

# Big Data Analytics Model for Preventing the Spread of COVID-19 During Hajj using the Proposed Smart Hajj Application

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**Abstract:** *Unlike the Pool of Bethesda, Makkah is a moment of sacrifice, a space of unified worship in the lives of Muslim worshippers. The Makkah experience symbolizes the “farewell pilgrimage” of the Prophet Muhammad through the Arabian desert in 632 A.D. (Aljazeera, 2021). The annual Hajj expedition to the Saudi holy city is the fifth of the five Muslim Pillars of Islam. Hajj occurs during Dhu’al-Hijjah, the last month of the year according to the Islamic calendar. Millions of people from across the world assemble to pray in the direction of Ka’bah, the holiest Islamic shrine constructed by Abraham and Ishmael. The 2012 Hajj attracted more than 3 million pilgrims journeyed to Hajj. However, the 2019 SARS-CoV-2 outbreak has since forced decision-makers for the Kingdom of Saudi Arabia to take further preventive measures in the interests of public health that affect the outcomes of the traditional prayer and worship. Saudi Arabian government officials significantly downsized capacity and instituted protocols for attendance to the 2020 and 2021 Hajj events due to the Covid-19 pandemic. In addition to Muslim pilgrimages, several nations have implemented mHealth apps designed for Covid-19 contact tracing, quarantine enforcement, symptom monitoring, and information provision for mass crowding events. Independently, the apps do not provide a holistic approach to Covid-19 transmission control in mass gatherings. A more universal, less intrusive technological approaches to managing and protecting the Hajj pilgrimage populations using credible, real-time data is needful. This study proposes an information-generating SMART app based on the success of prior apps, the implementation of a Smart Hajj application, which allows authorities to track Hajj pilgrim movement, and collect data as a part of efforts to prevent Covid-19 from disrupting centuries-old tradition Muslim pilgrimages to worship in sacred places.*

**Keywords:** Hajj, Covid-19, SMART app, Big Data, Saudi Arabia.

## I. INTRODUCTION

Unlike the Pool of Bethesda, Makkah is a moment of sacrifice, a space of unified worship in the lives of Muslim worshippers. The journey to Makkah symbolizes the “farewell pilgrimage” of the Prophet Muhammad through the Arabian desert in 632 A.D. [1].

During the event, racial, socioeconomic, and national

identities mesh into one Muslim identity as the global gathering of fasting and prayer promotes peace, spiritual cleansing, and goodwill toward others [1]. Historically, disease and armed conflict remain infamous as disrupters of Hajj, often preventing a complete execution of the event [1] [2] [3].

The postmodern Covid-19 public health crisis is the latest disrupter, driving transformations in Hajj pilgrimage administration and crowd management. Several mHealth apps have been designed for Covid-19 contact tracing, quarantine enforcement, symptom monitoring, and information provision. Independently, these apps do not provide a holistic approach to Covid-19 transmission control in mass gatherings.

This study proposes an information-generating SMART app based on the success of prior apps, the design and implementation of a Smart Hajj application, which would allow the authorities to track Hajj pilgrim movement, and collect data as a part of efforts to prevent Covid-19 from disrupting centuries-old tradition Muslim pilgrimages to worship in sacred places.

### 1.1 Hajj Pilgrimage to Makkah

Religious pilgrimages are rich in historical, anthropological information for researchers [4]. The annual Hajj pilgrimage to the Saudi holy city of Makkah is the fifth of the five Muslim Pillars of Islam. The journey occurs during Dhu’al-Hijjah, the last month of the year according to the Islamic calendar.

Millions of people assemble to pray in the direction of Ka’bah, the holiest Islamic shrine constructed by Abraham and Ishmael [5]. Most arrive weeks ahead of the start of Hajj, which endures for approximately one week [1]. From Makkah, the pilgrims move to the tent-city Mina for prayer and worship.

From Mina, Hajj pilgrims head to Mount Mercy at Arafat for more prayer and fasting. Following the Day of Arafat, the pilgrims move to Muzdalifah, where everyone collects pebbles. The pebbles are used the following day, yawn-ul hajj al-akbar, at Jamarat Bridge. Some return to Makkah, and all eventually return to Mina. An important part of Hajj is the meat distribution to the poor around the world on Eid al-Adha [1].

### 1.1.2 Hajj Pilgrimage in Postmodern Covid-19 Era

All Muslims must make the pilgrimage to Hajj at least once during their lives.

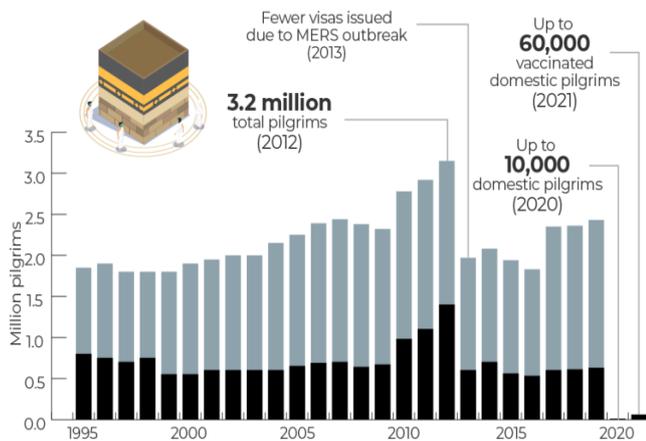
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As millions travel to the Grand Mosque dressed in Ihrams, Saudi government officials have significantly downsized the capacity for Hajj in 2020 and 2021 due to the Covid-19 pandemic [1]. The infographic in figure 1 illustrates the number of annual Hajj pilgrims with a timeline of public health crises from 1995 to 2021:



**Figure 1. Annual Hajj attendance record 1995 – 2020 (SA Statistics Authority, 2021)**

In 2012, Hajj pilgrimage attendance was at record highs of more than 3 million. The 2012 Middle East Respiratory Syndrome (MERS-CoV) outbreak appears to be a precursor to the Covid-19 pandemic as 2013 Hajj attendance fell to record lows with slow recovery [1]. Foreigners who attended Hajj returned to their home countries following high crowd exposure [6]. By 2021, only 60,000 local vaccinated Saudi Arabian citizens between 18 and 65 years old could attend Hajj. The Hajj attendance began to rebound from the effects of MERS in 2017. However, the first Covid-19 cases were reported in 2019 and quickly evolved into one of the world’s most devastating public health threats [3]. The restrictions placed on Hajj attendees from 2018 to 2022, according to the Saudi Arabia Ministry of Hajj and Umrah, are as follows [1]:

- Hajj 2018 Sunday, August 19 to Friday, August 24; 2.3 million in attendance
- Hajj 2019 Friday, August 9 to Wednesday, August 14; 2.5 million in attendance
- Hajj 2020 – Tuesday, July 28 to Sunday, August 2; no foreign pilgrims allowed, attendance restricted to 60,000
- Hajj 2021 – Saturday, July 17 to Thursday, July 22; no foreign pilgrims allowed, attendance limited to 60,000 Saudi residents and citizens
- Hajj 2022 – attendance limited to 1 million worldwide; only foreign and domestic, fully vaccinated Hajj attendees, age limit <65 years old.

The 2019 SARS-CoV-2 outbreak has forced decision-makers for the Kingdom of Saudi Arabia to take further preventive measures in the interests of public health that affect traditional prayer and worship. Pilgrims performed Tawaf around Ka’bah six feet apart, wearing masks during Hajj 2020 [1]. During Hajj events, the Grand Mosque is now frequently vacated for sterilization. The impact of Covid-19 social distancing on the Hajj pilgrimage over the past three years is illustrated in the crowd density differences in Figure 2:



**Figure 2. Hajj Grand Mosque crowd density 2018 vs. 2021 (Aljazeera, 2021)**

The 2018 Hajj crowd density (on the left) is reduced significantly by Covid-19 in 2021 (on the right) [12]. Only a fraction of the global Hajj population is in attendance at one time.

### 1.1.3 Government Crowd Management Strategies

Covid-19 transmissions present a unique public health issue, a challenge that persists during mass pilgrimages. The Saudi Government has spent billions of dollars on safety measures and crowd control strategies for pilgrims attending Hajj [1]. With more than 3 million people in limited space, the potential for disease transmissions, injuries, and fatalities can be unavoidable. Overcrowding issues can be mastered with modern logistics and software engineering applications [7].

### 1.2 Research Problem

The evolution of travel to Makkah, from the 1910 camel caravans to postmodern motorcars and aircraft, has significantly increased the number of attendees to Makkah over the past century [1]. Yet, recent Hajj access is limited by Saudi government protocols instituted to prevent the spread of deadly viruses such as MERS and Covid-19. Between 2019 and 2021, more than 100 million people worldwide have contracted Covid-19 and several cases ended in fatalities. Vaccinations and other health-related treatments, masks, and social distancing measures have significantly altered the traditional aura of sacredness and unity among the masses that defines the Hajj pilgrimage event. The Saudi Arabian government has instituted manual efforts, such as questionnaires, to track Hajj populations and movements during the global coronavirus crisis [1] [8]. However, a more universal, less intrusive technological method of managing and protecting the Hajj pilgrimage populations using credible, real-time data is needed.

### 1.3 Research Questions

This study aims to answer the following research questions:

R1: How can data collection and analysis contribute to Covid-19 transmission control during Hajj?

R2: What SMART application features will best benefit Hajj crowd control and monitoring in the wake of Covid-19?

R3: What role can technology play in future planning of annual Hajj pilgrimages?

## II. RELATED WORKS

The literature “prioritizes” religious actors and movements from “emic perspectives” that minimize secular place-making narratives to a form of vacating faith from the public space [9]. Diverse global populations, such as annual Hajj pilgrims, face public health dangers that persist as government challenges. Selected works presented in this review argue for crowd management improvements using advanced technology in the wake of global public health crises.

### 2.1 Faith Eventization Theory

Faith Eventization theory encompasses research of historical religious gatherings and the recognition of the significance of sacred sites [10]. Becci, Berhardt and Casanova (2013) highlighted the importance of researching “religious space conjunctures” in postmodern contexts due to a “rewriting” of narratives by secularizing modernity (p. 1). Berg (2019) suggests that these narratives segregate Muslim versus Evangelical ideologies within the boundaries of municipal public and private spaces. In the same light, Caidi (2019) contributed that religious pilgrimages to sacred sites are not only a transformational experience but also a source of knowledge regarding complex intelligence environments, particularly in emerging economies. Even Christian theology advocates for assembly of ‘believers’ as evidence of faith and faith-building through eventization (Hebrews 10:25 KJV). Both Muslim and Christian doctrines promote faith in action narratives, whereas action must evolve from simple prayer postures to calls for mass assembly. Dowson (2020) investigated how sacred pilgrimages to the Holy Land affect pilgrims and their local religious communities [21]. A qualitative ethnographic method based on Geertz (1973) “thick description” is used to assess the meaning and effect of faith eventization. Dowson (2020) found that religious pilgrimages create a “shared experience” that 1) enhances the religious community identity; 2) promotes community cohesion; 3) strengthens religious community faith; and, 4) enhances the individual pilgrim faith (p. 34). Faith eventization ideologies often associate sacred site assembly with physical healing, such as the Pool of Bethesda or the Pool of Siloam. Klimiuk and Moriarty (2021) investigated the impact of the Lourdes Pilgrimage on the attendees’ quality of life. The researcher administered a EuroQol EQ-D-5L questionnaire to 93 Lourdes pilgrims to assess self-rated health status. A total of 67% of the participants reported improved health due to participation in the pilgrimage. Participants rated communal, spiritual, and holistic values as the primary benefits of the Lourdes pilgrimage. Using a similar approach, Caidi (2019) interviewed 12 Hajj attendees from across the world to solicit perspectives on the Hajj experience. The participants supported that Hajj pilgrim information practices are diverse and “transcend individual affective, cognitive, and social processes” (p. 44). The information practice diversity results from post-nationalist networks of people who share imaginations and resources. Caidi (2019) concluded that the pilgrimage is a “lived religion”, a journey that provides corporal, spiritual, and textual information (p. 44).

### 2.1.1 Pilgrimages and Public Health Crises

Reid et al. (2021) highlighted the degree to which Covid-19 is the largest international public health crisis of the 21st century. Gu, Lu and Yang (2020) claim to have confirmed six Covid-19 cases among flight passengers returning from a Pakistani masjid pilgrimage in March 2021 [23][24]. The study focused on instances of pilgrims who travel to sacred sites returning to their home countries after contracting Covid-19. The six passengers are said to have attended the six-month event in Pakistan, worshipping daily without mask mandates. The Covid-19 infections were discovered when the passengers were inspected at the Guangzhou border [6]. The authors assume that the Covid-19 infections were contracted during the pilgrimage, although the assumption is not medically substantiated. As global society travels between cities, nations, and continents, tracking exposure to viruses is increasingly challenging. Even with modern technological capabilities, keeping up with crowds requires the application of several sociopolitical, public health, and information privacy theories.

### 2.2 Crowd Management Theory

Crowd management scenarios can be dense, accelerating into severe conditions that can cause injury depending on various circumstances. The Covid-19 pandemic creates an additional dimension of public health risk that requires the Ministry’s attention. The management of the crowd requires innovative strategies that are intelligent and effective. Further, crowd management strategies require multiple areas of collaboration, such as the expertise of civil engineering, physics, computer science, and psychology. Current methods of crowd organization and management lack perfection as guidance and a directional management system are required.

#### 2.2.2 Crowd Management Technology

[25] supported that the planning and the management strategies for executing effective management methods are still required to be more effective. The authors suggested a model for the crowd simulation using virtual environments. The researchers demonstrated augmented reality technology as a practical implementation that uses mobile technologies as an assistant for the authorities in Hajj. The Mobile Augmented Reality (MAR) tool gathers information about the pilgrims. This results in guiding them in the right direction, alerting them to pertinent malformation, and the lost pilgrims can be united with their group easily. The technology used text, audio, and video to identify the behaviors [13]. It is mentioned by various authors how MAR is helping the staff of Hajj to organize the pilgrims. For example, the team can identify the geo-located places by looking at the positioning of the MAR devices’ cameras, such as viewings by tablets or smartphones. The applications of the MAR can also be utilized in systems of Hajj Surveillance by the camera sensors. The MAR has a high capability to provide data transmissions and communications between the Hajj operators, ground, and the staff [14]. The Pakistani government has implemented a newly introduced GPS tracker for Hajj pilgrims. This GPS tracker is an electronic bracelet that creates a movement of coordination among the pilgrims [15].

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Despite this safety measure, incidents still occur during the Hajj due to the stampedes and collisions. Recently, in 2015 a total of at least 1500 deaths and 934 injuries were reported during the Hajj, making the event one of the deadliest in recent times [16]. The mass moving of people in a single direction can cause severe damage or harm because of the generated motion. Reversing the crowd's movement during Hajj is managed under strict supervision since the number of people moving in an advancing direction cannot be controlled. Placement of Global Positioning System (GPS) trackers, special teams, and highly trained officers are also necessary to prevent pilgrims' injuries [16]. Other various approaches are investigated by the authors that introduce more efficient conceptualizations of managing a crowd. The laminar flow is identified to study the crowd traffic, and by using this decision, a Decision Support System (DSS) is developed to control disturbances [7]. Another proposed system is an integration of a computer-based Graphical Information System (GIS) and fuzzy logic. This two-step model is designed to avoid disasters in the crowd, whereas the crowd behavior detection approach also represents the optical flow data that manages the bottleneck congestion on the roads connecting the sacred Hajj visitation sites [17]. The authors have introduced two threads to detect dangerous situations due to mismanagement of crowds. The queue model is another proposed model for the crowd's management to monitor the traffic congestion interconnecting the visiting sites during Hajj [15]. Similarly, to manage this issue, advanced technology makes the traffic system intelligent for the crowds. In other studies, a sensor system is developed to study frequency. A Wireless Sensor Network model was proposed to understand crowd behavior. The crowds are modeled using ABMS techniques. Patta (2019) used ABMS and presented a system called "SimCrowdControl" to enhance the decision-making by management in Hajj (p. 16).

### 2.2.3 Smart Applications for Public Health Management

Several mHealth applications have been introduced in response to Covid-19 [15]. Basic contact tracing apps that started in Singapore now use several methods of data collection and movement tracking using GPS and Bluetooth technology. The ALHOSN is the third contact tracing app published by the Abu Dhabi Department of Health. The app was published online and made available for download in 2020 [11]. Quarantine enforcement apps use geofencing and base station triangulation methods to monitor populations under quarantine. Symptom monitoring apps help users track symptoms that indicate infection. Abi Sen et al. (2021) proposed the Digital Streets crowd management tool to facilitate crowd management at Hajj. The tool uses color coding and signals to provide guidance to Hajj users. The tool also provides alerts from a central command center. The system design is based on a control algorithm. Sagar (2020) is developing the MySejahtera government Covid-19 Information Providing app for the Malaysian government. The tool instructs user on how to identify potential health risks by making self-assessments [18]. My Sejahtera also identifies data trends that indicate potential outbreaks and produces instructions for those who contract Covid-19.

## III. METHODOLOGY

The methodology for the SMART mobile app is a design that will meet the Kingdom goals and the needs of Hajj pilgrims

as the users. The strategy for the proposed Big Data SMART app is to reinforce existing Kingdom protocols that reduce the transmission of infectious diseases and potential injury occurrences among the masses in potentially overcrowded events. The process for the Big Data SMART app development is illustrated in the following block diagram:



Figure 3. Big Data app development process

A completed efficient SMART app design will contribute to the Kingdom progress toward Vision 2030 objectives.

### 3.1 Rationale for Research Design

The research approach was selected essentially because big data will ensure that the Ministry has access to all the pilgrims' data, making it easier to manage the situation of the COVID-19 pandemic and prevent more infections. The smart card system implemented by the Ministry of Hajj and Umrh uses big data to collect the pilgrims' information. By applying technology within the smart cards, the Ministry can collect all the data required to attend to the pilgrims' needs immediately within Makkah. An excellent example would be the identification of the areas where the majority of infections are being reported. Through big data analytics, the Ministry can advise the pilgrims to keep out of these areas. Additionally, analytics will also help the Ministry perform what-if analyses and use predictive models to predict the infection rates of COVID-19 within the Kingdom. With the proper information, the Ministry can enforce social distancing policies with probable cause and enough information to make informed decisions on how to effectively manage the pilgrims.

### 3.2 System Development

The information providing SMART app design will generate and organize critical data of Hajj pilgrim movement efficiently and in real-time. The app design will empower Kingdom administration to identify and track infection levels, issue warnings to the pilgrims about hotspot areas for diseases and enhance the response time since the data is real-time. With the smart card application system, contact tracing and isolation will be easier within Makkah to minimize the infection rates. This will be possible since the card shows the pilgrim's information, emphasizing their medical information, tests, and paces they visit in the Makkah center. The smart portal and card application systems ensure that the pilgrims' data are collected before they embark on the pilgrimage.

Therefore, the smart card Hajj application system can collect and analyze relevant data from various hospital reports where the patient has taken tests, thermo-gun reports, and overhead drones. The smart card application is spearheaded by the Internet of Things (IoT) and artificial intelligence (AI). Data concerning the operations and services made available to the Hajj pilgrims are collected using the unique identifier issued to all the pilgrims [19].

Hence, the data can be effectively analyzed, and informed decisions can be made based on data patterns and alerts. The proposed app will also integrate the Kingdom Coronavirus Vaccination Journey Satisfaction Index so that is administered electronically each year. The Index is used to collect and process Hajj attendee data [20]. The Saudi General Authority for Statistics (GASTAT) administered the questionnaire in 2019. The GASTAT questions on the survey administered to Hajj attendees requested the following information points:

- Nationality
- Vehicle type
- Number of attendees in vehicle
- Location of questionnaire completion
- Time of questionnaire completion

The data collection process divides the pilgrims into three groups: domestic pilgrims, foreign pilgrims, and the workers who serve the pilgrims. Table 1 shows the results of the questionnaire after the data was converted and stored in an electronic database:

Table 1. Hajj Statistics 1440 (GAS, 2019)		
مؤشر الرضا العام عن رحلة تلقي اللقاح في المملكة		
تاريخ النشر		2021 مارس 22
احصائيات		
1	عدد التقييمات	4,60,771
2	عدد جرات اللقاح	3M+
3	عدد مراكز اللقاح	500+
نسبة رضا المستفيد		
1	مؤشر الرضا العام	96%
2	نسبة الرضا في منطقة الرياض	90%
3	نسبة الرضا في منطقة مكة المكرمة	96%
4	نسبة الرضا في منطقة المدينة المنورة	95%
5	نسبة الرضا في المنطقة الشرقية	96%
6	نسبة الرضا في منطقة القصيم	94%
7	نسبة الرضا في منطقة حائل	94%
8	نسبة الرضا في منطقة الجوف	93%
9	نسبة الرضا في منطقة الحدود الشمالية	95%
10	نسبة الرضا في منطقة تبوك	95%
11	نسبة الرضا في منطقة عسير	95%
12	نسبة الرضا في منطقة الباحة	94%
13	نسبة الرضا في منطقة جيزان	95%
14	نسبة الرضا في منطقة نجران	95%

The data shows that 2,489,406 pilgrims were in attendance at the 2019 Hajj, approximately 630,000 of whom were Arabic and 1,855,000 pilgrims from foreign lands. Close to 33,000 pilgrims arrived in vehicles. The outcomes of the data analyses were shared with Kingdom clients.

### 3.3 System Architecture

Numerous public health issues must be considered during the Hajj as part of the control process. The IoT tools collect the required pilgrim demographics and movement data within the holy cities. The big data analytics then compare the

existing data and the new data to make conclusions using AI-driven systems. Additionally, the big data analytics model offers a simple creation of a data pool of all the pilgrims, facilitating a faster analysis [22]. Thus, prevention and control of the pandemic's further spread are possible since the Ministry workers can identify any infection cases faster and respond within no time. Hence, making it easier to enjoy the pilgrimage amid the COVID-19 pandemic. The proposed system architecture is illustrated in figure 4:

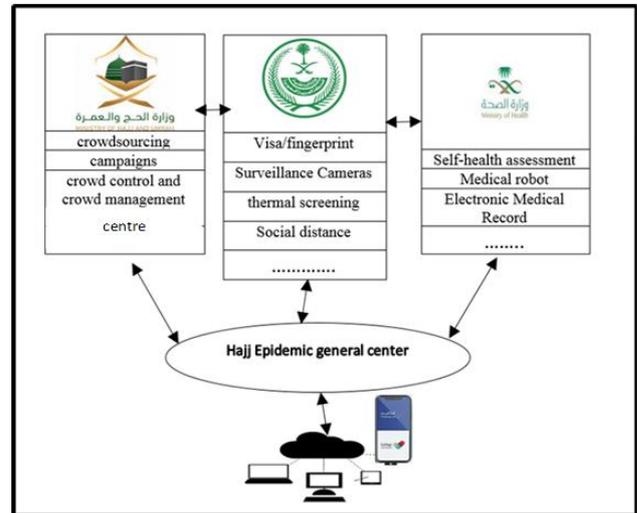


Figure 4. Proposed SMART Hajj System Architecture

The proposed Smart Hajj app will connect a large magnitude of data sets from diverse population sources. The Hajj Epidemic General Centre will be the management function that keeps track of all the collected data and processes it to prevent Covid-19 infections from spreading during the Hajj.

### 3.4 UX/UI Design

The user experience (UX) and user interface (UI) designs are based on a minimalist artistic approach reflecting the superior SA Kingdom technological capabilities and vision. The primary quality features for the SMART Hajj app will include a consistent modern design with fonts using Kingdom colors:



Figure 5. SMART Hajj App Interface

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The SMART Hajj app UX/UI design features are as follows:

- Simple system installations and setup
- Fundamental conversational language design
- Data privacy capabilities
- Bright, easy-accessible navigation tools
- GPS/Location tracking or Bluetooth proximity tracking
- Data Import/Export feature
- Chat feature

### 3.5 Content and Functionality

The primary function of the SMART app for the Ministry administration is the collection and analysis of pilgrim data. Essentially, this process is characterized by data correlation and drawing of patterns. The fourth step consists of identifying all possible solutions to solve problems and practices specified in the third step. For instance, the use of cloud computing could be an excellent resource for collaboration among the ministries. Lastly, the process involves presenting the results as per the outcomes. For instance, the Ministry may identify that the pilgrim has most older adults who need faster response times in case of any pandemic infections. Therefore, they may increase the number of health workers within Makkah during that period. Primary functions for the app users include a fast registration process, self-assessment features, a government help link, a symptoms helpline, and regional Covid-19 updates. The SMART app features will be available in 6 languages: Arabic, English, Chinese, Hindi, Swahili, and Russian. Notably, the big data analytics model connects Hajj and Umrah data to other ministries within Saudi Arabia. Therefore, the process of drawing patterns using analytics is possible. The model enables the Ministry to draw designs across other ministries on implementing policies and strategies to avoid the further spread of the pandemic.

## IV. CONCLUSION

The SARS-CoV-2 pandemic can only be managed effectively if all regions work together with the integration of networks and technology across the world. The growing number of Hajj pilgrims is an issue of concern, especially during the COVID-19 pandemic era, whereas social distancing has been an ongoing national protocol. The Ministry of Hajj and Umrah's innovation is evidenced in the enforcement of smart cards and platform use to ensure that the pilgrims can be monitored using modern technological methods. The aim of the proposed smart card design is to develop a system that can help the Ministry workers identify pilgrim locations at any time. Therefore, by employing Near Field Communication (NFC) technology and overall monitoring through the card barcode, the Ministry can minimize potential SARS-CoV-2 transmission. The research outcomes of the research support the following conclusions based on the research questions: Data collection and analysis provides critical intelligence used to manage Covid-19 transmission during Hajj. Emergency plan instructions and live chat features are the best SMART application features for Hajj pilgrimage control and monitoring in the wake of Covid-19. The intrusiveness of postmodern crowd management technologies in SMART application designs can be reduced by implementation of data privacy and security protocols. Technology can play the roles of information gathering and publication source, a monitoring tool, and reference source for future planning of annual Hajj pilgrimages. In the long run, implementing the smart card

Hajj portal and card application makes it easier to access the pilgrims' information to safeguard both the pilgrims' and the Makkah workers' health.

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