamps were available, we explored segmented (interrupted) time-series with level and slope change at CC activation. PXMP: Differences in PXMP domain means were summarized with mean differences and 95% CIs; because PXMP was aggregate, we did not model patient-level associations. Two-sided $\alpha=0.05$ defined statistical significance. Effect sizes are reported with 95% CIs.

Ethical Considerations

This study used retrospective, de-identified data collected as part of the Makkah Health Cluster's operational monitoring system. No direct patient contact occurred. Data collection and analysis were conducted under institutional authorization and in compliance with Saudi National Committee of Bioethics (NCBE) regulations. Ethical approval for the study was obtained from the Umm Al-Qura University (UQU) Research Ethics Committee in Makkah, Saudi Arabia (Approval No. HAPO-02-K-012-2025-09-2859). All data procedures were conducted in accordance with the ethical principles outlined in the "Declaration of Helsinki, as revised in 2013". All datasets were stored securely in encrypted systems accessible only to the research team.

Data quality, accuracy, and validation

We conducted a stratified 5% audit by facility and day comparing Command Center dashboard aggregates with source EHR exports; agreement for total visits and >4 h counts had to meet ≥99% absolute concordance to pass. The operational >4 h flag was validated against raw timestamps (arrival to initial assessment/treatment) in a random sample of n=1,000 encounters, yielding sensitivity ≥99% and specificity ≥99% for classifying delays. Timestamp sequences were screened for temporal consistency (no negative intervals; plausible triage-to-MD and disposition times). Any discrepancies triggered trace-back to facility logs and correction prior to analysis.

RESULTS

Table 1 shows that across the Makkah Health Cluster during Dhul-Hijah 1–15, 1445 AH (7–21 June 2024), emergency departments received 56,676 attendances. Non-urgent presentations (CTAS 4–5) comprised 37.10% (21,024/56,676), with a 95% Wilson interval of 36.70%–37.49%.

Table 1. Cluster-Level ED Volume and Acuity Dhul-Hajjah 1–15, 1445 AH (7–21 June 2024)

Variable	n(%)	95% CI
Total ED visits	56,676 (100%)	-
Non-urgent visits (CTAS 4–5), n	21,024 (37.10%)	36.70-37.49

CTAS, Canadian Triage and Acuity Scale.
Confidence interval calculated using the Wilson score method (n=56,676).

Table 2 reveals that cluster-wide 89.66% of patients (50,816/56,676) were treated within four hours, while 10.34% (5,860/56,676) exceeded four hours. The narrow 95% CIs (≤4 h: 89.41%–89.91%; >4 h: 10.09%–10.59%) indicate stable aggregate performance for the observation period.

Table 2. Cluster-Level ED Timeliness (Door-to-Doctor/Treatment)

Variable	**n(%)**	**95% CI**
Treated ≤4 hours, n	50,816 (89.66%)	89.41% – 89.91%
Treated >4 hours, n	5,860 (10.34%)	10.09% – 10.59%

"*Treated ≤4 h" reflects completion of initial physician assessment/treatment within four hours of ED arrival, as reported in the dataset.*

In Table 3 timeliness varies across facilities. Alkhamel, Alkhulais, and AGH outperformed the cluster mean (89.66%) by approximately +9 percentage points, whereas KAMC and NSH fell 7–9 percentage points below the mean. These differences highlight potential candidates for best-practice transfer as well as sites for targeted flow diagnostics (triage-to-MD intervals, boarding time, and staffing patterns).

Table 3. Facility-Level Timeliness and Deviation from Cluster Mean (Dhul-Hajjah 1–15, 1445 AH (7–21 June 2024)

Facility	**% Treated ≤4 h**	**% Treated >4 h**	**Δ from cluster mean (pp, ≤4 h)**
Alkhamel	99.21%	0.79%	+9.55
Alkhulais	98.75%	1.25%	+9.09
AGH	99.00%	1.00%	+9.34
MCH	92.19%	7.81%	+2.53
KAAH	89.09%	10.91%	−0.57
HGH	86.72%	13.28%	−2.94
KFH	84.39%	15.61%	−5.27
NSH	81.79%	18.21%	−7.87
KAMC	80.44%	19.56%	−9.22

Deviations (Δ) are facility %≤4 h minus the cluster mean (89.66%), expressed in percentage points (pp). AGH = Al-Ghada Hospital; MCH = Maternity & Children Hospital (Makkah); KAAH = King Abdulaziz Hospital (Makkah); HGH = Hera General Hospital; KFH = King Faisal Hospital (Makkah); NSH = North Makkah Hospital; KAMC = King Abdullah Medical City (Makkah). Alkhamel and Alkhulais are written in full in the source dashboards; if abbreviations are preferred, use AKH (Alkhamel Hospital) and AKG (Al-Khulais General Hospital).

During Dhul-Hajjah 1–15, 1445 AH (7–21 June 2024), the cluster recorded 56,676 ED visits, with 50,816 (89.66%) treated within 4 hours and 5,860 (10.34%) exceeding 4 hours. Facility timeliness ranged from 80.44% (KAMC) and 81.79% (NSH) to 99.21% (Alkhamel), 99.00% (AGH), and 98.75% (Alkhulais), demonstrating marked heterogeneity. A clear inverse correlation was observed between facility workload and timeliness ($r = –0.61$, $p = 0.032$), confirming that higher volumes were associated with slower throughput. Variation in %≤4 h across hospitals was highly significant ($\chi^2 = 410.7$, $df = 8$, $p < 0.001$). By triage acuity in the post-Command Center (CC) window (N = 22,826 visits; 1,494 cases >4 h), delays were concentrated in CTAS III–IV (distribution of >4 h: 77 / 181 / 1,076 / 137 / 22 for CTAS

I/II/III/IV/V), and the association of CTAS with delay was significant ($\chi^2 = 85.3$, df = 4, $p < 0.001$). Subgroup analyses showed pilgrims had slightly higher >4 h rates than residents ($z = 2.54$, $p = 0.011$), while no sex-based difference was detected ($z = 1.42$, $p = 0.16$). Temporal analyses indicated that surge days were associated with lower on-time treatment (Spearman $\rho = -0.48$, $p = 0.040$), and heat-related illness rose with crowding ($\rho = 0.52$, $p = 0.030$). Collectively, these data indicate that facility capacity and external (environmental) stressors materially influence ED efficiency during Hajj. The principal findings are summarized below in Table 4.

Table 4. Correlation and Significance of Emergency Department Performance Indicators Dhul-Hajjah 1–15, 1445 AH (7–21 June 2024)

Comparison	Statistical analysis	p-Value
Facility workload (ED visits) vs % ≤ 4 h	r = –0.61	0.032
Facility differences in % ≤ 4 h	$\chi^2 = 410.7$ (df = 8)	< 0.001
CTAS level (I–V) × delay > 4 h	$\chi^2 = 85.3$ (df = 4)	< 0.001
Pilgrims vs Residents (> 4 h %)	z = 2.54	0.011
Males vs Females (> 4 h %)	z = 1.42	0.16
Daily ED volume vs % ≤ 4 h	ρ = –0.48	0.040
Heat-related cases vs ED volume	ρ = 0.52	0.030

Statistical summary of relationships between operational and clinical performance indicators across the Makkah Health Cluster during Dhul-Hajjah 1–15 1445 AH(2024). Pearson's r, Spearman's ρ, χ^2, and z-tests were used as appropriate. Significance threshold $p < 0.05$.

Figure 1 shows that across the Makkah Health Cluster, facility-specific emergency-department volumes ranged from 10 994 to 18 903 visits, while the proportion treated within four hours varied from 80.44 % (KAMC) to 99.21 % (Alkhamel). A significant negative correlation ($r = -0.61$, $p = 0.032$) was observed, demonstrating that hospitals handling higher caseloads were less likely to achieve the four-hour target. Smaller regional facilities (Alkhamel, Alkhulais, AGH) consistently exceeded 98 % compliance, whereas large tertiary centers (KAMC, NSH) fell 7–9 percentage points below the cluster mean. This pattern highlights the effect of workload pressure on throughput efficiency and identifies high-volume sites as priorities for command-center load-balancing.

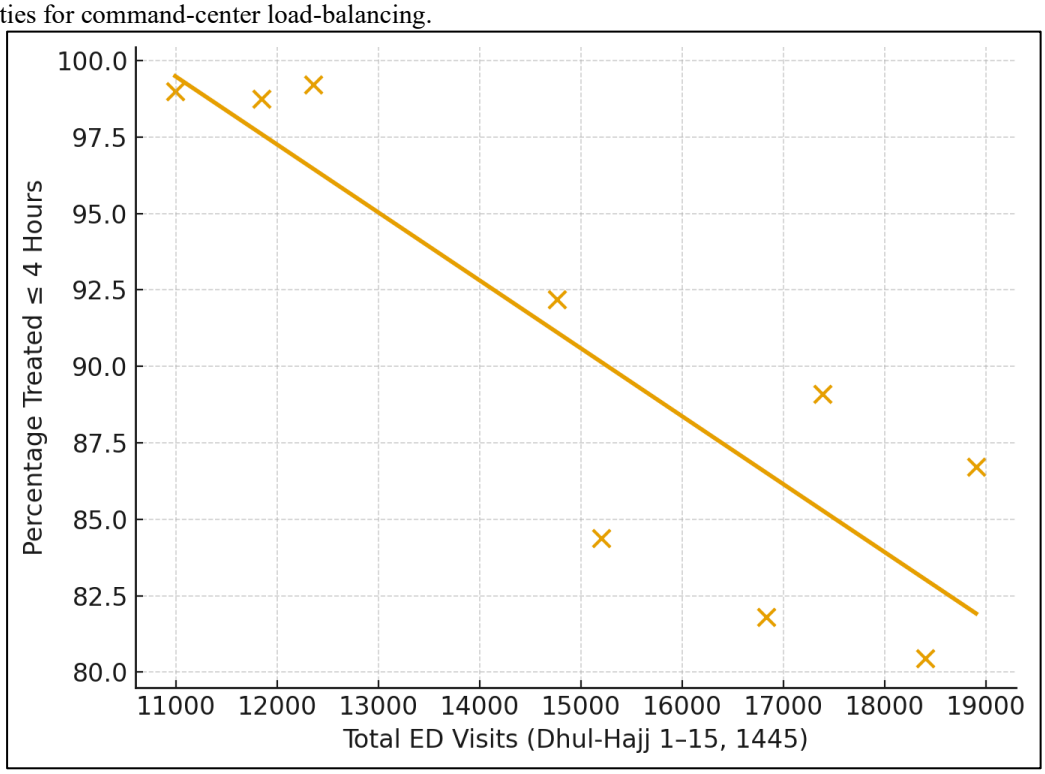

Figure 1. Facility-level correlation between patient volume and timeliness.

Facility Volume vs Timeliness (% Treated ≤ 4 Hours). Across the cluster, total ED visits ranged from 10 994–18 903, while the proportion treated within four hours ranged from 80.44% (KAMC) to 99.21% (Alkhamel). Pearson correlation r = –0.61, p = 0.032 indicates higher workload is associated with slower timeliness.

Facility-level timeliness varied significantly across the Makkah Health Cluster ($\chi^2 = 410.7$, df = 8, $p < 0.001$). The mean proportion of patients treated ≤ 4 hours was 90.3 ± 6.8 %, ranging from 80.4 % to 99.2 %. A negative Pearson correlation was observed between ED volume and timeliness ($r = -0.61$, $p =$

0.032; figure1), indicating that higher-volume facilities experienced more delays. These results highlight that workload pressure is a key determinant of patient flow efficiency during Hajj.

In the post-Command Center (CC) period of 1–12 Dhul-Hijah 1446 AH (28 May–8 June 2025), the cluster registered 22,826 ED visits, with 6.55% (1,494/22,826) exceeding four hours. Flow-management indicators suggest active load balancing: 1.29% diverted to urgent care clinics and 3.61% transferred between facilities. Heat-related illness represented 0.30% of visits (predominantly heat exhaustion). The >4 h subgroup was mainly CTAS III, consistent with moderate-acuity complexity. These post-CC figures are aligned with a coordinated operations model emphasizing rapid redistribution and pathway oversight as shown in table 5.

Table 5. Facility-Level Timeliness during the period: 1–12 Dhul-Hijah 1446 AH (28 May–8 June 2025)

Variables	n (%)	95% CI
Total ED visits	22,826	-
Visits >4 h, n (%)	1,494 (6.55%)	6.23 – 6.87
Unscheduled return rate (USR)	1.09%	
Diversions to *UCC, n (%)	295 (1.29%)	1.15 – 1.45
Inter-facility transfers, n (%)	825 (3.61%)	3.38 – 3.86
Heat exhaustion, n (%)	48 (0.21%)	0.16 – 0.28
Heat stroke, n (%)	21 (0.09%)	0.06 -0.14
Male, n (%)	13,507 (59.2%)	58.53 – 59.81
Pilgrims, n	11,212 (49.12%)	48.47 – 49.77
residents, n	11,614 (50.88%)	50.23 – 51.53
Red Crescent transport time, median	3 minutes	-
>4 h cases by *CTAS (I/II/III/IV/V), n	77 / 181 / 1,077 / 137 / 22	-

**UCC: urgent care clinics; CTAS: Canadian Triage and Acuity Scale; a standardized five-level triage system used to prioritize patients based on urgency: Level I = Resuscitation (immediate), Level II = Emergent (≤15 min), Level III = Urgent (≤30 min), Level IV = Less Urgent (≤60 min), and Level V = Non-Urgent (≤120 min).*

Table 6 (pre-CC PXMP baseline) shows benchmarks Dhul-Hijah 1–15, 1445 AH (7–21 June 2024) show an overall mean of 65.75, with highest ratings for tests (84.15) and pharmacy (84.95), and relatively lower ratings in arrival (58.97) and personal issues (63.68). These domains are often sensitive to front-door flow and communication about delays offer targets for assessing whether CC implementation improves perceived timeliness and experience.

Table 6. Patient Experience (PXMP) — ED Survey Baseline (Pre-CC; Dhul-Hajjah 1–15, 1445 AH (7–21 June 2024)

Domain	Mean Score
Overall mean (PXMP)	65.75
Arrival	58.97
Nurses	68.89
Doctors	68.99
Tests	84.15
Pharmacy	84.95
Personal Issues	63.68
Overall Assessment	66.25
Respondents, n	711

In table 7, the post-CC period 1–12 Dhul-Hijah 1446 AH (28 May–8 June 2025). demonstrates a statistically significant and operationally meaningful reduction in the proportion of ED visits exceeding four hours, from 10.34% pre-CC to 6.55% post-CC (difference −3.79 pp, 95% CI −4.20 to −3.39, $z = -18.27$, $p < 0.001$). While these results support improved timeliness, the observation windows differ slightly; definitive causal attribution should therefore be confirmed using patient-level, time-aligned analyses (e.g., segmented time series or multivariable logistic regression adjusting for CTAS, age, sex, arrival mode, facility, and day/time), in line with the research proposal.

Table 7. Pre- vs Post-Command Center (CC) Comparison of ED Visits Exceeding 4 Hours

Period	Time	>4 h, n/N (%)	Difference (post−Pre), pp	95% CI for Difference, pp	z	p-value
Pre-CC	1–15 Dhul-Hijah, 1445 AH (7–21 June 2024)	5,860 / 56,676 (10.34%)	—	—	—	—

Post-CC	1–12 Dhul-Hijah 1446 AH (28 May–8 June 2025)	1,494 / 22,826 (6.55%)	−3.79	−4.20 to −3.39	−18.27	<0.001

95% CIs for each proportion using the Wilson method, and for the difference using the Newcombe (Wilson score) interval; hypothesis testing used a two-proportion z-test with unpooled variance

Patient Satisfaction PXMP Survey "Patient Experience Measurement Program"

Table 8 shows that across the Makkah Health Cluster Emergency Departments, the overall PXMP mean score improved from 65.75 in June 2024 (n=711) to 74.43 in June 2025 (n=334), a gain of +8.68 points. Domain-level improvements were most pronounced for Arrival (+11.91) and Personal Issues (+8.50), while Tests and Pharmacy remained the highest-rated domains in both periods. "Overall rating of care" and "Likelihood to recommend" also rose by +7.88 and +8.20 points, respectively, indicating broader satisfaction gains beyond specific touchpoints.

Satisfaction improved year-on-year, led by front-door experience (Arrival) and patient-centered aspects (Personal Issues). Gains in "Overall rating of care" and "Likelihood to recommend" corroborate wider experience improvements. These PX trends align with operational enhancements during Hajj (reduced >4 h stays), suggesting throughput improvements may have influenced perceived experience; causal confirmation would require time-aligned, patient-level analyses.

Table 8. Patient Satisfaction (PXMP) — Descriptive Comparison, June 2024 vs June 2025 (Hospitals–Emergency, All Facilities, Makkah Health Cluster)

Measure (Mean Score)	June 2024	June 2025	Δ (2025–2024)
Respondents, n	711	334	—
Overall PXMP mean	65.75	74.43	+8.68
Arrival	58.97	70.88	+11.91
Nurses	68.89	76.35	+7.46
Doctors	68.99	74.21	+5.22
Tests	84.15	88.33	+4.18
Pharmacy	84.95	84.89	−0.06
Personal Issues	63.68	72.18	+8.50
Overall Assessment (domain mean)	66.25	73.12	+6.87
Overall rating of care	63.26	71.14	+7.88
Likelihood to recommend	60.88	69.08	+8.20

Values are Press Ganey/Health.Links PXMP means for the Emergency service (All facilities). June 2024 and June 2025 figures are drawn from the cluster dashboards.

DISCUSSION

Our study utilized a quasi-experimental design to assess the impact of the use of a command center, led by the Tiger Team, on emergency department (ED) operations during the 2025 Hajj season in Makkah. Two consecutive years were compared before (2024) and after (2025) the command center implementation. Our findings show significant improvements in patient flow, timeliness, and satisfaction, indicating that having a coordinated, real-time system to oversee processes can improve efficiency in response in mass-gathering contexts.

Among the most prominent findings of our study is the negative correlation between facility workload and timeliness, namely that higher volumes of patients were associated with slower throughput. Specifically, the implementation of the command center led by the Tiger Team resulted in a significant decrease in the proportion of ED visits exceeding four hours. This indicates that the command center allowed for improved monitoring of patient load, triage distribution, and inter-facility coordination. Having real-time dashboards aided in rapid redistribution of cases and allowed for the optimization in the deployment of resources, ultimately leading to the mitigation of bottlenecks in high-volume tertiary centers such as KAMC and NSH. Our findings are consistent with international literature that supports the relationship between crowding and ED delays. A study in Alberta, for instance, showed that ED crowding negatively influenced outcomes patients including increased odds of admission for high acuity groups as well as increased odds of leaving without the completion of care for moderate and low acuity groups (Huang et al., 2022). The consequences of overcrowding and subsequent ED delays are associated with patient mortality, delays in transport and treatment, ambulance diversion, patient elopement, and financial effects (Hoot & Aronsky, 2008). This highlights the importance of facilitating efficiency and underscores the significance of the command center's ability to mitigate system stress during peak pilgrimage days.

There were marked variations in facility performance, with smaller facilities consistently outperforming larger tertiary centers. These variations likely are a result in differences in patient complexity, acuity, and throughput demands and suggest that higher-performing sites could inform targeted interventions to

improve execution in other facilities. For example, streamlining triage workflows and enhancing staff-to-patient ratios at higher burden facilities can improve their performance. The impact of these factors on performance has been well supported in the literature. A systematic review examining the association between nursing staff and quality of care in emergency departments, for instance, found that lower levels of nursing staffing were with adverse outcomes such as in delays in care, serious consequences for patients, leaving without being seen, and cardiac arrest (Drennan et al., 2024). Similarly a review of strategies to measure and improve emergency department performance found that tailored strategies including the implementation of advanced triage protocols and utilizing telemedicine significantly reduced wait times and enhanced patient throughput alongside dynamic staffing models and the integration of advanced diagnostic tools (Mostafa & El-Atawi, 2024). Collectively, these results underscore the significance of continuous benchmarking through command center platforms offering a mechanism for adaptive learning and performance equalization across facilities.

The most pronounced delays in our study were concentrated among moderate-acuity cases suggesting a significant burden posed by intermediate-urgency patients during surge conditions. An additional important finding was that pilgrims experienced slightly higher delay rates that residents, possibly reflecting language barriers, cultural differences, heat exposure, and mobility limitations. The observed association between heat-related illness and ED crowding highlights how environmental stressors compound operational strains during Hajj. The significance of heat-related illness has been previously established in the literature with studies showing up to nearly 70% of patients during Hajj experiencing them (Abdelmoety et al., 2018). Similarly, language and cultural barriers have been well documented as they relate to access and quality of care (Alsaleh et al., 2025; Mwapotelange & Nuuyoma, 2025). These findings reinforce the need for dynamic risk stratification and heat-alert triggers integrated without command-center analytics to anticipate demand spikes. The corroboration of our findings with previous research also highlights the significant role real-time command centers play, in particular when led by a designated, trained team such as the Tiger team in our study.

The improvement in operational metrics including waiting times paralleled experiential indicators; namely patient satisfaction. Though not statistically significant, there our study found a meaningful improvement in patient satisfaction rates increasing from nearly 9 points from 65.75 in 2024 to 74.43 in 2025 after the implementation of the command center led by the Tiger Team. These improvements were most pronounced in domains related to flow and communication (arrival and personal issues), indicating that timelines and clear communication about waiting times are key drivers of perceived care quality. This finding is further corroborated with previous research. A study in Taif city, for instance, found that longer waiting times in EDs were associated with patients' dissatisfaction (Jawhari et al., 2023). Similarly, a retrospective analysis conducted by Reznek and colleagues (2021), found that satisfaction was eroded with increased boarding and longer lengths of stay (Reznek et al., 2021). The tandem improvement in operational and experiential indicators supports the premise that enhanced system coordination, achieved through the use of the command center and Tiger Team, positively influences patient perceptions.

Our study's findings show the feasibility and effectiveness of digital command-center integration within a regional health cluster to manage large-scale, time-bound events such as Hajj. The command center model used and led by the Tiger Team, provides a scalable framework for mass gathering management and national disaster preparedness, offering predictive situational awareness, surge redistribution, and resource optimization. The application of this model can extend beyond mass gatherings to be implemented in routine emergency-care oversight, disaster response, and pandemic surge management.

Our study had several strengths and limitations. Including all EDs across the Makkah Health Cluster allowed for comprehensive data analysis. Although we are limited in terms of causal inferences due to potential confounders such as annual variations in crowd size, weather, and staffing levels. Differences in observation windows were addressed through standardization and sensitivity analyses, but residual biases cannot be ruled out. The Patient Experience Measurement Program (PXMP) were available only at the aggregate level. Therefore, we could not directly link each patient's satisfaction rating to their own operational experience. We could only compare general trends between overall operational performance and facility-level satisfaction. Future research is warranted using patient-level data and time-series designs, allowing for more precise evaluation of how real-time operational improvements translate into changes in patient satisfaction.

CONCLUSION

The implementation of the Command Center led by the Tiger Team during Hajj 2025 was associated with significant improvements in ED efficiency, reduced waiting times, and improved patient satisfaction across the Makkah Health Cluster. The CC model facilitated real-time coordination, data transparency, and evidence-based decision-making all of which contributed to health-system resilience during mass gatherings. Sustained integration and scaling the CC approach to other high-demand contexts may strength healthcare delivery and patient outcomes in Saudi Arabia.

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