Design and Evaluation: KPI-Based Hospital Operations Monitoring Using CCTV-Based AI

Reformmed AI

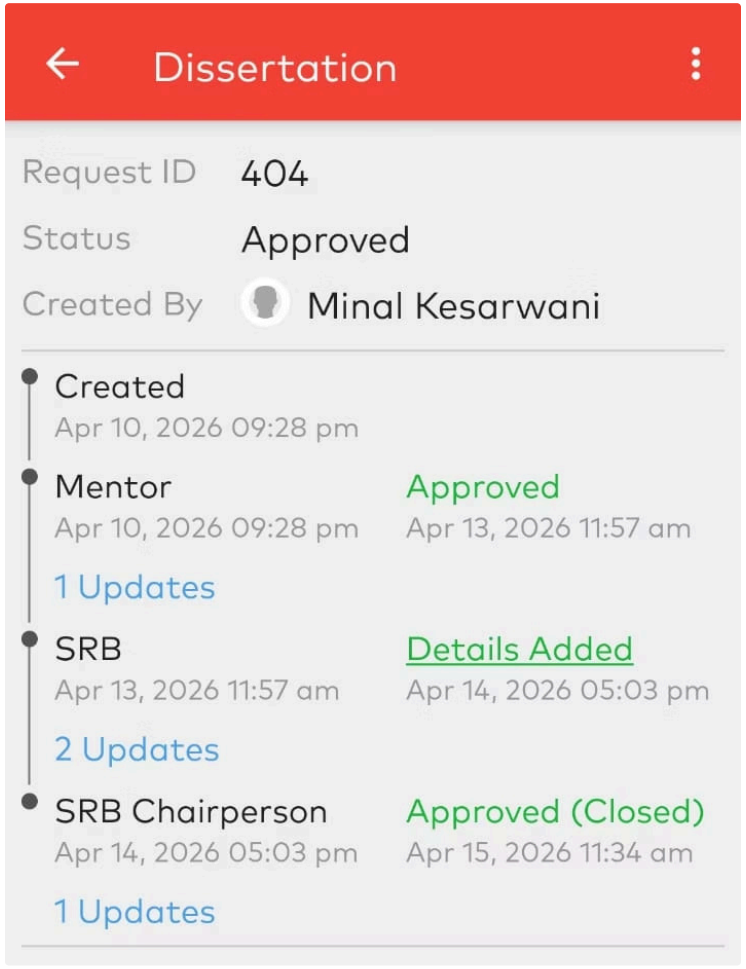
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Mentor Approval & SRB Approval

Mentor Approval

SRB Approval



Background

Efficient hospital operations are essential for delivering timely, safe, and high-quality healthcare. As outlined by NABH, continuous monitoring of patient flow, processes, and service delivery is critical for maintaining quality standards. Yet hospitals routinely face long waiting times, overcrowding, service delays, and inefficient staff utilisation — all of which negatively impact patient experience.

Limitations of Traditional Monitoring

Manual records and Hospital Information Systems (HIS) offer limited real-time visibility into queue formation, crowd density, and staff availability, restricting administrators from implementing timely corrective measures.

The AI Opportunity

CCTV-based AI surveillance systems offer continuous, non-intrusive monitoring integrated with real-time KPI dashboards — measuring waiting time, patient load, staff utilisation, and crowd density to support data-driven decision-making.

Limited studies have explored the integration of CCTV-based AI analytics with KPI-driven hospital performance monitoring. This study aims to bridge that gap while ensuring strict adherence to privacy, confidentiality, and ethical standards.

Objectives & Key Research Questions

Primary Objective

To design and evaluate a hospital operations monitoring system using CCTV-based Key Performance Indicators.

Secondary Objectives

Patient Flow Analysis

Analyse patient flow patterns across selected OPD service areas

Time Measurement

Measure waiting time, service time, and turnaround time

Staff Assessment

Assess staff presence, utilisation, and absenteeism patterns

Bottleneck Detection

Identify peak load periods and operational inefficiencies

Research Questions

- What are the key operational inefficiencies in OPD service areas?
- How does patient flow vary during peak and non-peak hours?
- What are the peak workload periods and their impact on service delivery?
- How effectively are staff resources utilised across departments?
- Can KPI monitoring through CCTV improve operational efficiency and patient satisfaction?

Scope: Selected OPD service areas at Hospital X — reception, registration, billing, pharmacy, waiting areas, and entry/exit points. AI-generated alert data from May 2026 was analysed.

Methodology

Study Design & Setting

An **observational and analytical design** was adopted to evaluate the KPI-based monitoring system in selected OPD areas of Hospital X. The dissertation spanned three months; the alert dataset covered **1–31 May 2026**.

Study Areas

- Reception and registration counters
- Billing counters and pharmacy
- Waiting areas and entry/exit points
- Laboratory and other OPD service points

Dataset Description

Each alert record represented an operational event triggered when a predefined KPI threshold was crossed. Variables included: date, time, monitored OPD area, alert type, severity, alert duration, and action status.

Sampling & Data Collection

Purposive sampling covered peak and non-peak hours with **24-hour monitoring** (day shift: 8 AM–8 PM; night shift: 8 PM–8 AM). The procedure involved camera mapping, ROI identification, pilot review, systematic footage analysis, and alert validation.

CCTV AI Surveillance Workflow

The system follows a structured four-step implementation workflow — from physical camera setup through to live dashboard analytics — ensuring comprehensive, real-time operational intelligence across all monitored OPD zones.

1

Step 1: Camera Mapping

- Identify camera locations
- Assess visibility and operational coverage
- Define Regions of Interest (ROI)

2

Step 2: AI Configuration

- People counting
- Queue detection
- Staff presence detection
- Crowd density monitoring
- Motion tracking & idle time detection

3

Step 3: KPI Integration

- Map operational KPIs with camera feeds
- Configure threshold limits
- Generate automated alerts

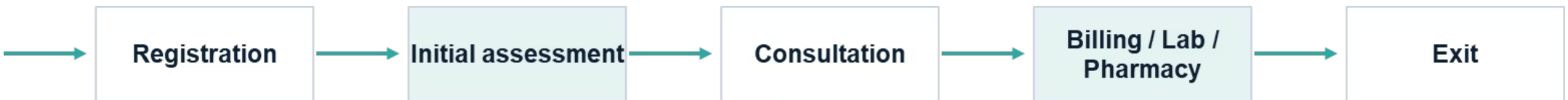
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Step 4: Dashboard Monitoring

- Real-time KPI dashboard
- Heatmap visualisation
- Peak hour analytics
- Daily operational summaries

OPD Workflow Mapping for CCTV-Based KPI Monitoring

The OPD workflow is designed as a sequential patient movement pathway where each operational stage acts as a monitored **Region of Interest (ROI)** for KPI generation through CCTV-based AI surveillance.



Registration

Patient entry, identity verification, and record creation

Initial Assessment

Triage and preliminary clinical evaluation

Consultation

Physician interaction and diagnosis

Billing / Lab / Pharmacy

Payment processing, diagnostics, and medicine dispensing

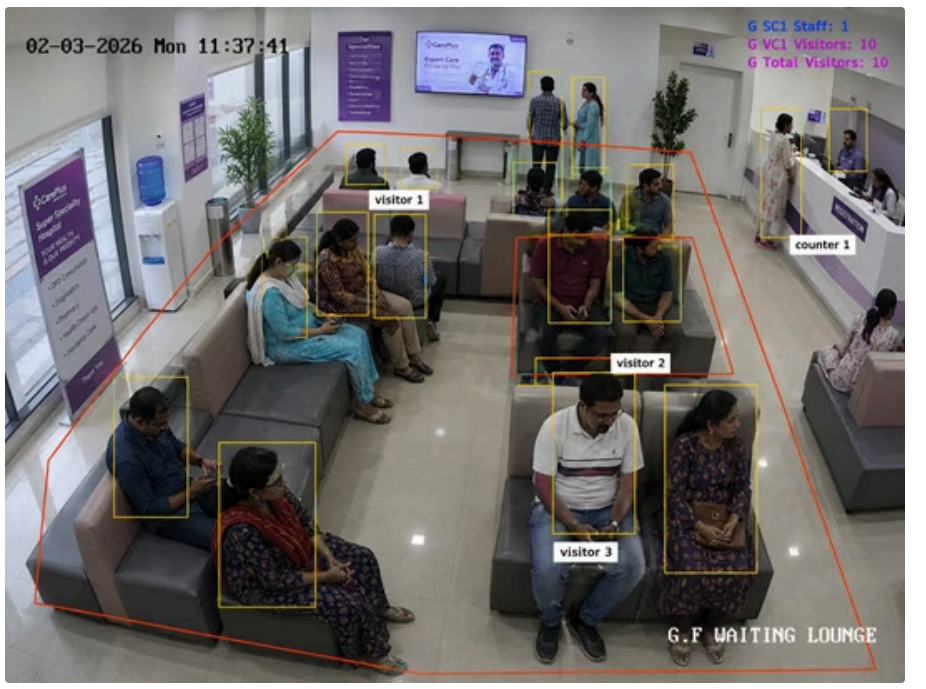
Exit

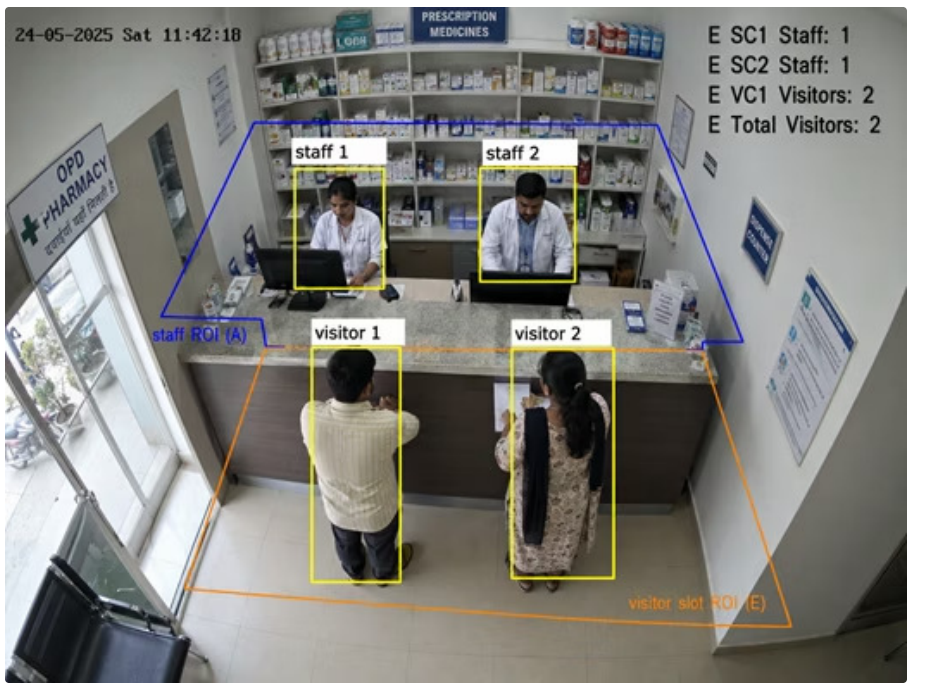
Patient departure and journey completion

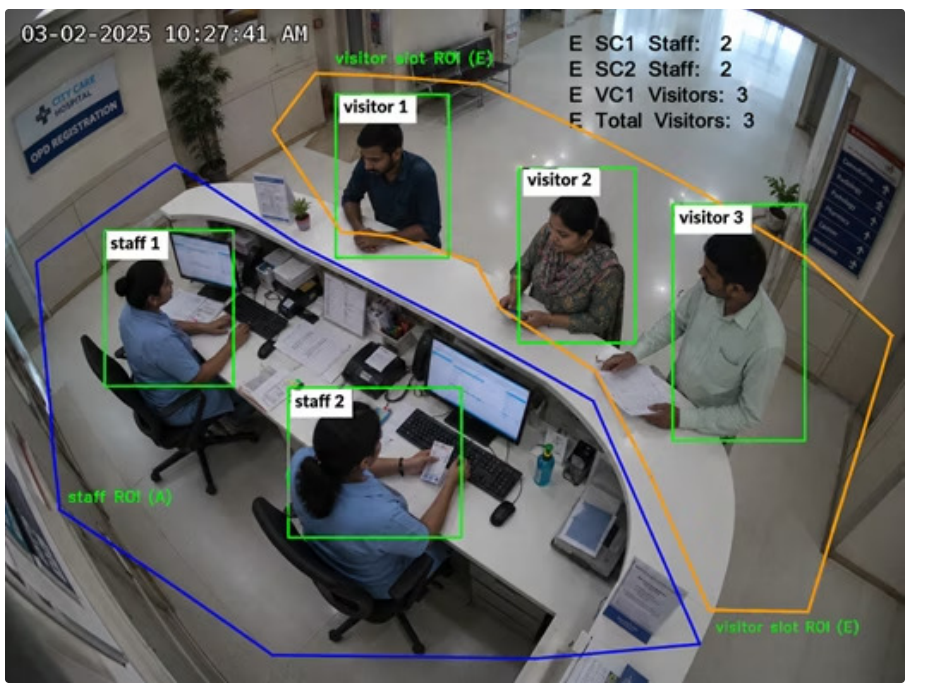
Each workflow stage acts as a Region of Interest (ROI) for generating operational KPIs such as **waiting time, queue length, service time, crowd density, and TAT**.

OPD Monitoring Zones (ROI – Region of Interest)

ROI	Zone	Purpose	Key KPIs
ROI-1	Entry Gate	Monitor patient inflow/outflow	Entry/exit time, hourly footfall
ROI-2	Registration Counter	Registration workflow efficiency	Queue length, waiting time, service time
ROI-3	Waiting Area	Monitor congestion and occupancy	Crowd density, overcrowding duration
ROI-4	Initial Assessment	Monitor triage workflow	Service time, patient processing rate
ROI-5	Consultation Room	Monitor consultations externally	Consultation duration, patient throughput
ROI-6	Billing Counter	Billing process efficiency	Billing TAT, queue waiting time
ROI-7	Pharmacy	Dispensing workflow	Queue time, pharmacy TAT
ROI-8	Patient Journey	Track full OPD pathway	Overall TAT, workflow delays
ROI-9	Staff Productivity	Staff operational efficiency	Staff-patient ratio, idle time
ROI-10	Peak Hour Zone	Operational load distribution	Peak load periods, congestion trends







AI Alert Logic Framework

KPI Definitions & Alert Thresholds

Alert Type	Threshold	Interpretation
High Waiting Time	>20 min	Patient in OPD beyond acceptable duration
High Service Time	>10 min	Counter interaction exceeded standard duration
Staff Absence	>5 min	No staff detected in defined service zone
OPD Crowding	>10 persons	Count exceeds safe operational benchmark
Queue Build-up	>5 persons	Queue exceeded operational benchmark
CCTV Downtime	>3 min	Camera stream interruption detected
Unattended Patient	>15 min	Patient without visible staff engagement

An alert is an automated notification triggered by the AI camera system when a specific condition is detected in a monitored zone. Alerts are sent to the responsible owner and escalate automatically if not resolved within the defined time window, supporting proactive hospital operations management and quality monitoring.

Critical Alert Classification

An alert was classified as critical when it crossed the predefined KPI threshold AND had potential to affect patient flow, service continuity, or patient experience. Criticality criteria included:

- Alert duration exceeded acceptable operational tolerance
- Alert occurred in a high-priority area (registration, billing, pharmacy, lab)
- Alert directly affected waiting time, queue, crowding, or unattended status
- Alert reflected a service continuity issue (e.g., prolonged staff absence)
- Alert required administrative attention or corrective action

AI Alert Escalation Framework

IIHMR DELHI

Escalation Types

⏱️ Timed Escalation

Alert sent to L1 owner first. Automatically escalates to L2, then L3 if unresolved within defined windows (5–15 min per level). Each level has a defined response time.

📋 Report Only

No live alert is triggered. The event is logged and included in daily/weekly reports reviewed by Quality Dept, HR, or MOD. Used for compliance monitoring.

⚡ Immediate Escalation

All levels (L1 → L4) notified simultaneously with no waiting period. Reserved for violence, cash fraud, or critical safety events.

Escalation Levels

1. **L4 — Medical Director / HR**

   Final escalation for critical or unresolved events

2. **L3 — Zonal Heads**

   Notified if L2 does not resolve. Senior oversight.

3. **L2 — Centre Head / Manager**

   Notified if L1 does not resolve within window

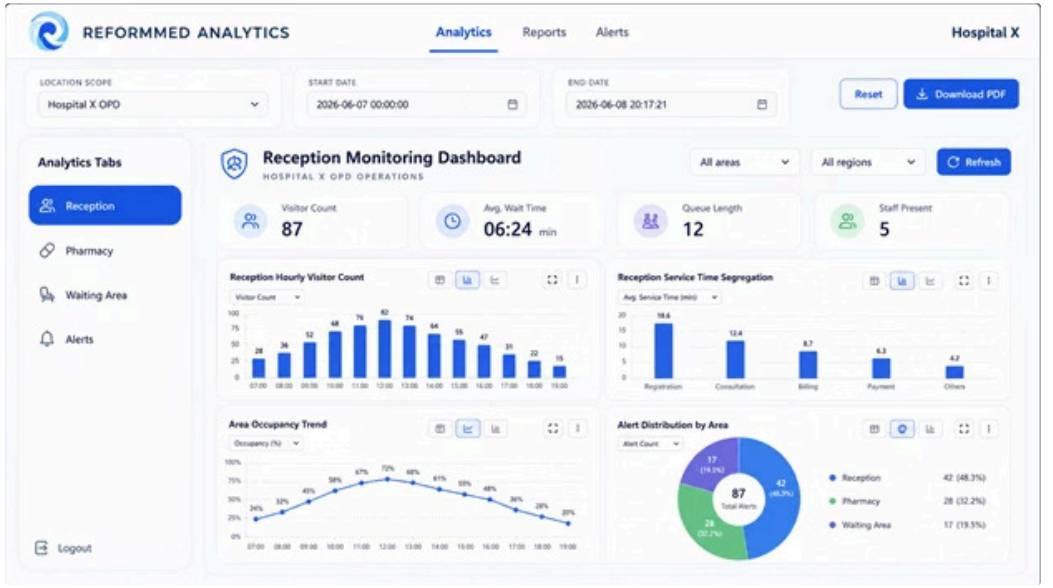
4. **L1 — Zone In-charge**

   OPD/IPD/Nursing Supervisor. First responder.

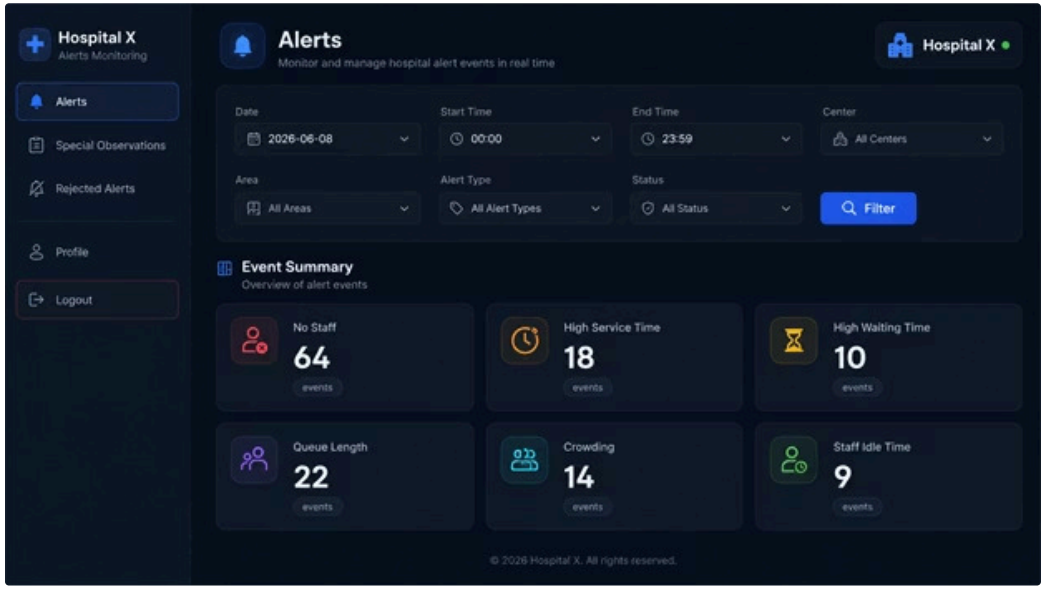
⚠ Failure to respond within your defined window will automatically escalate the alert to the next level. All escalations are logged and reviewed.

Analytics Dashboard

The Analytical Dashboard provides hospital administrators with a real-time view of OPD operations — from visitor counts and queue lengths to staff presence and alert distributions — enabling swift, evidence-based decisions.



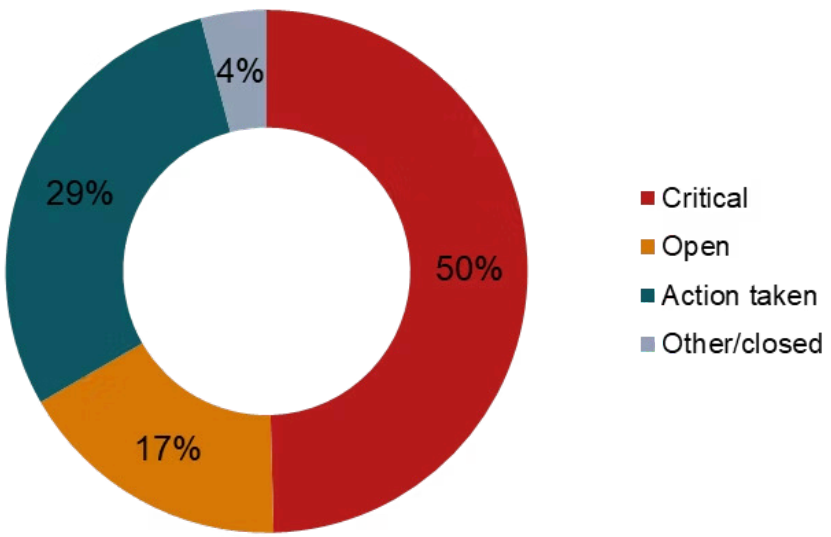
Reception Monitoring Dashboard — displays hourly visitor count, average wait time, queue length, and staff present in real time. Area occupancy trends and service time segregation are visible at a glance.



Alerts Event Summary Panel — categorises live alert events by type (No Staff, High Service Time, Queue Length, Crowding, etc.), enabling rapid identification and prioritisation of operational issues.

RESULTS 2

Overall Alert Summary — May 2026



Nearly half of all OPD alerts were critical, indicating significant operational pressure.

The monitoring infrastructure remained stable, with zero CCTV downtime alerts.

High staff absence, service time and queue-related alerts indicate multiple operational bottlenecks.

591

Total Alerts

Generated across all OPD zones in May 2026

19.1

Avg Alerts/Day

Consistent operational pressure throughout the month

293

Critical Alerts

Representing **49.6%** of all alerts generated

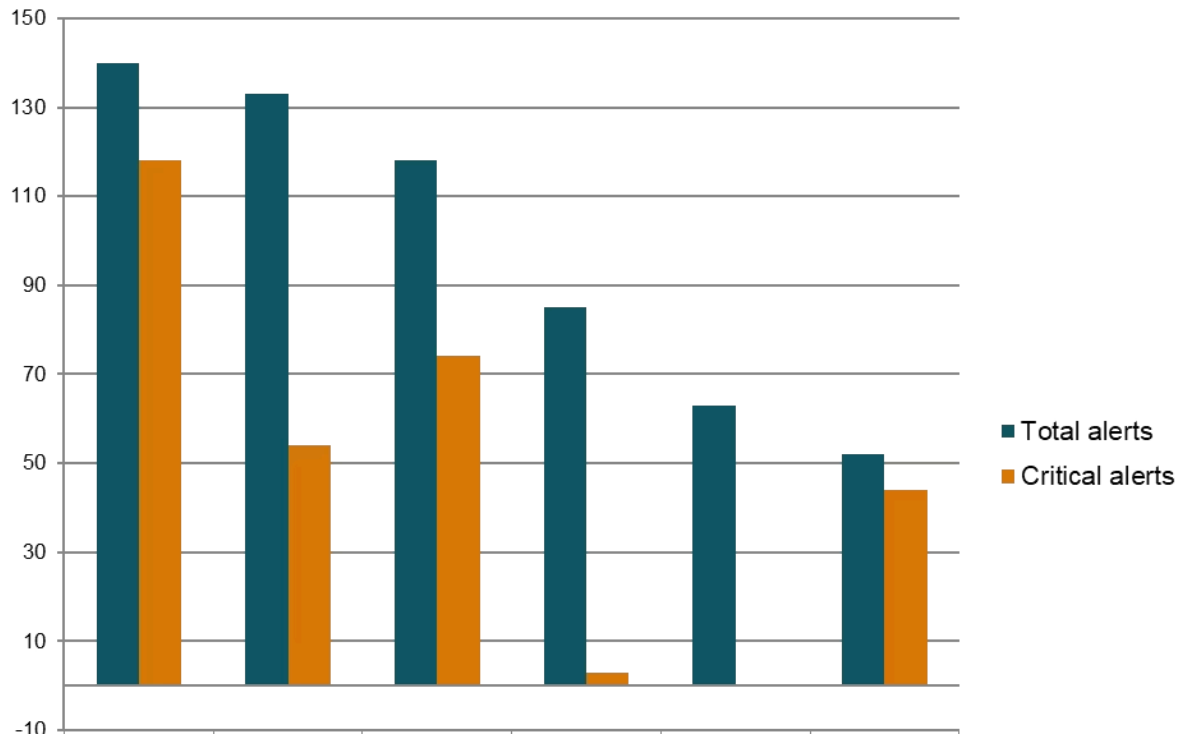
101

Open Alerts

Unresolved events requiring follow-up action

RESULTS 2

Alert Type-Wise Results



	Staff Absence	High Service Time	Queue Build-up	High Waiting Time	OPD Crowding	Unattended Patient
Total alerts	140	133	118	85	63	52
Critical alerts	118	54	74	3	0	44

Staff Absence

140 total alerts — Most frequent alert type, indicating persistent counter coverage gaps across OPD service areas.

High Service Time

133 alerts — Reflects delays across OPD service counters, with interactions consistently exceeding the 10-minute threshold.

Queue Build-up

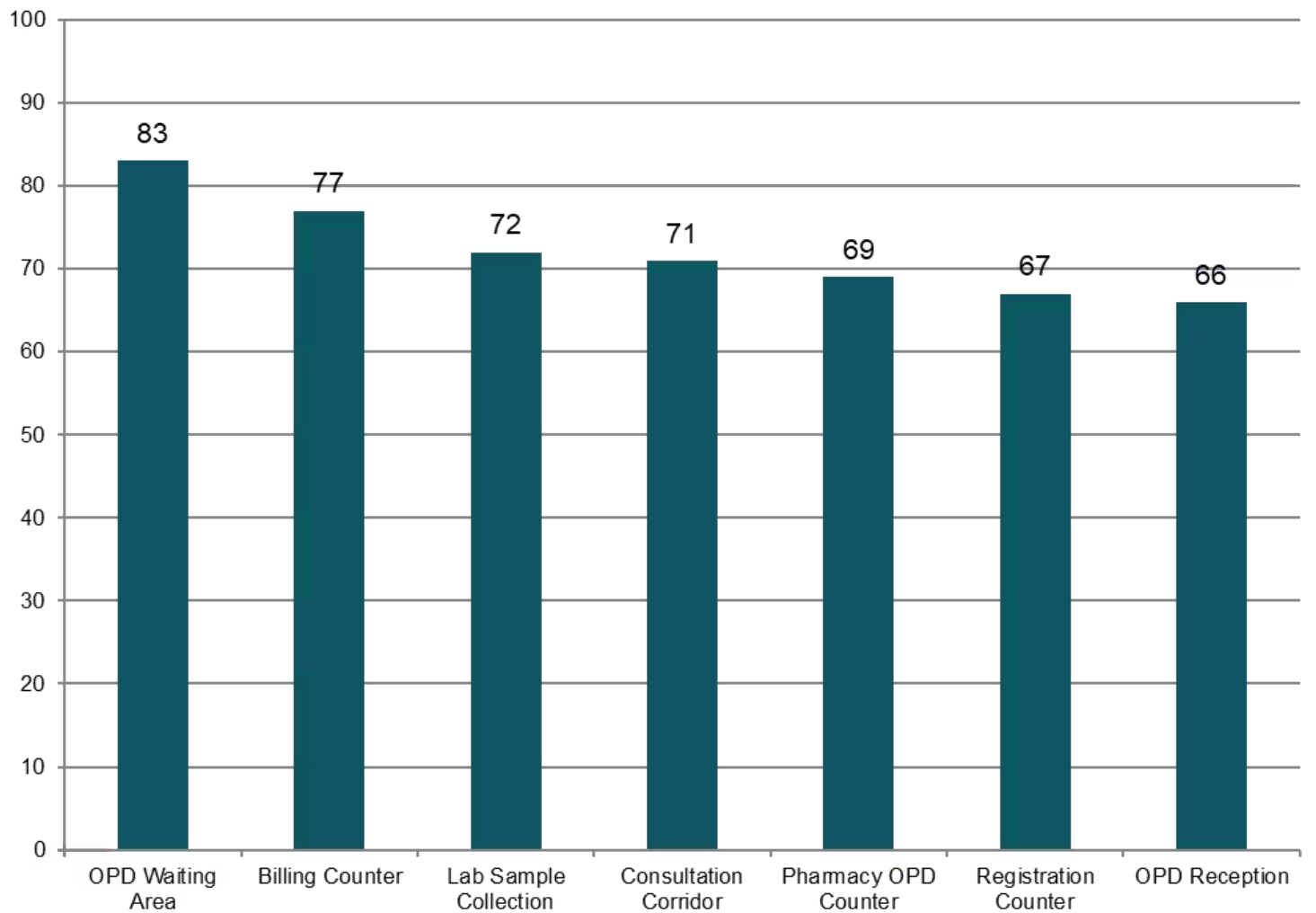
118 alerts (20% of total) — Signifies recurring congestion at service points, escalating patient waiting time.

Unattended Patient

44 of 52 were critical — Highest criticality rate, underscoring a direct patient safety and experience risk.

RESULTS 3

Area-Wise Alert Results



OPD Waiting Area

83 alerts with the highest average duration of **41.7 minutes** — the most operationally stressed zone.

Lab Sample Collection

52 critical alerts out of 72 total — indicating high-severity service disruptions at the laboratory intake point.

Pharmacy OPD Counter

49 critical alerts out of 69 total — high criticality rate reflecting dispensing workflow gaps and staff availability issues.

Billing Counter

Second-highest alert volume, with frequent queue build-up and high service time events impacting patient throughput.

Discussion: Key Operational Findings

The CCTV-based KPI monitoring study conducted over May 2026, covering a period of 31 days, highlighted several important operational issues within the OPD workflow.

Staff Absence

Emerged as the most frequent and critical issue, indicating that unattended counters directly affected service continuity and patient movement.

Service Delays

Commonly observed across OPD counters, suggesting possible challenges related to staff workload, documentation time, and process flow.

Queue Build-up

Identified as a major contributor to congestion, reflecting a mismatch between patient arrival patterns and available service capacity.

High Waiting-Time Alerts

Had the longest duration, showing that patients experienced prolonged waiting before or between services.

OPD Waiting Area

The most affected location, indicating the need for focused monitoring and workflow improvement in this zone.

CCTV Monitoring Continuity

Remained stable, with zero downtime alerts recorded during the study period.

Overall, the findings suggest that OPD inefficiencies were spread across multiple service points, highlighting the need for continuous system-level monitoring and timely operational interventions.

Key Takeaways & Conclusions

System Performance

- 591 operational alerts generated over 31 days with zero CCTV downtime, demonstrating robust monitoring infrastructure
- Nearly 50% of all alerts were classified as critical, confirming the clinical and operational value of real-time threshold-based surveillance

Operational Insights

- Staff absence was the single most frequent alert type, underscoring workforce management as the primary bottleneck
- OPD Waiting Area and Lab Sample Collection showed the highest alert burden and average durations

Study Significance

> "This study demonstrates that CCTV-based AI surveillance, integrated with operationally defined KPIs, can deliver actionable, real-time intelligence for hospital administrators — enabling proactive intervention, improved patient flow, and measurable gains in OPD efficiency."

Future Directions

IPD and Emergency

Extension to IPD and emergency departments

HIS Integration

Integration with HIS for end-to-end journey analytics

Longitudinal Evaluation

Longitudinal evaluation of operational improvement post-intervention

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Community Outreach Programme (COP) Activities

Total number of visits completed by the student: 10 visits

Day-wise Activities Conducted

01

Visit 1

Knowing about the allotted area

02

Visit 2

Mapping of the allotted area

03

Visit 3

Rapport building with respondents

04

Visit 4

Data collection

05

Visit 5

Data collection

06

Visit 6

Data collection

07

Visit 7

Interview with ASHA workers and ANMs

08

Visit 8

Observation of VHSND activities

09

Visit 9

Practical experience in communication with community members and frontline workers

10

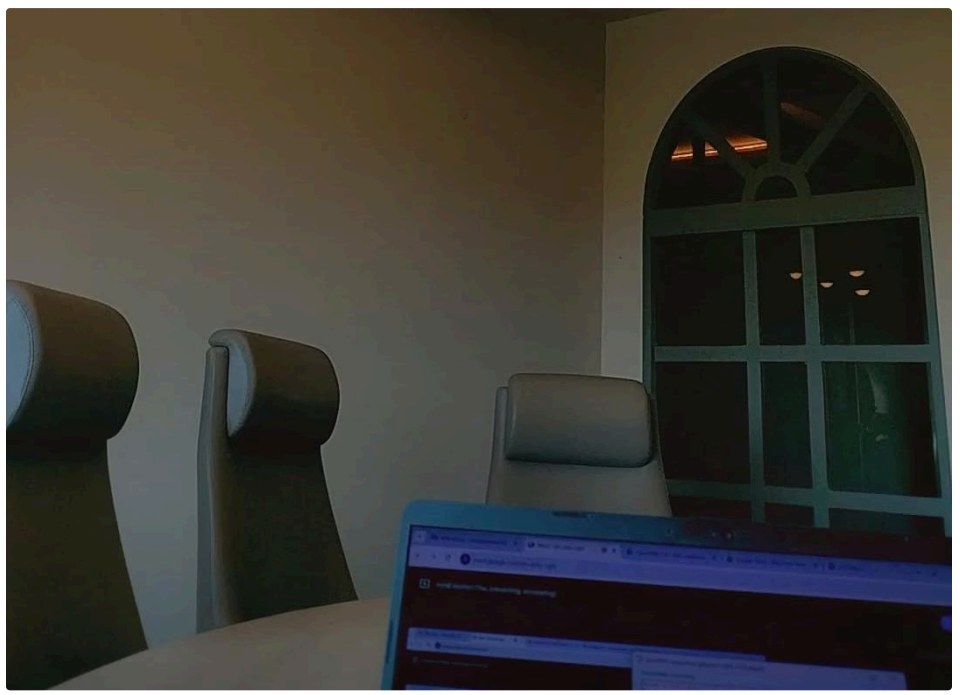
Visit 10

Review of field experiences and understanding community-level healthcare practices

Key Learnings from COP Activities

- Practical exposure to community health practices and primary healthcare services
- Understanding real-life problems faced by community members and healthcare workers
- Community health assessment and role of primary healthcare services
- Community mapping for identifying resources, households, and health facilities
- Communication, interviewing, observation, and data collection skills through interaction with ASHA workers, ANMs, and frontline workers
- Influence of social, economic, and environmental factors on health outcomes
- Practical knowledge of field research methods, stakeholder engagement, and community-based data collection

Pictorial Journey









Thank You

Any Questions?

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REFORMMED AI

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Using CCTV-Based AI Surveillance