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A Blueprint for Better: Improving Crowd Flow and Safety at Al-Rawda Area in Madinah

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Abstract

This research examines crowd management at the Prophet's Mosque in Madinah, with a focus on the Al-Rawda area, where visitors can view the Prophet's tomb. We used a systems management approach with process flows. Additionally, we used available data on pilgrims' arrivals at the Al-Rawda facility to conduct a crowd management analysis. The study found high visitor numbers, especially on Saturdays, and the current entry/exit system creates bottlenecks and overcrowding. We analyzed data and designed a service blueprint to identify these issues and propose improvements for future crowd management strategies. It includes planning for emergencies and potentially utilizing the data for crowd simulation in various scenarios. The Al-Rawdah faces a bottleneck on Saturdays due to the highest average visitor influx (15,249.8). The average visit duration and batch size result in approximately 23.5 batches per day on Saturdays, exceeding the ideal capacity. A multivariate model was developed to address daily visitor flows, considering visiting requirements and data available through the NUSUK application. The model is robust, as indicated by the p-value being less than the significance level.

Keywords
Al-Masjid Al-Nabawi, bottleneck, Control crowd, Rawdah, Prophet tomb, Umrah, Hajj, Process map, Service blueprint

1. Introduction:
Madinah, Saudi Arabia, is revered as the second-holiest city in Islam due to the Prophet Muhammad's Mosque, Masjid al-Nabawi (Akbulut and Ekin, 2020; Al-Ahmadi et al., 2021). This mosque holds immense significance because it was built on the site of the Prophet's burial place and home. According to Islamic tradition, a prayer in this mosque holds much greater weight than a thousand prayers in any other mosque. Consequently, Muslims prioritize performing many of their religious rituals near the mosque. The Prophet (peace and blessings be upon him) emphasized the importance of undertaking spiritual journeys to only three specific mosques: Al-Masjid al-Haram in Makkah, the Prophet's Mosque in Madinah, and the Mosque of Al-Aqsa, also known as the Mosque of Jerusalem (Sahih al-Bukhari 1189).

2. Literature Review
The mosque also features the revered Prophet's Chamber on its southeast side. This was the living space shared by the Prophet and Aisha bint Abi Bakr Al-Siddiq, the Mother of the Believers (Al-Ahmadi et al., 2021). Upon his passing, the Prophet was buried in this chamber, following his tradition of burying prophets at the place of their death. Several rules must be followed before entering the mosque. Visitors enter with serenity through the Salaam Gate at the front (Albattah et al, 2020). Specific steps are involved upon entering the Prophet's Chamber. The first act consists of greeting the Prophet, followed by greetings to Abu Bakr As-Siddiq and Umar Ibn Al-Khattab, two of the Prophet's closest companions. The Al-Rawdah is another significant area within the Prophet's Mosque. It encompasses the space from the front of the mosque, extending from the Prophet's Chamber to the pulpit he used. According to the Prophet, the Garden of Paradise lies between his pulpit and house.

Religious tourism has a significant impact on local communities, as exemplified by pilgrimages to sacred sites (Albattah et al, 2020). Most visitors to these holy sites, such as the House of the Virgin Mary, experience feelings of inspiration, honor, and deep gratitude. These sentiments are commonly shared by those who undertake religious pilgrimages. However, travelers motivated primarily by personal urges may experience conflicting emotions after their journeys (Dias et al., 2022; Ebrahimpour et al., 2019; Feliciani et al., 2022). A growing number of visitors are traveling to these sacred places for religious purposes, a trend that has become increasingly common.

2.1 Challenges of Crowd Management

One of the significant challenges crowd control management faces in the Al-Rawdah corridor, and the Al-Rawdah area of the Prophet's Mosque in Madinah, is the ever-increasing number of visitors participating in Hajj and Umrah pilgrimages. Evidence suggests a steady annual rise in visitor numbers, with millions of Muslims flocking to the site for these religious pilgrimages. For instance, Akbulut and Ekin (2020) and Al-Ahmadi et al. (2021) reported that over 2.5 million pilgrims attended the 2019 annual Hajj, with the Umrah pilgrimage attracting more than 7.5 million participants.

Upon completing Hajj and Umrah rituals, pilgrims traditionally travel from Makkah to Madinah to perform Al-Rawdah (offering greetings) at Prophet Muhammad's tomb in Al-Masjid an-Nabawi and then visit Al-Rawdah (Al-Ahmadi et al., 2021). Some Pilgrims first travel directly to the Prophet's Mosque in Madinah to avoid overcrowding in Makkah. The entrance to this area is on the western side, with the exit facing east. Al-Ahmadi and colleagues note that the visiting passageway has two entry points from the Al-Rawdah. This 8-10 meter wide and 92-meter long passage allows visitors to approach the Prophet's tomb at an average speed. Visitors then walk respectfully towards the tomb, entering a 22-meter-wide collider zone that starts at the Al-Rawdah. Here, people slowly pay their respects to the Prophet before exiting through the easternmost exit, a 2.95-meter-wide door [Rawdah (Al-Ahmadi et al., 2021; Albattah et al., 2020). Public health concerns, crowd density, crowd management, and rapid response protocols established by the Prophet's Mosque administration all contribute to the challenges of managing visits to Al-Rawdah (Johannsen et al., 2022; Mishra et al., 2022; Still et al., 2020; Subramanian et al., 2022; Barros and Aguilera, 2022).

3. Research Methodology

A mixed-methods approach was employed, combining qualitative and quantitative methods to provide a comprehensive understanding of crowd management strategies. Face-to-face interviews were conducted with crowd management professionals at the Prophet's Mosque and the General Presidency of the Grand Mosque. This method allowed an in-depth exploration of visitor experiences and management practices for collecting non-verbal data through observation. Multivariate statistical analysis was employed to examine the relationships between crowd size, available facilities, and the roles of service providers within the mosque's business processes. Techniques such as correlation and covariance analysis were used. Reliability and normality tests were conducted using various statistical tools to ensure data accuracy. Analysis of variance (ANOVA) was employed to measure variations in visitor flow based on timeframes (days, weeks, months, and years) for areas such as the Prophet's grave and the Al Rawdah. Correlation analysis was used to identify associations between visitor numbers across different timeframes. A flowchart was developed to illustrate the pre-, during-, and post-pandemic visitor movement patterns within the Al-Rawdah. Information for the flowchart was obtained through interviews with mosque management officials.

3.1 Sample Data

Determining an appropriate sample size was crucial for ensuring the reliability of the research findings. Target Population: Visitors to the Prophet's Mosque, estimated at 4,709,092 in the first quarter of 2023. We review the modifications implemented by management to manage visitor access to Al-Rawdah and the Prophet's tomb post-pandemic. Observations were conducted at the mosque entrances within the Al-Rawdah zone. These entrances are located between the pulpit and the Prophet's tomb, with an estimated width of 8-10 meters and a length of 92 meters. Average pedestrian walking speeds were recorded within the visiting corridor, pre-pandemic (1 meter per second) and during the pandemic (0.42 meters per second). The capacity for a single batch of visitors to the Al-Rawdah zone is 1,300 people. Vaccination status was a key criterion for entry during the pandemic, with only individuals who received two doses being permitted. The Nusuk mobile application was mandatory for all visitors, including residents and citizens, for registration (Basahel et al., 2021; Akbulut and Ekin, 2020). The data is available electronically in the NUSUK application. There are no direct methods for collecting data using the traditional research methodology. For

security reasons, direct observations at the facility are not possible. We have to depend on the new electronic system to gather data.

Process Mapping: A tabular form of a flowchart, as illustrated in Table 1, displays visitor movement patterns at both macro and micro levels, facilitating the identification of potential areas for improvement. Process mapping focuses on workflow rather than hierarchical structures. Descriptive Statistics: Process mapping information before the pandemic helps us construct the service blueprint (Figure 1), which visually represents the service system and the roles of the various stakeholders involved in service delivery. Service Blueprint: The service blueprint in Figure 1 illustrates the real-time visitor flow and its management, based on observed data, to depict overall crowd movement and management strategies within the Al-Rawdah area.

Statistics indicate a significant and consistent rise in visitor numbers to the Prophet's Mosque. Shambour and Gutub (2023) report that over 4.7 million pilgrims performed Umrah alone in the first quarter of 2023. To effectively manage these crowds, real-time data collection and analysis are crucial. Implementing wireless sensor networks (WSNs) within the mosque premises can provide valuable insights into visitor movement patterns. These sensor networks, consisting of strategically placed sensors that communicate with a central hub, can track visitor density in various sections of the mosque, including the Al-Rawdah.

3.2 Method of obtaining visitor information

The COVID-19 pandemic necessitated strict limitations on visitor capacity within the mosque, implemented through physical distancing measures and digital registration. Post-pandemic regulations require registration through the Nusuk app to access the Al-Rawdah. However, further advancements can be achieved by integrating the Nusuk app with other technologies to achieve a more holistic approach. Here, we explore specific techniques that utilize technology to enhance crowd management at the Prophet's Mosque. Further, the Twakkalna App was introduced during the COVID-19 outbreak. All residents, including visitors, must register through the application to monitor the crowd at crowded facilities.

Through flowcharts, we can identify bottlenecks and optimize visitor flow by analyzing visitor movement patterns before, during, and after the pandemic. This approach, developed in collaboration with mosque management professionals, can be significantly enhanced by incorporating real-time data. By overlaying real-time visitor density information onto the flowcharts, we can dynamically identify congestion points and adjust crowd management strategies accordingly (Coenegrachts et al., 2021; Feliciani et al, 2022); Galli and Wood, 2021). The Service Blueprint methodology, a core component of service engineering, provides a framework for evaluating and enhancing service delivery. Applying this method to analyze the Al-Rawdah visit process allows for pinpointing areas for improvement and addressing visitor concerns. Based on the initial visitor flow analysis, the optimized service blueprint reduces congestion in the following areas of the Prophet's Mosque in Madinah. Visiting Al-Rawdah after the pandemic: men were also required to register in the Nusuk app before entering the Holy Rawdah. The entrance of the place faced the southern courtyard of the Prophet Mosque. Also, during the inspection, visitors were required to have a reservation. The total time men spent on the visit was approximately 86 minutes. The situation was just after the pandemic when the facility was opened to the public for the first time.

The service blueprint approach helps identify bottlenecks within the Al-Rawdah visit process. These bottlenecks can be further pinpointed by integrating capacity analysis at locations within the mosque. For example, sensors can be placed at registration points, waiting areas, and entry/exit gates to track visitor dwell times and identify regions with slow throughput. This data can then be used to identify bottlenecks and implement targeted solutions. Dynamic Capacity Management: Utilizing real-time data and direct observations to adjust visitor capacity limitations for specific areas, including the Al-Rawdah. This can be achieved through automated signage systems that display updated capacity information and redirect visitors to less congested areas when necessary. Smart Queue Management Systems: Implementing intelligent queue management systems at registration points and waiting areas can significantly improve visitor flow. These systems can utilize technologies such as Radio Frequency Identification (RFID) tags or QR codes to track visitor locations and provide estimated wait times. Additionally, integrating these systems with the Nusuk app can allow visitors to virtually join queues and receive real-time updates on their wait time.

AI-powered Crowd Control: Utilizing artificial intelligence (AI) algorithms to analyze real-time data can enable predictive crowd control measures. AI can predict areas prone to congestion and proactively deploy crowd management personnel or install directional signage to prevent bottlenecks.

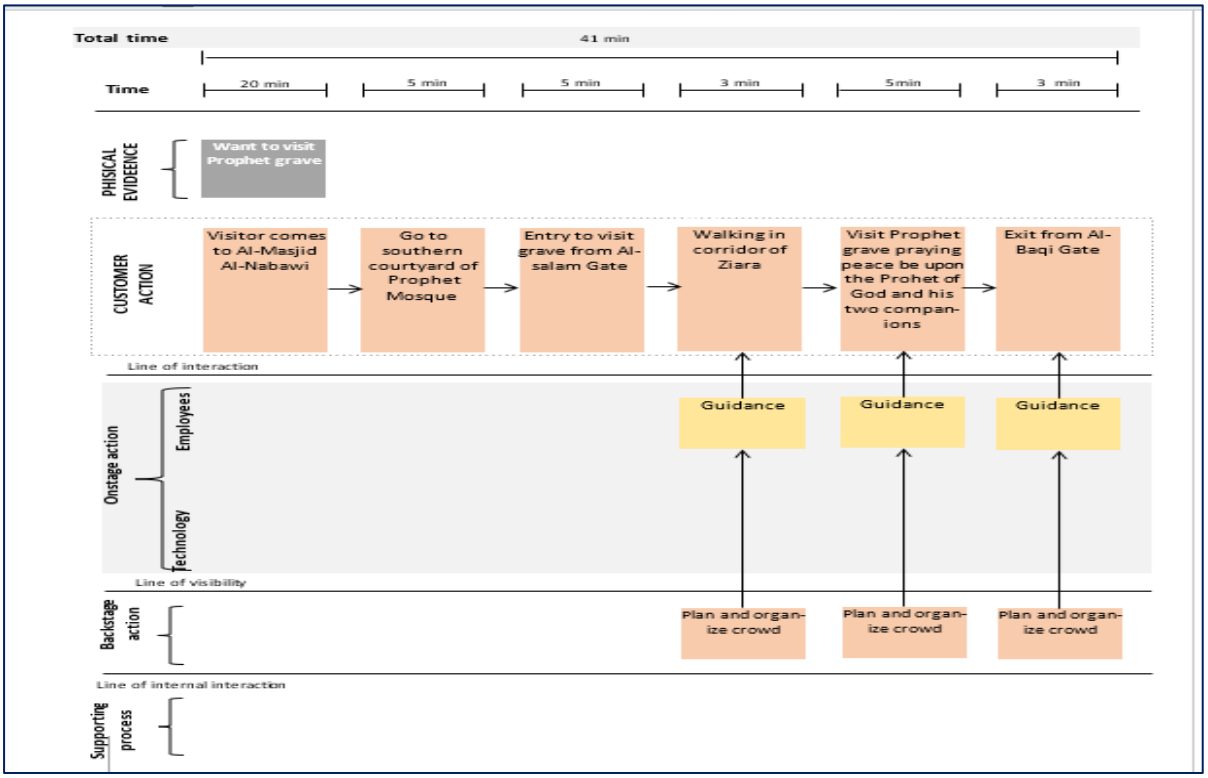

Figure 1. Service Blueprint Before the Pandamci

Table 1. The tabular form of the Flow Process Chart for the Al-Rawda after the pandemic

Stage 1: Visitor in Action	Maintain protocol (Prerequisites) • All visitors must register their request to visit Al-Rawda through the Nususk application. • Appropriate hygiene and cleanliness • Use Zamzam water for purification Preparation (5 minutes) • Maintain appropriate, clean attire as necessary. • Perform Wudu (ablution) outside the Al-Rawda area. • Obtain guidance and instructions from authorized personnel. Entry and Positioning (20 minutes) • Queue patiently and respectfully for entry. • Maintain silence and avoid disturbing others. • Follow designated entry and exit points. Greeting and Dua (20 minutes) • Stand facing the Qiblah within the designated Al-Rawda area. • Recite greetings and salutations upon the Prophet. • Offer supplications and duas in a hushed tone. Prayer (30 minutes) • Perform two units of prayer with devotion and focus. • Maintain proper prayer etiquette and avoid distractions. Exit (3 minutes) • Exit promptly and gracefully to allow others access. • Maintain silence and avoid causing congestion.
Stage 2 in Action	Monitor • Crowd management by trained security personnel, ensuring safety and order. • Guidance and assistance provided by authorized personnel • Availability of Zamzam water and other necessities.
Stage 3: Backstage Operation	Perform • Regular cleaning and maintenance of the Al-Rawda area • Continuous monitoring of crowd flow and security for safety • Coordination between different departments to ensure smooth operation • Training and development of staff on proper procedures
Stage 4 - Supporting Processes	Provide: • Logistics and transportation for pilgrims • Accommodation and lodging facilities • Information and communication channels • Healthcare services and emergency response

3.3. Visit Process with Technical Considerations

Pre-registration procedures: Exploring the integration of Tawakkalna and Nusuk apps with a centralized registration system for a seamless user experience. Tawakkalna is an app introduced during the COVID-19 outbreak. All residents and visitors, including pilgrims, are required to register their data for COVID-19 infection control and crowd management purposes. Inspection points and permit verification: These apps are necessary for visitors to obtain permission to access the facility. The feasibility of implementing automated permit verification systems using RFID or QR code technology to expedite visitor processing is worth considering. Waiting areas for men: Analyzing visitor flow within waiting areas and proposing optimizations like designated queuing areas or virtual queuing systems. Entry and exit procedures for the Al-Rawdah: Evaluating the effectiveness of current entry/exit procedures and exploring potential improvements, like designated entry and exit points or automated access

Table 2:.Reliability of Data: ANOVA test

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	53818459587	8	6727307448	793.331927	0	1.941027
Within Groups	29916784997	3528	8479814.342			
Total	83735244583	3536				

Table 3. Regression Coefficient Confidence Interval [Assumption – No intercept]

Independent Variable	Regression Coefficient b(i)	Standard Error Sb(i)	95% Confidence Limits of β(i) Lower	Upper
(C2=Friday)	**10929.03**	**1063.318**	**8838.394**	**13019.67**
(C3=Saturday)	**15249.8**	**1063.318**	**13159.16**	**17340.44**
(C4=Sunday)	**14254.84**	**1056.731**	**12177.15**	**16332.52**
(C5=Monday)	**13877.44**	**1066.38**	**11780.78**	**15974.1**
(C6=Tuesday)	**14032.78**	**1066.38**	**11936.12**	**16129.44**
(C7=Wednesday)	**14559.89**	**1066.38**	**12463.23**	**16656.54**
(C8=Thursday)	**15099.96**	**1066.38**	**13003.3**	**17196.62**
(C9=Covid[Y/N])	**-10236.85**	**1096.621**	**-12392.96**	**-8080.732**

Table 4. Daily visitors to Al-Rawdah Percentage of visitors per day

Day	Average visitor arrival	Percentage	No of Batch	Bottleneck
Friday	10,929.00	11.15%	16.8	No bottleneck
Saturday	15,249.80	15.56%	23.5	High
Sunday	14,254.80	14.55%	21.9	Medium
Monday	13,877.40	14.16%	21.3	Low
Tuesday	14,032.80	14.32%	21.6	Medium
Wednesday	14,559.90	14.86%	22.4	High
Thursday	15,100.00	15.41%	23.2	High
Total	**98,003.70**	**100.00%**		

Visitor Arrivals at the Al-Rawdah: Addressing Bottlenecks

This research analyzes visitor arrival data at the Al-Rawdah in the Prophet's Mosque, aiming to identify and address potential bottlenecks. The analysis employs statistical tests and modeling techniques to ensure the validity of the data and the reliability of the results. The Shapiro-Wilk test indicates a normal distribution for the model's error terms (except for the D'Agostino-Kurtosis test). This exception is due to occasional data control measures implemented by the mosque authorities. However, the ANOVA test in Table 2, with a p-value exceeding 0.05, indicates that the data are reliable within a 95% confidence interval.

Weekday Visitor Arrival Model

A regression model (Table 3) estimates weekday visitor arrivals using coefficients for specific days (e.g., C2 = Friday and C8 = Thursday), while C9 represents the COVID-19 epidemic period. The 95% confidence interval

confirms the validity of these coefficients. Notably, the negative coefficient for C9 indicates a significant decrease in visitor arrivals during the pandemic, driven by border closures. The analysis of variance in Table 4 demonstrates the model's validity at a 0.05 significance level. All factors (C2-C9) contribute significantly to the model, as evidenced by F-statistics and p-values. Similarly, Table 5 includes all model parameters based on p-values and t-statistics, further validating the model. Additionally, the confidence interval test on the regression coefficients confirms the model's robustness.

Bottleneck Identification

Table 4 details the daily expected visitor arrivals at the Al-Rawdah. Saturdays, coinciding with the weekend in Saudi Arabia, witness the highest visitor influx (15,249.8 on average). Considering the average visit duration of 68 minutes per batch per 650 visitors and 21 batches per day (24 hours), this translates to approximately 23.5 batches on Saturdays. It exceeds the ideal capacity, potentially creating a bottleneck on these days. The model construction assumes an intercept of zero, reflecting the focus on weekday arrivals. A multivariate model was developed to address the daily visitor flows. The data is available from the authority through the NUSUK real-time application. According to the visiting requirements at Al-Rawda, all visitors must register their request through the application. Table 2 indicates that the model's p-value is less than the significance level. Thus, the model is robust. The batch size determines overcapacity and undercapacity, thereby setting the maximum number of visitors per batch. The daily arrival from the multivariate model estimates the percentage of visitors who arrive.

4. Conclusion

This analysis successfully identifies a potential bottleneck on Saturdays at Al-Rawdah, attributed to high visitor volumes. The validated model provides valuable insights into visitor arrival patterns. The investigation into broader issues is still ongoing, as the recent expansion of the Prophet's Mosque continues. With this information, mosque authorities can implement targeted strategies to address the bottleneck, such as:

- Spreading Visitor Arrivals: Encouraging visitors to schedule visits on weekdays whenever possible.
- Batch Size Optimization: Adjust batch sizes to match available capacity, particularly on Saturdays.
- Improved Queue Management: Implementing efficient queuing systems to manage visitor flow during peak periods.

Key Findings and Their Significance:

- Service Blueprint for Effective Crowd Control: This research introduces a novel application of the service blueprint process. Evaluating the Al-Rawdah visit process helps identify bottlenecks and develop targeted solutions to improve visitor flow.
- Multivariate Statistical Model for Bottleneck Management: This study demonstrates the effectiveness of a multivariate statistical model in pinpointing bottleneck areas within the mosque. This knowledge empowers decision-makers to implement targeted strategies to manage congestion and optimize the visitor experience.
- Capacity Analysis and Visitor Flow Optimization: The research establishes a crucial link between Al-Rawdah's capacity and visitor flow within the entire Prophet's Mosque. This understanding enables informed adjustments to visitor scheduling, batch sizes, and queue management systems, ensuring efficient visitor movement. The management of the Prophet's Mosque defines the batch size based on Al-Rawda's capacity to accommodate visitors.

This research opens doors for further exploration and improvement:

- Simulation and Decision Support: Integrating findings with crowd simulation applications can empower authorities to test various management strategies and make data-driven decisions to optimize crowd control, particularly during peak periods (Ebrahimpour et al., 2019; Still et al., 2020; Subramanian et al., 2022).
- Visitor Education and Etiquette: Educating visitors about proper mosque etiquette before entry can contribute to a smoother overall experience. Additionally, exploring methods to reduce wait times can enhance visitor satisfaction and potentially increase visitor capacity.

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Biography

Professor Shamsuddin Ahmed is an accomplished industrial engineer with over 25 years of global experience spanning academia, research, consulting, and entrepreneurship. He holds a Ph.D. in Operations Research from Edith Cowan University, Australia, and an MASc in Industrial Engineering from Dalhousie University, Canada. He has held professorial and leadership roles at institutions including the Islamic University of Madinah (Current), NMIMS Mumbai, and KIMEP Kazakhstan. His research expertise covers supply chain management, operations research, financial engineering, risk management, and AI applications, with over 50 publications in ISI/Scopus-ranked journals. He has secured more than USD $200,000 in research funding and led high-impact consulting projects, including a SAR 41 million cost-saving initiative for IUM's university canteen. A recipient of multiple "Best Research" awards and the 2024 "Incredible Researcher of the World" honor, he has also founded successful startups and developed industry-standard software tools in simulation, Six Sigma, and enterprise risk management.