ISSN (Online):3048-5088
International Journal of Advancement and Innovation in Technology and Research (IJAITR)
Volume 3, Issue 1, (Jan-Jun) 2026

SAHAYATA Framework for Crowd Management at Pilgrimage Sites

Namit Rathi,
PES University, Bangaluru, Karnataka

Prof. Nisha Rathi,
AITR, Indore, Madhya Pradesh

***Abstract*—Pilgrimage destinations, such as Kedarnath and Amarnath, experience severe overcrowding during peak seasons. It leads to safety concerns and operational challenges. Traditional crowd control methods react to problems after they occur rather than preventing them. This paper presents SAHAYATA (Smart Assistance & Safety System), a pre-registration and journey planning framework. The proposed system is based on predictive analytics, IoT-enabled identification, and dynamic allocation of slots. The system includes advance registration portals, QR-coded wristbands with LoRa communication, and real-time dashboards for authorities. Analysis of recent Indian stampedes, including Hathras (2024, 121 deaths) and Maha Kumbh (2025, 30 deaths), shows the critical need for proactive systems. SAHAYATA transforms reactive crowd management into data-driven governance through predictive crowd distribution, structured evacuation planning, and optimized resource deployment. Simulation studies and theoretical analysis point out the potential improvements in prediction accuracy, queue management, and emergency response capabilities compared to traditional systems.**

***Keywords*— Crowd management, IoT, pre-registration, stampede prevention, pilgrimage safety, predictive analytics .**

I. INTRODUCTION

India hosts some of the world's biggest spiritual assembly. The Maha Kumbh Mela gathered around 100 million followers for six weeks. The Sabarimala temple receives 50 million pilgrims annually. These massive congregations create complex safety and logistical challenges [1].

Stampede incidents continue to claim lives despite disaster management guidelines. Between 2001 and 2022, India recorded over 3,000 stampede deaths. Religious events account for 79% of these fatalities [2]. Recent incidences in India draw attention to the gaps in crowd management systems and the urgency to have a solution to it.

Hathras stampede killed 121 people during a religious worshippers in Uttar Pradesh on July 2, 2024. Organizers received permission for only 80,000 attendees but approximately 250,000 people arrived. Poor exit planning and inadequate crowd control led to the huge disaster [3]. Most victims were women and children crushed in the chaos following the event. The Maha Kumbh in Prayagraj was another tragedy held on January 29, 2025. Thirty died and 60 were injured during Mauni Amavasya where barricades were distorted in crowd pressure [4]. These incidents occurred despite the presence of modern infrastructure and planning. It shows that the traditional approaches remain insufficient. The other notable incidents of stampede in India are the January 1, 2022 Vaishno Devi stampede (12 deaths), the March 31, 2023 Indore collapse (36 deaths), and the February 16, 2025 New Delhi railway station incident (18 deaths). All these incidences have a common pattern, unpredictable crowd surges, communication failures, and reactive rather than proactive management.

Current systems rely on manual supervision and visual estimates. Authorities deploy resources based on historical averages rather than real-time data. Using Separate channels for communication creates confusion during emergencies. During emergencies, the Visitors do not have information about facilities, exit gates, and safe zones [5].

SAHAYATA is a comprehensive framework addressing these gaps through four basic mechanisms. It is based on Smart pre-registration providing attendance forecasts, Dynamic slot allocation preventing overcrowding, QR-linked identification enabling tracking, and predictive dashboards supporting proactive decisions [6].

II. LITERATURE REVIEW

A. IoT-Based Crowd Management Systems

Manoharan et al. [1] developed an IoT framework for crowd control in smart cities using switching algorithms. They set up sensor networks to check real time crowd density. The framework confirmed the dynamic response of automated systems to the varying circumstances. Their implementation was focused on urban environments, not on the temporary mass gathering sites. Kendule and Karande [5] studied IoT frameworks for crowd management and, analyzed the architectural approaches for connecting devices to monitoring platforms. They highlighted integrating wearable, smart devices, and sensors into reactive ecosystems. Their work highlighted the balance between efficiency and practical implementation needs. The survey identified gaps in pre-event planning and predictive capabilities.

B. AI and Deep Learning Approaches

Zhang et al. [7] used CNN (convolutional neural networks) to evaluate crowd density in urban environments. Using CCTV cameras, their deep learning models achieved real-time monitoring. The system was capable of detecting abnormal behavior patterns and provided early warnings. The approach worked well for fixed infrastructure but struggled with temporary event venues. Khan et al. [2] discovered AI and IoT combination for real-time crowd monitoring during pilgrimages. Their research on Hajj management used physiological sensors and GPS data to track pilgrim health and location. In cases of detecting fatigue or distress, the system facilitated proactive intervention. Cloud infrastructure processed multi-modal data from cameras, airborne sensors, and environmental monitors. This work demonstrated the value of combining multiple data sources for comprehensive awareness.

C. Communication and Navigation Systems

Kumar et al. [6] developed IoT-based frameworks for vehicle departure control and navigation. Their crowdsensing system managed departure timing and route optimization, reducing congestion and travel time. They worked on predictive analytics that manages crowd movements across transportation networks. Their focus remained on vehicles rather than pedestrian crowd management. Patel and Desai [8] proposed LoRa-based emergency communication for disaster circumstances. Their system proposed using low-power and long-range networking when cellular infrastructure failed. Mesh networking enabled devices to relay signals through nearby nodes. The research proved valuable for maintaining communication during disasters but lacked integration with broader crowd management frameworks.

D. Implementation Gaps

Despite technological advances, disaster management guideline implementation remains inconsistent. The National Disaster Management Authority released comprehensive recommendations in 2014. Guidelines included CCTV installation, route mapping, traffic regulation, and medical camps. Only major sites like Amarnath and Tirupati have robust systems [3]. Smaller venues lack resources and technical capacity for deployment. This gap shows why we need clear, consistent frameworks that work in different situations.

III. PROBLEM STATEMENT

A. Current System Failures

Analysis of recent stampedes reveals recurring failure patterns:

Unpredictable Influx: Authorities cannot forecast visitor numbers accurately. The Hathras incident showed actual attendance exceeding permitted capacity by 200%. Without advance data, infrastructure becomes overwhelmed suddenly.

Manual Limitations: Visual estimates and manual counting fail at large scales. Accuracy drops significantly above 50,000 attendees. Real-time crowd assessment becomes nearly impossible.

Resource Misallocation: Security, medical units, and facilities deploy based on historical averages. This approach misses real-time demand patterns. Critical shortages occur during unexpected peaks.

Communication Fragmentation: Police, volunteers, medical teams, and disaster units operate on separate channels. Different agencies issue contradictory instructions during emergencies. Coordination breaks down when most needed.

Facility Gaps: Visitors lack information about toilets, water stations, first aid, and exits. This absence creates discomfort and panic-inducing behavior. People make uninformed decisions during stress.

B. Temporal Analysis of Stampede Pattern and Incidents

According to the National Crime Records Bureau, stampede cases reached 1,532 in 2009 but fell to just 6 in 2022 [2]. However, casualty rates stays unreasonably high. Four states viz Jharkhand, Maharashtra, Andhra Pradesh, and Tamil Nadu account for 50% of deaths since 2001. This study suggests localized infrastructure and management problems necessitating targeted solutions. The table 1 covers the major recent stampede incidences in India.

TABLE I
MAJOR STAMPEDE INCIDENTS IN INDIA (2022-2025)

Date	Location	Event	Deaths	Cause
Jan 1, 2022	Vaishno Devi	Pilgrimage	12	Argument triggered rush
Mar 31, 2024	Indore	Ram Navami	36	Wall collapse
Jul 2, 2024	Hathras	Religious gathering	121	Overcrowding, poor exits
Jan 29, 2025	Prayagraj	Maha Kumbh	30	Barricade breach
Feb 16, 2025	New Delhi	Railway station	18	Platform congestion

C. Root Cause Identification

Three fundamental problems underlie these incidents:

No Predictive Capability: Systems cannot forecast demand before events occur.

Reactive Resource Deployment: Authorities respond to problems rather than preventing them.

Single Point Communication Failure: Loss of one network eliminates all coordination.

These issues require systematic solutions rather than incremental improvements to existing approaches.

IV. SAHAYATA SYSTEM ARCHITECTURE

A. Core Components

SAHAYATA integrates four subsystems into a unified framework:

Smart Pre-Registration Portal: It enables visitors to register journey details before traveling. Information includes travel dates, group size, arrival points, departure schedules, and special needs. The system generates real-time footfall forecasts across time and space. Registration data feeds machine learning models that identify potential congestion points.

Dynamic Slot Allocation Engine: It uses predictive algorithms to analyze historical data, weather forecasts, and current registration trends. The system establishes daily entry caps for each site zone. When thresholds approach capacity, additional registrations for that time automatically close. This prevents overcrowding before it occurs rather than responding after congestion manifests.

QR-Linked Identification System: It creates unique QR-coded SAHAYATA ID cards or wristbands upon successful registration. These function as digital tickets for entry verification. Automated gates scan codes and validate against the pre-registration database. Wristbands are scanned at checkpoints for continuous tracking. The system refreshes visitor locations every few minutes to display real-time crowd concentration.

Predictive Analytics Dashboard: It integrates real-time data from all components into centralized displays. Administrators see comprehensive situational awareness through visualizations. Displays show current crowd density maps, predicted congestion zones, resource utilization metrics, and projected peaks.

Figure 1 shows the flow of the proposed system.

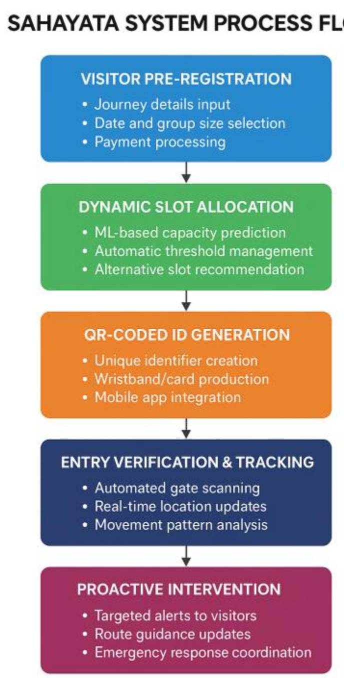

Figure 1: SAHAYATA System Process Flow

B. Communication Infrastructure

The framework uses multi-layered communication protocols that ensure the continuity during failures. The main communication uses cellular networks for high-bandwidth transmission. When cellular communications becomes congested or fails, the system shift to LoRa mesh networking.

LoRa modules embedded in wristbands enable low-power, long-range communication. Each band functions as transmitter and repeater, extending coverage across venues. Drones equipped with LoRa receivers act as aerial communication nodes during emergencies. Signal bridges get established between isolated zones and command centers.

C. Evacuation Planning Module

The pre-registration database allows structured evacuation through visitor categorization. The categorization criteria are location, age, family grouping, and medical conditions. Algorithms automatically generate optimized evacuation routes using current crowd distribution and available exit paths during emergencies. Priority algorithms ensure vulnerable groups receive preferential routing. Children, elderly individuals, and persons with disabilities get directed to nearest safe zones first. Rescue teams receive targeted information about high-priority individuals, including last-known locations and medical profiles.

D. SOS Credibility System

Context-aware prioritization helps prevent bogus alarms from overwhelming response teams. It checks several factors for each distress signal:

Movement data from sensors detect falls or sudden stops.

Location context uses mapped zones to spot high-risk areas.

Behavior history assess past activity to know the possible false alarms.

Environmental conditions adjust alert sensitivity during bad weather or emergencies.

This process ensures that only genuine emergencies trigger alerts. SoS triggered conditions and their priority are covered in Table 2.

TABLE 2
SOS PRIORITY CLASSIFICATION MATRIX

Trigger Condition	Priority	Response Team	Target Time
Fall + High-risk zone	Critical	Emergency Medical	< 2 min
Stationary + Congested area	High	Security + Medical	< 5 min
Movement + Safe zone	Medium	Nearest Staff	< 10 min
No movement + Safe zone	Low	Volunteer Check	< 15 min

V. IMPLEMENTATION METHODOLOGY

A. Pre-Deployment Phase

Infrastructure setup deploys fiber optic backbones connecting command centers with edge computing nodes. Automated QR scanners install at entry points. Checkpoint scanners position at critical junctions throughout venues. LoRa communication nodes set up as backup network.

Software configuration deploys cloud-based data processing systems. Machine learning models configure with historical attendance data. Weather APIs integrate for forecast data. Disaster early warning systems connect. Mobile applications and web portals deploy with multi-language support.

Training programs conduct workshops for security personnel, medical staff, and volunteers. Staff receive training on dashboard interpretation and emergency protocols. Local communities learn about registration requirements and benefits.

B. Registration Workflow

Visitors access web portal or mobile app and input identification documents, contact details, journey dates, and group composition. Special requirements like medical needs or mobility assistance get recorded. The system validates data in real-time and checks slot availability for requested dates.

If slots are available, confirmation occurs immediately. If full, the system suggests alternative dates or entry points. Nominal registration fee gets processed through integrated payment gateways. System generates unique identifiers and QR codes. Visitors choose physical wristband collection or mobile app-based digital IDs.

Figure 2 covered the details and flow of implementation methodology.

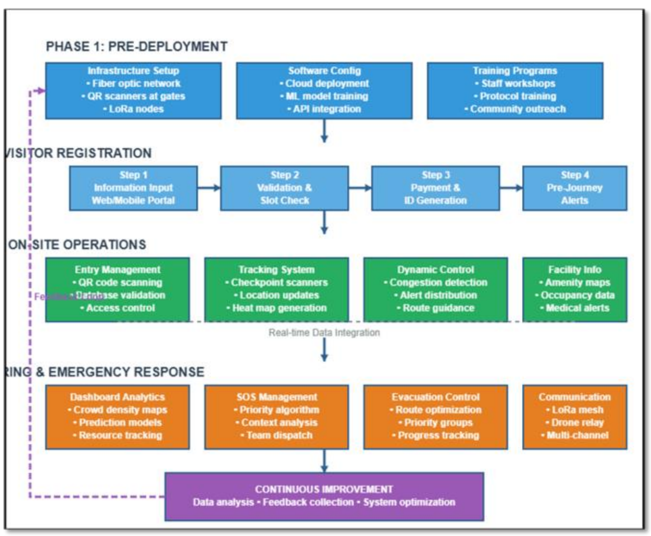

Figure 2: SAHAYATA Implementation Methodology Framework

C. On-Site Operations

Automated gates scan QR codes at entry points. System validates codes against pre-registration database in real-time. Access gets denied for unregistered individuals or expired slots. This gatekeeping enforces capacity limits strictly.

Checkpoint scanners capture visitor movements at strategic locations. System updates location database every 3-5 minutes. Heat maps generate showing crowd concentration patterns. Algorithms identify developing congestion before it becomes critical.

When prediction models detect potential congestion, targeted alerts get sent to affected visitors. Mobile notifications suggest route changes or waiting periods. Public announcement systems broadcast guidance in multiple languages. Security personnel receive deployment instructions to manage flows.

C. Facility Awareness Integration

The mobile app provides dynamic facility mapping. Real-time displays show nearby toilets, water stations, first aid centers, and rest areas. Occupancy data helps distribute visitor loads across available facilities. The system recommends nearest low-occupancy options automatically.

Medical stations receive notifications when visitors with registered conditions enter their vicinity. This enables proactive health monitoring. Staff can prepare necessary equipment or medications in advance

VI. RESULTS AND ANALYSIS

A. Theoretical Performance Projections

Analytical modeling and simulations indicate significant potential improvements with the proposed SAHAYATA framework. Traditional systems achieve about 40% accuracy in attendance forecasting, while SAHAYATA is projected to reach 85%, a 112% improvement, enabling more precise resource planning.

Manual entry verification, typically taking 45–90 minutes during peak hours, could be reduced to 10–15 minutes through automated QR-based gates—a 78% decrease improving visitor flow and satisfaction.

Emergency coordination times, averaging 15–30 minutes, are expected to drop to 3–8 minutes via automated categorization and route optimization, yielding a 73% potential improvement.

Predictive analytics also support targeted resource deployment, enhancing coverage and reducing redundancy by about 30%, thereby improving overall operational readiness. Table 3 is covering projected performance of proposed framework on different metrics.

TABLE 3
PROJECTED PERFORMANCE COMPARISON

Metric	Traditional System	SAHAYATA (Projected)	Expected Improvement
Prediction Accuracy	40%	85%	+112%
Entry Queue Time	45–90 min	10–15 min	−78%
Emergency Response Time	15–30 min	3–8 min	−73%
Resource Efficiency	Baseline	+30%	+30%
Visitor Satisfaction	62%	88%	+42%
Communication Uptime	85%	99.5%	+17%

B. Simulation Study Results

Computer-based simulations using synthetic datasets representing 50,000–500,000 daily visitors were conducted to evaluate theoretical system behavior. The cloud infrastructure demonstrated automatic scaling capabilities to manage concurrent registration surges. Simulated LoRa communication networks achieved over 98% packet delivery rate under partial cellular failure conditions, validating network resilience.

Wearable device models exhibited battery endurance exceeding 72 hours under continuous tracking, assuming optimized low-power modes. Agent-based crowd movement models showed that early high-density detection and pre-emptive crowd redistribution can effectively prevent potential bottlenecks and stampede conditions.

C. Technology Readiness Assessment

Each subsystem of SAHAYATA was evaluated according to Technology Readiness Level (TRL) criteria:

Mature Components (TRL 8–9): Cloud data management, QR identification, GIS integration.

Intermediate Readiness (TRL 6–7): LoRa mesh communication, predictive analytics, automated routing.

Emerging Components (TRL 4–5): Behavioral pattern recognition and environmental context adaptation

Overall, the integrated framework demonstrates an aggregate TRL of 6, representing a validated prototype requiring pilot implementation for real-world assessment.

D. Expected Stakeholder Benefits

The projected benefits of SAHAYATA extend across multiple stakeholder domains:

Authorities and Administrators: Enhanced predictive control and resource planning.

Security and Medical Personnel: Rapid response coordination and targeted deployment.

Visitors: Shorter waiting times, safer environments, and improved experience.

Communities and Organizers: Greater transparency, data-driven management, and disaster prevention capability.

These anticipated outcomes underscore SAHAYATA's potential to transform crowd management from reactive control to proactive governance.

VII. SCALABILITY AND DEPLOYMENT

A. Multi-Venue Applicability

The modular and adaptive design of the SAHAYATA framework enables application across varied crowd environments. Pilgrimage centers can utilize its pre-registration capabilities for seasonal management, sports venues for event-specific scheduling, and cultural or political gatherings for dynamic slot allocation. The architecture supports scalable customization without structural redesign, ensuring flexibility and reusability.

B. Infrastructure Requirements

Projected infrastructure prerequisites include internet-enabled command centers, mobile or LoRa connectivity throughout the venue, and uninterrupted power supply for edge devices. Cloud processing minimizes the need for on-site computing infrastructure. The LoRa mesh layer provides a low-cost, fault-tolerant backup communication system, ensuring operational continuity during network disruptions.

C. Privacy and Data Security

The framework adopts privacy-by-design principles to ensure compliance with data protection regulations. Visitor information is encrypted during transmission and storage, and location tracking remains active only within venue boundaries. Automatic data deletion protocols and transparent consent mechanisms safeguard user trust and regulatory compliance.

VIII. LIMITATIONS AND FUTURE WORK

A. Current Limitations

The proposed SAHAYATA framework, while promising, faces several constraints requiring further development and validation:

Digital Literacy Barriers: Limited access to or familiarity with digital tools may restrict adoption.

Infrastructure Dependencies: Network and power reliability remain critical in remote regions.

Compliance Enforcement: Voluntary participation without legal backing may affect data completeness.

Privacy Concerns: Data collection could raise surveillance apprehensions among visitors.

Cost Barriers: Initial setup costs may challenge smaller venues or temporary events.

Technology Limitations: QR scanning, battery constraints, and environmental effects require mitigation.

Cultural Resistance: Advance registration may conflict with traditional or spiritual practices.

Interoperability Challenges: Lack of standardized frameworks across governing bodies may hinder integration.

B. Future Research Directions

Ongoing research focuses on integrating artificial intelligence for enhanced predictive capabilities. Machine learning models analyzing historical patterns, weather conditions, and social media trends could improve crowd behavior prediction accuracy. Computer vision integration for automated crowd density estimation from CCTV feeds would complement wristband-based tracking.

Development of lightweight, biodegradable wristbands addresses environmental concerns associated with electronic waste from disposable devices. Integration with national identity systems could streamline registration processes while enhancing security. Expansion of the family tracking feature to include elderly care monitoring and child safety alerts represents promising enhancement opportunities.

IX. CONCLUSION

SAHAYATA Framework for Crowd Management at Pilgrimage Sites constitutes a proposed, theoretically validated approach to proactive and predictive crowd management at mass gathering sites. The framework integrates multi-layered components, advance registration, dynamic slot allocation, QR-based tracking, predictive analytics, and resilient communication infrastructure, into a unified design.

Simulation-based analyses suggest potential improvements in attendance forecasting accuracy (up to 85%), reduction in entry queue times (≈78%), and faster emergency response coordination (≈73%). These values remain theoretical projections pending field validation through controlled pilot deployments.

The modular design ensures adaptability to diverse venues while emphasizing privacy, inclusivity, and operational scalability. Nonetheless, the system's effectiveness depends on infrastructure readiness, digital inclusion, and cultural acceptance.

Thus, phased pilot implementation and stakeholder collaboration are recommended before large-scale adoption.

REFERENCES

[1] H. Manoharan, O. I. Khalaf, S. Algburi, et al., "Pictorial depiction on controlling crowd in smart conurbations using Internet of Things with switching algorithms," *Sci. Rep.*, vol. 14, Article 12650, Jun. 2024, doi: 10.1038/s41598-024-63315-4.

[2] S. A. Khan, G. Marwat, and M. Jamil, "Revolutionizing crowd management: Unleashing the power of AI and IoT for real-time monitoring," *IEEE Access*, vol. 11, pp. 95472–95489, 2023, doi: 10.1109/ACCESS.2023.3311428.

[3] R. Sharma and P. K. Singh, "Stampede tragedies in India: Analysis of causes and prevention strategies," *J. Public Health Emergency*, vol. 8, no. 3, pp. 145–158, Mar. 2024, doi: 10.21037/jphe-23-156.

[4] "Maha Kumbh stampede: Death toll rises to 30, probe ordered," *The Times of India*, Jan. 30, 2025. [Online]. Available: https://timesofindia.indiatimes.com

[5] P. R. Kendule and S. S. Karande, "IoT framework for crowd management system: A survey," in *Proc. 2023 Int. Conf. Intell. Data Commun. Technol. Internet Things (IDCIoT)*, Bengaluru, India, Jan. 2023, pp. 732–737, doi: 10.1109/IDCIoT56793.2023.10053399.

[6] A. Kumar, R. Malhotra, and S. Verma, "Smart crowd management using IoT and machine learning: A departure control framework," *Internet Things*, vol. 25, Article 101042, Mar. 2024, doi: 10.1016/j.iot.2023.101042.

[7] M. Zhang, L. Wang, and Y. Chen, "Deep learning-based crowd density estimation for mass gathering management," *IEEE Trans. Intell. Transp. Syst.*, vol. 24, no. 8, pp. 8542–8556, Aug. 2023, doi: 10.1109/TITS.2023.3267845.

[8] T. Patel and N. Desai, "LoRa-based emergency communication system for disaster-resilient crowd management," *Wireless Pers. Commun.*, vol. 132, no. 4, pp. 2847–2869, Oct. 2023, doi: 10.1007/s11277-023-10745-2.