DISASTER MANAGEMENT IN FRESH-FOOD MARKETS: USING A MICROSCOPIC TRAFFIC SIMULATION

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Abstract

This study aims to 1) analyze and model the microscopic movement behavior of people in a typical fresh market, and 2) develop and evaluate an evacuation model for emergency situations (e.g., fire, earthquake) within fresh market areas to identify critical points and propose market management strategies during emergencies. The study developed and applied the Social Force Model (SFM) via PTV Viswalk to simulate evacuation behavior in Thai fresh markets. The research designed and evaluated the effectiveness of three market layout improvement measures: (1) removing stalls, (2) widening walkways, and (3) combining both measures. Simulation results indicate that the third measure (combining both) is the most effective, reducing the maximum evacuation time by 50% (from 420 seconds to 210 seconds) for 3,000 people, and by 38.5% (from 260 seconds to 160 seconds) for 1,500 people. This reduction is significantly higher than using only stall removal (30.9%) or only walkway widening (28.6%). Furthermore, the model clearly identified bottlenecks at main intersections and accumulation points before emergency exits. The findings provide guidance for designing emergency escape routes, establishing safety standards, and conducting effective evacuation drills that align with the actual behavior of people in fresh market areas.

Keywords: social force model, PTV Viswalk, Fresh-Food Market, evacuation, microscopic traffic

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Introduction

Managing crowded public spaces during emergencies is a critical issue that has gained significant attention, especially concerning fresh markets. These markets are vital economic and social centers that not only serve as places for commerce and community income but also attract large crowds daily. This makes them highly vulnerable to severe damage from sudden disasters like fires or earthquakes. Given their complex physical layouts, dense product arrangements, and the diverse behaviors of people, understanding movement patterns within these spaces is essential for effective disaster planning and impact mitigation.

The vulnerability of Thai fresh markets is clearly evident from several real-life incidents. For instance, the fire incident at the old In Buri Market in Sing Buri Province in August 2023 saw the rapid spread of flames across more than 34 wooden shophouses, resulting in one fatality and affecting over 60 people. The fire started from an electrical wire that ignited and quickly spread in the congested area (Thairath, 2023). A similar case is the fire at the Pak Thong Chai Community Market in Nakhon Ratchasima Province in 2022, which resulted in the death of an elderly woman and the damage damage to over 10 dwellings, with estimated damages exceeding 70 million baht (Thai PBS News, 2022). This market had previously suffered recurrent fire incidents in 2011, and a systemic solution remains absent. Meanwhile, a fire incident at the Si Mum Mueang Market in Bangkok in the same year caused the death of a four-year-old girl due to asphyxiation, as smoke accumulated in the enclosed and congested space, preventing officials from reaching her in time (PPTV, 2022). Even the risk of earthquakes must be considered. While there are no past reports of fresh markets being directly damaged by earthquakes, the recent seismic activity in late 2023—with an epicenter in Laos and Loei Province—was perceptibly felt in many areas of Bangkok, including high-rise buildings and some residences (Thairath, 2023). This demonstrates a clear trend of increasing risk and underscores that the capital area is not as secure from natural disasters as previously believed. Given the nature of many market structures, particularly fresh markets built with wooden frames or old commercial buildings not designed to withstand seismic forces, the congestion of the operational space combined with the lack of engineering reinforcement in old market buildings could lead to a "domino collapse" if a moderate-sized earthquake occurs in the future. This risk highlights the urgent need for preparedness and disaster management plans for fresh market areas in various disaster scenarios.

However, the literature review indicates that research concerning disaster management in fresh markets remains limited, a situation contrary to the clearly increasing risks. Both the Food and Agriculture Organization of the United Nations (FAO, 2023) and Reddy, Singh, and Anbumozhi (ERIA, 2016) have reported and emphasized the high vulnerability of fresh markets in the Southeast Asian region to natural hazards (such as floods and fires) and pointed to the urgent necessity of developing local disaster management plans specific to the context of fresh food markets. Most existing research focuses on broad contexts (Macro-level) or, even when addressing micro-level risks, tends to focus on static factors in different contexts. For instance, Hatmoko and Larassati (2021) focus on identifying major fire, safety, and structural vulnerabilities; these works do not incorporate aspects of real-time crowd behavior or spatial dynamics necessary for micro-level emergency evacuation planning. Similarly, Widyajayanti et al. (2021) examined flood abatement in market areas through physical infrastructure planning, without addressing the dynamic movement patterns of market users. Even within the Thai context, research such as Yamuang et al. (2023) tends to rely on static community-level assessments, rather than considering the internal and temporal dynamics of fresh market environments. Nevertheless, these studies cannot genuinely reflect the unique characteristics of highly dynamic Thai fresh markets, as these markets involve continuous physical changes and fluctuating pedestrian density throughout the day. Consequently, the research gap lies in the dimension of micro-level crowd behavior analysis. Specifically, research linking crowd behavior with market spatial planning to accommodate emergencies remains scarce and lacks in-depth case studies on highly transient fresh markets, such as those found in Thailand.

Therefore, this research aims to fill that knowledge gap by analyzing and developing a microscopic pedestrian movement model within a fresh market. We will use the Social Force Model (SFM) with the PTV Viswalk software, an effective tool for simulating how people move in crowded areas (Helbing & Molnár, 1995; PTV Group, 2024). The goal is to gain detailed insights into movement patterns in both normal conditions and simulated emergency scenarios. The analysis will help us evaluate the efficiency of current evacuation plans, identify bottlenecks and physical obstacles, and lead to the development of more appropriate and effective area management and disaster response strategies.

Research Objectives

1. To analyze and create a micro-level model of pedestrian behavior within a fresh market under normal circumstances.

2. To develop and evaluate an evacuation model for emergency disaster scenarios (e.g., fire and earthquake) within a fresh market to identify critical points and suggest management guidelines.

Scope of Research

This study focuses on evaluating and developing a pedestrian model for a fresh market. The study area is Min Buri Market in Bangkok. Data collection was conducted from August to October 2024. The scope of the data includes: (1) physical information about the market, such as its layout, walkways, main entrances and exits, and store locations; (2) pedestrian behavior data, including volume, speed, and time spent shopping. The results of this study will focus specifically on analyzing pedestrian behavior and proposing physical improvements to enhance evacuation efficiency.

Materials and methods

1. Review of Theoretical Concepts and Development of the Study Framework: In this study, the research team defined its approach and data collection into two parts: (1) data on the physical characteristics of the market and (2)data on pedestrian movement behavior. This information was used to develop a market traffic model with the PTV Viswalk software. The study reviewed pedestrian behavior, a key component in traffic system planning and design. The fundamental principles for analyzing pedestrian traffic are often based on a microscopic level. Khisty & Lall (2003) comprehensively defined and presented important variables for pedestrian traffic analysis, which are divided into six main categories: pedestrian speed, pedestrian flow rate, unit width flow, platooning, pedestrian density, and pedestrian space. Furthermore, a pedestrian's body shape also influences the determination of space required for comfort and safety. This is accurately and significantly referenced from the elliptical area surrounding a person's body, which is matched by detecting the shoulder's cross-sectional points between adjacent frames (Weiyao & Mingliang, 2016). Examples include shoulder width and body depth. Such

models are often used in spatial design models for areas like walkways, footbridges, escalators, and transport station spaces to align with real-world usage and to appropriately assess density or level of service, as shown in Figure 1.

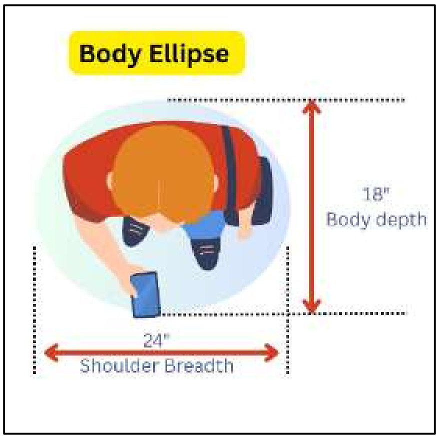

Figure 1 Pedestrian Space Requirements (Body Ellipse)

Source: Adapted from (Fruin, 1971)

Pedestrian movement simulation requires models that reflect behavior and interactions in a real-world environment. The Social Force Model (SFM) is one of the most widely accepted approaches for explaining pedestrian movement at a microscopic level.

The SFM was developed based on the fundamentals of Newtonian mechanics. Helbing & Molnár (1995) proposed a concept that likens a pedestrian's movement to a particle influenced by various forces. These include a driving force that arises from the pedestrian's intention to move towards a destination, a repulsive force from obstacles or other individuals, and a social attractive force, such as moving together in a group. The Social Force Model represents the summation of these forces: self-propulsion, the interaction between individuals, and forces from obstacles, as shown in the following

equation: is $F_i = \frac{m_i\left(v_i^{0(t)} - v_{i(t)}\right)}{\tau_i} + \sum_j F_{\{ij\}} + \sum_W F_{\{iW\}}$

The SFM model can accurately simulate self-organization behaviors and responses to crowded environments (Bakar et al., 2018). The various factors used in the model and the characteristics of pedestrian interactions within the SFM can be shown as in Figure 2.

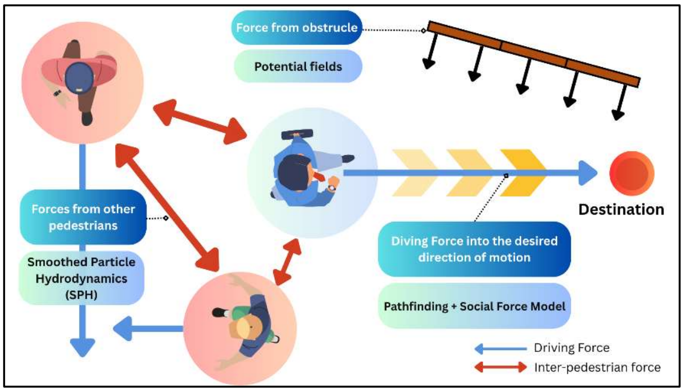

Figure 2 Pedestrian Interactions in the SFM

Source: Adapted from Laufer (2009)

Furthermore, a review of research on pedestrian movement behavior in emergency management found that the SFM concept is particularly promising and well-suited for simulating evacuation behavior within the context of Thai fresh markets. This is because the SFM concept considers the internal driving force of individuals, the repulsive force between people and obstacles, and attractive force at a microscopic level to create density maps and evaluate evacuation routes under crowded conditions. This approach differs from other methods like Agent-based models (Malleson et al., 2020; Xiong et al., 2012) or Smoothed Particle Hydrodynamics (SPH) (Toll et al., 2021), which tend to focus on crowd aggregation without fully accounting for interpersonal forces. Therefore, the SFM is considered more appropriate for simulating dense crowds in emergency situations and for evaluating optimal evacuation routes under crowded conditions.

2. On-site Field Survey: The research team conducted a field survey at Min Buri Market. Data collected included physical characteristics such as the layout, usable areas, entrances, exits, and stall sizes to simulate the actual environment. Pedestrian traffic data, including the number of people entering and exiting, walking speed, and average time spent shopping, were also gathered. This data was then used to develop and calibrate the microscopic traffic model, as shown in Figure 3.

Figure 3 Study Area and Environment inside Min Buri Fresh Market.

3. Model Development: The research team developed a pedestrian traffic model based on the physical data from the field survey. Pedestrian volume and behavior data were imported into the model to reflect real-world conditions. The simulation of market walking behavior applied movement and density data surveys (Siddharth & Vedagiri, 2023) by finding optimal parameters through genetic algorithms and non-linear regression to adjust key values. These values include **τ** (reaction time), A_social and B_social (social force parameters), **λ** (direction parameter), and VD (vision distance) to match actual behavior (Seer et al., 2014).

4. Model Calibration and Validation: The researchers calibrated the model by comparing simulated pedestrian behavior with real-world data to enhance the accuracy of performance evaluation. Then, the model was validated by evaluating the results and performance indicators against real conditions to ensure it can effectively assess and plan market space management.

The calibration and validation process involved comparing simulation results with survey data using average speed, density, and flow patterns as parameters. The model's accuracy was also tested using Root Mean Square Error (RMSE) and Mean Absolute Percentage Error (MAPE), showing differences between the model and survey data with an RMSE of 15.86 persons/hour and a MAPE of 5.50% for inbound flow, and an RMSE of 16.62 persons/hour and a MAPE of 5.61% for outbound flow, before being applied to different market scenarios (Xi et al., 2010; Silvera et al., 2020; Yang et al., 2024). For simulating walking behavior in the study area, specific calibrated parameter values were used to reflect the unique environment and behavior of market-goers: **τ** = 0.5 seconds, A_social = 2.50 N, B_social = 0.350 m, λ = 0.25, VD = 4.0 m, Noise = 2.0, and a desired speed = 0.56 m/s. These values reflect the slow walking pace, frequent stops for shopping, and acceptance of crowding in a confined space. Details of this behavior are shown in Figure 4.

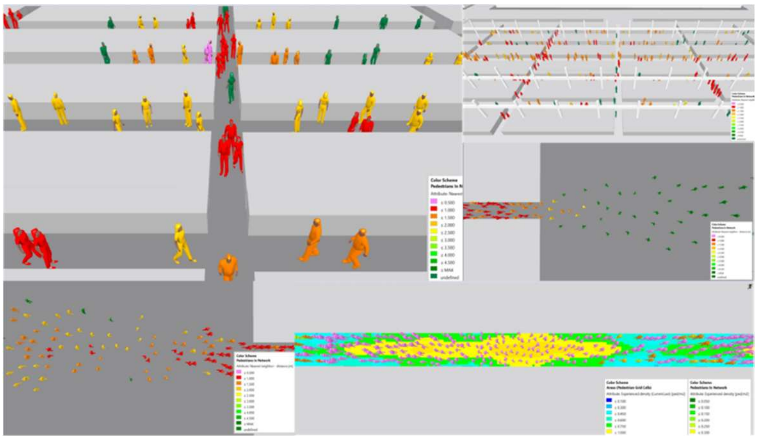

Figure 4 Calibrated market walking behavior from the developed model.

5. Model Analysis and Evaluation: This study evaluates pedestrian traffic performance in the current situation to analyze the impact of physical characteristics and pedestrian volume. It uses Static indicators to measure the state of the area, density, and pedestrian speed, as well as Dynamic indicators to assess the impact on evacuation during a disaster by analyzing the evacuation time. This analysis will support improvements to the environment and the effective management of space usage.

Ethical Approval: This study utilizes data originally collected under the research project approved by the Ramkhamhaeng University, Approval No. RU-HRE 64/0161. The present article conducts additional analyses and scenario-based simulations using this approved dataset without involving any new data collection. All procedures remain within the ethical scope of the originally approved protocol.

Results

The evaluation of the pedestrian traffic model in the market revealed that the maximum number of people was 228, which aligns with the market's normal capacity for a Level of Service (LOS) A-B as per design standards for commercial areas (approximately 25-35 sq ft/person or 2.3-3.3 sq m/person) (Fruin, 1971).

Pedestrian Behavior Analysis

Density analysis showed pedestrian concentration at the market's center, a key junction and major commercial area. The evaluation of walking speed found that on the open walkway, the average speed was 4-6 km/h, which is within the normal range for commercial areas, consistent with studies by Teknomo (2002) and the free-flow speed analysis by Seyfried et al. (2005). In front of stalls, the speed dropped to 0-2 km/h, reflecting browsing behavior, a finding consistent with Hoogendoorn & Bovy (2004), who noted a 60-70% reduction in speed in areas of interest. This foundational data served as the parameters for simulating evacuation scenarios and for future planning and management improvements.

Proposed Solutions for Reducing Evacuation Time

To analyze ways to reduce evacuation time, the researchers considered the physical constraints affecting pedestrian flow in emergencies and simulated three management approaches to compare their impact on Maximum Evacuation Time.

Approach 1: Removing Barriers

The field survey revealed that while barriers around the market help control entry and exit under normal conditions, they become obstacles during an emergency. This aligns with safety design principles which state that obstacles can reduce evacuation efficiency (Kinsey et al., 2019; Korhonen & Hostikka, 2009). The researchers proposed removing these barriers to increase crowd mobility during evacuation. The study's findings suggest that removing the barriers would significantly reduce evacuation time and the risk of bottlenecks.

Approach 2: Widening Walkways

The field survey found that the main walkways are 1.50-2.0 meters wide, which meets the standard for emergency exits as per Ministerial Regulation No. 55 of the Building Control Act B.E. 2522 and the NFPA 101 Life Safety Code (NFPA, 2021). However, this width may cause bottlenecks in an emergency. The simulation results indicated that the central area, where four market entrances intersect, has the highest pedestrian density, significantly increasing evacuation time. The researchers proposed widening the main walkways to 3.00 meters, which would effectively reduce evacuation time, especially during peak hours.

Approach 3: Removing Barriers and Widening Walkways

Based on the synergistic effect in safety engineering, which posits that combining multiple measures yields better results than using a single measure, this approach combines the removal of barriers around the market with the widening of the main walkways from 1.50 meters to 3.00 meters. This would increase the channels for pedestrian flow and resolve structural constraints. It is expected to significantly reduce density, the occurrence of bottlenecks, and evacuation time compared to both the baseline and the single-measure approaches.

Analysis and Comparison of Evacuation Density

The study set the number of people in the market at 1,500, which is 6.6 times the normal capacity. This was done to simulate a critical scenario that might occur during festivals or special events with high density and bottlenecks, which could impede evacuation. The simulation results showed a clear difference between the baseline case and each management approach, as illustrated in Figure 5, clearly identifying critical points affecting evacuation efficiency within the market.

Baseline Case

In the baseline simulation, most areas within the market had a density of ≤ 0.3 persons/sq.m., which is considered a smooth flow for pedestrian movement. However, along the main walkways and near the exits, density values ranged from 0.6-1.0 persons/sq.m., signaling the beginning of crowd accumulation during evacuation. The central area of the market, in particular, connected to main routes with a geometric bottleneck (Still, 2000), which occurs when the circulation area suddenly decreases, potentially causing delays or blockages in high-density emergency situations.

Approach 1: Removing Barriers

Removing the barriers around the market to increase the number of exit routes significantly improved density distribution. The simulation found that most areas had a density of ≤ 0.3 persons/sq.m., and the number of accumulation points near exits was reduced compared to the baseline. This improvement allowed the crowd to move out of the area continuously, reducing accumulation at critical points and lowering the risk of bottlenecks, a common problem during evacuations.

Approach 2: Widening Walkways

Widening the main walkways from 1.50 meters to 3.00 meters increased the capacity to handle a higher volume of pedestrians and reduced accumulation on the main routes. The simulation results showed a clear decrease in average density, with most areas at ≤ 0.75 persons/sq.m. (blue-green). No areas with a density exceeding 1.0 person/sq.m. were found, indicating a reduced risk of evacuation delays. However, some spots near the market's center still showed slightly higher density values than Approach 1, suggesting that widening walkways alone may not be sufficient to disperse a very large crowd.

Approach 3: Removing Barriers and Widening Walkways

The integrated approach, combining the removal of barriers with the widening of the main walkways, yielded the best results. Most areas had a density of ≤ 0.3 persons/sq.m., and virtually no accumulation points were observed. The simulation showed the greatest reduction in both average and maximum density and completely eliminated bottlenecks on the main routes and near the exits. This approach provides the highest level of evacuation efficiency and safety, even in situations where the number of people is well above the market's normal capacity.

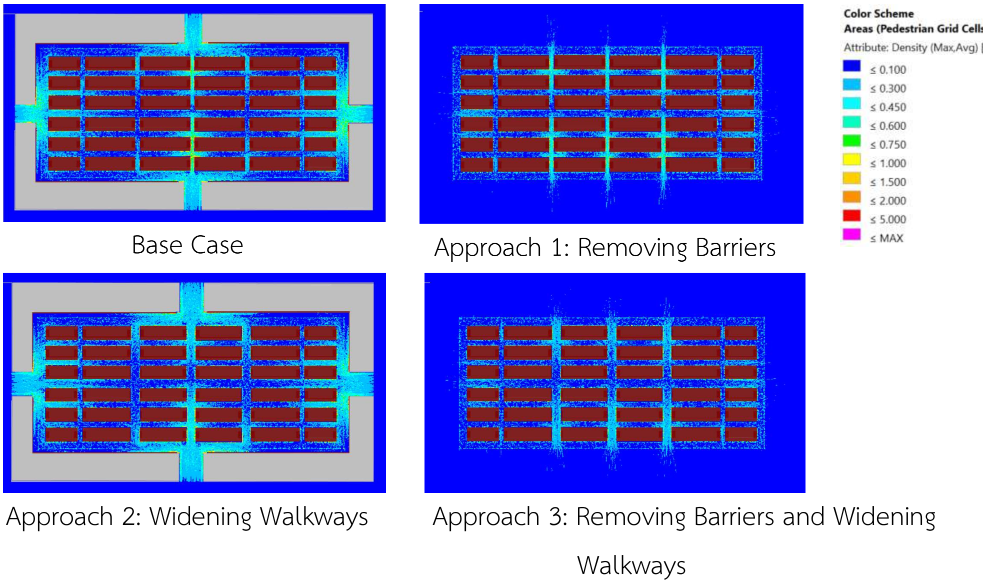

Figure 5 Comparison of pedestrian density distribution for each approach.

Analysis and Comparison of Maximum Evacuation Time

The study analyzed the relationship between the number of people in the market and the Maximum Evacuation Time, using the principle of RSET (Required Safe

Egress Time) compared to ASET (Available Safe Egress Time) to evaluate safety (Gwynne & Rosenbaum, 2016). Four scenarios were compared: the baseline case, removing barriers, widening walkways, and a combination of both, as illustrated in Figure 5.

From the data, the baseline case was found to have the highest maximum evacuation time. With 3,000 people, the maximum time was 420 seconds, which exceeds the recommended safety standard of < 300 seconds for public buildings according to NFPA 101. With 1,500 people, the time was 260 seconds.

Conversely, the removing barriers approach successfully reduced the maximum evacuation time. For 3,000 people, the evacuation time decreased to 290 seconds, a reduction of approximately 30.9% compared to the baseline, which aligns with Kleinrock's (1975) Queuing Theory, which states that increasing the number of service channels reduces the waiting time in the system. For 1,500 people, the time was reduced to 185 seconds, a decrease of approximately 28.8%.

For the widening walkways approach, with 3,000 people, the maximum evacuation time was 300 seconds, a reduction of about 28.6% from the baseline. This is consistent with Weidmann's (1993) Flow-Density Relationship, which states that increasing width linearly increases flow. With 1,500 people, the time was 200 seconds, a reduction of approximately 23.1%. The result was similar to the "removing barriers" case but slightly less effective across all population sizes.

The best result was found in the combined approach of removing barriers and widening walkways. For 3,000 people, the maximum evacuation time was reduced to just 210 seconds, a decrease of 50% from the baseline, which places it within standard safety criteria and is consistent with the principle of synergistic effects from combining measures. For 1,500 people, the evacuation time was reduced to 160 seconds, a decrease of approximately 38.5% from the baseline.

Based on this comparison, it is clear that both removing barriers and widening walkways are effective in reducing evacuation time. The combined use of both measures provides the best results for reducing crowd density and increasing mobility, which is critically important for managing evacuations in crowded market areas during an emergency.

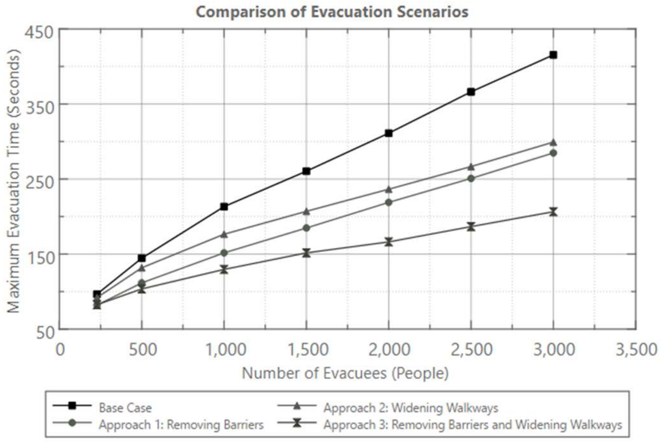

Figure 6 Comparison of maximum evacuation time under each management approach.

Figure 7 presents the Speed-Density, Speed-Flow, and Flow-Density relationships for pedestrians in the Base Case and improved scenarios. The Flow-Density graph (bottom) shows that all improvement scenarios achieved higher maximum flow than the Base Case (~7.5 p/s), with the combined strategy (Approach 3: Removing Barriers and Widening Walkways) reaching the highest flow (~14.4 p/s) and Approach 2 (Widening Walkways) also improving capacity (~10.35 p/s) over Approach 1 (Removing Barriers). The Speed-Density (top-left) and Speed-Flow (top-right) graphs indicate that pedestrians maintained higher speeds and flow rates across all densities in the improved scenarios, with Approach 3 being particularly effective (~1.8 m/s at 0.20 p/m² compared to approximately 1.4 m/s in the Base Case). These findings align with previous studies using VISSIM and other simulation tools, which show that while individual strategies can enhance pedestrian movement, a combined approach provides the greatest improvement in flow efficiency and evacuation capacity (Elmitiny, Ramasamy, & Radwan, 2007; Lee, Lee, & Jun, 2018; Ding, Xu, Xie, et al., 2023; Wang, Zhu, & Xiao, 2023).

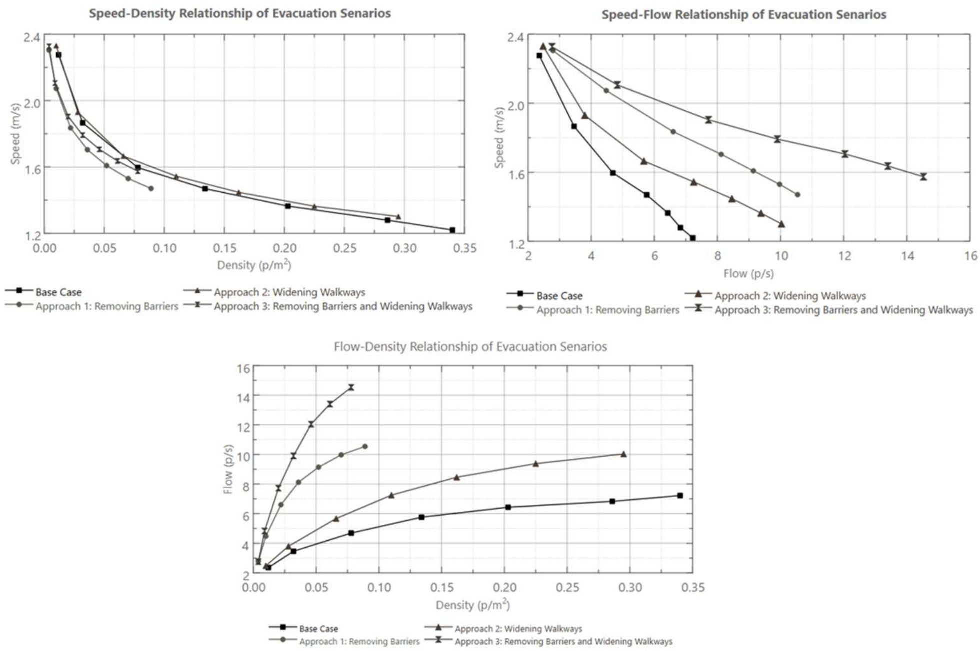

Figure 7 Speed-Density, Speed-Flow, and Flow-Density of pedestrians under the Base Case and improvement scenarios.

Discussions

This study had two main objectives: (1) to analyze and create a micro-level model of pedestrian behavior in a fresh market under normal conditions, and (2) to develop and evaluate an evacuation model for emergency scenarios such as fire, flash floods, and earthquakes in order to identify critical points and suggest area management guidelines.

For the first objective, the survey of Min Buri Market found that people's walking speed slowed down to 0–2 km/h near stalls, compared to 4–6 km/h on main walkways. This slowdown caused bottlenecks in the center of the market. The developed model successfully identified these critical points, which can be used to inform future improvements in area management. The second objective, the study evaluated four scenarios: the baseline case, removing barriers, widening walkways, and a combined approach. The simulation results showed that single measures, such as removing barriers or widening walkways, reduced evacuation time by approximately 23–31%, but some accumulation points remained. By contrast, the integrated approach—combining barrier removal with walkway widening—yielded the most effective outcome. It reduced the maximum evacuation time by up to 50% (for 3,000 people, the time was reduced from 420 to 210 seconds) and almost entirely eliminated bottlenecks and density issues in the area.

This study demonstrates that bottlenecks in the market are primarily caused by people slowing down to shop. The model confirmed that removing barriers in conjunction with widening walkways is the most effective solution, reducing evacuation time by up to 50%. This constitutes the key recommendation for improving market safety in emergencies, especially where encroaching stalls and vehicle parking obstruct main traffic routes.

Practical implications:

The findings indicate that most evacuation routes in the market are narrow, and the presence of barriers—intended to direct pedestrian flows or maintain order—creates bottlenecks at key junctions. These barriers can become significant obstacles during emergency evacuations. Therefore, market layouts should be improved by removing unnecessary barriers and widening main walkways to allow for safe and efficient movement. Such measures should also be considered as part of disaster management standards, ensuring that designated evacuation routes remain continuous with main walkways for timely egress.

The analysis of user behavior also revealed that delays in finding emergency exits often stem from a lack of clear signage. Accordingly, it is essential to install emergency exit signs and evacuation maps in all key areas, along with an automated alert system. These interventions would significantly improve awareness and reduce evacuation times.

Finally, field experiments indicated that evacuation drills can reduce average evacuation time by more than 20%. Therefore, regular evacuation drills—at least once per year—should be conducted using diverse scenarios such as fire or earthquake events. These drills should assess the readiness of both vendors and market staff, followed by post-drill evaluations using clear Key Performance Indicators (KPIs) to ensure continuous and systematic improvements to evacuation procedures.

Conclusions

This study highlights that bottlenecks in markets are caused by pedestrians slowing down to shop, and demonstrates through the Social Force Model that removing barriers in combination with widening walkways is the most effective intervention. This integrated measure reduced evacuation time by up to 50% and effectively eliminated congestion, thereby providing a robust basis for enhancing market safety in emergency situations. Nevertheless, this study has limitations in fully reflecting the dynamic and ever-changing conditions of real environments. Future research should integrate real-time data collection to capture pedestrian density and movement patterns at different times. By combining such data with AI-based analysis of CCTV footage, model parameters can be refined to better represent actual conditions and adapt to changes in real time.

Furthermore, initial findings suggest variations in speed and movement among different age groups, particularly children and the elderly, who take longer to make decisions and move. Future studies could examine demographic variables in greater detail, including short-distance walking speeds, rest periods during evacuation, and disorientation rates. Such analyses would facilitate the design of tailored evacuation measures and training guidelines for diverse user groups.

Lastly, while this study quantitatively assessed how market layout improvements reduce evacuation time, it did not incorporate a cost–benefit analysis, which is essential for policy-level decision-making. Future research should collect and compare data on implementation costs—including labor, equipment, and maintenance—with the safety benefits of reduced risks to life and property. This would provide a clearer framework for decision-making and support more efficient allocation of resources.

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