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AI-Driven Risk Management Framework for Hajj Seasons: Predictive Models for Proactive Safety and Resilience

Abdelrahman Sheta *

AI, Sustainable Tourism, Religious Tourism, Project Management, Computer and Systems Engineering, Mansoura University, Jeddah, Saudi Arabia, Egypt.

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Abstract

Annual Hajj pilgrimage is one of the most complicated mass events in the world with millions of pilgrims, active environmental factors, and crucial safety issues. The conventional methods of risk management, although they partially work, are mostly based on reactive models that are not able to foresee the fast-changing risks like overcrowding, heat stress, and health emergencies among the population. The article suggests the use of AI-driven risk management framework that can allow making predictions, adaptive, and data-driven decisions during the Hajj season. Based on the new research findings on AI-based healthcare, edge computing, digital twins, and intelligent event management, the framework incorporates real-time data collection, prediction based on machine learning, and decision support systems to improve proactive safety and operational resilience. The model promotes early hazard detection, efficient resource distribution, and multi-agency reaction with the help of predictive analytics. Ethical, cultural and data governance is also considered in order to make sure that there is transparency, equity and congruency with the Islamic values. The paper ends by outlining the way forward to deploy AI-enabled safety systems in the future Hajj operations, with cross-sector collaboration, sustainability and learning as its key themes to develop a robust and intelligent pilgrimage ecosystem.

Keywords: Artificial Intelligence; Risk Management; Hajj Pilgrimage; Predictive Analytics; Proactive Safety; Digital Twins; Edge Computing; Resilient Systems

1. Introduction

1.1. Overview of Hajj's scale, complexity, and safety challenges

The pilgrimage to Hajj that is conducted once every year in the Kingdom of Saudi Arabia is one of the largest and most complicated human assemblies in the world. Every year, over two million pilgrims of over 180 nations come to Makkah and the related holy places to carry out a set of highly spiritual practices during the short period of time and within a very narrow geographical area. The massive nature of the event produces a complex operating environment where it is important to have a perfect coordination of health services, transport, accommodation and crowd control systems. The population of this scope and variety is a multifaceted challenge, be it the number of people in the crowd and the heat pressure, the problem of the spread of infectious diseases, the logistical bottleneck, and coordination of emergency responses. The presence of historical events like stampede and epidemic diseases experiences highlight the necessity of successful, proactive, and data-driven management systems that have the ability to foresee possible risks and reduce them even before they begin to become dangerous. The challenges of providing safety, health, and operational resilience during Hajj are also becoming more complex with escalating global mobility and climate variability, and to maintain this

* Corresponding author: Abdelrahman Sheta

safety and spiritual integrity of this significant religious experience, it is necessary to integrate innovative technologies to implement an Artificial Intelligence, predictive analytics, and real-time decision-support structures.

1.2. Emerging Role of AI in Mass Event Management

Artificial Intelligence (AI) is an emerging trend that has overtaken the management of large-scale events, increasing awareness of the situation and streamlining logistics, as well as allowing the researcher to make decisions proactively. When applied to the context of mass events like the Hajj, the AI technologies, including machine learning and computer vision, predictive analytics, and edge computing have no analogues in terms of monitoring and control of the complicated environment. AI-based applications are capable of running real-time data collected by various devices, including surveillance cameras, wearable devices, environmental sensors and health databases to anticipate potential dangers, such as crowd congestion, heat-related diseases or emergencies. The concepts of smart automation and predictive modeling are demonstrated in studies like Alquayt et al. (2025) and Al-Dhaher et al. (2025) and mention how the introduction of AI into Hajj can transform the system and improve healthcare delivery, crowd management, and emergency preparedness. In addition, AI-powered by Internet of Things (IoT) infrastructure and digital twins enable real-time simulation and scenario testing that help Hajj authorities to make effective decisions. With this technological synergy, authorities are able to shift their responsiveness to process to proactive responsiveness to risks, thereby making the safety, efficiency, and spiritual experience of millions of pilgrims safe, efficient, and spiritual. With the further development of event management in the world, the Hajj is a valuable chance to become the first to introduce AI-based solutions with technological progress and cultural/ethical awareness.

Research Problem and Objectives

Although the infrastructure development of Hajj, health care organisation and intelligent city mechanisms have made tremendous progress, risk management in a huge and time-limited, and culturally sensitive event is a major issue. Common risk management practices in Hajj are usually based on replication as a response, manual coordination, and piecemeal sources of information that may slow down taking key decisions and efficiency of the entire system. The growing congestion of pilgrims, together with changing health, environmental and security threats, is the reason why a more dynamic, integrated, and predictive risk management system is demanded. Although recent research (Alquayt et al., 2025; Al Sulaiman et al., 2025; Al-Dhaher et al., 2025) shows potential of AI application in the healthcare and logistics field in Hajj, there is still no detailed AI-driven framework aimed at predicting, evaluating and reducing the risks in each of the operational dimensions, i.e., health, crowds, environment, and emergency response.

The key purpose of the research is to design an AI-based Risk Management Framework conceptualized to specific Hajj seasons based on the use of predictive models to promote proactive safety and operational resilience. In particular, the research will be conducted to:

- The review of existing issues and threat factors related to the organization of Hajj in the context of the mass pilgrim movement.
- Determine the main AI technologies and predictive modeling methods that can be used to predict health, crowd and environmental risks.
- Develop a single platform, which incorporates AI, IoT, and digital twin technologies to make real-time risk predictions and support decisions.
- Suggest ethical, governance, and policy principles to make sure of responsible and culturally responsible AI usage during Hajj.

In these aims, the proposed study aims to both inform the academic literature and practice in implementing AI-enhanced resilience systems to mass gatherings, making Hajj a global best practice in AI-enhanced risk management.

2. Literature review

2.1. AI and digital transformation in Hajj and other mass gatherings

Large-scale pilgrimage events, especially the Hajj, have increasingly been transformed digitally over the past years with the adoption of Artificial Intelligence (AI), smart city systems, and information-driven forms of governance. AI is an extremely important tool to improve efficiency, safety and experience on the several levels of operation of an organization, including healthcare and transportation, as well as crowd control. Alquayt et al. (2025) assert that AI-based healthcare innovations in Hajj have contributed quite a lot to clinical responsiveness, disease monitoring, and emergency triage with real-time analytics and predictive diagnostics. Likewise, Al-Dhaher et al. (2025) highlight the

role of edge computing and AI algorithms to solve the problem of optimizing the flow of crowds and reducing the number of people at the most important ritual places and, therefore, the risk of accidents and delays. In addition to Hajj, the world mass events like the Kumbh Mela in India, Olympics have resorted to smart systems to monitor the environment, optimize visitor flow and provide security surveillance (Kumar and Ratten, 2025). These applications illustrate how AI-powered decision support applications can substitute having responsive management with proactive control processes.

Regarding the situation in the context of the Saudi Arabian vision 2030, the digital transformation programs have made the Hajj a place to test the implementation of smart infrastructure and AI-based rulemaking. The introduction of wearables based on the IoT, smart transport systems, and digital twins offers authorities more visibility than ever before on real-time conditions, which can be used to coordinate various agencies using data. Nevertheless, as pointed out by Al Sulaiman et al. (2025), such systems can work only under the condition of no violation of ethical issues, privacy of data, and fair distribution of resources, as well as technological competency. The combination of AI, digital infrastructure, and the ability to make pilgrimage more resilient, efficient, and spiritually uplifting, therefore, becomes a pivotal point in terms of other large-scale events globally that wish to find the right balance between innovation and cultural and ethical accountability.

2.2. Predictive Models in Health, Safety, and Crowd Management

In large scale events, predictive modeling is now a standard of intelligent risk management systems, allowing authorities to switch their focus towards crisis management to proactive safety measures. In the Hajj case, predictive analytics facilitates real-time prediction of crowds, health-related cases, and environmental risks, which are vital in avoiding massive interruptions. As Almutairi et al. (2025) emphasised, it is important to use ubiquitous systems of health management, which operate on AI-based predictive algorithms to identify possible outbreaks and track the health indicators of pilgrims remotely. In a similar fashion, Al-Dhaher et al. (2025) showed how to use AI and edge computing models to forecast the congestions and dynamically modify the crowd flow to minimize the chances of stampede and overcrowding at locations of rituals.

2.3. Ethical, Security, and Governance Considerations in AI Applications

The use of Artificial Intelligence in large-scale religious events like the Hajj presents compound ethical, security, and governance issues that have to be managed to create responsible and culturally sensitive applications thereof. With the growing use of AI systems in sensitive health, biometric, and behavioral data, protection of privacy and assurance of data integrity become most important. According to Al Sulaiman et al. (2025), the ethical use of AI in Hajj should be capable of generating an equilibrium between technological effectiveness and human dignity, transparency, and responsibility. The information obtained about pilgrims (geolocation, physiological indicators and movement patterns) will have to be processed according to the rigid privacy regulations in accordance with the international data protection laws such as the General Data Protection Regulation (GDPR) without violating Islamic ethical principles of trust, fairness, and human welfare.

Cybersecurity also comes up as a vital issue, as the IoT networks and analytics systems running on clouds might become vulnerable. According to Goswami (2025), AI-based cybersecurity auditing is essential in terms of detecting possible threats in real-time, especially in high-density digital environments. The governance mechanisms are also necessary in order to have inter-agency coordination, ethical regulation, and fair access to AI-enabled services. The insights on the task force provided by Alquayt et al. (2025) and Al Sulaiman et al. (2025) suggest establishing multi-disciplinary AI ethics committees in the Hajj operations to manage data governance, transparency of algorithms, and responsibility of risk.

3. Methodological framework

3.1. Structure of the Proposed AI-Driven Risk Management System

The suggested Risk Management Framework at Hajj Seasons is an AI-based multi-layered, adaptive framework that is planned to employ a range of data sources, predictive analytics, and decision-support to support proactive safety and resilience. The structure of the system includes four layers that are interconnected, i.e., data collection and sensing, predictive analytics and modeling, decision-support and response coordination, and ethical governance and oversight. All the layers work in harmony to make it possible to monitor in real-time, predict the risk dynamically, and make timely and informed interventions during pilgrimage.

3.1.1. Data Collection and Sensing Layer:

It is a basic layer that receives real-time information on various sources, such as IoT-integrated crowd sensors, wearable health devices, environmental monitoring systems, CCTV networks, and mobile applications. Such inputs are fed into a safe cloud-based facility at all times. This layer will facilitate continuous data aggregation, as per the methods demonstrated by Al-Dhaher et al. (2025) and Almutairi et al. (2025), to offer situational awareness when working on the ritual sites, including Mina, Arafat, and Muzdalifah.

3.1.2. Predictive Analytics and Layer of Modeling:

This layer uses machine learning, deep learning and statistical inference models to detect emerging risks before they get out of control. Predictive algorithms examine crowd density, body temperature, and movement velocity patterns and environmental conditions to predict any possible incidents like congestion, heatstroke, or health emergence. Research works such as Nasir et al. (2025) and Al Zami et al. (2025) show applications of digital twins and behavioral detection models relying on YOLO, which can be used to simulate several real-life situations and allow authorities to experiment with mitigation ideas.

3.1.3. Response Coordination Layer: Decision-Support Layer:

This layer offers operation intelligence to the Hajj authorities and the emergency services via an integrated dashboard. It maps out risk scores, comes up with early warnings, and suggests the best interventions, including rerouting pilgrim flows or medical units deployment. Robots and automatic warnings facilitate the interaction between healthcare personnel, security forces, and transport operators in time to mitigate the response time during emergencies.

3.1.4. Aspects of Ethical Governance and Oversight Layer:

The last layer is to make sure that the structure is based on ethical, legal, and religious guidelines. It controls the privacy of data, transparency of algorithms and justice and advances responsible AI practices. According to the suggestions of Al Sulaiman et al. (2025) and Mughoyaroh et al. (2025), this layer instills control mechanisms by having special ethics committees that control how well the technology is used to meet the requirements of data protection and human rights, without violating the privacy of pilgrims or their spiritual experience.

3.2. Predictive Analytics, IoT, and Digital Twins for Situational Awareness

The proposed AI-driven risk management system is based on the integration of predictive analytics, Internet of Things (IoT), and digital twins technologies, which will serve as the operational background of the suggested system enabling the Hajj authorities to have access to real-time situational awareness and make informed decisions based on the data. All of these technologies allow a continuous monitoring, prediction of risks, and simulation of scenarios and turn complicated, dynamically changing situations into actionable intelligence.

Predictive analytics is based on machine learning and deep neural networks to process the heterogeneous data streams of health sensors, surveillance systems and environmental monitors. Predictive models are able to detect the early warning signs of possible risks of overcrowding, heat-related stress, or health anomaly among pilgrims through continuous pattern recognition and anomaly detection (Alquayt et al., 2025; Khedher et al., 2025). These analytics can convert raw information into probability of risk scores and trend prediction to enable authorities to act proactively and not reactively.

The Internet of Things (IoT) is the sensory network of the system that connects millions of interdepended machines that are distributed throughout the holy places. Smart devices and sensors in the environment provide real-time physiological and atmospheric measurements temperature, humidity, heart rate, motion patterns, and AI-enabled cameras give out dynamic crowd movements. The paragraph by Al-Dhaher et al. (2025) provides an explanation that the use of AI and edge computing in the IoT network can reduce the latency rates to the lowest possible, which guarantees the timely identification of the abnormal conditions in the network, even in the situations when the bandwidth is limited. IoT-based communication infrastructure, in turn, allows a smooth coordination process between the security, medical and logistics teams.

Table 1 AI-Driven Risk Management Framework for Hajj Seasons

Framework Layer / Component	Core Technologies	Primary Functions	Expected Outcomes
Data Collection and Sensing	IoT sensors, wearable devices, CCTV, mobile apps, edge computing	Real-time data acquisition on health, crowd density, movement, and environment	Continuous situational monitoring and early anomaly detection
Predictive Analytics and Modeling	Machine learning, deep learning, AI-based forecasting, big data analytics	Risk prediction (health, crowd, environment); anomaly detection; event correlation	Proactive identification of hazards before escalation
Digital Twin and Simulation	3D modeling, simulation platforms, cloud computing	Real-time replication of Hajj sites to test emergency and crowd scenarios	Scenario planning and data-driven decision testing
Decision Support and Response Coordination	AI dashboards, automated alerts, GIS systems	Visualization of risk maps; coordination between health, safety, and logistics units	Rapid, informed response and inter-agency collaboration
Ethical Governance and Oversight	AI ethics frameworks, cybersecurity systems, data privacy protocols	Oversight of data integrity, transparency, and cultural compliance	Trustworthy and responsible AI deployment during Hajj

4. Proposed framework

4.1. Core Components of the AI-Driven Risk Management Framework

The suggested AI-based framework of Hajj safety and resilience has some key elements that will work harmoniously to predict, prevent and manage hazards in a variety of operational areas. All the elements contribute uniquely but at the same time interrelated towards converting raw data into actionable intelligence so that the overall pilgrimage safety and healthcare systems operate in a cost-effective and ethical manner.

4.1.1. Early Warning Systems and Risk Prediction Systems.

This element uses predictive analytics and machine learning algorithms to recognize possible risks like crowds surges, heat overheating, or disease outbreaks and prevent them. Using the past data, environmental factors, and the present data, AI models can produce early warnings that allow quick decision-making and the deployment of resources in time (Nasir et al., 2025; Almutairi et al., 2025).

4.1.2. Dynamic Crowd Routing and Management.

Computer vision devices using AI and IoT sensors are used to monitor the crowd number, speed of movement, and congestion in key areas. Predictive algorithms propose alternative paths, control entering and leaving traffic, and avoid congestion in the problematic areas. This dynamic system will minimise the chances of accidents, also optimise the movement of pilgrims to different ritual sites like Mina, Arafat, and Grand Mosque (Al-Dhaher et al., 2025).

4.1.3. Health Surveillance and Incident Prognostication.

There are wearable health devices and mobile applications that constantly check the vital signs of pilgrims and send the information to AI based health management systems. The predictive diagnostics will aid in predicting possible health crises to enable the medical teams to prioritise high-risk people and direct the medical resources more efficiently (Al Sulaiman et al., 2025; Al Sulaiman et al., 2025).

4.1.4. Application to Hajj Operations and Emergency Management

The given AI-based risk management system is supposed to fit properly into the current Hajj command and control systems, specifically, Hajj Operations Center in Makkah and Madinah. These centers already organize logistics, transportation, movement of the crowd, and health services, but conventionally, they exchange data manually and respond to the services. Incorporating predictive analytics and real-time monitoring, the AI framework will turn these

processes into an active and data-driven ecosystem that is safer and more efficient (Al-Dhaher et al., 2025; Alquayt et al., 2025).

4.2. Interception with Command-and-Control Systems

The system constantly gathers data on the form of metrics, i.e. the level of crowd density, the temperature of the environment, and the biometric health indicators, via IoT networks and edge-based data streams. This information is automatically updated on central dashboards employed by safety and health authorities. The predictive engine examines the anomalies, including overheating zones or pressure in the crowd and sends automated notifications to the operating units, allowing them to respond fast before it becomes difficult (Nasir et al., 2025).

4.2.1. Response and Allocation of resources in case of emergency.

In cases of emergency like a crowd surge, medical distress or environmental risks, the AI algorithms of the framework analyze the level of threat and prescribe the most efficient evacuation routes, resource allocation, etc. Spatial awareness and speed of response are made easier in combination with ambulance tracking, drone surveillance, and GIS-based mapping. This scheme helps to deploy the emergency resources in the areas where they are required the most, enhancing the reduction of casualties and the lowest possible interference (Al Sulaiman et al., 2025; Almutairi et al., 2025).

4.2.2. Cross-Agency Collaboration.

The platform enables the Ministry of Health, Civil Defense, and the General Presidency to communicate with each other on the issues of the Two Holy Mosques through the secure AI-assisted coordination channels. Communal dashboards facilitate common situational perspectives and minimize the response time among various agencies. With explainable AI models in place, automated recommendations will be clear and culturally suitable in the Hajj religious setting (Mughoyaroh et al., 2025).

5. Challenges and Ethical Considerations

5.1. Data Privacy and AI Transparency

The implementation of AI technologies in the Hajj procedures should be followed by the principles of privacy, transparency, and ethical data management. Because pilgrim data, including biometric identifiers, location, and health data, is sensitive, it is urgently required to develop the framework to guarantee not only legal but also religious-cultural sensitivity (Al Sulaiman et al., 2025).

5.1.1. Protection of Pilgrim Data.

AI systems are largely dependent on the ongoing gathering of data shown by the IoT sensors, wearables, and surveillance infrastructure. All this information should be encrypted during the transmission and storage in order to stop unauthorized access and misuse. Such an important role is played by edge computing due to the possibility to process data locally and decrease the amount of personal data that is sent to the cloud servers (Al-Dhaher et al., 2025). The privacy-by-design principles are used to guarantee that the data minimization, anonymization and secure consent mechanisms are incorporated into the system architecture.

5.1.2. Clear and Understandable AI Models.

Public and institutional trust may only be developed through transparency. The nature of the prediction models applied in identifying anomalies in crowds or health-related issues ought to be explainable to the human supervisors so that they understand the way AI arrives at its conclusion. Explainable AI (XAI) methods, e.g., being able to reason by rules, rule-based interpretation of visual models, etc., allow operational decision-makers to justify AI-driven suggestions prior to taking important steps. It is especially critical when it comes to a religious matter, the choices made in which may carry a lot of ethical and spiritual weight (Mughoyaroh et al., 2025).

5.1.3. Regulatory and Ethical Control.

The framework should adhere to Saudi data protection legislation, and both international standards e.g. the GDPR to interoperability and ethical benchmarking. The creation of an AI Ethics and Privacy Board as a subdivision of the Hajj authority is capable of offering constant audit, bias identification, and moral investigation of the deployed algorithms. This type of institutional control guarantees responsibility, discrimination, and the orientation of the application of AI to the Islamic ethical principles of fairness, justice, and the respect to human dignity (Alquayt et al., 2025).

5.2. Cultural and Religious Sensitivity in AI Applications

Integration of Artificial Intelligence in Hajj operations should not interfere with the sacred status of pilgrimage and go against the Islamic ethical, cultural, and spiritual provisions. Technology must not interfere with the holiness or the heartfelt aspect of the pilgrimage experience. Thus, cultural and religious sensitivity should be considered at all levels of AI design, implementation, and communication (Mughoyaroh et al., 2025).

5.2.1. Facilitation of Alignment with the Islamic Values.

The AIs of monitoring health, crowd regulation, or navigation should be constructed so that the ethical guidelines of the Sharia can be followed. This entails the aspect of making the decision-making process of AI reflect fairness (adl), compassion (rahmah), and accountability (amanah). As an example, predictive models applied to control pilgrim flow should focus on human welfare and safety rather than on operational efficiency. Pilgrims must also have any automation that engages with them in a respectful and polite tone, language and visual depiction without interrupting or culturally offending interface (Al Sulaiman et al., 2025).

5.2.2. Inclusivity and Accessibility.

The pilgrims at Hajj have over 150 countries of origin and are diverse in terms of lingo, culture, and physiques. AI applications should thus facilitate multilingual dialogue, gender involved procedures, and provision of elderly or disabled pilgrims. There can be emotion-aware or context-aware systems, such as stress or fatigue detection and empathetic advice based on the requirements of the pilgrim. This non-discriminatory structure reinforces the religious and community cohesion that characterizes the Hajj (Alquayt et al., 2025).

5.2.3. The prevention of Algorithmic Bias and Misinterpretation.

The biases in AI models due to cultural bias may result in the unfair treatment, misclassification, or simply inappropriate automated decision-making. Local gestures, local attire or even local rituals can be misconstrued by algorithms that have been trained with world data. There is a need to conduct continuous auditing, localize datasets, and cooperate with Islamic scholars and Hajj specialists to make sure that AI systems analyze behavior within the context and understand and respect it (Kumar and Ratten, 2025).

6. Policy Implications and Future Directions

6.1. Strategic Roadmap for AI Deployment in Hajj Safety

The effective use of AI in the management of Hajj safety will entail a multi-stage roadmap to ensure the use of technology is carefully timed, that is, there should be a balanced approach to technological innovation and ethical, institutional, and operational preparedness. The suggested roadmap will give more importance to governance, capacity building, interoperability, and continuous improvement, to make the adoption of AI sustainable and consistent with Saudi Vision 2030.

6.1.1. Phase 1: Foundation and Policy Development (Short-Term, 1 2 Years).

This step is directed at the creation of the regulatory and institutional background. Such measures as the formation of a National AI Task Force on Pilgrimage Safety, the development of ethical and data governance frameworks and pilot programmes in selected Hajj sites are key activities. Priority use cases, i.e. crowd analytics, health risk prediction, and logistics optimization, should be defined in stakeholder workshops with the Ministry of Hajj and Umrah, Ministry of Health, and Civil Defense (Al Sulaiman et al., 2025).

6.1.2. Phase 2: Phase of Integration and Capacity Building (Medium-Term, 35 Years).

After the underlying systems are confirmed, the second task is to apply AI modules to the current command and control centers. Hajj operators, medical staff and security forces training programs will guarantee the human-AI cooperation. The real-time analytics at scale will be facilitated by investment in data infrastructure, e.g., secure edge server and 5G connectivity. Collaborations with higher education and AI startups may also be used to hasten the innovation but retain local talent (Alquayt et al., 2025).

6.1.3. Phase 3: International Co-operation and Standardization.

Saudi Arabia can be in the forefront in coming up with international standards in the safety of AI-enabled mass gathering. Partnerships with WHO, IEEE and OIC will allow exchange of knowledge and ethical harmonization and

interoperability between world pilgrimage systems. Setting up a Center of AI in Religious Tourism and Mass Gatherings may institutionalize continued research and innovation in the field (Mughoyaroh et al., 2025).

Table 2 Strategic Roadmap for AI Deployment in Hajj Safety

Phase	Time Horizon	Strategic Focus	Key Actions and Deliverables	Expected Outcomes
Phase 1: Foundation and Policy Development	Short-term (1–2 years)	Governance, ethics, and pilot programs	• Establish National AI Task Force for Hajj Safety• Develop ethical and data governance frameworks• Launch small-scale AI pilot projects in health and crowd monitoring	Regulatory readiness, inter-agency alignment, and pilot validation
Phase 2: Integration and Capacity Building	Medium-term (3–5 years)	System integration and human–AI training	• Integrate AI modules with command centers• Train Hajj safety and health personnel• Expand data infrastructure and secure IoT networks	Enhanced interoperability and workforce competence
Phase 3: Predictive Intelligence and Automation	Long-term (5–10 years)	Advanced analytics and automation	• Deploy predictive models and digital twins• Implement autonomous emergency response tools• Conduct pre-event simulations for risk optimization	Proactive and self-learning Hajj safety system
Phase 4: Global Collaboration and Standardization	Continuous (post-implementation)	International leadership and research collaboration	• Establish global partnerships (WHO, OIC, IEEE) • Create Center for AI in Religious Tourism and Mass Gatherings• Develop standardized ethical protocols	Global recognition and sustainable innovation ecosystem
Ongoing Evaluation and Governance	Cross-cutting	Monitoring, feedback, and adaptive improvement	• Conduct annual AI ethics audits• Gather user and stakeholder feedback• Continuously refine models for transparency and resilience	Ethical compliance, continuous improvement, and trust building

6.2. Institutional Collaboration and Sustainable Innovation

The future achievement of AI-focused risk management of Hajj is based on institutional cooperation, innovation, and balancing technological capacity and moral responsibility. Since the Hajj is one of the most complex and largest annual events in the world, the needs of this event in terms of safety cannot be addressed independently by a single institution. Thus, a networked system of government, educational and non-government agencies and collaborators is necessary to guarantee operational resilience and sustainability (Alquayt et al., 2025).

6.2.1. Multi-Stakeholder Governance.

The successful implementation of AI will need a single system of governance, comprising of the Ministry of Hajj and Umrah, the Ministry of Health, the Saudi Data and Artificial Intelligence Authority (SDAIA), and Civil Defense. These agencies ought to work together to form a Central AI Governance Board on Pilgrimage Safety that will provide standards, compliance checks and interoperability of AI platforms. The common responsibility and explicit policies will eliminate overlaps, enhance transparency, and reinforce national data sovereignty (Al Sulaiman et al., 2025).

6.2.2. Academia–Industry Partnerships.

Long term innovation relies on a well-built longitudinal research, testing, and applied development pipeline. Universities, AI research centers, and private technology companies can also find ways to collaborate to develop adaptive algorithms, simulation models and intelligent sensing systems that can suit the Hajj environment. Setting up

innovations centres in Makkah and Madinah will promote experimentation, knowledge exchange and local entrepreneurial AI to resilience of safety and health (Al-Dhaher et al., 2025; Mughoyaroh et al., 2025).

6.2.3. Global Cooperation and Business Ethics.

Due to the international character of the Hajj, ensuring that standardized AI safety procedures are created in the context of mass events is also an international cooperation. Collaborations with other international bodies like WHO, UNESCO and the Organisation of Islamic Cooperation (OIC) can be used to cross-border harmonize the AI ethics, data handling and cultural sensitivity standards. This would enable Saudi Arabia to become an example of responsible AI innovation within the framework of religion and humanitarian affairs (Kumar and Ratten, 2025).

7. Conclusion

The Hajj pilgrimage is one of the most logistically complicated and spiritually important events of humanity, which attracts millions of people every year to a common place of worship, devotion, and movement. Protecting the safety, health, and resilience of this religious event cannot be simply a matter of risk management as it has always been since a plan needs smart, data-driven mechanisms, which can foresee issues before they arise. The research has put forward an AI-based risk management model aiming to change the Hajj operations to be responsive mechanisms but rather anticipatory and predictive safety ecosystems.

The framework combines the most important technologies, which include IoT sensors, predictive analytics, digital twins, and ethical governance, into one system that constantly monitors the environmental, health, and crowd statuses. The layered architecture allows the real-time data collection, early risks identification and aligned decisions among several agencies. Using the model in context with Hajj Operations Center, it will help in quicker response to emergencies, resource optimization, and adaptive learning to continually improve.

The article has developed a strategic roadmap of AI implementation to support the current initiatives of Saudi Arabia toward digital transformation in pilgrimage management. The roadmap has four stages, namely, (1) creating governance and policy background, (2) building human and technical capacity, (3) scaling predictive intelligence and automation, and (4) fostering global cooperation and standardization. The application of this roadmap will guarantee both ethical and operational preparedness and sustainability as per the Saudi Vision 2030.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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