

AI Applications in Mega Events: Hajj and Umrah as a Case Study تطبيقات الذكاء الاصطناعي في الأحداث الكبرى: الحج والعمرة كدراسة حالة

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Abstract:

Objectives: This paper explores the application of Artificial Intelligence (AI) in optimizing and streamlining these services at mega events. AI enhances efficiency, improves decision-making, and helps manage complex workflows by analyzing large volumes of data and automating tasks.

Methods: The research methodology in this paper is based on a narrative approach to analyze the impact of AI on Hajj and Umrah management, focusing on key service areas, including transportation, robotics, crowd management, distribution and scheduling, identification and detection, prediction and forecasting, healthcare, and sentiment analysis.

Results: The studies reviewed have demonstrated the effectiveness of AI in enhancing safety, crowd flow, transportation, and resource management in Hajj and Umrah. However, challenges such as reliance on simulation, real-time adaptability, poor integration of technologies, and the need for a forward-looking approach to embrace emerging developments underscore the need for further research and development.

Keywords: artificial intelligence; mega events; hajj; umrah; real-world challenges.

الملخص:

الأهداف: يستكشف هذا البحث تطبيق الذكاء الاصطناعي في تحسين وتبسيط هذه الخدمات في الأحداث الكبرى. يعزز الذكاء الاصطناعي الكفاءة ويحسن عملية اتخاذ القرار ويساعد في إدارة سير العمل المعقدة من خلال تحليل كميات كبيرة من البيانات وأتمتة المهام.

المنهجية: تعتمد منهجية البحث على نهج سردي لتحليل تأثير الذكاء الاصطناعي على إدارة الحج والعمرة، مع التركيز على مجالات الخدمة الرئيسية، بما في ذلك النقل والروبوتات وإدارة الحشود والتوزيع والجدولة والتحديد والكشف والتنبؤ والرعاية الصحية وتحليل المشاعر.

النتائج: أثبتت الدراسات التي تمت مراجعتها فعالية الذكاء الاصطناعي في تعزيز السلامة وتدفق الحشود والنقل وإدارة الموارد في الحج والعمرة. ومع ذلك، فإن التحديات مثل الاعتماد على المحاكاة، والقدرة على التكيف في الوقت الفعلي، وضعف تكامل التكنولوجيات، والحاجة إلى نهج استشرافي لاحتضان التطورات الناشئة تؤكد الحاجة إلى المزيد من البحث والتطوير.

الكلمات المفتاحية: الذكاء الاصطناعي؛ الفعاليات الضخمة؛ الحج؛ العمرة؛ التحديات الواقعية.

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1 Introduction

Mega events have become crucial platforms for demonstrating advanced technology and offering solutions to a diverse range of real-world challenges. These challenges include the increasing demand for connectivity, crowd management, surveillance, marketing, and many others. One of the important mega events in the world is Hajj and Umrah, in which millions of people come to the Kingdom of Saudi Arabia to perform their Islamic rituals. Managing this large number of people is considered a challenge to Saudi authorities, since many services have to be provided to pilgrims in a limited area and short time. During their stay in Makkah, pilgrims need many services in their places of residence, which are provided by many agencies. Among these services are luggage delivery, Zamzam water distribution, tour guidance, health awareness leaflet distribution, and more (Khan and Shambour, 2023). Providing such services to the vast numbers of pilgrims undoubtedly requires significant time, effort, and coordination from service providers.

AI serves as a powerful tool for optimizing and enhancing services at mega events, improving efficiency, and ensuring customer satisfaction (Ali et al., 2024). It also plays a crucial role in resource management and elevating the host's reputation. By automating routine tasks, improving decision-making, and analyzing large data volumes, AI quickly identifies patterns, predicts outcomes, and optimizes workflows, reducing costs and improving service quality (Shah, 2024).

AI underpins various fields such as optimization, search algorithms, machine learning, and decision-making. Methods such as heuristic algorithms, machine learning models, and expert systems have been successfully applied in various application areas to address complex real-world challenges (Ahamad and Mishra, 2024).

In mega events, services span various areas, and it is important to ensure smooth operations to provide these services and hence enhance customer experiences. In this paper, the utilization of AI for optimization and facilitating services in mega events is discussed. The main areas of services are covered, discussing some characteristics of each area that influence the process of providing services. Additionally, illustrative examples from Hajj and Umrah mega events are provided with in-depth insights drawn from specific applications in the context of the Hajj and Umrah ecosystem.

The paper is organized as follows. Section II discusses the methodology of this research. Then, Section III covers the areas where AI is applied in mega events, with examples from Hajj and Umrah. These areas include transportation, robotics, crowd management, distribution and scheduling, identification and detection, prediction and forecasting, healthcare, and sentiment analysis. The findings of this research are discussed in Section IV. Finally, the paper is concluded in Section V.

2 Research Methodology

The methodology employed in this paper involves a narrative approach to explore how AI is applied in managing mega events, particularly in the context of Hajj and Umrah.

The paper organizes its analysis into distinct service areas where AI is applied, such as:

- Transportation: AI for route optimization, safety, and efficient scheduling.
- Robotics: Use of robots for services like guidance, cleaning, and security.
- Crowd Management: Tools and models for monitoring, predicting, and managing crowds.
- Distribution and Scheduling: AI-based optimization of resource allocation and logistical operations.
- Identification and Detection: AI for security and identity verification.
- Prediction and Forecasting: Neural networks and machine learning models for resource demand prediction.
- Healthcare: AI-driven tools for predictive analytics and patient care.
- Sentiment Analysis: Analyzing people's satisfaction and feedback using natural language processing (NLP).

This methodology ensures objectivity, coherence, and relevance to the subject of AI in the Hajj and Umrah context.

3 Areas of AI application in mega events

3.1 Transportation

Optimizing transportation services in the context of mega events is critical for facilitating the smooth and efficient movement of attendees to and from various locations. For example, managing transportation routes entails identifying the most optimal paths for different modes of transportation, considering factors such as traffic congestion, road conditions, and proximity to event venues and accommodations. Utilizing AI techniques can help in determining the most efficient routes to minimize travel time and congestion. In addition, optimizing transportation schedules involves coordinating the departure and arrival times of vehicles to ensure timely and convenient transportation services for attendees. This includes aligning schedules with peak attendance times, event schedules, and other logistical considerations. Furthermore, mega events often involve a variety of transportation modes, including buses, shuttles, trains, and taxis. Optimizing the selection and utilization of transportation modes based on factors such as capacity, accessibility, and cost-effectiveness is essential (Krishna, 2023).

- **Transporting a High Volume of Pilgrims**

In Hajj and Umrah, millions of Muslim pilgrims from all over the world come to visit the Holy City of Makkah, resulting in exceptionally high demand for transportation during peak periods. AI techniques that can handle large-scale optimization problems and efficiently manage large passenger volumes are essential. These include greedy algorithms, genetic algorithms, harmony search algorithms, particle swarm optimization, and many more.

Felemban et al. (2019) investigated the movement of large crowds to perform specific tasks, such as coordinating the movement of pilgrims safely and efficiently spatially and temporally using the train during the Hajj rituals. Several factors influence the scheduling process. Firstly, the type of train movement is a key consideration. Secondly, the model takes into account the locations of both the current pilgrim camp and the destination camp. Thirdly, the allowable routes to and from the camp stations are crucial in the scheduling process. Additionally, to prevent crowd-related disasters, it is essential to monitor the station's capacity to ensure it can accommodate the pilgrims. This approach was implemented during the 2019 Hajj for three specific movements (B, C, D) in the Mashaer region.

Khan and Shambour (2023) and Shambour et al. (2024) focused on analyzing the transportation of pilgrim groups from Arafat to Muzdalifah sites using different optimization search algorithms. The authors introduced several hard and soft constraints to manage the scheduling of large numbers of pilgrims. The findings revealed that the proposed approach could increase the number of pilgrims by three times while meeting all the hard constraints and fulfilling most of the soft constraints. This indicates that the accommodation capacity in Muzdalifah could be utilized at three times its current rate.

- **Safety in Crowd Transportation**

Ensuring the safety and security of pilgrims and effectively managing crowds are paramount during Hajj and Umrah. It is crucial to optimize transportation services while considering safety measures, crowd flow dynamics, and emergency response protocols.

For example, Intelligent shelter allotment (ISA) is a fundamental aspect of emergency planning, however, it encounters certain issues including conflicts in movement and choke points in the transportation network. Nearest exit or shelter (NES) and capacity-constrained route planning (CCRP) have their limitations. Yang et al. (2023) devised a new Crowd-Separated Allocation of Routes, Exits and Shelters (CARES) strategy which tends to prompt evacuations with a lower risk of conflicts. Performance tests case study on the Hajj process in Makkah – Saudi Arabia has illustrated that CARES provides solutions to both issues of evacuation quicker than NES and significantly lower risks of development conflicts among evacuating individuals than the case with CCRP (Yang et al., 2015).

- **Route Optimization**

AI mechanisms can be utilized to optimize transportation routes for pilgrim buses, shuttles, and other modes of transportation. For example, by encoding routes as chromosomes and applying genetic operators such as crossover and mutation, Genetic Algorithms (GA) can efficiently search for optimal or near-optimal routes that minimize travel time, distance, or congestion while serving the needs of pilgrims.

Yasein and Khan (2023) developed a shuttle bus transportation system model to demonstrate the benefits of using it as an alternative to traditional transportation. The model also offers a valuable tool for decision-makers

to determine the optimal system parameters to achieve maximum efficiency. It was successfully tested and assessed based on factors such as evacuation time, traffic congestion, and the average travel time between Arafat and Muzdalifah sites.

Khan and Shambour (2023) proposed a method to improve service delivery to pilgrims by identifying optimal routes and cost-effective means of transportation to meet the needs of pilgrims during their stay in the holy cities. Several algorithms were used to identify the best routes to deliver the service based on the locations of pilgrims' residences. In most cases, the results were in favor of multi-search algorithms over other algorithms, which outperformed in discovering the most efficient routes with the least distances.

Gazzawe and Albahar (2024) suggested integrating AI and advanced communication technologies to enhance traffic management in Makkah. It recommended using smart cameras for real-time traffic monitoring. By analyzing the flow of traffic, the system can detect alternative routes and optimize traffic movement, such as converting entry lanes to exit lanes, particularly during peak times.

3.2 Robotics

From logistics to security and interactive experiences, robots help manage the complexity and scale of mega events that attract massive crowds because of their ability to enhance operational efficiency, improve safety, provide real-time data, and create memorable experiences for attendees. By integrating robotics, event organizers can better manage the scale and complexity of these events, ensuring a smoother, safer, and more innovative environment for all participants (Birdir et al., 2020).

The use of artificial intelligence in the form of robotics has been applied in the Holy mosques to provide some services, such as distributing Zamzam water and Holy Quran. In addition, a "guiding robot" has been developed to provide guidance and advice for pilgrims and answer their questions in 11 languages. Furthermore, special robots have been used for cleaning and sanitizing the Holy Kaaba roof, floor cleaning and disinfecting functions, and monitoring body temperature (Barnawi and Aksoy, 2023).

3.3 Crowd Management

AI is essential for managing crowds at mega events by providing real-time monitoring, predictive insights, automated management tools, and optimized resource allocation. These capabilities enhance safety, streamline attendee flow, and create a better, more secure experience for everyone involved.

Rehman and Felemban (2019) introduced an interactive crowd management tool designed to safely reschedule pilgrim groups based on their preferences for the stoning ritual at the Jamarat building. The main objective of the proposed interactive tool is to enable users to manage and schedule requests by considering safety and time preference factors. The safety aspect ensures that the capacity of each route does not exceed the limits set by authorities, while the time preference accounts for the pilgrim's schedule based on the Islamic School of Jurisprudence. The proposed approach facilitates gradual and interactive scheduling of pilgrim movements and was successfully implemented during the 2019 Hajj season.

Basalamah et al. (2023) developed a novel synthetic dataset for crowd detection in public places. The authors proposed a bidirectional long short-term memory (Bi-LSTM) model to enhance the effectiveness of crowd detection using synthetic datasets in real-world scenarios. To address the gap between synthetic and real data, they applied a domain adaptation strategy, pre-training the model on the synthetic data and then fine-tuning it on real data. The results demonstrated a substantial improvement in performance on real datasets after the model was trained with the synthetic dataset.

Haase et al. (2019) presented a model to solve the problem of scheduling pilgrim movements for the Jamarat ritual. The first phase of the study focused on facilitating the spatial use of infrastructure capacity to avoid dangerous pedestrian density. It then reduced the overall dissatisfaction of pilgrims with the scheduled time slots. The results were simulated to determine the necessary adjustments to the scheduling constraints.

3.4 Distribution and Scheduling

AI techniques are vital for the distribution and scheduling of services during mega events, where there is a need to manage complex logistics and accommodate vast numbers of attendees. These large-scale events demand efficient resource allocation, real-time adaptation, and precise scheduling to ensure smooth operations and high service quality (Shambour & Khan, 2019).

During Hajj and Umrah, services are subject to various resource constraints and regulatory requirements, including capacity limitations, scheduling restrictions, and traffic regulations. AI algorithms with constraint handling mechanisms and adaptive strategies are necessary to ensure the fulfillment of constraints while optimizing services (Shambour & Khan, 2019).

Morgan and Khayyat (2018) proposed an optimization methodology that aims to reduce the distance between the holy sites' service points. Using genetic algorithms, they sought to identify the most efficient distribution of service points to enhance performance for visitors and pilgrims. This methodology was applied to the placement of ambulances in the densely populated Arafat area. The service points considered include ambulances, police vehicles, fire trucks, food trucks, and stations for water and other beverages.

Shambour et al. (2017) developed a framework that aims to develop an effective technique to improve the distribution of pilgrims' camps within the Mina area before Hajj. The distribution of accommodation to pilgrims is an important issue in Hajj and should be distributed in a way that meets the best practices for housing pilgrims and allocating places for various services to them. In this paper, several constraints were taken into consideration, which can be divided into hard constraints and soft controls. The paper recommended maximizing the available resources and exploiting them effectively, which consequently contributes to increasing the accommodation capacity in Mina.

Later, Shambour and Khan developed two algorithms to resolve the scheduling process of accommodation in the Mina area using heuristic and hyper heuristic approaches (Shambour and Khan, 2019a; Shambour and Khan, 2022a). The conducted simulations demonstrate that the suggested algorithms are capable of efficiently searching the space and avoiding local minima while iterating.

Furthermore, the mechanism followed in the Hajj terminal at King Abdulaziz International Airport was studied in the literature (Shambour & Khan, 2019b; Shambour & Khan, 2022b; Shambour & Abu-Hashem, 2023). The process starts from the terminal gates and ends at the plaza during the 2018 Hajj season, where the mathematical representation of the constraints was represented, as well as the objective function, which was defined to reduce the waiting time of passengers at the different stages of the airport. A simulation of the scheduling process was conducted using three algorithms to find the algorithm with the best performance in finding the lowest value of the objective function and then discussing the different results and the effect of the variables of the objective function on increasing or decreasing the waiting time of passengers from one stage to another. The simulation results showed that the longest passengers waiting time was at the terminal gates because of the shortage of vacant places in the passport areas. The baggage area comes after the terminal gates area, and followed by the passport areas, and then the customs areas. The area before entering the terminal gates has the shortest waiting time.

3.5 Identification and detection

During mega events, there is a high demand for identification processes, where safety, security, and efficiency are top priorities. With massive crowds and heightened security demands, traditional identification methods may fall short in terms of speed, accuracy, and adaptability. Therefore, AI techniques are very important in such cases.

Jabra et al. (2020) introduced an artificial intelligence system that detects and identifies pilgrims and their attributes using convolutional neural networks (CNNs) and deep learning. They compiled a comprehensive dataset featuring both pilgrim and non-pilgrim samples, covering different genders and environmental conditions. Two advanced CNN models were then trained specifically for pilgrim detection, followed by a comparative analysis to assess their effectiveness in this particular application. Although the precision of their proposed algorithms is not perfect in many cases, it can reach around 80% in some instances. This indicates that the use of CNN algorithms for pilgrim detection has the potential for further improvement in accuracy.

Al-Ghamdi et al. (2023) applied a deep learning-based detection model to detect face masks during religious mass gatherings such as hajj and umrah. The model uses convolution neural networks (CNN) and fuzzy neural networks (FNN) to detect and classify faces with and without masks.

In another work, Felemban et al. (2023) introduced a deep learning framework designed to detect crowd congestion. The framework begins by splitting the input video stream into overlapping segments. Dense trajectories are extracted from each segment, and a spatio-temporal image is created to capture the relative motion within that segment. A CNN is then used to extract hierarchical features from the fully connected layer and to learn the influence of trajectory representations. The CNN classifies each spatio-temporal image into two categories: 'congested' and 'normal.' Following classification, a score map is generated by encoding the images with their corresponding class scores. To identify congested regions within the video, non-maximum suppression is applied to the score map.

3.6 Prediction and forecasting

In mega-events, AI-powered forecasting enables organizers to anticipate and address potential issues, optimize resource allocation, and enhance the overall event experience. By leveraging predictive insights, mega event

managers can operate with greater precision, adaptability, and confidence, ensuring the event runs smoothly and safely for all participants.

Albahar et al. (2023) developed a deep learning model that applies the expectation-confirmation theory to assess the pilgrim's satisfaction with hospitality services. The model was trained and evaluated using data from hotel reviews related to Hajj. The results demonstrated that the proposed model was highly effective, achieving an accuracy of 97% in predicting pilgrim satisfaction.

A neural network approach was utilized in (Shambour et al., 2017) to predict water and electricity demands in Makkah during Ramadan for the years 1440-1441 AH. The authors analyzed data from the previous five years. This study was among the first to address one of the most important needs of pilgrims.

3.7 Healthcare

In (Alghamdi, 2024) a review of the applications of machine learning (ML) in healthcare during hajj seasons is discussed. The main areas of ML algorithms that benefit Hajj include smart patient data records, predictive analytics, imaging diagnosis, and intelligent connectivity. The documentation workflow is simplified using an advanced Smart Electronic Health Record (EHR), which provides healthcare professionals with important insights to enhance their practices. Furthermore, AI-driven predictive analytics can play a crucial role in identifying and managing health risks among pilgrims. Smart sensing devices, which continuously monitor vital signs and other health indicators, enable early detection of potential health issues, allowing for prompt intervention and care. These devices employ machine learning algorithms to process the data and offer personalized insights to individuals. Additionally, AI-powered chatbots have the potential to transform how patients access medical advice, providing reliable information and support anytime and anywhere. By leveraging this technology, healthcare providers can engage with users, deliver useful health content, and foster meaningful interactions that generate valuable leads.

3.8 Sentiment Analysis

Sentiment analysis is a valuable tool for understanding public opinion and measuring attendee satisfaction during mega events. Analyzing social media posts, surveys, reviews, and other public communications, provides insights into attendees' feelings, preferences, and areas for improvement. Using AI for sentiment analysis enables organizers to gain a deeper understanding of attendee emotions, enhancing event planning, real-time management, and post-event evaluation. AI-driven sentiment analysis interprets large volumes of textual data with precision to identify and measure attendee sentiments effectively.

Aldhubaib (2020), Shambour (2022), and Gutub et al. (2023) used CNN and LSTM approaches to analyze pilgrims' sentiments during the Hajj season. This analysis provides a comprehensive overview and valuable insights to decision makers, enabling them to make informed decisions in real time. Their research focused on how individuals perceive different situations during the COVID-19 pandemic in the context of the Hajj season, as well as their satisfaction with the services provided.

4 Discussion

It is important to note that while some approaches offer significant effectiveness in improving many aspects such as safety, crowd flow, distribution, transportation, etc., this field requires further development and research to keep pace with the rapid advancement of modern technologies and methods. The studies reviewed in this paper offer innovative solutions to various challenges in managing major events such as Hajj and Umrah. However, a careful analysis reveals some limitations and opportunities for improvement that deserve attention.

One recurring issue in the reviewed research is the reliance on simulation-based methods to validate proposed solutions. While simulation provides a controlled environment to test strategies, it often fails to replicate the full complexity and unpredictability of real-world conditions. For example, studies on transportation optimization and crowd management typically rely on pre-defined parameters and assumptions that may not hold in dynamic and uncertain scenarios. This limits the practical application of proposed solutions, especially in large-scale, high-risk events such as Hajj, where variables such as weather, human behavior, and unforeseen incidents play a significant role. Real-world implementation and validation are crucial to bridge the gap between theoretical models and practical results.

Another challenge lies in the adaptability and scalability of many of the proposed approaches. Many studies, such as those using AI-based optimization or scheduling algorithms, focus on static or semi-dynamic environments. However, mega-events feature rapidly changing conditions that require real-time adaptability. For example, crowd dynamics can shift suddenly due to emergencies, delays, or miscommunications, rendering

pre-calculated solutions insufficient. Incorporating adaptive learning models, such as reinforcement learning or advanced real-time predictive analytics, could address this shortcoming by enabling systems to continuously evolve and respond to changes as they occur. Furthermore, there is a lack of integration between different technologies and domains. The studies reviewed addressed isolated aspects of mega-event management, such as transportation, crowd safety, or sentiment analysis, without considering how these components interact as part of a larger system. For example, transportation systems optimized for efficiency may inadvertently create bottlenecks at entry points, while safety strategies designed for evacuation may conflict with optimizing crowd flow. A comprehensive, systems-level approach that combines AI, IoT, and data analytics across all aspects of event management can lead to more comprehensive and effective solutions.

Finally, the pace of technological advancement challenges the longevity and relevance of existing solutions. Many studies rely on methods and tools that may become obsolete as new technologies emerge. For example, advances in AI, such as generative models, have the potential to revolutionize data-driven decision-making in ways not yet explored in the reviewed research. To remain relevant, researchers must take a forward-looking approach, continually updating their methods and frameworks to take advantage of the latest technological innovations.

5 Conclusion

AI holds transformative potential for enhancing service delivery and operational efficiency in mega events, addressing unique challenges posed by large-scale gatherings. This paper has demonstrated how AI optimizes key mega events domains such as transportation, crowd management, healthcare, logistics, and more, with a particular focus on the Hajj and Umrah context. By effectively managing large crowds and providing essential services within limited timeframes and confined spaces, AI streamlines complex systems, improves attendee satisfaction, and supports service providers. The paper examined specific AI applications in Hajj and Umrah across transportation, robotics, crowd management, distribution and scheduling, identification and detection, prediction and forecasting, healthcare, and sentiment analysis. Ultimately, leveraging AI in mega events not only benefits organizers and providers, but also sets new standards in event management, showcasing AI's capacity to meet and exceed real-world demands.

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