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ANALYSIS OF THE CROWD MANAGEMENT AND PEDESTRIAN MOVEMENT DURING HAJJ PILGRIMAGE ON MAKKAH

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Abstract

The Hajj pilgrimage, the world's largest annual mass gathering, poses significant challenges in crowd management and pedestrian movement due to the sheer number of participants and logistical complexities. This study emphasizes the need for effective strategies to ensure the safety of millions of pilgrims in Mecca, Saudi Arabia. By reviewing literature and analysing pedestrian movement systems, it identifies key bottlenecks and safety risks, especially during high-density periods like Nafra day. Field observations from 2019 to 2024, including the post-COVID-19 era, offer insights into crowd behaviour and the effectiveness of management strategies. The study highlights the importance of integrating advanced simulation tools with urban design to optimize pedestrian pathways and prevent overcrowding, contributing to Saudi Vision 2030's goals of enhancing the pilgrimage experience and ensuring participant safety.

Keywords: crowd management, Hajj pilgrimage, Saudi Arabia

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INTRODUCTION

Major global events like the Olympic Games, FIFA World Cups, and the Hajj pilgrimage draw large crowds, placing heavy demands on host locations. The Hajj pilgrimage, with millions of participants, exemplifies these challenges, requiring extensive planning and resource allocation to ensure safety. The 2015 Mina stampede, which resulted in over 2,000 deaths, highlights the critical need for effective crowd management (Yue et al., n.d.). Saudi Arabia's Ministry of Municipal and Rural Affairs has implemented decision support systems (Baydoun et al., 2024). However, further research is essential to refine strategies and improve public space planning, particularly in the context of Islamic architecture and its principles of community and spirituality (Baydoun et al., 2023). This study explores crowd management parameters and evaluates pedestrian movement during the Hajj, aiming to enhance safety, efficiency, and the overall pilgrim experience, and prevent future disasters. It further evaluates the effectiveness of facility and identified potential improvements by simulating the behaviour of the pilgrims and analysed the crowd distribution.

LITERATURE REVIEW

Crowd movement and management during the Hajj pilgrimage

Pedestrian crowds are dynamic, shaped by various factors. Effective crowd management ensures safety and efficiency through careful planning and resource allocation (Al-Shaery et al., 2020). According to literature, density (physical space) and crowding (perceived space) influences pedestrian behaviour and the crowd dynamics. Furthermore, crowd well-being is also shaped by emotional and psychological states within crowded environments and influenced by social interactions and individual needs. While safety becomes critical in uncontrollable crowds, understanding factors like relatedness and autonomy is also the key to enhancing well-being (Beermann, n.d.). other factors influencing crowd movement are aged and gender. Elderly pedestrians have distinct movement patterns due to aging-related physical changes like reduced eyesight and balance, affecting their walking speed and reaction times. Current design standards often neglect their needs (Xuan et al., 2023). Elderly mobility and its movement is important factor in creating more inclusive pedestrian environments.

Crowd monitoring and measures

Effective crowd management relies on robust monitoring and traditional methods like CCTV are limited. But with advances in smartphone-based sensing and data analytics these technologies can offer better insights into crowd density and movement (Darsena et al., 2023). These tools help to monitor movement and later needed to be included in the development of strategies in order to reduce risks and improve public safety. Crowd management requires understanding and controlling behaviour as traditional methods like CCTV have some limitations, pedestrian simulation models are able to predict dynamics and guide design for the movement of pilgrims. Metrics like density and flow rate are vital, but distinguishing between physical density and perceived crowding is key to addressing discomfort and safety risks. Large-scale events like the Hajj pilgrimage risk crowd-related disasters. Effective management demands careful planning, coordination, and resource allocation. Checkpoint design and operation are crucial for controlling crowd flow and ensuring safety.

Crowd management principles and strategies

Crowd management ensures safety and comfort in large gatherings by proactively planning and designing spaces, unlike crowd control, which reacts to issues. For religious events, it involves respecting cultural practices and collaborating with religious authorities. Effective strategies include "Before Event" planning, "During Event" measures for unforeseen issues, and "After Event" policies to alleviate post-event crowding, creating safe and enjoyable experiences for participants (Haghani et al., 2023). Figure 2 shows the crowd event timeline.

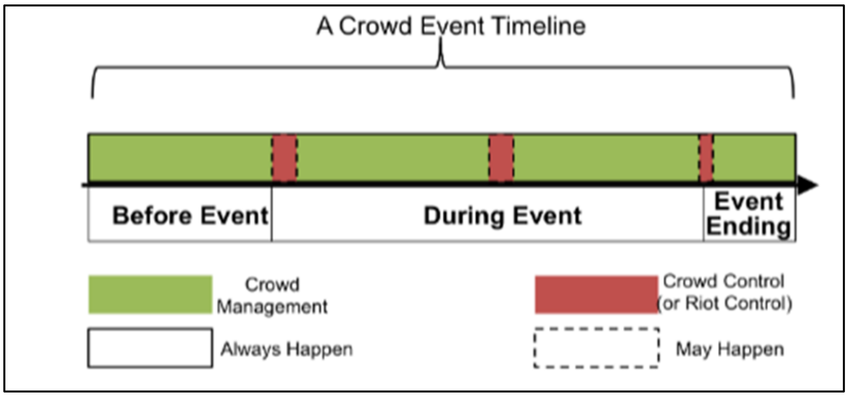


Figure 1: The crowd event timeline

Existing frameworks like the Pedestrian Fundamental Diagram (PFD) and Social Force Model (SFM) analyse pedestrian flow and simulate behaviour. While useful, they have limitations, and further research is needed for large-scale urban environments (Yuan et al., n.d.). Design principles for the Hajj pilgrimage include spatial organization, human scale, crowd dynamics, sacred geometry, safety, and sustainability. These principles ensure effective pedestrian flow, safety, and a meaningful experience for pilgrims (Felemban et al., 2020). By understanding crowd behaviour and integrating sacred symbolism while prioritizing safety and sustainability, the Hajj can offer a safe and efficient experience for millions. The research combines urban design and crowd management frameworks to optimize pedestrian movement and the key elements include clear pathways, sidewalks, amenities, lighting, and wayfinding. It also involves planning, monitoring, communication, and safety factors in providing effective solutions for pedestrian movement during the Hajj pilgrimage.

RESEARCH METHODOLOGY

This study uses a mixed-methods approach to optimize pedestrian movement along the Arafah-Muzdalifah pathway during Hajj 2019 and Hajj 2023. By combining quantitative data (counts, simulations) and qualitative data (observations, video analysis, interviews), it analyses flow dynamics, identifies bottlenecks, and proposes design improvements to enhance pilgrim safety and experience. Field observations with SimWalk simulation are adopted to identify pedestrian behaviour during Hajj and the field work observations are able to capture real-time dynamics, while SimWalk programme will models the movement virtually. This integration helps identify bottlenecks, assess design interventions, and develop strategies to optimize flow and safety.

SimWalk Simulation

Simulating pedestrian behaviour is crucial for managing crowd dynamics. While macroscopic models look at overall flow, microscopic models analyse individual behaviour for more accurate predictions. This study highlights the value of microscopic simulations in understanding interactions, evaluating designs, and informing crowd management strategies. In term of parameters, the simulation parameters include pedestrian attributes (speed, size, behaviour), environmental factors (facilities, obstacles), modelling worst-case peak densities and Origin-Destination data that represented flow patterns. Pedestrian movement at large-scale events present challenges due to high density and hazards. Simulation tools help plan and manage crowd flow by modelling behaviour, environments, and emergencies. This study proposes a checklist to evaluate simulation software based on environmental representation, pedestrian modelling, output analysis, and robustness.

Data collection procedure

Pedestrian behaviour data was collected via on-site observations, video recordings, and manual counts, with cameras discreetly placed to avoid disturbance (see Figure 2). This data was analysed using Excel and Silicon Coach software to inform a SimWalk simulation of the Arafah-Muzdalifah pathway. Comparing simulation results with real-world observations helped identify strategies for improving crowd management and urban design.

Figure 2: Camera locations along the pathway between Arafat and Muzdalifah

SimWalk process

SimWalk is useful for crowd management and evacuation simulations but has limitations in modelling complex pedestrian behaviours. While it provides basic crowd modelling and outputs like movement patterns, density, and speed, its suitability for detailed behaviour analysis is limited.

Overview to the routes of Arafah and Muzdalifah

Pedestrian paths in Mecca's holy sites, from Muzdalifah through Arafat to Mina, are designed for pilgrim comfort and safety. Features include paved surfaces, benches, shade, misting systems, concrete barriers, LED lighting, and accessibility for people with disabilities (see Figure 3). These paths are essential infrastructure for the Hajj pilgrimage. Pedestrian walking speed varies by gender and age. Males typically walk faster than females (1.5 m/s vs. 1.2 m/s). Older pedestrians, especially those over 55, walk slower due to decreased physical capabilities, though age-related variations are less pronounced than gender differences. Pedestrian simulation models predict crowd behaviour by simulating individual movements and interactions. They help improve transportation systems and understand dynamics by considering factors like density, design, and attributes. Analysing outputs identifies bottlenecks, optimizes space, and enhances safety and comfort.

Figure 3: The Beginning of the Pedestrian Path from Arafat to Muzdalifah

Justification of choosing the pathway strip

Pedestrian pathways connect Mount Arafat and Muzdalifah were separate from vehicle roads. Six routes link Namira Mosque and Jabal al-Rahmah, with Route 1 being the most congested due to its proximity to services and Jabal al-Rahmah. Mobile medical services are provided on Route 1 to support pilgrims. High pedestrian density is noted near charitable distribution vehicles on Route 1, where video recording was conducted to analyse flow. Scaffolding was installed at key points for camera placement to capture movement data. Video cameras on Route 1 captured pedestrian flow in both directions during peak times. The selected area, with the highest density (2.32 people/m²) and various features (toilets, water fountains, charity trucks), provided diverse data for analysis.

RESULTS AND ANALYSIS

Observation of Hajj 2019 and Hajj 2023/1444 AH

This research, in collaboration with the Custodian of the Two Holy Mosques Institute for Hajj and Umrah Research, involved fieldwork during Hajj, including observations and data collection. The Institute provided support, equipment, and personnel, enabling comprehensive data and insights for the study. Field observation during Hajj 1444 AH revealed significant changes in charity car distribution. The mobile service model replaced the fixed distribution points used in previous years. However, the observed queuing patterns, influenced by visibility and road direction, disrupted pedestrian paths.

Figure 4: The queue heading to the charity distribution truck

Observation of Hajj 2023/1444 AH
SILICONCOACH analysis

Video analysis revealed average usage times during Hajj: charity distribution (2 minutes), bathrooms (10 minutes), waiting areas (5 minutes), water fountains (10 minutes), and seats (10 minutes). These insights aid in improving facility design and resource allocation for future pilgrimages. Figure 5 shows camera locations and directions.

Figure 5: The location and direction of cameras

Summary of the Extracted Information from The Selected Area for Analysis

Table 1 provides a comprehensive overview of the distribution of activities within the studied area, along with insights into the density of individuals per square meter.

Table 1: The distribution of activities

Activity	Number of individuals	Percentage
Walking	232	75%
Waiting area	19	7%
Queue	55	18%
Total	**309**	**100**

Additional Information:

- Total Area Studied: 25 meters * 5 meters = 125 square meters.
- Total Number of People in the Area: 309 people.
- Excluding Those Sitting (19 people): 309 - 19 = 290 people.
- Density Calculation: Approximately 2.32 people per square meter (290 people / 125 square meters).

Video analysis showed average service usage times: 2 minutes for charity distribution, 10 minutes for bathrooms, 5 minutes for non-designated waiting areas, and 10 minutes for water fountains and chairs. These findings offer insights for improving facility design and resource allocation during future Hajj pilgrimages.

SIMWALK simulation

Initialization and Model Setup

SimWalk PRO was used to create a simulation model of the pedestrian pathway, incorporating a detailed map, pedestrian parameters (average speed, age distribution, gender ratio), and facilities (charity vendors, toilets, waiting areas, water fountains). The simulation included 6,000 pedestrians, with service usage and scheduling adjusted to reflect observed behaviour. These inputs facilitated a realistic simulation of pedestrian flow and service utilization during Hajj, as shown in Figure 7.

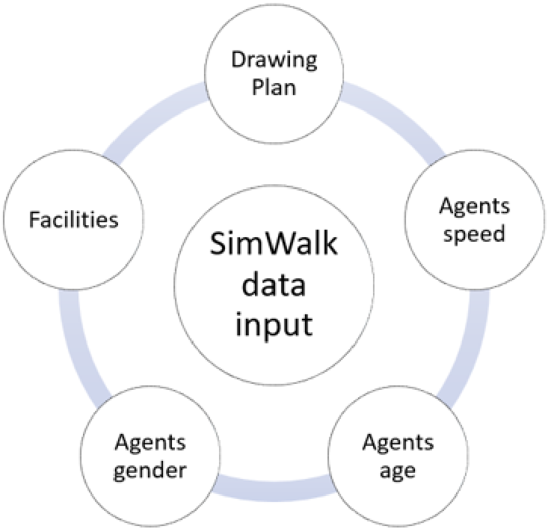


Figure 6: Data input for SIMWALK

Simulation scenarios

Current state Scenario

This research offers a detailed analysis of urban planning strategies for the unidirectional pathway during Nafrah day, with actionable insights based on simulation results. The model accurately reflects real-world data and conditions. Figure 7 shows the AutoCAD drawing of the current pathway scenario, including five parameters used to test speed and congestion.

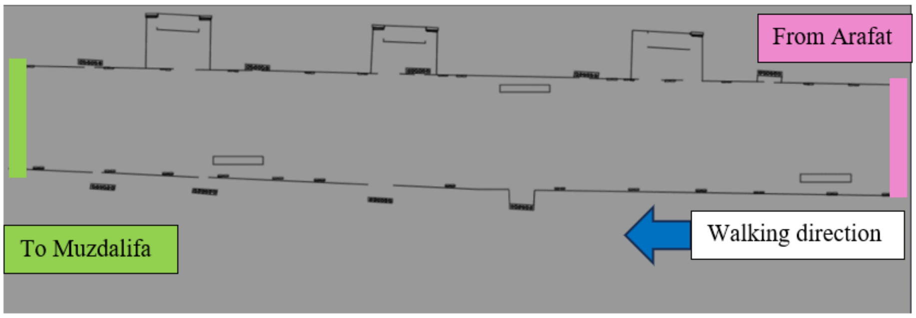


Figure 7: The plan of the first proposal for the road. All charitable distribution trucks have been removed, while the rest of the services have been kept as they are

a. Density - level of Service

Analysis of the Density-Level of Service (LOS) diagram reveals severe congestion along the Arafah-Muzdalifah pathway during Nafrah day, with over 91% experiencing moderate to severe issues. To improve pedestrian movement and safety, it's recommended to redistribute services, implement real-time monitoring, and redesign the pathway to address bottlenecks.

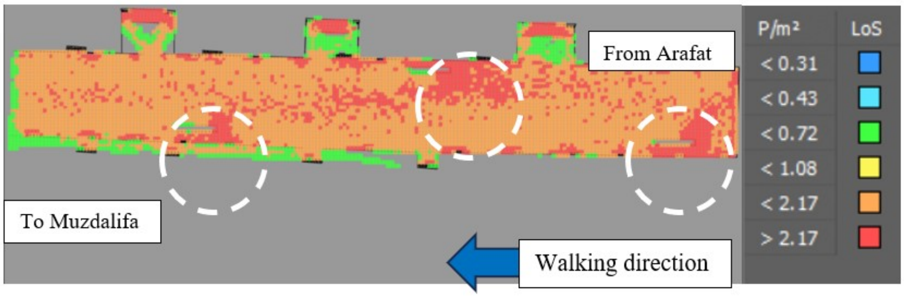


Figure 8: The current state Density - level of Service diagram

b. Spatial utilization

Spatial analysis shows that 76.05% of the pathway is highly utilized, 11.37% is moderately utilized, and 12.58% has low to moderate use. These findings identify congestion areas and suggest strategies to improve pedestrian flow and reduce bottlenecks.

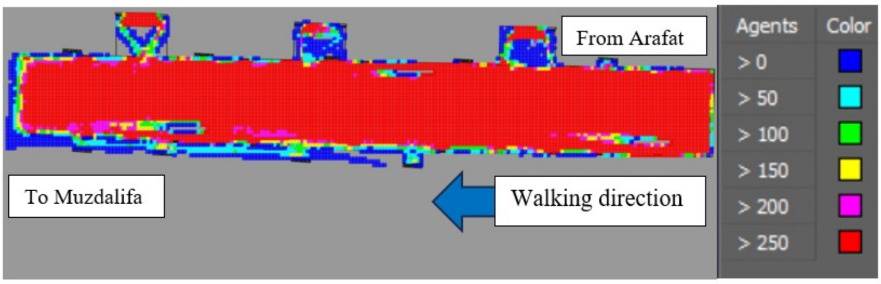


Figure 9: The Spatial utilization diagram

c. Speed loss diagram

Speed loss analysis shows that 89.52% of the pathway experiences significant speed reduction, 4.28% has moderate speed loss, and 5.19% has low speed loss. This highlights areas where congestion hampers pedestrian movement.

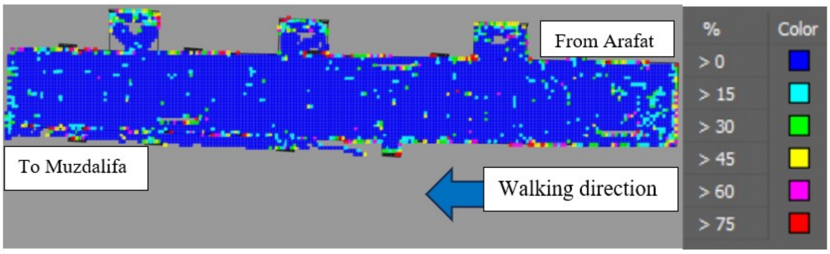


Figure 10: The speed loss diagram

The proposed scenarios

Scenario 1 Analysis: Implementation of Squares with Service Areas

A design proposal added three squares along the Arafah-Muzdalifah pathway, featuring charitable distribution points, seating, and waiting areas. Curved connections enhance movement flexibility, with distribution areas on the left, followed by plazas, seating, and waiting areas.

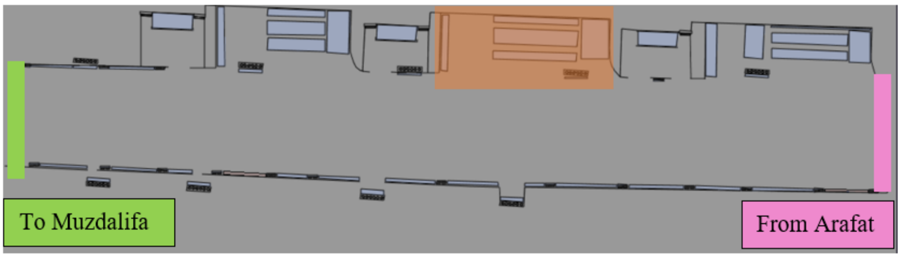


Figure 11: The scenario 5

a. Density - level of Service

Introducing squares with service areas reduced congestion. The orange zone (58.33%) remains dominant, indicating moderate to high density. The red zone (28.96%) is reduced compared to previous scenarios. The blue zone is absent, indicating minimal congestion in specific areas.

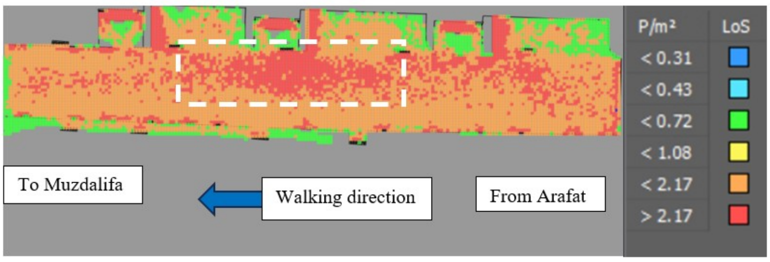


Figure 12: The scenario 5 - level of Service diagram

b. Spatial utilization
Introducing squares with service areas improved spatial utilization. The red zone (63.07%) indicates high usage, while the blue zone increased to 20.07%, showing moderate usage. The decrease in lighter zones suggests improved pedestrian flow and reduced congestion.

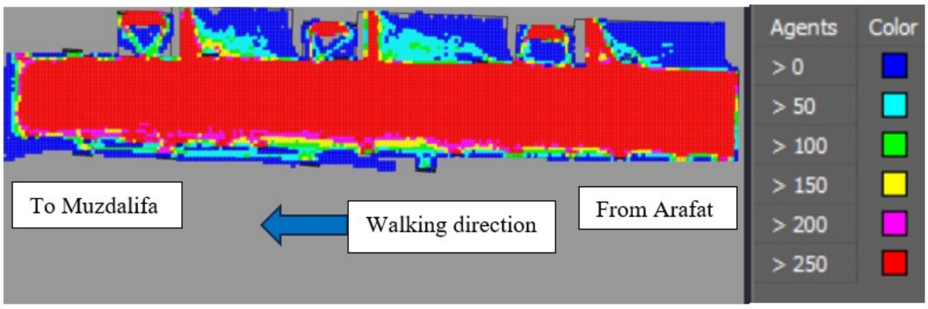


Figure 13: The scenario 5- spatial utilisation diagram

c. Speed loss diagram
Introducing squares with service areas did not significantly improve speed loss. The blue zone remains dominant (89.33%), indicating significant speed reduction due to high pedestrian density.

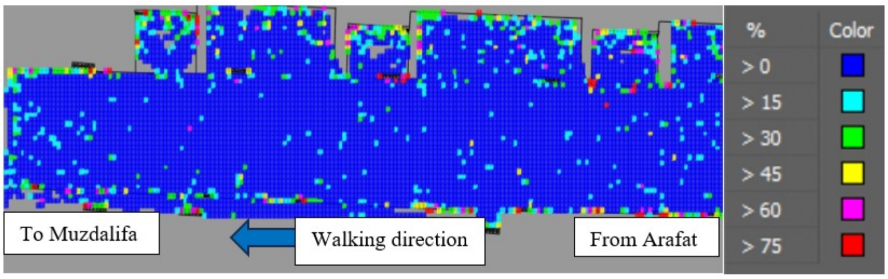


Figure 14: The scenario 5- The speed loss diagram

Scenario 2 Analysis: Services Moved Outside with Enhanced Square Utilization
Services were relocated outside the right of way with curved connections between the road and redesigned squares. The first and third squares featured water bars, seating, and waiting areas, while the second was for charitable distribution. Water fountains were added to and relocated within the squares, bathrooms were enlarged, and their entrances were cleared.

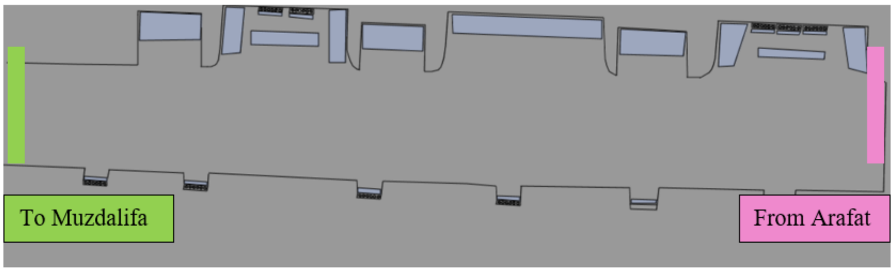


Figure 15: The scenario 6 plan

a. Density - level of Service

Relocating all services outside the pathway reduced congestion. The orange zone (62.14%) remains dominant, indicating moderate to high density. The red zone (37.14%) is reduced compared to previous scenarios. The green zone (0.72%) is small, indicating minimal congestion.

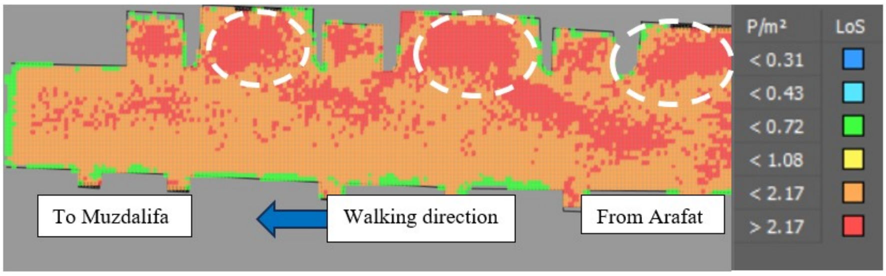


Figure 16: The scenario 6 - level of Service diagram

b. Spatial utilization

Relocating services and redesigning squares enhanced spatial utilization. The red zone (66.92%) remains dominant, while the blue zone increased to 10.84%. The reduction in lighter zones indicates improved pedestrian flow and reduced congestion.

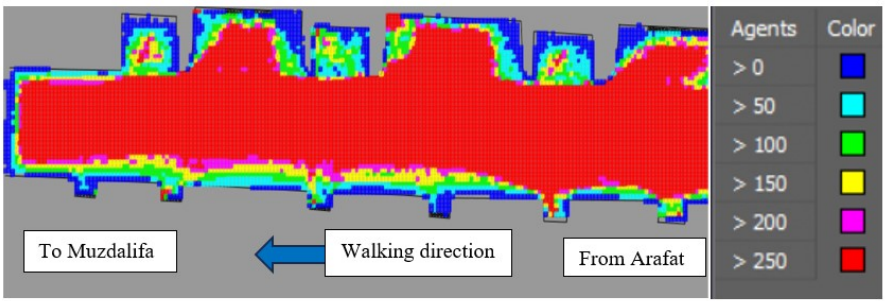


Figure 17: The scenario 6- spatial utilisation diagram

c. Speed loss diagram
Relocating services and redesigning squares did not significantly reduce speed loss. The blue zone remains dominant (94.02%), indicating ongoing congestion and significant speed reduction.

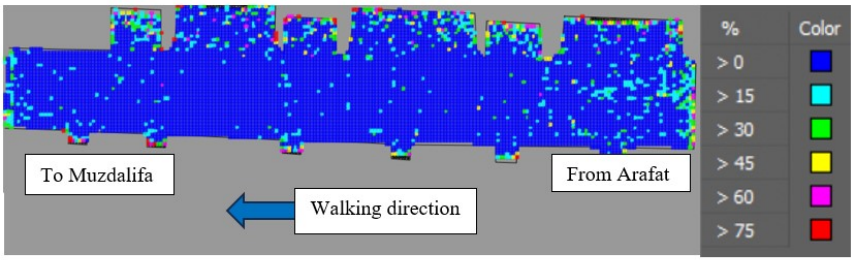


Figure 18: The scenario 6- The speed loss diagram

RESULTS AND DISCUSSION

A comparative analysis of various scenarios evaluated urban design strategies for improving pedestrian movement during Hajj, focusing on pedestrian speeds, crowd densities, waiting times, and flow efficiency. The current scenario showed moderate pedestrian speeds, high crowd densities, extended waiting times, and moderate flow efficiency. Scenario 1 and 2 demonstrated significant improvements in these metrics, with Scenario 2, which included relocated services and redesigned squares, proving to be the most effective strategy. This approach provides valuable insights for enhancing urban design and managing crowds during the pilgrimage.

Table 2: Comparison of Pedestrian Flow Scenarios: Evaluating Speeds, Densities, Waiting Times, and Efficiency

Scenario	Pedestrian Speeds	Crowd Densities	Waiting Times at Amenities	Overall Flow Efficiency
Current	Moderate	High in Orange/Red zones	Long at critical points	Moderate
Scenario 1	Higher speeds in some areas	Moderate to high in squares	Moderate to high	Moderate to high
Scenario 2	Highest speeds	Lowest in redesigned squares	Lowest in redesigned squares	Highest

A comparative analysis of six pedestrian flow scenarios was conducted, evaluating pedestrian speeds, crowd densities, waiting times, and flow efficiency and can be seen in Table 3. The current scenario showed moderate speeds, high densities, long waiting times, and moderate efficiency. Scenario 1 improved speeds and densities with redesigned squares, achieving a density range of 50-70 P/m². Scenario 2, with optimized flow and strategic amenity placement, achieved the highest speeds and lowest densities, with a range of 30-50 P/m². This highlights the effectiveness of strategic planning in enhancing pedestrian flow and reducing congestion.

Table 3: Summary of Pedestrian Flow Scenarios: LOS Density and Level of Service Analysis

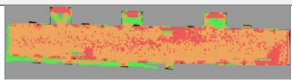
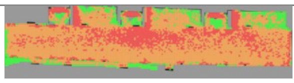
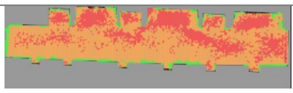
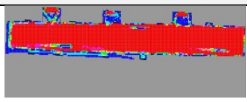
Scenario	Simulation capture	Explanation	LOS Density/level of service P/m^2
Current state		Represents existing conditions with moderate to high density levels and varied LOS	60 – 80 Based on observed data and simulation results
1.		Illustrates increased activity in redesigned squares, affecting LOS moderately	50 – 70 Higher speeds in some areas due to square redesign
2.		Shows lowest congestion and improved flow efficiency in redesigned areas	30 – 50 Highest speeds due to optimized layout and service placement

Table 4 compares six pedestrian flow scenarios, focusing on spatial utilization and agent-based simulation results. The current scenario serves as a baseline, while Scenario 1 shows improved utilization in redesigned squares. Scenario 2, with an optimized layout and redesigned service areas, achieves the most efficient spatial use. This highlights the importance of strategic spatial planning in managing pedestrian flow and reducing congestion during large-scale events like Hajj, with Scenario 2 demonstrating the most effective approach.

Table 4: Analysis of Spatial Utilization and Agent-Based Simulation for Pedestrian Flow Scenarios

Scenario	**Simulation capture**	**Explanation**	**Spatial utilization agent**
Current state		Represents current spatial utilization patterns observed in the pathway between Arafah and Muzdalifah during the Hajj pilgrimage season	Various existing locations

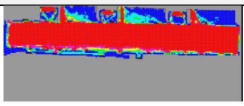
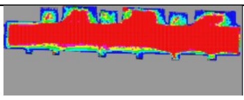
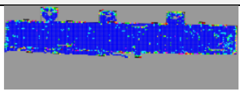
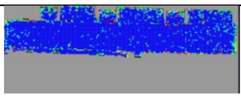
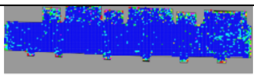
Scenario	Simulation capture	Explanation	Spatial utilization agent
1.		Illustrates enhanced spatial utilization in newly redesigned squares to improve flow dynamics	Redesigned squares
2.		Shows the most efficient spatial utilization with an optimized layout and service placement strategy	Curved road connections and redesigned service areas

Table 5 analyses six pedestrian flow scenarios, focusing on speed loss percentages. The current scenario shows varied speed loss based on existing conditions. Scenario 1, with redesigned squares and pathways, achieves enhanced speed and efficiency with an 88.35% speed loss. Scenario 2, featuring optimized layout and service placement, demonstrates the lowest speed loss at 94.02%. This underscores the importance of strategic spatial planning and service placement for improving pedestrian speed and efficiency during large-scale events like Hajj, with Scenario 2 highlighting the effectiveness of these strategies.

Table 5: Analysis of Pedestrian Speed Loss in Different Scenarios During Hajj Pilgrimage

Scenario	Simulation capture	Explanation	Speed loss %
Current state		Represents current speed loss patterns observed in the pathway between Arafah and Muzdalifah during the Hajj pilgrimage season	Varies based on observations
1.		Illustrates improved speed and efficiency in newly redesigned squares and pathways	88.35
2.		Shows the most optimized speed loss with an efficient layout and strategic service placement	94.02

Density - level of service (los)

Scenario 2 consistently demonstrated the lowest percentage of high-density areas, indicating better pedestrian dispersion compared to other scenarios. Scenario 1 improved density distribution but faced challenges. Overall, Scenario 2 emerged as promising strategies for reducing high-density areas and enhancing pedestrian flow.

Spatial utilization

Scenario 2 achieved the best balance in space utilization along the pathway through effective service relocation and square redesign. While Scenario 1 also improved spatial use, Scenario 2 proved most effective for optimizing space and managing pedestrian flow.

Speed loss

Scenario 2 achieved the lowest speed loss, indicating smoother pedestrian movement due to strategic service relocation and improved square design. Scenario 1, though featuring redesigned squares, had higher speed loss. Overall, Scenario 2 proved most effective in reducing density, balancing spatial utilization, and minimizing speed loss, making it a strong strategy for enhancing crowd management during Hajj.

Recommendation on urban planning strategies and solutions

This study recommends strategies to enhance public space during the Hajj pilgrimage through targeted urban planning. Key interventions include optimizing charitable distribution sites, centralizing seating, and redesigning restrooms and water fountains for better access. Three new squares along the pathway, with amenities and curved connections, aim to improve pedestrian flow and safety by relocating services outside the main pathway. These measures collectively enhance infrastructure efficiency and the overall pilgrim experience.

Framework development for optimizing pedestrian movement

Based on the analysis of the above scenarios and the current situation, a framework has been developed to optimize pedestrian movement systems (PMS) during the Hajj pilgrimage. This framework combines urban design principles, crowd management strategies, and crowd dynamics theory. It focuses on creating safe, comfortable environments with clear, vehicle-free pathways, wide sidewalks, and well-placed amenities. Effective crowd management includes robust planning, clear signage, and continuous monitoring. By addressing density and layout, the framework aims to enhance safety and efficiency during Hajj and offers practical insights for managing crowds in various urban settings.

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CONCLUSION

This study develops a framework to optimize pedestrian movement along the Arafah-Muzdalifah pathway during Hajj. By analysing various scenarios and integrating theoretical models, it highlights improvements in pedestrian flow and safety through better urban design, service relocations, and designated public spaces. Key recommendations include proactive planning, stakeholder collaboration, and the use of advanced technologies for crowd monitoring and emergency management. This research offers practical insights for enhancing infrastructure, public safety, and the overall pilgrimage experience.

REFERENCES

Al-Shaery, A. M., Alshehri, S. S., Farooqi, N. S., & Khozium, M. O. (2020). In-Depth Survey to Detect, Monitor and Manage Crowd. *IEEE Access*, *8*, 209008–209019. https://doi.org/10.1109/ACCESS.2020.3038334

Baydoun, Z., Alghamdi, N. A., & Kamarudin, Z. (2023). THE ISLAMIC ART AND DESIGN ELEMENTS APPLIED IN THE ISLAMIC CITY, A CASE STUDY OF PUTRAJAYA ISLAMIC CITY. *PLANNING MALAYSIA*, *21*(1), 314–328. https://doi.org/10.21837/PM.V21I25.1241

Baydoun, Z., Norishah, T., Baydoun, R., & Adam, M. (2024). Placement Principles of Islamic Calligraphy in Architecture: Insights from the Al-Hambra and Al-Azem Palaces. *Buildings 2024, Vol. 14, Page 2025*, *14*(7), 2025. https://doi.org/10.3390/BUILDINGS14072025

Beermann, M. (n.d.). *The Relationship between Pedestrian Density, Walking Speed and Psychological Stress: Examining Physiological Arousal in Crowded Situations*.

Cysek-Pawlak, M. M., & Pabich, M. (2021). Walkability – the New Urbanism principle for urban regeneration. *Journal of Urbanism: International Research on Placemaking and Urban Sustainability*, *14*(4), 409–433. https://doi.org/10.1080/17549175.2020.1834435

Darsena, D., Gelli, G., Iudice, I., & Verde, F. (2023). Sensing Technologies for Crowd Management, Adaptation, and Information Dissemination in Public Transportation Systems: A Review. *IEEE Sensors Journal*, *23*(1), 68–87. https://doi.org/10.1109/JSEN.2022.3223297

Felemban, E. A., Rehman, F. U., Biabani, S. A. A., Ahmad, A., Naseer, A., Majid, A. R. M. A., Hussain, O. K., Qamar, A. M., Falemban, R., & Zanjir, F. (2020). Digital Revolution for Hajj Crowd Management: A Technology Survey. *IEEE Access*, *8*, 208583–208609. https://doi.org/10.1109/ACCESS.2020.3037396

Haghani, M., Coughlan, M., Crabb, B., Dierickx, A., Feliciani, C., van Gelder, R., Geoerg, P., Hocaoglu, N., Laws, S., Lovreglio, R., Miles, Z., Nicolas, A., O'Toole, W. J., Schaap, S., Semmens, T., Shahhoseini, Z., Spaaij, R., Tatrai, A., Webster, J., & Wilson, A. (2023). A roadmap for the future of crowd safety research and practice: Introducing the Swiss Cheese Model of Crowd Safety and the imperative of a Vision Zero target. *Safety Science*, *168*, 106292. https://doi.org/10.1016/J.SSCI.2023.106292

Xuan, C. ;, Zhang, B. ;, Jia, X., Ojima, T., Jeong, S., Xuan, C., Zhang, B., & Jia, X. (2023). The Effect of Human Settlement Pedestrian Environment on Gait of Older People:

An Umbrella Review. *International Journal of Environmental Research and Public Health 2023, Vol. 20, Page 1567*, *20*(2), 1567. https://doi.org/10.3390/IJERPH20021567

Yuan, Z., He, B., Wan, Y., Wang, J., & Huang, B. (n.d.). *Simulation Study of Pedestrian Behavior in the Commercial Passageways of Subway Stations Considering Visual Attraction*. https://doi.org/10.2139/SSRN.4869187

Yue, Z., Ling, Z., Barahona Da Fonseca, F., Kadi, A., Habibi, R., Hu, X., Barakat, H., Zahalqa, H., & Gillem, M. (n.d.). *URBAN DESIGN AND PLANNING Volume 338 Contents*. *338*.

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