

(Research Article)

# Assessing Emergency Egress on Retail Environments Through Pathfinder Simulation

Charisa Pradiptajati <sup>1\*</sup>, Noor Cholis Idham <sup>2</sup>, Rania Ababssi <sup>3</sup>

<sup>1-3</sup> Department of Architecture, Faculty of Civil Engineering and Planning, Universitas Islam Indonesia, Yogyakarta, Indonesia; [21512076@students.uii.ac.id](mailto:21512076@students.uii.ac.id)

\* Corresponding Author: [21512076@students.uii.ac.id](mailto:21512076@students.uii.ac.id)

**Abstract:** Retail environments with high occupant density often experience crowding, which can compromise safety during emergencies, particularly when spatial layouts create constrained circulation and obstructed exits. This study evaluates the evacuation layout of Superindo Monjali, a supermarket in Yogyakarta, using Pathfinder simulation. The analysis focused on circulation geometry, aisle arrangements, cashier positioning, and exit visibility to assess how spatial configurations influence crowd movement and evacuation efficiency. Simulation results showed that, while total evacuation time (39.3 seconds) met recommended safety standards for single-storey buildings, localized bottlenecks, uneven flow distribution, and underutilization of secondary exits highlighted significant architectural limitations. These findings indicate that operational management alone is insufficient to ensure safe egress; spatial design must support efficient and balanced occupant movement. Based on the results, recommendations include improving exit visibility and accessibility, optimizing aisle and circulation layouts, and enhancing signage and wayfinding. The study demonstrates that architectural layout is a critical determinant of evacuation performance and provides a replicable framework for enhancing emergency preparedness in high-density retail settings.

**Keywords:** Building Safety; Crowd Analysis; Evacuation Route; Pathfinder Simulation; Retail Environment.

## 1. Introduction

In emergency situations, the unavailability of safe and efficient evacuation routes can be a disaster. Evacuation planning is a critical component of building safety regulations, ensuring that all occupants can be moved to a secure location in the event of an emergency (Kuligowski et al., 2010). The effectiveness of emergency egress systems is fundamentally dependent on the establishment and enforcement of comprehensive safety regulations that govern exit design, accessibility, and emergency preparedness (Gwynne et al., 2016)

Retail environments, such as supermarkets, are characterized by high occupant loads, complex layouts, and the presence of merchandise, all of which can hinder evacuation and increase the risk of congestion and delays (Lovreglio et al., 2015). Recent study by Liu et al. (2023) highlight the need for tailored egress strategies in retail settings, including the strategic placement of exits, effective crowd management techniques, and regular staff training. These measures are critical for ensuring rapid and orderly evacuation, particularly during peak shopping periods or special events.

Recent advancements in evacuation modeling software have significantly enhanced the ability to enable more accurate risk assessments and design optimizations. Pathfinder is a leading agent-based evacuation simulation tool widely adopted by researchers and safety professionals for modeling pedestrian movement and evaluating egress strategies in various environments, including transit stations, commercial buildings, and large public venues (Kuligowski et al., 2010). By simulating diverse emergency scenarios, Pathfinder enables the identification of potential congestion points and bottlenecks, allowing for the testing and refinement of egress designs to improve evacuation efficiency and safety (Zheng et al., 2022). The

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use of such tools supports data-driven decision-making and enhances the overall safety of building occupants, particularly in high-occupancy settings like retail stores and public venues.

The practice of emergency egress is closely linked to the disaster rate of an area. Continuous evaluation of regulatory practices is crucial to ensure that safety standards keep pace with emerging risks and technological advancements, thereby maintaining their effectiveness in real-world scenarios (Lancel et al., 2023). The importance of this assessment is underscored by the disaster vulnerability of Sleman Regency, which recorded 259 incidents in 2023 alone. The most frequent events included 112 building fires, 62 forest and land fires, and 48 landslides, placing Sleman among the highest-risk zones in the Yogyakarta Special Region (*BPBD Daerah Istimewa Yogyakarta*, 2024). These conditions demand proactive evacuation strategies in commercial buildings to reduce casualties and ensure safety. Such strategies align with national and international building safety standards, including Peraturan Menteri Pekerjaan Umum dan Perumahan Rakyat Nomor 14/PRT/M/2017, which mandates accessible, unobstructed, and clearly marked evacuation routes (Kuligowski et al., 2010).



**Figure 1.** Superindo Monjali.  
Source: Field survey, 2025

This study focuses on Superindo Monjali, a supermarket located on Palagan Street in Sleman. The building typology and function represent typical high-density retail environments. Situated in a mixed-use urban neighborhood frequented by both local residents and passersby, Superindo Monjali is as a relevant case study for evaluating evacuation planning in Indonesian commercial buildings. Therefore, the guiding research questions are:

- a. How effective is the current evacuation layout of the Superindo Monjali supermarket, particularly in terms of circulation geometry, exit placement, and spatial visibility, in supporting safe and efficient evacuation performance when tested through Pathfinder simulation under peak occupancy conditions?
- b. How do spatial configurations such as aisle arrangement, cashier positioning, and exit accessibility influence crowd movement patterns and evacuation efficiency in the supermarket environment?

## 2. Literature Review

### 2.1 Code Compliance

Emergency evacuation is a critical aspect of building safety, particularly in high-occupancy settings such as supermarkets. In Indonesia, Peraturan Menteri Pekerjaan Umum dan Perumahan Rakyat Nomor 14/PRT/M/2017 on Building Construction Facility Requirements mandates that Each building, in accordance with its function and building classification, must meet the requirements for easy horizontal connections between spaces/buildings to support the implementation of the building's function. For single-story buildings like Superindo Monjali, the focus lies in horizontal circulation, including adequate corridor widths, proper exit placement, and effective signage.

In Indonesian retail spaces such as supermarkets, emergency evacuation relies heavily on effective horizontal circulation, particularly through doors and corridors. According to Permen PUPR No. 14/PRT/M/2017, main entrance doors must have a minimum width of 90 cm, while other doors require at least 80 cm to accommodate high foot traffic during emergencies. Doors in high-occupancy areas like sales floors or back rooms must open outward to avoid congestion during panic situations. Additionally, a clear space of 152.5 x 152.5 cm in front of doors must be maintained, free from furniture or displays. This is especially relevant

in supermarkets, where crowded layouts and misplaced items can obstruct evacuation. Sliding doors, used at Superindo entrances, are permitted if they open automatically within 3 seconds and can be operated manually within 15 seconds during power failures, ensuring functionality under all conditions (Peraturan Menteri Pekerjaan Umum Dan Perumahan Rakyat Nomor 14/PRT/M/2017, 2017).

In performance-based fire safety engineering, evacuation performance is commonly evaluated by comparing the Required Safe Egress Time (RSET) with acceptable benchmark values reported in the literature. Several studies and SFPE-based practices indicate that evacuation times within approximately 2.5 minutes (150 seconds) for single-storey public buildings are generally considered acceptable under non-extreme fire scenarios (Hurley et al., 2016).

## 2.2 Evacuation Time Analysis (Simulation-Based Study)

Simulation-based methods have become increasingly important for evaluating evacuation performance, especially in complex, high-occupancy buildings. Among the various tools available, Pathfinder has emerged as a widely used agent-based simulation software that enables detailed modeling of occupant behavior and egress timing. In a study by Almeida et al. (2016), Pathfinder was used to simulate emergency evacuations in a Portuguese concert hall. The study demonstrated how different architectural configurations, such as blocked exits or modified seating arrangements, could significantly alter evacuation times. While simulated results were often faster than observed real-life evacuation footage due to the idealized nature of modeled occupant behavior, the tool proved effective for testing layout alternatives and identifying vulnerabilities in the evacuation strategy.

Similarly, Saika et al. (2024) utilized Pathfinder to evaluate evacuation effectiveness in a five-story student dormitory in Yogyakarta. The initial simulations revealed critical delays at staircase bottlenecks, with evacuation times exceeding the 2.5-minute threshold recommended by SFPE standards. After proposing design modifications, such as widening stairs and improving exit access, simulation results showed a reduced evacuation time of just 82 seconds. This underscores the importance of using simulation not only to predict evacuation duration but also to assess the impact of design changes on life safety outcomes.

Both studies highlight the utility of Pathfinder as a practical and flexible planning tool. It enables architects and safety engineers to assess evacuation scenarios under varying conditions, test compliance with safety standards, and refine spatial strategies before real emergencies occur. For environments such as retail stores, where occupant density and behavior are less predictable, simulation can play a critical role in designing safer and more responsive evacuation systems.

## 2.3 Spatial Layout Evaluation

Spatial layout plays a critical role in the effectiveness of evacuation during emergencies, as it directly affects how people move through and understand the built environment. Saika et al. (2024), in a study of a student dormitory, demonstrated that narrow staircases and corridor bottlenecks significantly slowed evacuation, with initial times exceeding standard safety limits. After modifying spatial configurations, such as widening staircases and removing obstructions, evacuation times were notably reduced, confirming that even minor layout changes can have a substantial impact on safety outcomes. This is related to the narrow corridor in the retail environment.

Furthermore, Campos et al. (2012) highlighted that evacuation routes, especially in disaster-prone contexts, must be free of intersection points and conflicting flows to avoid congestion and reduce accident risks. They introduced the concept of "disjoint routes," where spatial layout is carefully designed so that paths to different shelters do not overlap, ensuring smoother evacuation. These findings align with the broader review by Kuligowski et al. (2010), who stressed that the configuration of exits, corridor dimensions, and visual cues are among the most influential features affecting occupant movement and route choice during emergencies. Collectively, these studies underscore that effective spatial layout evaluation must integrate building geometry, user behavior, and dynamic evacuation conditions, offering valuable guidance for designing safer retail or residential environments.

## 3. Metode

### 3.1 Data Collection Methods

Data collection was conducted through site visits and direct measurements at Superindo Monjali, to capture the actual spatial and architectural conditions of the building. During the site visits, measurements were manually taken for key evacuation components, including corridor widths, exit placements, door dimensions, and vertical circulation elements such as stairs and ramps. Photographs and field sketches were also used to support documentation of spatial layout and signage visibility. All collected data was compiled into a 2D plan and used to construct a 3D digital model of the supermarket.

### 3.2 Data Analysis Methods

The collected spatial data was analyzed using Pathfinder, a simulation tool designed to model human movement and emergency evacuation. A 3D model of Superindo Monjali was built within the software using the measured dimensions. The simulation included virtual agents representing shoppers and staff, whose movement characteristics, such as walking speed, reaction time, and emergency behavior, were based on standardized values from evacuation literature.

In the absence of precise peak occupancy data, the simulation used 100 virtual agents to represent high-density conditions in the store. This number is derived from the occupant load factor for mercantile use on the street floor, as recommended in the NFPA 101 Life Safety Code (2000), which specifies 2.8 m<sup>2</sup> per person. Using this standard and the measured sales area of Superindo Monjali, 100 agents represent a realistic high-occupancy scenario, suitable for evaluating circulation, exit placement, and spatial visibility under stress conditions. The analysis identified which areas delayed evacuation and whether the existing layout complied with regulatory safety standards.

## 4. Results And Discussion

### 4.1 Site Analysis and Modeling

Superindo Palagan, located on Jalan Palagan Tentara Pelajar in Sleman, Yogyakarta, is a mid-sized, single-story grocery store. Upon entry, visitors are welcomed by a clean, air-conditioned space organized in a standard retail layout. However, one critical observation emerged during the site visit: the customer zone has only one primary access point, a front-facing automatic sliding glass door that serves as both the entrance and main exit. Additionally, there is a single designated emergency exit located at the side of the store.

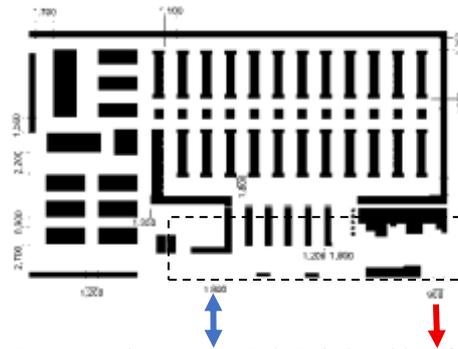


**Figure 2.** Superindo Monjali Siteplan.

This figure illustrates the external layout of Superindo Monjali, indicating the front main entrance and the emergency exit which directing to the designated evacuation assembly point.

Source: Field survey, 2025

As customers enter through the automatic door, they are directed along a circulation path beginning with promotional displays. The store interior is arranged into aisles approximately 1.5 meters wide, with tall shelving units that limit visibility across the store. This shelving creates a series of narrow corridors, making it difficult for customers to orient themselves or locate exits quickly, especially under emergency pressure.



**Figure 3.** Interior Layout and Entrance-Exit Relationship of Superindo Monjali.

The figure shows the spatial arrangement of aisles in relation to the main entrance (blue arrow) and the emergency exit (red arrow), highlighting the linear circulation flow and limited egress options. Source: Field survey, 2025

The initial analysis of Superindo Monjali's spatial configuration already reveals several critical vulnerabilities in its current evacuation design. The most significant concern is the reliance on a single automatic sliding door as the main entry and exit point regularly for all customers. This access limitation creates a bottleneck that is likely to impede the rapid movement of occupants during an emergency, especially in high-density situations such as peak shopping hours. Field observations further identified that the cashier zone is frequently congested, particularly during checkout queues. This congestion could potentially block the only available exit path, severely hampering evacuation efforts.



**Figure 4.** Emergency Exit Visibility and Circulation Constraints at Superindo Palagan.

This zoomed-in figure focuses on the front entrance (blue arrow) and emergency exit (red arrow), highlighting visual obstructions caused by limited signage and blocked paths that may hinder evacuation during emergencies.

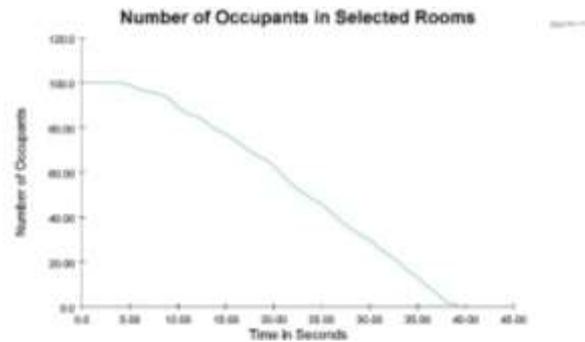
Source: Field survey, 2025

Given the store's interior configuration, lack of visibility, and critical dependence on a single automatic door for entry and exit, it presents notable risks in emergency scenarios. The digital model of Superindo Palagan (Figure 5) was developed based on direct site observation and measurement, focusing on circulation paths, shelving layout, exit positioning and visibility. This model serves as the basis for evaluating the evacuation strategy using Pathfinder.

An emergency exit is located at the front face of the store, but during the site visit, its access was found to be obstructed by trolleys and merchandise (Figure 6). This contradicts safety standards that require emergency exits to be clearly visible and accessible at all times. Wayfinding is another critical issue; signage within the store is minimal, and there is a lack of clear visual guidance directing occupants to emergency exits.

#### 4.2 Simulation Result

The Pathfinder simulation evaluated evacuation patterns at Superindo Monjali to understand how the store's spatial layout affects egress performance. While the occupant counts graph highlights the overall evacuation time, the heatmap visualization provides deeper insights into congestion points and movement behavior within the interior layout.

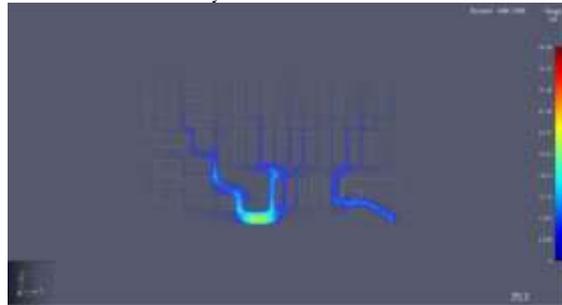


**Figure 5.** Occupant Count Graph Showing Evacuation Timeline.

This graph illustrates the decrease in occupant numbers over time during the simulation, showing a steady evacuation flow until full clearance was achieved at 39.3 seconds.

Source: Pathfinder Simulation, 2025

The occupant counts graph shows that all 100 occupants successfully evacuated within approximately 39.3 seconds. According to performance-based fire safety standards, evacuation times within approximately 2.5 minutes (150 seconds) for single-storey public buildings are considered acceptable under non-extreme fire scenarios (Hurley et al., 2016). Therefore, the total evacuation time in the simulation meets safety benchmarks, indicating that, in principle, the store can be evacuated efficiently.



**Figure 6.** Heatmap Visualization Highlighting Congestion Areas.

This heatmap depicts movement intensity during evacuation, with green-to-yellow zones indicating localized slowdowns caused by narrow aisles and restricted visibility.

Source: Pathfinder Simulation, 2025

The heatmap visualization provides a more detailed understanding of how the spatial layout influences evacuation behavior. The simulation indicates that most occupants concentrated their movement toward a single main entrance–exit, an automatic sliding glass door located at the front of the store. This area appears in green to yellow tones, representing a usage duration of approximately 15 to 25 seconds, which reflects localized delays. These slowdowns are likely caused by spatial convergence, where multiple occupants flow merge into narrower corridors near the cashier zone and entrance area.

This condition creates a clear bottleneck, as the evacuation process becomes highly dependent on a single egress point. Meanwhile, the secondary emergency exit, although present in the physical layout, shows minimal usage in the simulation. This pattern suggests limited spatial visibility and weak directional cues toward the rear exit, causing occupants to rely on the more familiar and visually dominant front entrance.

From an architectural perspective, this indicates that the effectiveness of the evacuation system is strongly influenced by the configuration of circulation paths, aisle orientation, and visual access to exits. Although the total evacuation time appears relatively short, the flow pattern reveals an uneven distribution of occupants, congestion near the checkout area, and underutilization of the secondary exit. Such conditions may significantly reduce safety margins during high-stress or high-density emergency situations.

## 5. Conclusions

This study evaluated the evacuation layout of Superindo Monjali using Pathfinder simulations under peak occupancy conditions. The results showed that, under ideal conditions, the total evacuation time met recommended safety standards, indicating that occupants could exit the store within an acceptable timeframe.

However, the simulations revealed significant architectural limitations that impacted flow distribution. Circulation geometry, aisle layout, cashier position, and exit visibility created localized bottlenecks, particularly near the main entrance and cashier area, while secondary emergency exits were underutilized due to poor visibility and weak directional signage. These spatial factors led to uneven occupant distribution, which could compromise safety in a real-life emergency scenario, particularly in the event of panic, obstruction, or reduced visibility. To improve evacuation performance, targeted architectural interventions are recommended: (1) Improving the visibility and accessibility of emergency exits to encourage a more balanced occupant flow. (2) Optimizing aisle and circulation layouts to reduce congestion, particularly around the cashier area. (3) Improving signage and directional signage to efficiently guide occupants to all exits.

Overall, although the store met standard evacuation time benchmarks, layout through circulation design, exit placement, and visibility remained a critical determinant of evacuation efficiency and safety. The simulation-based evaluation provided actionable insights for architectural improvements and a replicable framework to enhance evacuation safety in high-density retail environments.

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