EMERGENCY EVACUATION ANALYSIS OF PASAR PRAWIROTAMAN, YOGYAKARTA USING PATHFINDER SIMULATION

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ABSTRACT

Multi-story public markets pose distinctive challenges for emergency evacuation owing to their fluctuating crowd densities, diverse users, and complex vertical layouts. This study evaluates whether the evacuation performance of Pasar Prawirotaman, a revitalized public market in Yogyakarta, Indonesia, satisfies life-safety requirements under different occupancy conditions. The market spans six levels from a basement to an open rooftop and relies on four corner staircases for emergency egress, because its elevator and escalators must be shut down during a fire; its predominantly older trader population also moves and reacts more slowly than a general retail population. Pathfinder agent-based simulation modelled occupant movement at three occupancy levels, low, normal, and peak, and the Required Safe Egress Time (RSET) was compared against a conservative literature-based Available Safe Egress Time (ASET) benchmark of 300 seconds. Movement-based egress times were 152, 232, and 272 seconds. The safety factor fell from 1.97 at low occupancy, which meets the target of 1.5, to 1.29 at normal and 1.10 at peak occupancy, both of which fail it; the building therefore does not satisfy the ASET > RSET criterion with an adequate margin under ordinary and crowded conditions. Occupants converged on a single staircase and a single exit instead of spreading across the four available stairs, and individual congestion rose almost fourfold as the crowd grew. Adding a staircase adjacent to the primary exit reduced RSET by seven to eleven percent, whereas the same stair placed away from any exit produced no improvement. Egress performance is therefore governed by the position of vertical access rather than by the number of stairs.

Keywords: *Agent-Based Modeling, Available Safe Egress Time (ASET), Evacuation Simulation, Required Safe Egress Time (RSET), Vertical Circulation Configuration*

INTRODUCTION

Emergency evacuation is a critical determinant of life safety in dense public buildings, yet its performance is rarely evaluated through systematic simulation before a crisis occurs. In multi-story commercial facilities, the ability of all occupants to safely exit depends on spatial configuration, crowd density, and the accessibility of vertical circulation routes, factors that code compliance alone cannot fully capture (Gao, Lee and Lee, 2023).

In Indonesia, the conversion of traditional single-story markets into modern multi-story commercial structures, as at Pasar Prawirotaman itself (Kemantren Mergangsan, 2021), has intensified this concern, expanding occupant capacity and egress travel distance without proportional investment in evacuation performance assessment. These revitalization projects have brought tangible improvements in functionality, infrastructure quality, and urban aesthetics. Yet their implications for emergency evacuation performance have received little systematic attention in the Indonesian context.

Two gaps are evident in the existing literature. The first is a building-type gap. Evacuation-simulation research on commercial buildings is dominated by shopping malls and large urban complexes (Han, Liu and Zhang, 2021; Liu and Li, 2023; Jiang *et al.*, 2025), whose regular floor plates, centralized atria, and comparatively young and mobile users differ substantially from the dense stall grids, peripheral vertical cores, and older trader populations that characterize public markets, so their findings do not transfer to this building type without testing. The second is a regional gap. The most directly related work applied Pathfinder to an academic building and assessed its routes largely against regulatory checklists (Putri, Idham and Ababssi, 2025); the evacuation performance of multi-story public markets, and its evaluation through a performance-based safety-margin framework, remains unexamined. Meeting minimum code requirements for exit widths and travel distances is not sufficient on its own: it cannot capture how large crowds actually behave under stress, nor identify spatial bottlenecks that emerge under specific occupancy and building-configuration conditions (Kuligowski and Peacock, 2005).

Pasar Prawirotaman, located in the Mergangsan sub-district of Yogyakarta, presents a particularly compelling case (Figure 1). Following a revitalization completed in 2020, the building was redesigned as a four-story structure with a basement parking level, housing traditional market stalls alongside modern commercial and creative-economy facilities (Kemantren Mergangsan, 2021; Pemerintah Kota Yogyakarta, 2020). In 2024, it earned first place in the National Market Competition organized by the Directorate General of Cipta Karya, Ministry of Public Works and Housing (PUPR), giving it national standing as a model for market revitalization (Pemerintah Kota Yogyakarta, 2024). Its location within the Prawirotaman tourism corridor means it draws consistently high foot traffic from local residents and both domestic and international visitors.



Figure 1. Architectural Design Perspective of Pasar Prawirotaman Prepared for the 2019–2020 Revitalization
Source: Kementerian PUPR, published in TIMES Indonesia, 2019

Despite a growing body of literature on Pasar Prawirotaman, covering its architectural revitalization design (Kurnia and Kurniawan, 2020), green-building performance assessment (Arndarnijariah and Saputro, 2021), stakeholder dynamics (Safitri and Winarni, 2024), and socioeconomic impact (Atmadji and Putri, 2025), no study has examined the building's emergency evacuation performance. The spatial configuration of its vertical access elements, and what this means for occupant safety under emergency conditions, remains undocumented. This is a meaningful gap given the building's national recognition and consistently high visitor numbers.

The case is also more than local. Indonesia's market-revitalization programme has produced a generation of multi-story markets that share a defining configuration: a stall-dense lower market, leisure or co-working floors above, vertical cores pushed towards the building perimeter, and lifts and escalators that are withdrawn from service the moment an alarm sounds. Because these features, rather than anything peculiar to this site, are what shape egress here, findings from Pasar Prawirotaman are expected to transfer in kind to other revitalized Indonesian public markets of comparable configuration, and the assessment procedure applied below is intended to be reusable on them.

This research aims to fill that gap by applying Pathfinder agent-based simulation to assess the emergency evacuation performance of Pasar Prawirotaman, focusing on whether the building's current vertical access configuration meets life-safety standards. Three questions guide the study:

1. Does the evacuation performance of Pasar Prawirotaman, as assessed through Pathfinder simulation, comply with the required ASET > RSET safety standard under low, normal, and peak occupancy?
2. How does the building's vertical access configuration affect occupant egress efficiency as the occupant load increases?
3. To what extent can repositioning vertical access closer to the primary exits improve the safety margin?

In answering them the study contributes two things beyond the case itself: a replicable performance-based assessment procedure for revitalized public markets, and evidence on which design lever, the number of staircases or their position relative to the exits, actually governs egress performance. Both are intended to be directly usable in the design review of market revitalization projects and in evacuation planning by market management and local government.

THEORY / RESEARCH METHODS

Theoretical Background and Conceptual Framework

Emergency evacuation in multi-story buildings is shaped by three key factors: the building's spatial configuration, including the location and capacity of exits, corridors, and vertical access elements; occupant characteristics such as crowd density, demographics, mobility, and response time; and the nature of the emergency event, which sets the ASET (Proulx, 2008). In commercial buildings, crowd density can swing dramatically between quiet and busy periods, and research on market and shopping-complex evacuations consistently shows that congestion bottlenecks cluster at staircase entry points, exit doorways, and corridor junctions, wherever the volume of evacuating occupants exceeds the physical capacity of the path (Liu and Li, 2023). These bottlenecks grow worse with the distance occupants must travel to reach them (Selim, Salama and Gaber, 2024). Lei and Tai (2019) found that positioning exits directly opposite staircases significantly reduces evacuation time and stabilizes occupant flow, while research on bottleneck dynamics confirms that the distance between a spatial constriction and the nearest exit is the single most influential factor in how severe a bottleneck becomes (Wang *et al.*, 2022).

Spatial capacity alone, however, does not determine which route occupants actually take. Exit choice is a decision made under uncertainty, shaped by familiarity with the route, the distance to each exit, the number of people already using it, and the presence of smoke; discrete-choice models fitted to evacuation experiments consistently identify familiarity and observed crowding as strong predictors, which is why occupants frequently bypass a nearer exit in favour of the one they habitually use (Lovreglio, Fonzone and dell'Olio, 2016). Wayfinding provision moderates this tendency only partially: experimental work shows that a substantial share of evacuees do not register standard exit signage at all, and that the behaviour of surrounding people can override the guidance a sign provides (Zhu *et al.*, 2020). Occupant capability matters alongside choice. Older adults and people with reduced mobility descend stairs substantially more slowly than the general population and are over-represented among the last to leave a building (Kuligowski *et al.*, 2013), a consideration of direct relevance to a traditional market whose traders are predominantly over 40.

Indonesia's fire-safety framework establishes clear technical requirements for vertical access in multi-story buildings. The Minister of Public Works Regulation No. 26/PRT/M/2008 and SNI 03-1746-2000 form the primary regulatory foundation (Badan Standardisasi Nasional, 2000; Menteri Pekerjaan Umum, 2008), while

elevators are explicitly prohibited from use as evacuation routes and must be recalled to the ground floor when a fire alarm activates, per SNI 03-6574-2001 (Badan Standardisasi Nasional, 2001). Escalators are likewise deactivated during emergencies and may become physical obstacles. In practice, only conventional and dedicated emergency staircases remain valid vertical evacuation routes, and how close these are to the building's exits directly determines total travel distance and therefore RSET.

Beyond prohibiting lifts and escalators as evacuation routes, SNI 03-1746-2000 sets the prescriptive baseline for means of egress (Badan Standardisasi Nasional, 2000). It requires at least two means of egress from every building or storey (clause 14.3); sizes egress capacity at 0.8 cm of stair width and 0.5 cm of level-component width per person for ordinary occupancies (clause 6.3.1); mandates a minimum clear egress-door width of 80 cm (clause 5.1.2.1); prohibits dead-end corridors (clause 14.4); and limits the travel distance to the nearest exit (clause 14.1). These prescriptive criteria form the minimum baseline against which the building is first assessed. Because compliance with them cannot capture how large crowds behave under load, this study complements the baseline with the performance-based ASET-RSET evaluation set out below.

A more rigorous approach is offered by performance-based fire engineering, which centers on comparing the Available Safe Egress Time (ASET) against the Required Safe Egress Time (RSET). A building is considered safe when ASET exceeds RSET, ideally by a factor of 1.5 to 2.0 (Society of Fire Protection Engineers (SFPE), 2016). Agent-based evacuation simulation software such as Pathfinder (Thunderhead Engineering) models each occupant individually, capturing realistic crowd dynamics, bottleneck formation, and the influence of architectural configuration on how efficiently people evacuate (Thunderhead Engineering, 2024). This performance-based, agent-based approach is well suited to assessing how the building's vertical-access configuration shapes egress performance, and the procedures below operationalise it for the case of Pasar Prawirotaman.

These strands combine into the conceptual framework set out in Figure 2. Three groups of input variables govern egress performance: the building configuration, comprising the number and clear width of the stairs, their position relative to the exits, and the corridor approach distance; the occupant characteristics, comprising density, age and mobility profile, and pre-movement time; and occupant behaviour, comprising exit familiarity, route-choice convergence, and response to wayfinding. Agent-based simulation translates these inputs into the RSET, which is then set against the ASET derived from the design fire, and the ratio of the two gives the safety factor on which the life-safety verdict rests. Where the verdict falls short, the framework closes with a design-intervention loop in which the configuration is revised and re-simulated; this is the logic of Scenario 4 below. The framework makes explicit the proposition this study tests, namely that the position of vertical access, rather than its quantity, is the configuration variable that most strongly conditions RSET.

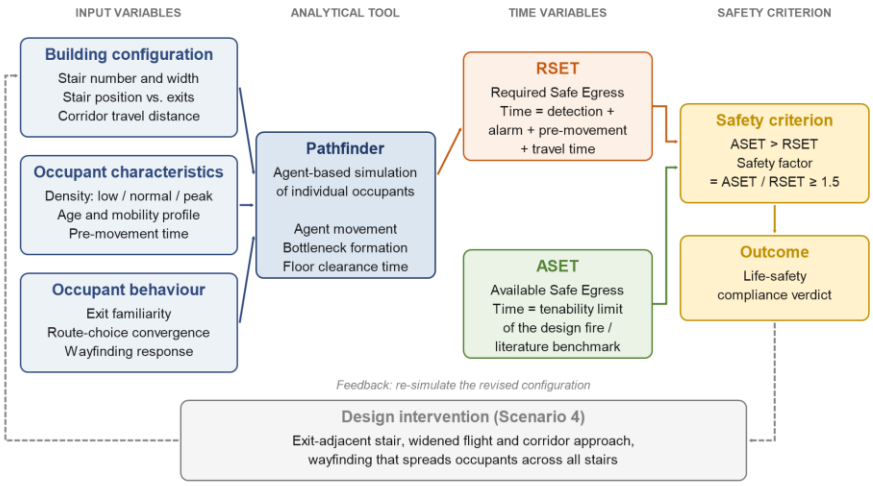


Figure 2. Conceptual Framework Linking Building Configuration, Occupant Characteristics, and Occupant Behaviour, through Agent-Based Simulation, to the RSET-against-ASET Safety Assessment and its Design-Intervention Feedback Loop

Research Design

This study uses a simulation-based quantitative research design, with agent-based pedestrian movement modeling as its core analytical tool. Simulation-based performance evaluation is an established approach in architectural research, including studies published in this journal (Meutia *et al.*, 2025). Pathfinder (Thunderhead Engineering Consultants) was selected for its validated accuracy in commercial-complex evacuation studies (Han, Liu and Zhang, 2021), its support for multi-floor building models, and its wide use in peer-reviewed evacuation research (Safari *et al.*, 2025; Bellas *et al.*, 2026). The analysis follows the performance-based fire-engineering framework, evaluating evacuation safety against the criterion ASET > RSET (Society of Fire Protection Engineers (SFPE), 2016). The dependent variable is the Required Safe Egress Time (RSET); the primary independent variable is occupancy density (low, normal, and peak); and the key moderating variable is the spatial configuration of vertical access elements specifically the distance between the corner staircases and the primary exits.

Building Model Development

A three-dimensional model of Pasar Prawirotaman is built in Pathfinder. Geometry is derived from architectural drawings, direct field measurements (corridor and door widths, staircase geometry, and the longitudinal distance between the corner staircases and the front exits), and photographic site documentation. The model represents the basement and all above-ground floors, the front passenger elevator, the four corner staircases, the escalators, all exit positions and widths, and the internal corridor and stall layouts.

Occupant Parameters

Occupant movement parameters are drawn from established reference values in the SFPE fire-engineering literature (Society of Fire Protection Engineers (SFPE), 2003) and NIST Technical Notes, calibrated for this market, whose population the field survey found to be dominated by traders aged over 40 alongside a smaller share of younger visitors (students and young adults aged 17 and above). To reflect this older, slower-moving profile, which evacuation research identifies as especially vulnerable during emergencies (Kuligowski *et al.*, 2013; Kristiadi and Sabatini, 2025), horizontal walking speeds are set at 1.1 m/s for unobstructed adults, 0.7 m/s under congested conditions, and 0.6 m/s for older traders, with stair-descent speed at 0.6 m/s, which falls within the range of local descent speeds reported in NIST Technical Note 1839 (Kuligowski *et al.*, 2014). Pre-movement time is estimated at 45 to 120 seconds, longer than a typical retail setting, because traders tend to secure cash, goods, or stalls before leaving. The demographic composition adopted is approximately 60% older traders and adults (40 years and over), 30% mobile younger adults, and 10% children and load-carrying occupants.

Simulation Scenarios

Four scenarios are defined. Scenario 1 (Low Occupancy) represents 30% of maximum design occupancy, such as early-morning trading. Scenario 2 (Normal Occupancy) represents 60%, reflecting an ordinary weekday. Scenario 3 (Peak Occupancy) represents 100%, such as weekends, public holidays, or events. Scenario 4 (Optimized Layout) is a hypothetical comparison in which an additional staircase is placed near the primary front exits, allowing the RSET improvement achievable through spatial redesign to be quantified. Each scenario was executed as a single representative run in Pathfinder using the default steering behaviour model. The 95th-percentile values reported below therefore describe the distribution of individual exit times within a run, not variation between runs; what follows from that, and the repeated runs that would be required to characterise between-run stochastic variability, is set out in Section 3.12.

Analysis Metrics

For each scenario, the following outputs are extracted and analyzed: total evacuation time (RSET); occupant flow rate at each exit and staircase entry; peak occupant density (persons/m²) at identified bottleneck locations; spatial density heat maps at 60-second intervals throughout the evacuation; and clearance time for each floor level.

Safety Criterion Assessment

Because a site-specific fire simulation is beyond the scope of this study, the available safe egress time is approximated from conservative published values for comparable multi-story commercial and market occupancies, together with a fast design-fire assumption suited to a market filled with combustible goods. The criterion ASET

greater than RSET, with a target safety factor of at least 1.5, is then evaluated for each scenario and interpreted against the requirements of SNI 03-1746-2000 and Minister of Public Works Regulation No. 26/PRT/M/2008.

RESULTS AND DISCUSSION

This section first summarises the field-survey findings that establish the building model and occupant parameters, then presents the results of the agent-based simulation. The field survey combined physical measurement, photographic documentation, and on-site observation carried out at Pasar Prawirotaman.

Vertical Configuration of the Building

The building comprises six vertical levels, as shown in the existing floor plans in Figure 3. The red dashed lines trace each level's horizontal egress route toward the corner staircases. A basement accommodates parking; the ground floor and the first and second floors house the traditional market, organized by commodity; the third floor provides communal space, a co-working area, and a food court; and an open rooftop serves as an informal leisure space. Floors are named throughout this paper by the convention used on the architectural drawings, in which the entry level is the ground floor and the levels above it are numbered from one; the building is therefore four storeys above ground, plus a basement and a rooftop. Some official descriptions of the building instead number the same four above-ground levels one to four; on that convention the communal level identified here as Floor 3 is their fourth floor. This vertical mix matters for evacuation: the upper non-market levels are leisure-oriented spaces where occupants tend to linger and may be slower to react to an alarm, while also facing the longest vertical descent to the ground-level exits.

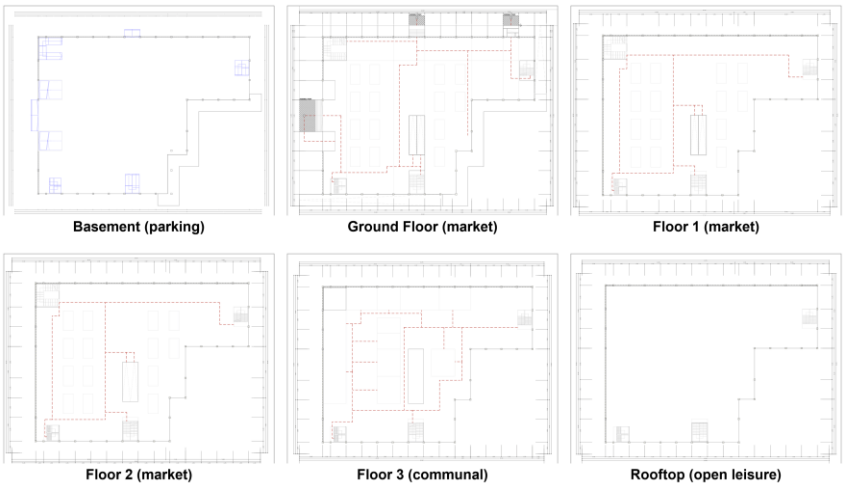


Figure 3. Existing Floor Plans of Pasar Prawirotaman, from Basement to Rooftop

Vertical Circulation Inventory

Contrary to the single-staircase assumption of earlier desk analysis, the survey found the building served by four staircases distributed around its perimeter, plus one front passenger elevator and a pair of bidirectional escalators. Their positions on a typical market floor are shown in Figure 4, which locates the four staircases and the central escalators relative to the internal circulation. The four staircases comprise two conventional open stairs, each approximately 2.5 m wide (Figure 5 and Figure 6), and two enclosed evacuation (fire) stairs, each approximately 3 m wide (Figure 7 and Figure 8). The conventional stairs are integrated into the market circulation and carry directory signage indicating the goods sold on each floor, while the evacuation stairs are bare, fire-separated concrete shafts. Critically, both the elevator and the escalators must be taken out of service during a fire, leaving the four corner staircases as the only valid vertical evacuation routes for the entire building.

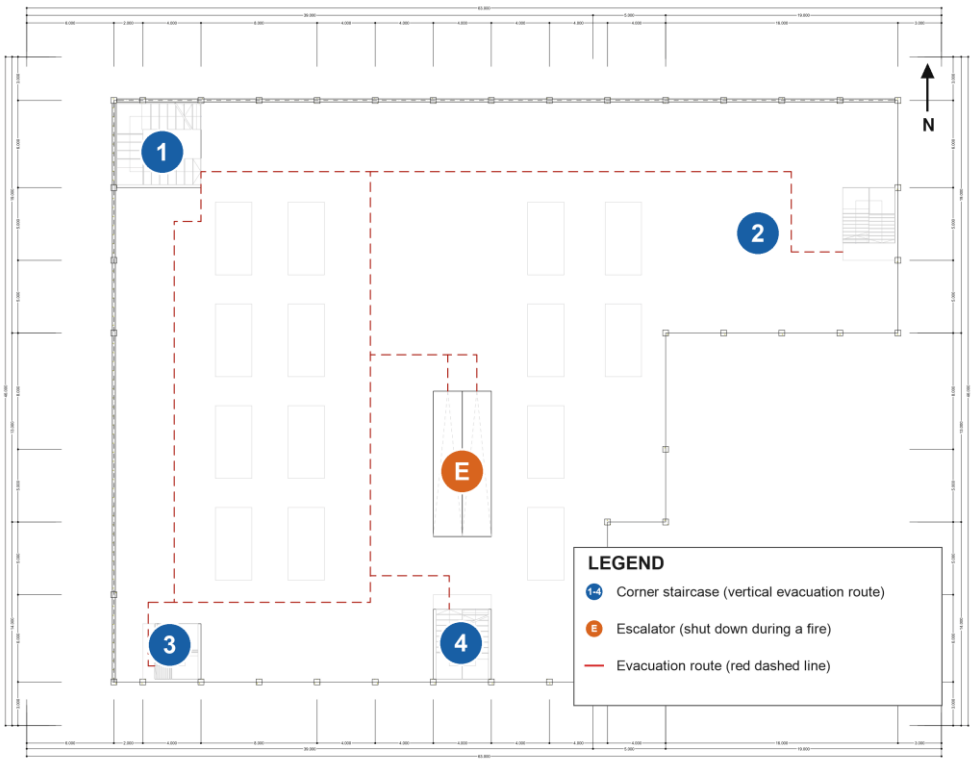


Figure 4. Locations of the Four Corner Staircases (1 to 4) and the Central Escalators (E) on a Typical Market Floor



Figure 5. Glass-enclosed Entry Separating the Conventional Market Staircase from the Trading Floor, With the First Flight Visible Beyond (Approx. 2.5 m Wide), Pasar Prawirotaman



Figure 6. Conventional Market Staircase with Floor-Directory Signage at the Landing, Showing the Inter-Floor Flight (Approx. 2.5 m Wide)

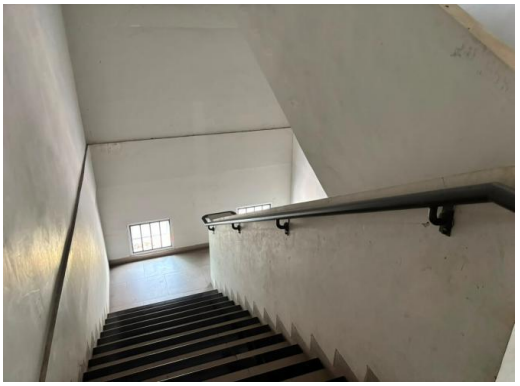


Figure 7. Enclosed Concrete Evacuation (Fire) Staircase, Approx. 3 m wide, One of the Two Dedicated Evacuation Stairs at The Building Corners



Figure 8. Enclosed Evacuation Staircase, Switchback View of the Fire-Separated Concrete Shaft (Approx. 3 m Wide)

Occupant Demographic Profile

Observation of the on-site population indicated that occupants are predominantly traders and adult shoppers aged over 40, many of them actively tending stalls and handling goods, with a smaller group of younger visitors, high-school students and university-aged young adults of roughly 17 years and above, particularly around the third-floor co-working and food-court areas. This older, task-absorbed profile lowers mean walking and stair-descent speeds and lengthens pre-movement time relative to a general retail setting, and it directly informed the occupant parameters in Section 2.4.

Egress Routes and Assembly Points

At ground level, occupant flow discharges toward the building's main frontage and the surrounding street circulation (Figure 10). The ground-floor plan in Figure 9 traces the horizontal egress routes from each staircase discharge to the exits and the two designated assembly points. The survey identified two designated assembly points serving the building, located to the north and to the west. Two separated assembly points are favourable for dispersing the evacuating crowd, provided that ground-level egress paths guide occupants from each staircase discharge toward the nearer assembly point without unnecessary crossing or convergence. Figure 11 illustrates the intended emergency egress scenario, with occupants descending the front staircase and moving out toward the assembly area.

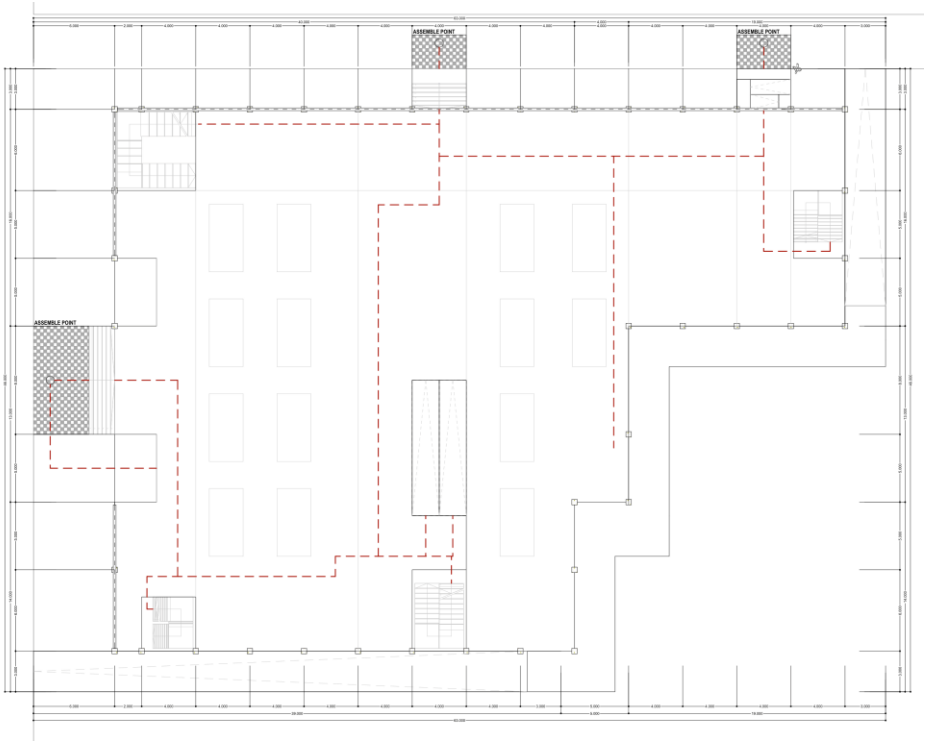


Figure 9. Ground-Floor Plan Showing Horizontal Egress Routes (Red) From the Staircase Discharges Toward the Exits and the Two Assembly Points, North and West

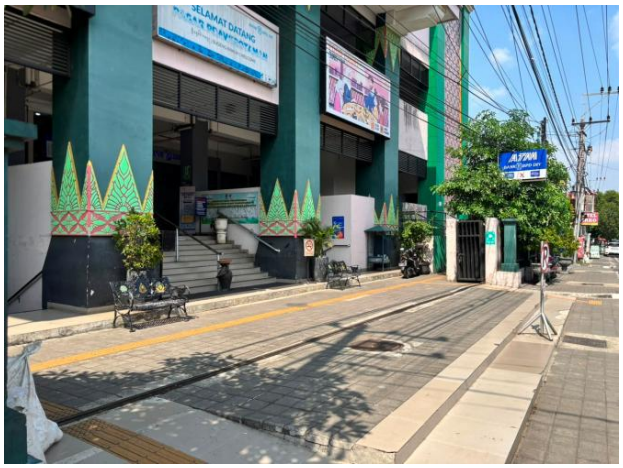


Figure 10. Building Frontage and Ground-Level Egress Route Leading Toward the Assembly Points to the North and West



Figure 11. Conceptual Illustration of the Emergency Egress Scenario: Occupants Descending the Front Staircase Toward the Assembly Point During a Fire

Implications for the Simulation

Taken together, these findings reframe the building's evacuation concern. The issue is not the absence of stairs, but whether four corner-distributed staircases used by a predominantly older population descending from as high as the rooftop can clear the building within the available safe egress time once the elevator and escalators are disabled, and whether real wayfinding behaviour will load the stairs evenly or concentrate occupants on the familiar central route. These questions are examined directly through the agent-based simulation, and its results are reported in the following subsections.

Occupancy Scenarios

The three occupancy scenarios were populated from the building's official capacity. Pasar Prawirotaman provides 619 trading stalls (Pemerintah Kota Yogyakarta, 2020). The number of traders was tied directly to the stall count, and shoppers were added at a peak ratio of roughly one shopper per trader, which gives a full weekend design load of about 1,420 people. The normal and low scenarios represent 60 and 30 percent of that figure. Each occupant was assigned one of the movement profiles defined in Section 2.4, with the older trader and adult group forming the largest share on the market floors and younger visitors dominating the upper co-working and food-court level. Table 1 lists the resulting population on each of the six levels.

Table 1. Occupant Population on each Level for the Three Scenarios

Level	Low (30%)	Normal (60%)	Peak (100%)
Basement	9	18	30
Ground Floor	129	258	430
Floor 1	141	282	470
Floor 2	87	174	290

Level	Low (30%)	Normal (60%)	Peak (100%)
Floor 3	39	78	130
Rooftop	21	42	70
Total	**426**	**852**	**1,420**

Evacuation Time and Egress Progression

Table 2 reports the movement-based egress times produced by the simulation. The last occupant left the building after 152 seconds under low occupancy, 232 seconds under normal occupancy, and 272 seconds under peak occupancy. Because every occupant began moving at the start of the run, these values capture travel time only. Adding a conservative allowance of about 180 seconds for detection, alarm, and pre-movement, which is typical for a market where traders pause to secure cash and goods (Society of Fire Protection Engineers (SFPE), 2016), raises the total required safe egress time to roughly 5.5, 6.9, and 7.5 minutes.

Table 2. Simulated Egress Metrics across the Three Occupancy Scenarios

Metric	Low	Normal	Peak
Occupants	426	852	1,420
Movement-based RSET (s)	152	232	272
Average exit time (s)	65	87	102
95th-percentile exit (s)	128	194	230
Time to clear 50% (s)	60	71	86
Occupants congested > 60 s	0.5%	20.5%	23.7%
Estimated total RSET (min)*	5.5	6.9	7.5

**Estimated total RSET adds a conservative 180-second detection and pre-movement allowance to the simulated travel time*

Figure 12 plots the number of occupants still inside the building over time. The curves reveal a pattern that the headline numbers alone do not. Tripling the occupant load, from 426 to 1,420 people, lengthened the total clearance time by only about 80 percent, yet the average time an individual spent held up in congestion grew almost fourfold, from around 10 seconds to 37 seconds. At peak occupancy nearly one occupant in four stood still for more than a minute, compared with fewer than one in two hundred at low occupancy. This is the signature of a system approaching its flow capacity, where the stairs and exits reach a fixed throughput and additional occupants simply extend the queue rather than being cleared any faster (Wang *et al.*, 2022).

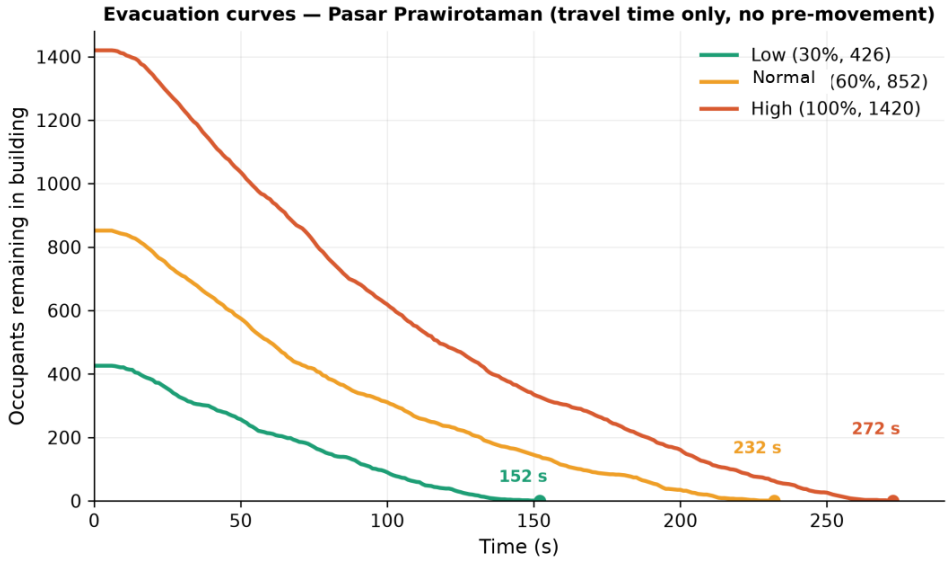


Figure 12. Occupants Remaining in the Building over Time for the Three Occupancy Scenarios (Last Occupant Out at 152 s, 232 s, and 272 s)

Bottleneck Formation and Uneven Egress

The simulation confirms the concern raised by the field survey. Occupants did not spread evenly across the four corner staircases but converged on a single dominant route. At peak occupancy one staircase carried 825 of the 1,420 occupants, which is 58 percent of the building, and one ground-floor exit discharged 60 percent of everyone at a sustained rate of 3.4 persons per second. The other stairs and doors stayed comparatively underused. This concentration grew worse as the crowd increased, with the share passing through the busiest exit rising from 53 percent at low occupancy to 60 percent at peak. The behaviour is consistent with evidence that occupants tend to head for familiar or main routes rather than the nearest available exit, which creates localised bottlenecks even when the total exit capacity is adequate (Lovreglio, Fonzone and dell'Olio, 2016).

Figure 13 and Figure 14 show the maximum congestion recorded on the first and second market floors at peak occupancy. Most of each floor stays clear, but sharp hotspots form at the entrances to specific corner stairs, where occupants queue for well over a hundred seconds while adjacent stairs remain lightly loaded. This uneven loading, rather than a shortage of stairs, is what limits the building performance.

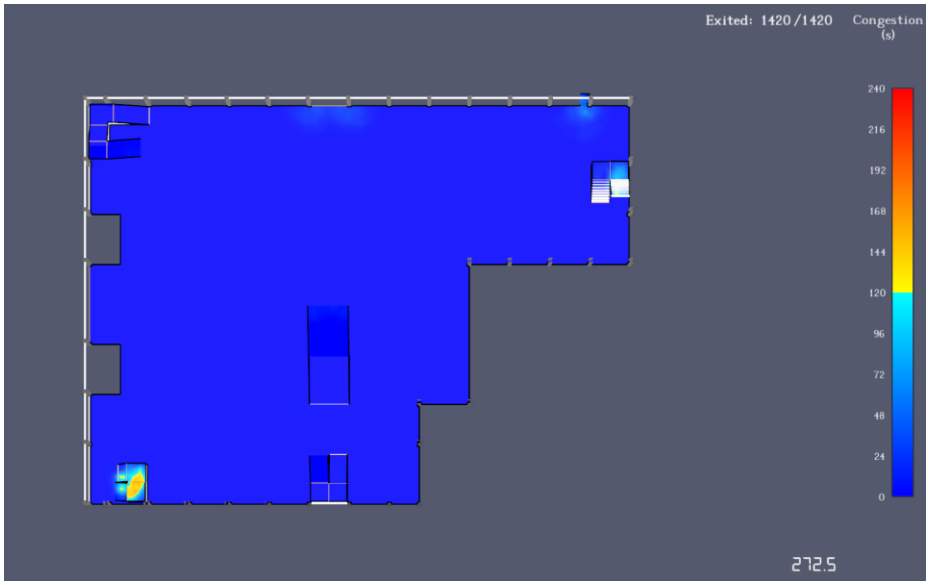


Figure 13. Maximum Congestion Time on the First Market Floor at Peak Occupancy (Pathfinder Output)



Figure 14. Maximum Congestion Time Recorded on the Second Market Floor at Peak Occupancy, on the Same 0 To 240 s Colour Scale as Figure 13

The delay fell hardest on the upper floors. The third floor, which contains the co-working area and food court, cleared in 43 seconds under low occupancy but took 204 seconds at peak, an increase of almost five times, while the ground floor rose by less than double. Occupants on the upper leisure floors, many of them younger

visitors, were held longest because they joined the tail of the same overloaded staircase already carrying the floors beneath them. Most of the accumulated delay occurred on the floor circulation approaching the stairs rather than on the stair flights themselves, which points to the corridors feeding the dominant staircase as the true constriction.

The slowest groups were the most exposed. In every scenario the final occupant to leave the building belonged to the load-carrying and reduced-mobility profile, at 152, 232, and 272 seconds, and elderly occupants consistently finished above the average. Because these groups are well represented in a traditional market, the bottleneck places its heaviest burden on the occupants least able to absorb it. A formal fire and smoke model were beyond the scope of this study, so the available safe egress time is compared against conservative tenability limits reported for market occupancies rather than a site-specific value (Society of Fire Protection Engineers (SFPE), 2016). Even under that cautious comparison, the safety margin narrows sharply as the crowd grows, and the evidence points to the vertical access layout, rather than a shortage of overall exit capacity, as the factor that governs safe egress.

Assessment Against Prescriptive Requirements

Before the performance-based comparison, the building is assessed against the prescriptive requirements of SNI 03-1746-2000 (Badan Standardisasi Nasional, 2000). It provides four means of vertical egress, well above the minimum of two (clause 14.3), and every staircase and egress door exceeds the 80 cm minimum clear width (clause 5.1.2.1). Applying the stairway capacity factor of 0.8 cm per person (clause 6.3.1) to the combined stair width of about 11 m, however, yields a nominal egress capacity of roughly 1,375 persons, marginally below the peak occupant load of 1,420. The building therefore satisfies the prescriptive requirements for the number and width of its stairs, yet sits at or slightly below the required capacity at full occupancy. This prescriptive check establishes the regulatory baseline; the performance-based comparison that follows shows how the building actually behaves under that load.

Safety Margin: ASET versus RSET

The final step compares the required safe egress time against the available safe egress time, which is the criterion set out in the research question. Because a site-specific fire and smoke simulation was beyond the scope of this study, the available safe egress time is approximated from published values for comparable multi-story commercial occupancies. In a recent performance-based study of a large urban commercial complex, the available safe egress time at individual staircases ranged from about 261 to 325 seconds, and the required safe egress time exceeded it at several stairs, producing negative safety margins before the layout was optimised (Jiang *et al.*, 2025). Taking a conservative reading of these values, together with a fast design-fire assumption appropriate to a market filled with combustible goods (Society of Fire Protection Engineers (SFPE), 2016), a benchmark available safe egress time of about

300 seconds is adopted here, a figure that is treated throughout as an indicative reference point rather than a measured tenability limit for this building.

Table 3. Simulated RSET Compared against a Conservative Literature-based ASET Benchmark

Scenario	RSET (s)	ASET (s)	Margin (s)	Safety factor	Meets 1.5
Low	152	300	148	1.97	Yes
Normal	232	300	68	1.29	No
Peak	272	300	28	1.10	No

Table 3 sets the simulated movement-based egress times against this benchmark. Under low occupancy the margin is comfortable and clears the target safety factor of 1.5. Under normal and peak occupancy, the safety factor falls to 1.29 and 1.10, both below the target, and the peak case leaves only about 28 seconds of margin. Once the detection and pre-movement allowance discussed earlier is added, the margin narrows further and can turn negative, which means the building may not satisfy the criterion once realistic reaction time is included. Because Pasar Prawirotaman has relatively low floor-to-floor heights, smoke would fill each level faster than in a tall mall atrium, so its true available safe egress time could be shorter still, tightening the peak margin even more.

This comparison is an indicative benchmark rather than a definitive verdict, because the available safe egress time is drawn from literature rather than a site-specific fire model. Even so, it reinforces the central finding. The safety margin is adequate only when the building is lightly occupied, and it becomes critical under the crowd conditions that a popular weekend market regularly experiences. The pressure on that margin comes from the same source identified throughout this study, the uneven loading of the corner staircases that lengthens the required safe egress time, not from the fire behaviour itself.

Scenario 4: Optimized Vertical-Access Layout

The final scenario evaluated an optimized layout in which an additional staircase was introduced adjacent to the primary front exit (Figure 15), the position that minimises the travel distance between the vertical core and the point of discharge, and given a widened flight. Occupant populations, profiles, and movement parameters were held identical to the existing-condition scenarios, so that any change is attributable to the added, exit-adjacent stair alone. The optimized layout improved egress performance at every occupancy level (Table 4). The movement-based egress time fell from 152 to 141 seconds at low occupancy, from 232 to 206 seconds at normal occupancy, and from 272 to 248 seconds at peak, a reduction of roughly seven to eleven percent. The share of occupants held in congestion for more than sixty seconds fell from 23.7 to 21.4 percent at peak, and the 95th-percentile exit time from 230 to 202 seconds. Congestion remained concentrated on the floor circulation rather than the stair flights, but its magnitude declined, consistent with the shorter approach created by placing the new stair beside the exit.

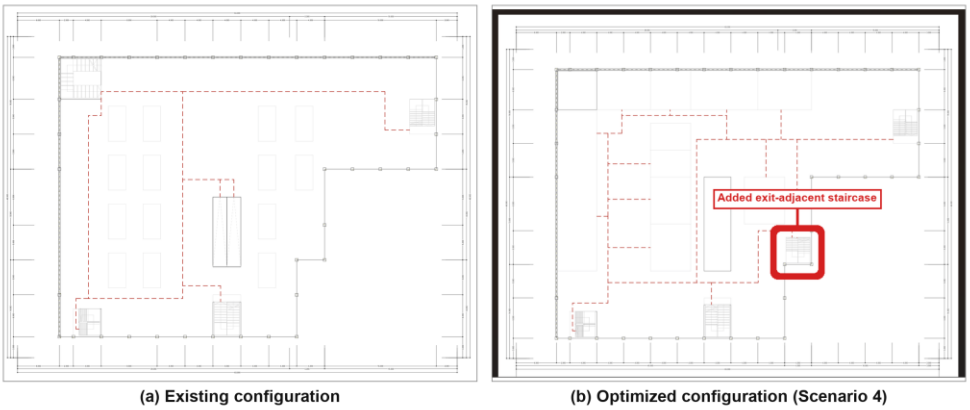


Figure 15. Typical Market-floor Plan of the Existing (a) and Optimized (b) Configurations for Scenario 4

Table 4. Egress Performance of the Existing versus Optimized Vertical-access Layout, Evaluated against a 300-second ASET Benchmark

Scenario	RSET existing(s)	RSET optimized(s)	Change	Safety factor existing	Safety factor optimized
Low	152	141	-7.2%	1.97	2.13
Normal	232	206	-11.2%	1.29	1.46
Peak	272	248	-8.8%	1.10	1.21

Correspondingly, the peak safety factor rose from 1.10 to 1.21 and the normal case from 1.29 to 1.46, although both remain below the 1.5 target. Notably, an earlier variant that placed the added stair in the peripheral western zone, far from any exit, produced no such improvement, underscoring that the position of the stair relative to the exit, and not its mere addition, is what governs the gain. As with the existing-condition scenarios, these Scenario 4 results come from single simulation runs, so the reported improvements are indicative in magnitude; Section 3.12 sets out what follows from that.

Limitations of the Study

Three limitations qualify the findings above. The first, and the most consequential for the safety verdict, is that no site-specific fire and smoke model was built. The available safe egress time used here is a benchmark of about 300 seconds drawn from published values for comparable multi-story commercial occupancies (Society of Fire Protection Engineers (SFPE), 2016; Jiang *et al.*, 2025), not a measured tenability limit for this building. The true ASET at Pasar Prawirotaman depends on its fuel load, compartmentation, floor-to-floor heights, and smoke-management provisions, and could be materially shorter or longer than the benchmark adopted. The safety factors in Table 3 and Table 4 should therefore be read as an indicative ranking across scenarios and layouts rather than as a compliance determination and coupling the

evacuation model with a Fire Dynamics Simulator or PyroSim fire model is the necessary next step before any regulatory conclusion is drawn.

The second limitation concerns the simulation protocol. Each scenario was run once, so the reported egress times carry no estimate of between-run variability. Agent-based models are stochastic, and repeated runs would be needed to report a mean and a confidence interval for RSET, and to establish whether the seven to eleven percent improvement attributed to the optimized layout in Section 3.11 exceeds run-to-run noise. The direction of that improvement is supported by the contrast with the peripheral-stair variant, which produced no gain at all, but its precise magnitude should be treated as provisional.

The third limitation lies in the occupant inputs. Walking speeds, stair-descent speeds, and the 45 to 120 second pre-movement window were taken from published reference values (Society of Fire Protection Engineers (SFPE), 2003; Kuligowski *et al.*, 2013, 2014) and calibrated to the observed demographic profile, rather than measured on site through an evacuation drill or a behavioural survey; the demographic split itself rests on systematic observation rather than a census of occupants. Exit choice was modelled through Pathfinder's default steering behaviour, which reproduces convergence on familiar routes but does not represent smoke-driven route abandonment, social influence, or staff intervention, all of which are known to shape exit selection (Lovreglio, Fonzone and dell'Olio, 2016; Zhu *et al.*, 2020). Finally, the model assumes that all four staircases remain usable throughout the evacuation; a fire that blocked the dominant staircase would produce a materially different result and is not covered by the scenarios reported here.

CONCLUSIONS

This study set out to test whether the emergency evacuation performance of Pasar Prawirotaman meets accepted life-safety standards, and how its vertical access layout shapes that performance. Agent-based simulation of three occupancy scenarios shows that the building can be cleared, but that the time and crowding involved rise steeply with occupancy. Movement-based egress times of 152, 232, and 272 seconds, which extend to an estimated 5.5 to 7.5 minutes once detection and pre-movement are included, are accompanied by a nearly fourfold rise in individual congestion. Set against a conservative literature-based available safe egress time of about 300 seconds, the safety factor falls from 1.97 at low occupancy to 1.29 at normal and 1.10 at peak, so the ASET > RSET criterion is satisfied with an adequate margin only when the building is lightly occupied. Because that benchmark is drawn from published values for comparable occupancies rather than from a site-specific fire model, this verdict is an indicative ranking rather than a compliance determination, and it should not be read as either certifying or condemning the building until a coupled fire and smoke simulation has been carried out. The core problem is not a shortage of stairs but their uneven use. Occupants converge on one staircase and one exit that together carry the majority of the building, while the remaining corner routes stay underused, and the upper leisure floors and the slowest-moving occupants bear the greatest delay.

On this basis the study tested an optimized layout in which an additional staircase was placed adjacent to the primary exit and widened. This intervention reduced the required safe egress time by seven to eleven percent across all occupancy levels and raised the peak safety factor from 1.10 to 1.21, whereas an earlier variant that added the same stair in the peripheral western zone, far from any exit, produced no improvement. Egress performance is therefore governed by the position of vertical access relative to the exits, not by the number of stairs alone. Because the peak safety factor still falls short of the 1.5 target, exit-adjacent stair provision is necessary but not sufficient: it should be combined with wider corridor approaches and clearer wayfinding that distribute occupants across all stairs from the moment of alarm, together with evacuation planning that gives explicit priority to the upper floors and to elderly and load-carrying occupants, who are the most exposed to the bottleneck.
To the authors' knowledge this is one of the first performance-based evacuation assessments of a revitalized Indonesian public market to combine Pathfinder agent-based simulation with an ASET-RSET safety-margin analysis, and the first evacuation study of Pasar Prawirotaman. Its wider value lies less in the specific times reported than in the design lesson they isolate. Indonesia's market-revitalization programme has produced many multi-story markets sharing the same configuration: a stall-dense lower market, leisure floors above, vertical cores at the perimeter, and lifts and escalators withdrawn from service the moment an alarm sounds. For those buildings, the finding that egress is governed by the position of vertical access rather than its quantity converts an expensive remedy, adding staircases, into a cheaper and more effective one, placing them where the exits already are. Design review for such projects should accordingly test the stair-to-exit relationship explicitly, rather than treating the count and clear width of stairs as sufficient evidence of egress adequacy.

These conclusions carry the limitations set out in Section 3.12: the available safe egress time is literature-derived rather than site-specific, the scenarios rest on single simulation runs, and the occupant parameters are calibrated from published values and systematic observation rather than measured in a drill. Coupling the evacuation model with a site-specific fire and smoke simulation, repeating each scenario to establish confidence intervals, and validating the pre-movement and walking-speed assumptions against an observed evacuation drill would allow the indicative safety margins reported here to be converted into a firm compliance judgement. The approach demonstrated here nonetheless offers a replicable, evidence-based method for evaluating and improving the evacuation safety of revitalised public markets in Indonesia.

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