# Enhancing Pilgrim and Transport Management during Hajj through Color-Coded Stripes on Nusuk Cards and Buses

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**Abstract**
It is a major challenge to manage pilgrim movements and transportation during Hajj, as well as ensure their safety and smooth operations. This paper suggests integrating color-coded strips on pilgrims' Nusuk cards based on their status and special needs while simultaneously placing matching color-coded strips on their buses to streamline categorization and transport management. Currently, each authorized pilgrim receives a Nusuk card with a barcode for electronic verification. Enhancing this with a color-coded stripe that identifies their category: Blue for internal pilgrims, Purple for external pilgrims, Blue-Green for those with special needs (elderly and disabled) and Purple-Red for VIP external pilgrims could simplify and speed up the pilgrim identification process. This color-coding system extends to buses, where the same colors are applied, enabling efficient transport coordination. Buses carrying internal pilgrims would have Blue permits, those with external pilgrims Purple permits and buses accommodating special needs pilgrims would have Blue-Green permits. The suggested system doesn't require electronic verification like barcodes and goes beyond traditional geographic-based organization by introducing a color-coding framework that enhances personalized care and management for pilgrims based on their specific needs. Simulations were conducted to evaluate the effectiveness of this method in managing pilgrim flow and transportation during peak crowd times by simulating different scenarios, particularly during the Nafrah, Tawaf and Sai and Jamarat ritual. Results indicate that the color-coded system significantly improves crowd management and transport efficiency, offering a solution for enhancing the overall Hajj experience for both pilgrims and organizers. This study gives a foundation for future enhancements and serves as a model for managing crowded events.

***Keywords:***
*Hajj, Color-coded, Crowded events, Nusuk*

## 1. Introduction

Hajj is the largest crowded event in the world, whereas managing this crowd and facilitating their transportation within the holy sites presents a significant challenge for the Saudi government as Makkah population is around 2 million with an additional 2 million pilgrims arriving annually for Hajj[1]. Due to the nature of the rituals, all pilgrims must stay in a specific area during Arafat day and leave simultaneously at sunset[2]. This leads to significant congestion, as there are only 7 dedicated bus roads between Arafat and Muzdalifah, 4 main bus roads from Muzdalifah to Mina and 2 main routes from Mina to the Holy Mosque (Masjid al-Haram) in Makkah. Managing traffic congestion becomes a major challenge due to the limited availability of these routes[3].

There is a lack of integration and coordination among relevant authorities in emergency situations which has led to an increase in cases of lost pilgrims due to weaknesses in the guidance system. Transporting special needs pilgrims, such as the elderly and disabled, is another difficulty across the limited transport methods[2]. In addition, the small number of medical stations equipped with essential and advanced medical tools around the holy sites impacts the speed and quality of healthcare services. Also, emergency vehicles struggle to enter the crowded holy sites and stampedes frequently occur as pilgrims rush to board buses or the 'Mashaer' trains.
Technical issues with the Nusuk card [4]further complicate the situation, such as difficulty in updating the pilgrims' geographical locations, identifying the cards themselves and issuing them to both staff and pilgrims. There remains a significant reliance on human resources both from the government and civilians especially in organizing pilgrim movement and transportation largely due to the insufficient implementation of technological solutions. This study aims to enhance the organization and efficiency of crowd control and transportation during Hajj by proposing a color-coded system represented as a strip on the Nusuk card and on pilgrim buses. The system is simple: Blue for internal pilgrims, Purple for external pilgrims, Blue-Green for those with special needs (e.g., the elderly and disabled) and Purple-Red for VIP external pilgrims.

Future advancements could involve testing the color-coded system in a real Hajj situation to optimize

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colors that would aid in better crowd and bus transportation management. A color-coded reference sheet could be developed to define each category and provided to both government authorities and civilians managing Hajj or appropriate training could be conducted.

The contributions of this study are as follows:

- Defining the categories of the color-coded system.
- Simulating the benefits of this system in enhancing crowd management and pilgrim bus transportation based on provided scenarios.

The rest of the paper's sections are organized as follows: Section 2 covers related work and background on crowd management systems, Section 3 outlines the proposed color-coded system and its implementation, Section 4 presents the simulation and analysis of results, Section 5 discusses future advancements and concludes the paper with key findings and recommendations.

## 2. Related Work

Crowd management is a major concern in all contexts related to Hajj as keeping track, controlling and managing pilgrims' movement through various rituals of Hajj is the most important issue for the Saudi Government as it ensures the safety and comfort of pilgrims and ending the Hajj season without any unpredicted incidents. Research has explored various approaches to improving crowd management during Hajj, such as crowd counting, density estimation, localization, behavior monitoring and anomaly detection. For instance, Nasir et al. [5] developed the Crowd Anomaly Detection Framework (CADF), which combines a modular backbone, multi-scale feature fusion and soft non-maximum suppression (soft-NMS) to improve the detection of abnormal behavior in dense crowds during Hajj. That lays the groundwork for further enhancements in real-time crowd monitoring, highlighting the importance of multi-level data processing to better understand crowd dynamics. In a similar effort, Alhothali et al. [6] proposed a model to detect and localize anomalous events in dense crowd scenes for video surveillance and implemented a deep convolutional neural network (CNN) to detect and track individuals, extracting spatial and temporal features like optical flow and motion changes. The extracted features are then classified into seven categories of abnormal events using a support vector machine (SVM), and they evaluated their approach on the Hajj2 dataset with 18 videos, providing a more precise anomaly detection method than prior global frame-level techniques. Another research effort [4] introduced an intelligence-based crowd management framework that applies anomaly detection rules to monitor, predict and detect crowd accidents, facilitating a quick response to incidents. It also incorporated a Machine Learning model for predicting and detecting crowd-related issues such as density estimation, localization, and behavior monitoring, using real-time monitoring and predictive analytics to forecast potential crowd accidents based on historical data and real-time inputs. Moreover, the Saudi Ministry of Hajj and Umrah provided the Nusuk platform and app to manage the massive crowd during Hajj and ensure the smooth movement of pilgrims. Initially, the app was primarily used to book time slots for performing Umrah, track the number of pilgrims inside the Grand Mosque every hour and assign appropriate routes for them. Today, Nusuk serves as a major platform for digitally managing the crowd during Hajj, starting with streamlining the arrival procedures for millions of pilgrims. The Nusuk app is used along with the Nusuk card which includes the pilgrim's information and a barcode containing all their medical details and accommodation address during their sacred journey [7]. That helps redirect pilgrims when they are lost, provides real-time assistance and ensures quicker medical service in emergencies, as the barcode holds their full medical information. Although this system is effective, it opens opportunities for further enhancement. One such improvement, integrating a color-coded strip system on Nusuk cards and buses, as proposed in this paper, builds on Nusuk advancement by allowing for faster identification and navigation of pilgrims as well as reducing the reliance on electronic verification. The color codes could easily distinguish between different categories of pilgrims such as internal and external groups and special-needs pilgrims, facilitating more efficient crowd flow and emergency responses. That aims to extend the functionality of the existing crowd management system by simplifying real-time decision-making for authorities and staff during Hajj.

## 3. Methodology

### A. The proposed Color-Coded System

A simple and effective system for identifying and organizing pilgrims during Hajj could present a solid solution that reduces the complexity of the current identification system such as the need for electronic verification or a specialized platform requiring an internet connection. Hence, this study offers a simplified approach to managing pilgrim movements and transportation by assigning distinct color codes to different categories of pilgrims based on their status and specific needs. The categories include:

- Blue for internal pilgrims (from within Saudi Arabia)
- Purple for external pilgrims (from outside Saudi Arabia)
- Blue-Green for pilgrims with special needs (elderly, disabled)
- Purple-Red for VIP external pilgrims

The same color coding would be applied to Hajj campaign buses to ensure that pilgrims and their transportation are consistently organized according to the same scheme which helps not only in identifying pilgrims visually but also in improving the organization of transportation logistics and ensuring the right resources are allocated to the right groups.

### B. Color Code Assignment Process

Pilgrims are issued Nusuk cards in the form of printed cards at the time of their registration or approval for Hajj and they can view or download them digitally from the Nusuk app. Each card includes a barcode for electronically verifying the pilgrim's identity and details. In addition to this barcode, the proposed method adds a colored stripe to the top of the permit cards. The color of the stripe corresponds to the pilgrim's category, as outlined above, to ensure that they are immediately identifiable based on their needs and status. This assignment happens during the issuance of the Nusuk permit card and is integrated with the pilgrim's official Hajj records. The same color coding is applied to the buses used in transporting pilgrims. Buses are designated for specific categories. For example, buses marked with a Blue stripe only carry internal pilgrims, while those marked with Purple-Red are designated for VIP external pilgrims. That categorization simplifies boarding processes and reduces confusion in transport hubs, allowing for smoother operations during peak times.

### C. Design of the Permits and Buses

The Nusuk card will feature a colored stripe at the top for easy identification. The stripe will be wide enough to be easily seen at a distance but not so large as to obscure other important information on the permit, such as the pilgrim's barcode and personal details. Also, buses will feature matching color-coded stripes on their exteriors, marking them as designated for specific groups of pilgrims. The placement of these stripes will ensure they are visible from various angles to help transportation staff, volunteers and pilgrims easily identify the right buses.

### D. Logistics and Infrastructure Requirements

Implementing the color-coded system needs minimal changes to the existing infrastructure. At registration points and transportation hubs, staff would be trained to recognize and enforce the color codes. Barcode scanners already used on Nusuk cards would continue to be employed for electronic checks, while the color codes would provide an additional layer for quick visual verification. Transport hubs may need to be outfitted with signage corresponding to the color categories to further direct pilgrims to the correct buses. No significant technological infrastructure upgrades are required for this system beyond the physical addition of color strips to Nusuk cards and buses.

### E. Simulation Setup and Modelling

Simulations were carried out on various Hajj scenarios, such as peak crowd times and the flow of pilgrims. These simulations were created to assess how the color-coded system improves the movement and organization of pilgrims. The simulations tested the system's ability to reduce congestion at transportation hubs by clearly designating buses and boarding areas according to the assigned color codes. This method allowed for smoother transitions between different stages of the pilgrim journey, particularly during times of high congestion.

### F. Practical Considerations for Implementation

The proposed color-coded system has been designed to be flexible, scalable and adjustable to the varying demands of Hajj. Consistently implementing the color codes across different regions and transportation operators is a major challenge. To tackle that, clear guidelines and standardized practices will be established to ensure that all authorized Hajj campaigns follow the same color-coding protocols. Also, since the system integrates with existing verification processes, it does not require any upgrade to the current methods but serves as an enhancement to the identification and organization process. Eventually, this system can be integrated with digital verification tools to further improve operations.

### G. Initial Testing and Feedback

System simulations showed that it could greatly improve how crowds and transportation are managed. The simulations highlighted the system's simplicity and ease of use, especially in visually identifying and organizing pilgrims. The findings suggest that the proposed method could quickly benefit Hajj, offering a practical way to improve crowd control and transportation.

## 4. Result and Discussion

The results have been conducted on different scenarios during Hajj and the simulation was carried out using Python as follows:

### A. The Nafrah from Arafat to Muzdalifah

Many pilgrims attempting to board buses simultaneously during the Nafrah can lead to congestion and delays. Buses can be categorized by implementing the suggested color-coded system. For example, internal pilgrims with blue-striped Nusuk cards would easily identify their designated blue buses, reducing confusion and loading times, while pilgrims with special needs, marked with Blue-Green stripes, would be given priority boarding to ensure their comfort and safety. The simulation was first implemented by simply showing the pilgrims divided into different Hajj campaigns, and then each campaign used the color-coded method to categorize their pilgrims.

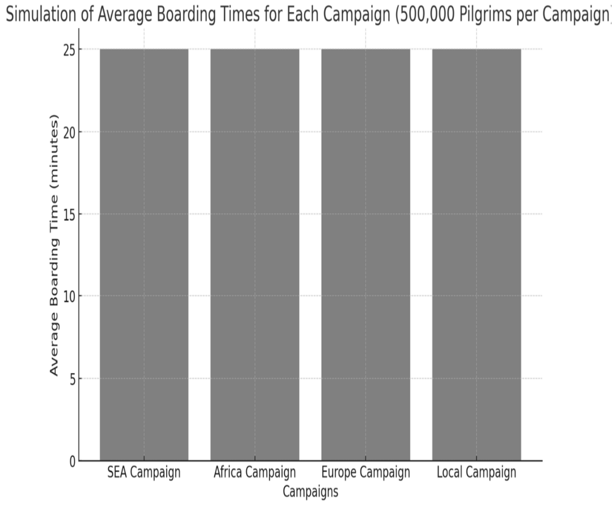


**Figure 1** Average boarding times for each campaign (SEA, Africa, Europe, and Local) without color-coded

Figure 1 shows the simulation of the average boarding times for each campaign (SEA, Africa, Europe and Local), each consisting of 500,000 pilgrims and 10,000 buses. The chart shows the boarding times based on each campaign.

shows the simulation results of the color-coded system indicating the average boarding time for each campaign is approximately 23.75 minutes. While this reflects the implementation of a faster boarding process for VIP (Purple-Red) and special needs (Blue-Green) pilgrims compared to regular pilgrims, the average boarding times did not improve significantly compared to the implementation without the color-coded system, Also, the simulation showed a consistent average boarding times across all campaigns (SEA, Africa, Europe, and Local) duo to similar pilgrim distribution and bus capacities.

The color-coded system could be more impactful with a few enhancements on boarding strategies such as increased priority for special needs and VIP Pilgrims by reducing the boarding times through the allocation of more buses. Secondly, optimizing bus allocation by increasing the proportion of buses for special needs and VIP categories rather than evenly distributing them.

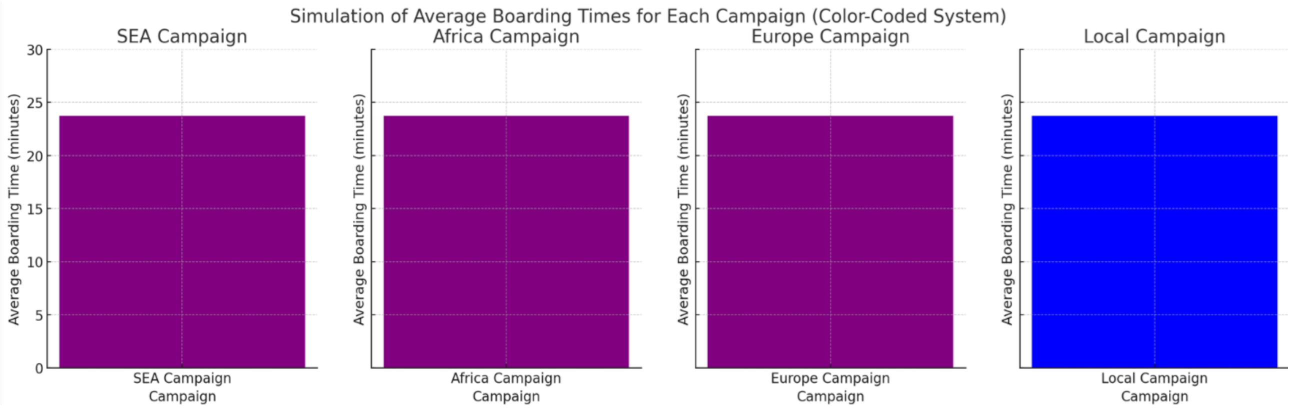


**Figure 2 Average boarding time for each campaign after implementing color-coded**

The adjustments include
• Special Needs Pilgrims (Blue-Green): Boarding time reduced to 10 minutes.
• VIP External Pilgrims (Purple-Red): Boarding time reduced to 12 minutes.
• Regular Pilgrims (Blue and Purple): Boarding times remain at 25 and 20 minutes respectively, but more buses will be allocated to VIP and special needs pilgrims. Figure 3 shows that after implementing the enhancements, the simulation shows a significant reduction in average boarding times, especially for VIP (Purple-Red) and special needs (Blue-Green) pilgrims, compared to regular pilgrims (Blue and Purple). This improvement is achieved by:

- Reducing boarding times for VIP and special needs pilgrims.
- Allocating more buses to these groups to prioritize their boarding.
- Implementing a faster verification process.

That enhancements lead to a more efficient boarding process, with the average boarding time for special needs and VIP pilgrims significantly reduced while overall boarding times are much shorter than in the previous simulation, indicating that these enhancements are effective in improving the system.

## B. Tawaf and Sa'i

Python was used in this study to simulate the evacuation process during Hajj for Tawaf and Sa'i in case of an emergency leveraging Nusuk card and the Mesa library. The key aspects of this simulation include creating an agent-based model to represent each pilgrim identified by the information sorted in the Nusuk card, simulating evacuation strategies where pilgrims are guided to designated exits based on their proximity and visualizing the evacuation in a grid space. The evacuation of Tawaf and Sa'i was simulated in two ways: the first way without any categorization of pilgrims and the second incorporating the categorization of pilgrims (Blue for internal, Purple for external, Blue-Green for special needs, and Purple-Red for VIP external pilgrims). The simulation was adjusted by assigning pilgrims a category based on the color-coded system during their creation, introducing behavioral differences based on the category such as different speeds and priority for evacuation. For example, special needs pilgrims (Blue-Green) have priority access to exits or take longer to evacuate and VIP external pilgrims (Purple-Red) move faster towards exits. Finally, the visualization was updated to reflect the number of pilgrims evacuated for each category. Figure 4 shows that all 1,000 pilgrims were evacuated. The evacuation process started quickly but slowed down toward the end with all 1000 pilgrims evacuated after approximately 1,400 time steps. Figure 5 shows that simulation effectively models the evacuation of 1,000 pilgrims categorized by color-coded stripes, demonstrating that they all reach the exit after 16 time steps. That indicates how quickly the evacuation progresses over time.

The difference between the two simulations is that evacuating all pilgrims in the first simulation without color-coded categorization required a significantly higher number of time steps, while in the second simulation with color-coded categorization, the evacuation occurred more quickly, as indicated by the lower number of time steps needed to reach 1,000 evacuated pilgrims.

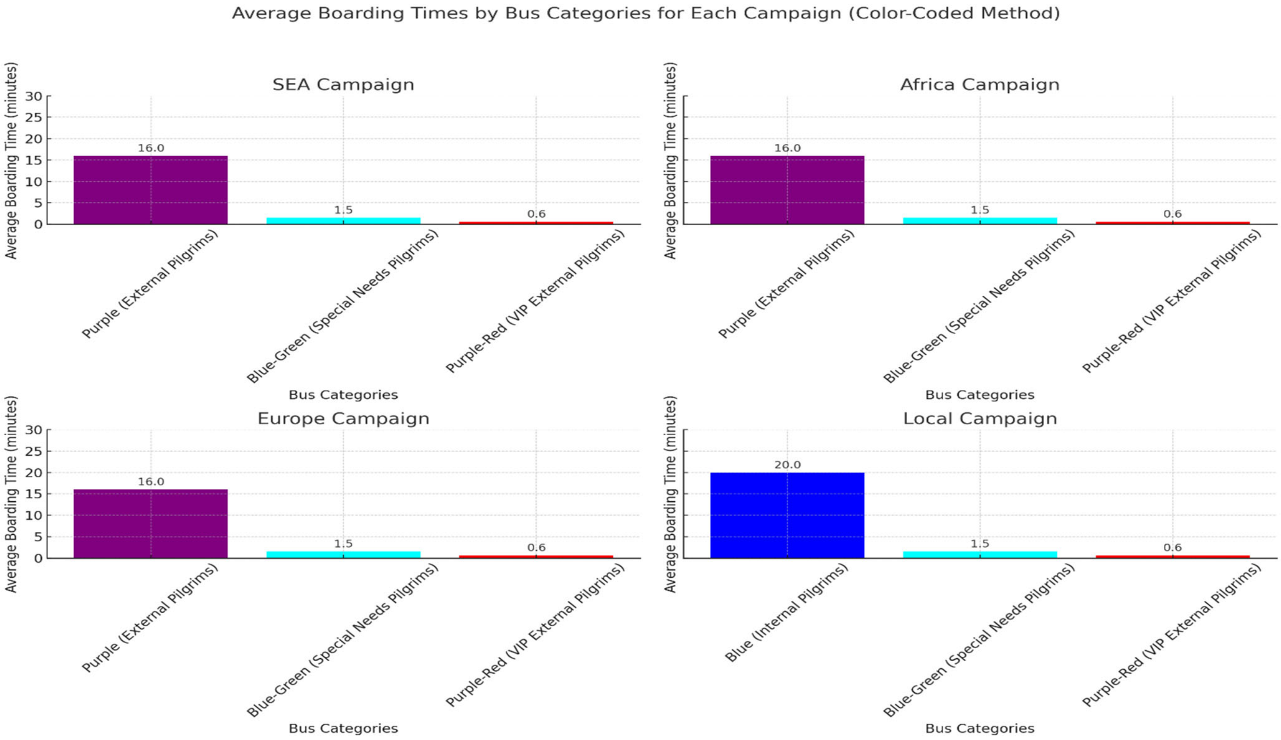


**Figure 3 Enhancing Average boarding times**

Moreover, in the second simulation the pilgrims were categorized based on the color-coded system: Blue for internal pilgrims, Purple for external pilgrims, Blue-Green for special needs and Purple-Red for VIPs. This categorization likely influenced how pilgrims moved toward the exit thereby allowing for more efficient routing or prioritization, such as special needs pilgrims (Blue-Green) had priority access, enabling faster evacuation and VIP pilgrims (Purple-Red) had more optimized paths, resulting in quicker evacuation for this group.

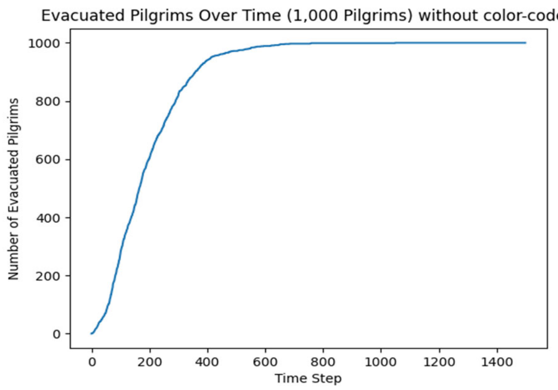


**Figure 4 Evacuated 1000 pilgrims**

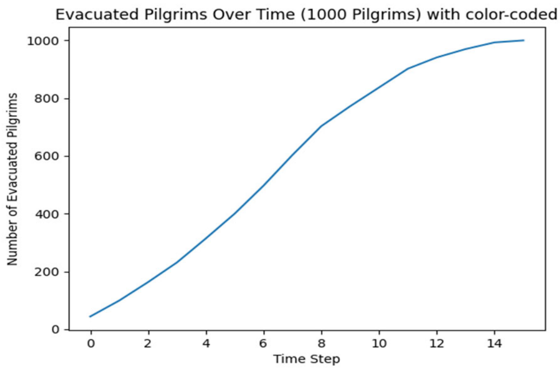


**Figure 5 Evacuated 1000 pilgrims over time**

The reason for this could be explained by the fact that the color-coded categorization showed better management of movement where pilgrims were grouped based on needs or importance and had different priorities for reaching the exits. That more organized approach led to a smoother and quicker evacuation. Also, the structured movement by granting special needs and VIP pilgrims earlier access to exits, reduced bottlenecks and congestion, resulting in a more efficient evacuation process.

### C. Jamarat (Stoning of the Devil)

The Jamarat (Stoning of the Devil) ritual was simulated with and without the color-coded categorization and the result are plotted in Figure 6 and Figure **7**, respectively. Each pilgrim is represented as an agent with attributes such as speed and time to complete the ritual and initially all pilgrims are treated equally without any special categorization. The Jamarat area is represented as a space where pilgrims gather to perform the ritual. Pilgrims move towards a designated area to complete the stoning ritual, with all pilgrims start at the same time and moving towards the stoning area. Pilgrims' movements are influenced by crowd density and proximity to the exit.

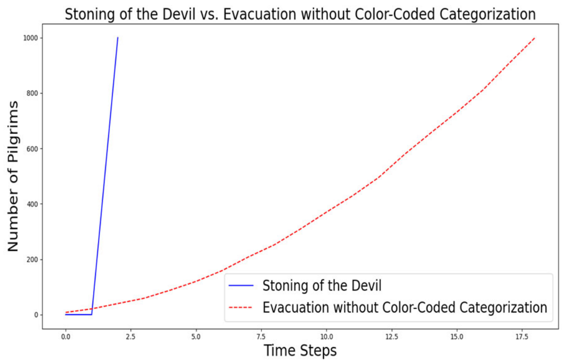


**Figure 6 Stoning of the Devil vs. Evacuation without Color-Coded**

Figure 6 shows that 1000 pilgrims take only 2 time steps to perform the stoning ritual, but after they finish, it takes around 18-20 time steps to exit the stoning area.

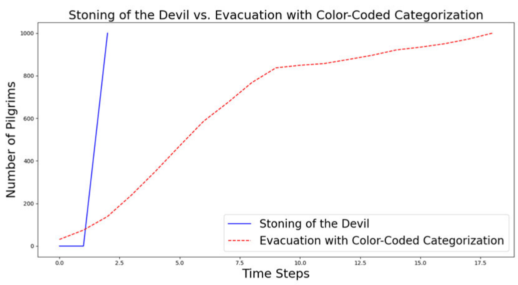


**Figure 7 Stoning of the Devil vs. Evacuation with Color-Coded**

Figure 7 shows that the evacuation with color-coded categorization progresses faster initially, especially in the middle time steps (around time step 3-7) showing a steeper increase in the number of evacuated pilgrims. It takes around 13-15 time steps for all 1,000 pilgrims to evacuate with the color-coded system.

The color-coded system showed a significant improvement in the efficiency of the evacuation process and reduced the total time needed to evacuate all pilgrims by several time steps, which represent a major reduction in scenarios where quick evacuation is important for safety and crowd control. That improvement is due to the fact that the color-coded system allowed VIP pilgrims (with faster speeds) and special needs pilgrims (with priority access) to evacuate more quickly thereby reducing overall congestion.

## 5. Future Advancements and Conclusion

Simulating the use of the color-coded method during Hajj as carried out in this study could be further improved by incorporating more complex agent-based models that consider real-time factors such as crowd density, weather conditions and fatigue. That could allow the system to simulate more realistic scenarios and better adapt to sudden changes such as in emergency situations. Artificial intelligence-based evacuation models could offer more granular routing instructions to ensure that vulnerable groups are evacuated first, which would further reduce congestion and improve safety outcomes.

In addition, the data collected from simulations and real-world implementations of the color-coded system could be analyzed to identify patterns in pilgrim behavior and used to inform future improvements, allowing for more precise planning of transportation, accommodation and crowd control strategies.

This study has demonstrated that the implementation of a color-coded system during Hajj can enhance pilgrim and transport management particularly during major rituals like the Nafrah, Tawaf, Sa'i and the Jamarat. By assigning different categories to pilgrims based on their needs such as special needs and VIP status, the color-coded system effectively reduced boarding times, improved evacuation efficiency and enhanced the overall flow of pilgrim movements.

In the simulation of the Nafrah from Arafat to Muzdalifah, while the initial implementation of the color-coded system did not significantly reduce average boarding times, enhancements such as allocating more buses to VIP and special needs pilgrims showed a marked improvement. This adjustment reduced the boarding time for special needs pilgrims to 10 minutes and VIP pilgrims to 12 minutes, improving the system's overall efficiency. For Tawaf and Sa'i, using a color-coded system for evacuation during emergencies showed a faster and more organized evacuation compared to the simulation without categorization. The simulation demonstrated that the categorized pilgrims such as Blue-Green for special needs were evacuated more efficiently, with priority given to those with greater needs, thereby reducing bottlenecks and improving safety.

The Jamarat ritual simulation further validated the benefits of the color-coded system by showing a quicker evacuation for VIP and special needs pilgrims. That led to a smoother process overall, with the total evacuation time being significantly reduced compared to the non-categorized scenario. The introduction of categorization based on the color-coded Nusuk cards contributed to more structured and prioritized movements, leading to faster completion of the ritual and evacuation, minimizing congestion and enhancing safety.

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