Improving Emergency Preparedness with a Mobile Application for Respiratory Therapy Resource Coordination

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***Abstract*—Mass gatherings such as Hajj and Umrah, along with pandemic outbreaks, place a significant strain on healthcare systems, particularly respiratory therapy (RT) services, where shortages of respiratory therapists, ventilators, and specialized equipment can compromise emergency response due to increased patient volume, environmental exposure, and heightened risk of respiratory diseases. This study presents a conceptual model of a mobile-based resource coordination system designed to enhance emergency preparedness and response for respiratory therapy services during pandemics and mass-gathering events, such as Hajj and Umrah. The proposed system integrates a real-time database with mobile clinical decision support to provide RT managers and supervisors with centralized visibility of ventilators, staffing levels, and critical respiratory equipment across healthcare facilities. By enabling real-time monitoring and predictive, alert-driven decision support, the system aims to support proactive resource allocation, staff deployment, and equipment distribution. Although the work is conceptual and does not include empirical evaluation, it provides a well-defined architectural framework suitable for future implementation that aligns respiratory care workflows with real-time monitoring and forecast-driven decision support in settings such as Hajj, Umrah, and large-scale public health emergencies.**

***Keywords*—Respiratory therapy; mass gatherings; Hajj and Umrah; emergency preparedness; health information systems**

I. Introduction

Mass-gathering events and pandemic cases pose unprecedented challenges to healthcare systems worldwide, and respiratory care services are particularly vulnerable to resource shortages and logistical difficulties. The Hajj pilgrimage, which annually takes place in Saudi Arabia and attracts over two million pilgrims, and the Umrah pilgrimage, which draws a steady stream of pilgrims to the country throughout the year, place intense pressure on the healthcare infrastructure in the region [1]. As Hui and Zumla show, the frequency of such events, combined with the risk of respiratory pandemics already evident in COVID-19, is a stark indicator that more developed systems of resource coordination are needed that can be flexible in responding to varying healthcare needs [2].

The use of respiratory therapy services is evident in the treatment of patients with acute respiratory disease, chronic obstructive pulmonary disease (COPD), and other respiratory conditions, which may be exacerbated by crowded environments, environmental factors, and stress associated with mass events [3]. The current resource management systems in the healthcare sector are disjointed, and there is minimal real-time awareness at the facility and regional levels. Mbau et al. suggest that such disintegration can lead to inefficiencies in resource distribution, delayed responses, and poor patient outcomes during a crisis when respiratory care needs are critical. The intersection of mobile technology, artificial intelligence, and real-time data analytics offers an opportunity to revolutionize how emergency preparedness and response are coordinated to deliver respiratory therapy services [4].

This study is based on observations of resource coordination issues during past mass-gathering events, such as Hajj and Umrah, as well as during pandemic responses in the Saudi healthcare system. This work is highly applicable in health informatics because it leverages key features, such as mobile applications and predictive analytics, to address existing gaps in emergency preparedness and resource coordination. The proposed system is expected to develop a unified framework that will enhance coordination opportunities while maintaining the flexibility needed to respond to diverse emergencies.

Although the healthcare and emergency preparedness plan has intensified the use of technology, respiratory therapy departments have experienced significant challenges in coordinating resources during surges associated with mass-gathering events and pandemic outbreaks. Current systems fail to provide real-time updates on resource availability across facilities, leading to inefficient allocation of ventilators, RT staff, and other vital resources. This fragmentation results in slow response times, insufficient resources in areas where they are needed most, and ineffective patient care during periods of peak respiratory demand. An integrated, technology-driven coordination system is necessary to streamline resource utilization and enhance emergency response capacity in respiratory care services.

This study aims to propose a conceptual framework for integrating mobile application technology and predictive analytics to develop a real-time resource coordination system for respiratory therapy services. The system will strengthen emergency preparedness and response capacity for mass-gathering events such as Hajj and Umrah, as well as for pandemic conditions that necessitate rapid mobilization and coordination of resources.

This study addresses a critical gap in emergency healthcare preparedness, especially in the regions that experience mass gathering events regularly or are threatened by the pandemic. The proposed system can substantially enhance response coordination and patient outcomes during high-demand periods by integrating advanced technologies with the practical requirements of resource management. The framework developed in this work's context may serve as an example for regions facing similar challenges. It might be involved in emergency healthcare preparedness and health informatics on a larger scale.

Whereas most existing emergency preparedness and digital health platforms focus on hospital-wide capacity management or generic clinical decision support, this work explicitly targets respiratory therapy operations in large-scale mass gatherings, with an emphasis on Hajj and Umrah. These events pose greater challenges for respiratory care due to extreme crowd density, which increases the risk of environmental exposure, infectious disease transmission, and sudden surges in demand for ventilators and respiratory therapy staffing. The novelty of the proposed system lies in its respiratory-therapy-specific focus, integrating real-time monitoring of ventilators, respiratory therapists, and critical respiratory equipment with predictive analytics to anticipate upcoming respiratory demand during these mass gatherings.

In addition, the system enables proactive, end-to-end coordination through its unique combination of mobile decision support and respiratory-therapy–oriented workflows, addressing the operational realities of Hajj and Umrah rather than treating respiratory assets as generalized hospital resources.

A. Contributions

This research work presents the following contributions:

1) Technical contribution: Design of the cloud-based mobile application architecture for the integration of real-time data of respiratory therapy resources, such as ventilators, respiratory therapy staff, and critical respiratory devices, with prediction analytics for surge preparation for Hajj and Umrah events.

2) Clinical and operational contribution: A respiratory therapy–focused coordination framework that facilitates proactive allocation/escalation for ventilators and other respiratory devices and equipment, and respiratory therapy staff for mass gathering events requiring respiratory interventions.

3) Decision-support contribution: Designing role-based dashboards that improve situational awareness for respiratory therapy team leaders, emergency command centers, as well as other roles, to make decisions for the Hajj/Umrah events.

4) Scalability contribution: A sharing model of respiratory therapy coordination that could be replicated for other mass gathering situations involving respiratory surge demands.

II. Related Work

A. Emergency Preparedness and Mass Gathering Events

Alahmari et al. reported the overall mitigation strategies adopted during the Hajj 2021, which emphasized the importance of coordinated healthcare responses in ensuring health security. The research also highlighted the benefits of resource coordination and real-time monitoring to achieve effective health outcomes during the pilgrimage, demonstrating the utility of integrated technological solutions in emergency preparedness [1].

Another systematic review by Alrabie et al. also underscores the complexity of respiratory care management in mass gatherings. Their findings indicated numerous gaps in the coordinating mechanisms and that superior communication systems were needed to enable rapid decision-making and resource mobilization in emergencies. It was also recorded that communication breakdowns are among the leading causes of response delays and inefficient resource use during peak demand [3].

In a related study, Hui and Zumla identified that mass-gathering events also pose epidemiological problems, directly affecting respiratory care services. The dense population increases the risk of respiratory disease transmission, and the healthcare system must be prepared to manage the resulting influx. These events require highly sophisticated coordination mechanisms to ensure the adequate deployment of resources across multiple health facilities that must attend to pilgrims and local communities simultaneously [2].

B. Technology Integration in Emergency Healthcare Systems

Sarani et al. have developed a data-driven respiratory infection management system that demonstrated the capabilities of epidemic preparedness by real-time data analytics and automated alerts. Mobile communication devices enabled faster response times and more efficient resource allocation within their system [5].

Healthcare technology has enabled more sophisticated approaches to emergency preparedness, and cloud-hosted platforms and computing resources provide the scalability required during surges. Such technological solutions have been particularly helpful in respiratory care, where equipment availability and the organization of personnel have become significant determinants of patient outcomes [6].

Tanggono et al. analyzed the use of mobile health solutions and geographic information systems (GIS) during disaster response and concluded that mobile apps could enhance communication efficiency and resource awareness in emergencies. Their study emphasized the significance of user-friendly interfaces and real-time data synchronization in effective mobile health solutions [7].

C. Artificial Intelligence and Predictive Analytics in Healthcare Resource Management

Jani notes that AI-based predictive analytics could allocate resources in hospitals, and the outcomes demonstrate that machine learning methods can efficiently determine which resources are needed and how they should be allocated. Their system also reduced resource shortages and improved overall response coordination, in addition to providing early-warning capabilities, thereby making resource positioning proactive [8].

Karthika et al. found that machine learning algorithms have proven particularly helpful in respiratory care, as multidimensional physiological information and equipment-use patterns can be used to predict patient needs and maximize resource utilization [6]. These systems can process multiple data streams simultaneously, including patients' vital signs, equipment status, staff availability, and historical utilization trends, to inform recommendations for resource management across the end-to-end system [8].

Prasad et al. developed an IoT-based system to monitor ventilator supply and utilization across multiple medical facilities. IoT adaptation and real-time analytics have attracted considerable attention in the respiratory care field and have yielded substantial benefits, offering a new perspective on equipment status and utilization patterns across facilities. Their platform was transformed into real-time equipment status monitoring, automatic alerts when resources were approaching critical thresholds, and increased resource utilization and faster response times in emergency settings [9].

D. Mobile Applications in Healthcare Emergency Response

In their study on mobile apps in disaster response, Winders et al. found that these apps significantly improved resource tracking and communication, demonstrating their potential to facilitate rapid information sharing and decision-making [10].

The development of mobile healthcare applications should be planned and executed to address user needs, technical limitations, and work requirements. Successful emergency-centered applications are characterized by usability, offline capability, and robust security to remain usable even in suboptimal conditions [7].

Naranjo-Rojas et al. developed a mobile application to coordinate respiratory therapy resources within a regional healthcare network, resulting in improved resource utilization and faster response times during peak periods. Their system demonstrated the effectiveness of real-time communication and centralized resource visibility in delivering respiratory care efficiently [11].

E. Pandemic Preparedness and Respiratory Care Systems

Jokhdar et al. reported that adequate mitigation measures implemented during Hajj 2020 resulted in no COVID-19 cases, attributable to extensive coordination and real-time monitoring systems. Their solution demonstrated that integrated technology solutions would enable a pandemic response and preserve the delivery of essential healthcare services [12].

According to Embrett et al., resource coordination systems positively influenced pandemic response, as healthcare systems that used integrated resource management platforms achieved better outcomes and more effective resource utilization. Their study highlighted the significance of real-time visibility and automated coordination mechanisms in pandemic preparedness plans [13].

F. Gaps in the Literature

While the literature supports the need for technology integration in healthcare emergency planning, much remains unclear about the operation of resource coordination systems for respiratory therapy services during pandemics and large-scale events. The research available is more focused on specific technologies or types of events rather than comprehensive solutions available under emergencies.

Moreover, most available research examines the use of technology within the broader healthcare context. It lacks consideration of issues specific to the operation of respiratory care coordination in high-demand situations [14]. While Prasad et al. describe mixing of smartphone apps with IoT sensors and AI analytics in healthcare, they did not address the highly specialized topic of employing these instruments in emergency respiratory therapy resource coordination [9].

In addition, Bignami et al. describe emergency planning response to discrete scenarios; they have no practical, scalable, sustaining systems that can be customized for regions or medical centers. More importantly, no end-to-end scenarios exist that incorporate real-time resource monitoring via predictive analytics and specialized respiratory therapy systems on smartphones. Therefore, research on specialized smartphone-integrated systems for efficient resource management and decision support in high-demand scenarios such as pandemics or mega-events is timely [15].

III. Methodology and System Architecture

The system is designed using a methodical, multi-stage process involving stakeholder groups. The planning stage includes the first phase of identifying infrastructure and systems architecture with respiratory therapy departments, hospital information systems departments, and emergency management coordinators to identify systems requirements and points of intersection with standard healthcare information systems.

The technical design is a cloud platform supporting predictive analytics-driven informed decision-making. The smartphone app retrieves data on ventilator availability, oxygen supply, personnel schedules, and other critical resources from hospital inventory systems and respiratory therapy managers. Such information is used to predict demand patterns, identify shortages, and generate automated alerts when resources approach critical thresholds.

The smartphone user interface is customized to meet the needs of directors and respiratory therapy administration and includes easy-to-use dashboards for real-time resource availability, personnel allocation, and emergency notifications. The software enables users to request resource transfers, call other facilities, and suggest optimal resource allocation based on current demand patterns and predictive analytics. With predictive analytics, the system addresses real-time problems

and forecasts future requirements, replacing crisis management with forward-thinking planning.

Implementation focuses on privacy and security, including the encrypted exchange of information, secure authentication, and adherence to medical privacy laws, such as HIPAA. The system is networked with role-based access controls, allowing only authorized personnel to access sensitive information while providing flexibility for emergency response coordination.

The implementation plan includes change management and education for respiratory therapy personnel, emergency response coordinators, and managers, and encompasses comprehensive training programs. This education includes learning to use the system and integrating it into standard emergency response procedures.

System performance and user acceptability are evaluated through controlled pilot tests before general installation. An integrated pilot exercise would be conducted on-site to validate the system's performance in accurately monitoring available resources, generating appropriate alerts, and coordinating actions during simulated emergencies.

IV. Results and Discussion

A. System Capabilities and Functional Outcomes

The proposed mobile-based coordination system is designed to provide real-time visibility into respiratory therapy resources across healthcare facilities, including ventilator availability, respiratory staffing levels, and emergency respiratory equipment and devices. By integrating predictive analytics with centralized dashboards, the system facilitates early identification of future resource shortages and timely escalations before critical thresholds are reached.

The proposed framework emphasizes automated data aggregation and alert-driven decision support, in contrast to traditional resource management approaches that rely on manual reporting or updates provided after an event has occurred. This capability is critical in high-demand facilities, where rapid fluctuations in patient volume require continuous monitoring, restocking, and a coordinated response.

B. Impact on Respiratory Therapy Operations During Hajj and Umrah

Such mass-gathering events, including Hajj and Umrah, place respiratory therapy services under sudden, geographically distributed surges in demand, influenced by crowd density and exposure to environments associated with a heightened risk of illness. The proposed system is designed to support respiratory therapy leaders and emergency coordinators by providing a unified view of resource availability across facilities serving pilgrims.

The system can reduce response delays, improve workload distribution, and enhance continuity of respiratory care by proactively balancing the allocation of ventilator and respiratory therapy personnel. Predictive alerts support decision-makers by identifying demand trends and resource redistribution patterns before shortages develop, thereby promoting more resilient respiratory therapy operations during mass gatherings.

C. Comparison with Existing Emergency Coordination Approaches

Current emergency preparedness platforms often serve as either a hospital-wide capacity indicator or general clinical decision support, with limited attention to respiratory therapy–specific workflows. By contrast, the proposed framework places the operational realities of respiratory therapy services at its core, integrating role-based dashboards and decision-support features attuned to respiratory care leadership.

Previous mobile health and resource management systems have demonstrated benefits in improving communication and visibility. However, few studies address the combined challenges of respiratory therapy coordination, predictive analytics, and mass-gathering preparedness in an integrated manner. This conceptually advances the existing approaches by aligning respiratory therapy workflows with mobile, forecast-driven coordination mechanisms suited to high-demand surge situations.

D. Lessons Learned

Concept development provided a valuable understanding of emergency planning and deployment of health facility assets. The integration of technologies such as predictive analytics and smartphones would be pursued, requiring careful consideration of user needs, technical solutions, and operational constraints. The key to success lies not in technology alone, but in its ability to streamline existing workflows rather than obscure them. Stakeholder participation in the design and implementation process cannot be overstated. Respiratory therapy specialists, emergency management coordinators, and hospital administrators have distinct perceptions and needs that must be considered when designing systems. The interdisciplinary collaboration involved in this work contributed significantly to the development of workable health informatics solutions.

Technology solutions must also be scalable and adaptable, essential components of emergency preparedness systems. The proposed real-time resource coordination applications should be versatile enough to adapt to various emergencies with minimal changes in functionality and familiarity. This trade-off between comprehensiveness and usability is a key issue in the design of health informatics systems.

V. Conclusion

Mass gatherings pose significant challenges to the healthcare system, given the concentration of large populations within a small geographic area over a short period, thereby imposing extreme strain on supporting infrastructure. This includes respiratory therapy services, which must rapidly surge to provide ventilator support, staffing, and respiratory equipment, without compromising quality.

The work presented here describes a respiratory-therapy–focused real-time resource coordination system to support emergency preparedness in high-demand situations, such as pandemics and large-scale religious gatherings, such as Hajj and Umrah. Predictive analytics are integrated with mobile decision support in the proposed approach to enhance

anticipatory planning and operational coordination of respiratory therapy resources.

This is a conceptual system and involves neither live deployment nor formal performance evaluation. However, it provides an implementation-ready framework for aligning respiratory care workflows with real-time monitoring and forecast-driven decision support.

Although implementation complexity and resource constraints remain, this framework demonstrates the potential of health information technologies to support collaboration, timely responses, and situational awareness during respiratory surges. Future efforts will focus on pilot implementation of the system during mass-gathering events and on evaluating its effectiveness using respiratory-therapy–specific measures, such as ventilator utilization and staffing response time.

Future research should include pilot testing of the proposed system at mass-gathering events to scientifically evaluate its effectiveness and utility. Research should also investigate its interoperability with hospital information systems, scalability, and cost-effectiveness for developing a resource coordination system for respiratory therapy services.

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