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Balancing efficiency and safety in classroom evacuation: An enhanced social force model integrating panic, obstacles, and multi-exit dynamics

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Abstract

This study aims to enhance evacuation efficiency and occupant safety during classroom emergencies. An improved social force model was developed, incorporating dynamic panic evolution, pedestrian interactions with obstacles, and strategies for utilizing multiple exits to more accurately capture complex evacuation behaviors. Simulation experiments systematically varied desired speeds, panic coefficients, and spatial layouts to evaluate their impacts on evacuation time, injury probability, and flow stability. The findings indicate that moderate speeds (around 3 m/s) minimize both evacuation time and injuries, while excessive speeds combined with high panic levels lead to congestion, unstable flows, and an increased risk of injuries, exemplifying the "faster-is-slower" phenomenon. Furthermore, simply adding exits without considering behavioral dynamics does not guarantee improved evacuation performance. The study concludes that successful evacuations require the coordinated management of movement behaviors and strategic spatial design. Practical implications include providing a decision-support tool for school administrators and safety engineers to optimize classroom layouts, conduct more realistic evacuation drills, and implement behavior-informed emergency response plans that enhance disaster resilience in high-density educational environments.

Keywords: Desired speed, Emergency evacuation, Emergency management, Panic coefficient.

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1. Introduction

On March 28, 2025, a catastrophic magnitude 7.7 earthquake struck central Myanmar, with the epicenter near Mandalay. This disaster resulted in over 3,600 fatalities and more than 5,000 injuries, severely damaging infrastructure, including schools and healthcare facilities [1]. The tremors were felt across neighboring countries, notably in Thailand, where several schools reported structural damage such as cracked walls and ceilings, leading to temporary closures and heightened concerns about building safety. The earthquake's impact on Thailand underscores the transboundary nature of seismic risks in Southeast Asia. Many school buildings in Thailand were constructed without stringent seismic considerations, making them vulnerable to distant yet potent earthquakes. This event highlights the urgent need for comprehensive disaster preparedness strategies, including the development of robust emergency evacuation models tailored to school environments. Incorporating lessons from the recent Myanmar earthquake, this study aims to enhance the safety and efficiency of school evacuations in Thailand. By integrating advanced simulation models that account for panic behavior, physical obstacles, and multiple exit dynamics, we seek to provide actionable insights for policymakers and educators to bolster disaster resilience in educational settings.

Earthquakes represent substantial school safety hazards, especially threatening classroom students, primarily because earthquakes occur abruptly, providing limited time for effective evacuation responses [2, 3]. Schools represent densely populated environments where young and potentially vulnerable individuals are confined within limited spaces, making the provision of clear guidance and well-designed evacuation procedures critically important [4, 5]. Therefore, ensuring swift and orderly movement from classrooms to designated safe areas is vital to reduce the risk of injuries and fatalities. This urgency emphasizes the critical importance of carefully planned evacuation pathways and precise estimates of evacuation timing [6, 7]. Previous studies have consistently highlighted that the layout and connectivity of school buildings significantly influence evacuation effectiveness, evacuation durations, and overall emergency response efficiency [8, 9]. Specific elements, such as corridor widths, stair configurations, classroom door placements, and proximity to exits, directly impact evacuation flows, congestion patterns, and students' ability to evacuate quickly and safely [10, 11]. Consequently, thoughtfully incorporating these architectural elements into evacuation planning is essential to ensuring the highest level of safety during earthquake emergencies.

Advanced computational techniques particularly agent-based modeling (ABM) and Geographic Information Systems (GIS), have been extensively employed in a collaborative effort to deepen the understanding and enhance the effectiveness of evacuation planning. These methodologies allow detailed simulations of pedestrian movement, identification of critical congestion points, and evaluation of various evacuation scenarios within complex school settings [12-14]. ABM simulations, in particular, offer valuable insights by illustrating how individual student behaviors, movement speeds, and interactions collectively influence evacuation outcomes [15]. Additionally, GIS-based analyses provide precise mapping and clear visualization of evacuation paths, guiding planners on necessary route improvements and effective evacuation management strategies. Based on the social force model combined with panic effects [16-18], the students' earthquake emergency evacuation efficiencies are improved to further ensure the safety of students in school.

Despite advances in evacuation planning, traditional approaches often overlook crucial behavioral and psychological factors that influence how students respond during emergencies [2, 19, 20]. Research shows that students may react in various ways, such as hesitating, becoming confused, or experiencing panic, which can significantly hinder evacuation efforts [19]. Furthermore, standard evacuation drills conducted in controlled environments often fail to mimic real emergencies. This discrepancy can lead to overly optimistic estimates of evacuation times and poor route planning [20]. It is crucial to incorporate realistic behavioral factors into evacuation simulations to remedy these issues. These factors should include age-specific decision-making, stress-induced responses, and the impact of peer behavior. Many studies emphasize the importance of continually updating and refining evacuation plans based on insights gained from real-world drills and simulation data. This focus on ongoing updates helps reassure stakeholders about the adaptability of evacuation plans, ensuring they remain effective, context-specific, and responsive to changing behavioral patterns and environmental conditions. Moreover, the implementation of real-time monitoring systems and feedback loops linking practice drills to planning activities has been shown to enhance preparedness and decrease student evacuation times during emergencies [13, 21]. Adopting these iterative and data-driven practices in school emergency planning can significantly improve the practicality and effectiveness of evacuation strategies.

Moreover, international comparative case studies reveal significant differences in evacuation preparedness and response effectiveness, which stem from variations in educational systems, local building codes, and emergency management frameworks. Therefore, examining global best practices offers valuable insights for improving local evacuation strategies and strengthening student safety [3, 4]. The primary objective of this study is to systematically optimize evacuation design and accurately estimate evacuation durations specifically for school classrooms during earthquake emergencies. This study takes a unique approach, incorporating realistic behavioral dynamics, utilizing advanced spatial and computational techniques, and drawing on international best-practice insights. This innovative approach has the potential to substantially enhance school emergency preparedness, improve the efficiency of evacuation protocols, ensure student safety, and strengthen community resilience in the face of seismic hazards.

2. Methodology

2.1. The Social Force Model

In our study, pedestrian evacuation is modeled using an enhanced social force framework, in which each individual is treated as a particle whose motion is governed by a set of differential equations. The fundamental dynamics for pedestrian i are given by Zhou et al. [18].

$$m_i \, {}^{dv_i}/_{dt} = \frac{m_i}{\tau_i}\left(v_{0,i}e_{0,i} - v_i\right) + \sum_{j\neq i} f_{ij} + \sum_W f_{iW} \quad (1)$$

$$ {}^{dr_i}/_{dt} = v_i \quad (2)$$

Where m_i is the mass, $v_{0,i}$ the desired speed, and $e_{0,i}$ the desired direction of pedestrian i. The relaxation time τ_i characterizes the response rate to adjust the actual velocity v_i toward the desired velocity. The forces f_{ij} and f_{iw} represent the interaction forces with other pedestrians and with obstacles (e.g., walls and desks), respectively.

The interpersonal interaction force is modeled as.

$$f_{ij} = A\exp\left(\frac{r_{ij}-d_{ij}}{B}\right) n_{ij} + kg\left(r_{ij} - d_{ij}\right)n_{ij} + \kappa g\left(\left(r_{ij} - d_{ij}\right)\Delta v_{t,ji}t_{ij} \quad (3)$$

Where $d_{ij}=\|r_i-r_j\|$is the distance between pedestrians i and j, r_{ij} is the sum of their effective radii, and $n_{ij}=(r_i-r_j)/d_{ij}$ is the unit vector pointing from j to i. The function g(x)=max(x,0) ensures that repulsive and collision forces act only when pedestrians are overlapping. The constants A and B control the magnitude and decay of the psychological repulsion, while k and κ are the constants for the physical collision (body force) and sliding friction, respectively.

2.2. Enhanced Local Avoidance

A common limitation of the standard social force model is that pedestrians can become "deadlocked" in narrow passages, such as when they are trapped between desks. To overcome this, we augment the self-driven force term by modifying the desired direction when a pedestrian is in close proximity to an obstacle. Let e_{exit} be denoted as the basic exit direction, and let d_{min} be the minimum distance from the pedestrian to any obstacle. When d_{min} is less than a threshold d_{th} (set to 0.5 m in our simulations), we introduce a local avoidance adjustment. Specifically, we compute a tangential direction.

$$e_{tangent} = \begin{bmatrix} -e_{obs,y} \\ e_{obs,x} \end{bmatrix} \quad (4)$$

Where e_{obs} is the unit vector pointing from the pedestrian to the nearest obstacle. In addition, a fixed downward direction.

$$e_{down} = \begin{bmatrix} 0 \\ 1 \end{bmatrix} \quad (6)$$

Which is incorporated to help guide the pedestrian along a potentially less congested path. The new desired direction is then defined as.

$$e_{ewn} = \alpha e_{exit} + \frac{1-\alpha}{2}(e_{tangent} + e_{down}) \quad (7)$$

$$\text{with } \alpha = \min\left(1, {}^{d_{th}}/_{d_{min}}\right) \quad (8)$$

$$e_{new} = \frac{e_{new}}{\|e_{new}\|} \quad (9)$$

The self-driven force is updated accordingly as.

$$F_{drive,i} = \frac{m_i}{\tau_i}(v_{0,i}e_{new} - v_i) \quad (10)$$

This modification enables pedestrians who are trapped in narrow gaps to "side-step" and slide downward, thereby breaking local deadlocks. If a panic coefficient p is incorporated with the social force model, the self-driving force term is modified to reflect not only the "desired" speed but also the level of panic, which amplifies an individual's motivation to move faster. For example, the self-driving force in Equation 10 may be reformulated as:

$$F_{drive,i} = \frac{m_i}{\tau_i}(v_{0,i}(1+p)e_{new} - v_i) \quad (11)$$

With increased panic (p>0), the effective desired speed is higher, thus leading to a stronger self-driving force. Alternatively, the panic coefficient may also be used to scale repulsive forces in Eq. (3) to represent more aggressive interactions in high-panic situations, which is represented as:

$$f_{ij} = A\exp\left(\frac{r_{ij}-d_{ij}}{B/(1+p)}\right) n_{ij} + kg\left(r_{ij} - d_{ij}\right)n_{ij} + \kappa g\left(\left(r_{ij} - d_{ij}\right)\Delta v_{t,ji}t_{ij} \quad (12)$$

Where decreasing the effective B increases the intensity of repulsion when panic is high. The panic coefficient is integrated into the model by scaling the self-driving force as well as adjusting the repulsive interaction terms, thereby capturing the increased urgency and potential for overcrowding under high panic conditions. In summary, incorporating p allows the model to capture the dynamic interplay between desired speed, crowd psychology, and the resulting impact on evacuation outcomes.

2.3. Random Perturbation and Queueing

In addition to the local avoidance adjustment, we incorporate a small random perturbation to the net force when a pedestrian's velocity magnitude falls below a predefined threshold. This perturbation, scaled appropriately, helps to break the symmetry in cases of complete stagnation. Moreover, in the exit region, a queueing mechanism is implemented to ensure that if multiple pedestrians are contending for a narrow exit, only the foremost individual proceeds while the others temporarily reduce their speed or shift laterally, thereby preventing a persistent deadlock at the exit. In this mechanism, a pedestrian's self-driving force based on their position in the queue (or headway) relative to another pedestrian immediately ahead is adjusted. One common formulation is to use a weighting function that scales the desired speed depending on the available gap. For example, let d_i be denoted the distance (or headway) between pedestrian i and another pedestrian in front. Define a weighting function.

$$w_i = \min\left\{1, {}^{d_i}/_{d_{destired}}\right\} \quad (13)$$

Where $d_{desired}$ is the desired (or safe) spacing between pedestrians. The standard self-driving force term in Equation 10 is modified to include the weighting factor w_i as follows.

$$F_{drive,i} = \frac{m_i}{\tau_i}(v_{0,i} w_i e_{new} - v_i) \quad (14)$$

Equation 14 means that if the headway d_i is less than the desired value, then $w_i<1$ and the effective desired speed is reduced, which naturally encourages the formation of an orderly queue. Alternatively, we can explicitly model a braking force when the actual spacing is below a safe threshold. Define the braking force as.

$$F_{break,i} = k_b \max\{0, d_{safe} - d_i\} e_{i,front} \quad (15)$$

Where d_{safe} is a safe spacing, k_b is a braking constant, and $e_{i,front}$ is a unit vector from pedestrian i toward the pedestrian immediately ahead. The overall driving force then becomes the following.

$$F_{drive,i}^{total} = F_{drive,i} - F_{break,i} \quad (16)$$

This additional braking force explicitly reduces the acceleration if the gap is insufficient, helping to prevent overly aggressive forward movement in a queue.

3. Results and Discussion

The simulation domain is a rectangular classroom (20 m × 10 m) with an exit on the right wall. No obstacles are modeled in the room. Pedestrians (N = 30) are randomly distributed in the left part of the room and are governed by the enhanced social force model described above, a model known for its accuracy in predicting pedestrian behavior. The equations are integrated using an explicit Euler scheme with a time step of 0.01 s. For each simulation run, if all pedestrians evacuate before the maximum simulation time is reached, the evacuation time is recorded; otherwise, the maximum simulation time is used. In addition, the number of injured pedestrians (determined by collision forces exceeding a threshold of 1500N [17]) and the pedestrian flow (number of evacuees divided by the actual simulation time) are computed. By the basic social force model described in sections 2.1 and 2.2, our approach effectively addresses the problem of pedestrians getting stuck at the exit. This model provides predictions of evacuation time, injury count, and flow dynamics and offers valuable insights for emergency evacuation planning and seismic disaster mitigation. Figure 1 shows the 30 pedestrians with a desired velocity of 1.5 to escape from the classroom for 5 seconds.

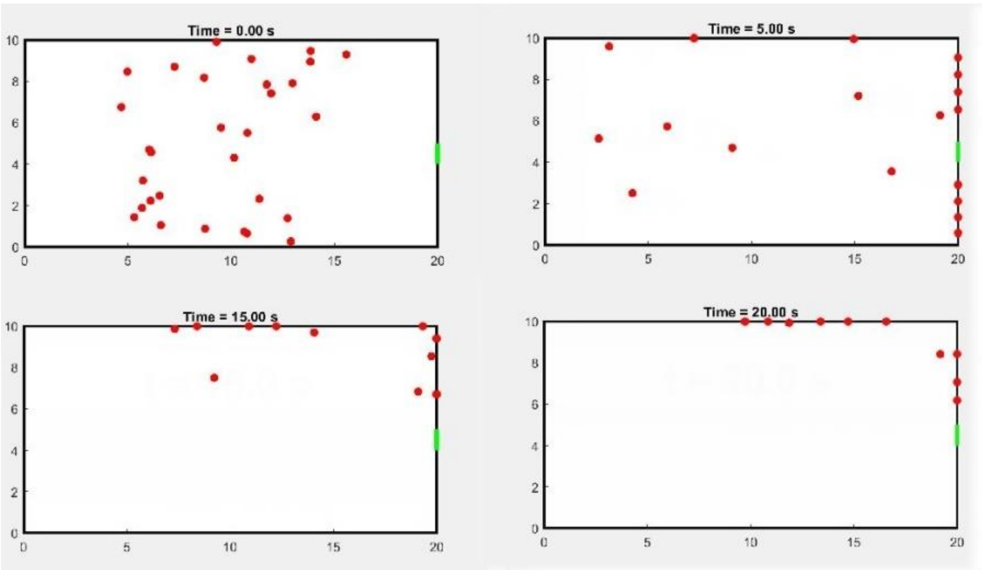

Figure 1.
Progressive Snapshots of a Classroom Evacuation at 0 s, 5 s, 15 s, and 20 s.

Each panel depicts the spatial distribution of evacuees (red circles) with desired velocity 1.5m/s within the classroom at a specific simulation time, with the exit located at the right boundary (green line). As time progresses, individuals move toward the exit, illustrating that movement dynamics evolve over the course of the evacuation.

The ranges of desired velocities are assumed to be from 0.5 to 10m/s. For each desired velocity, we simulate the classroom evacuation 1000 times and calculate the average values for the three parameters described above. Figure 2 shows the simulated results.

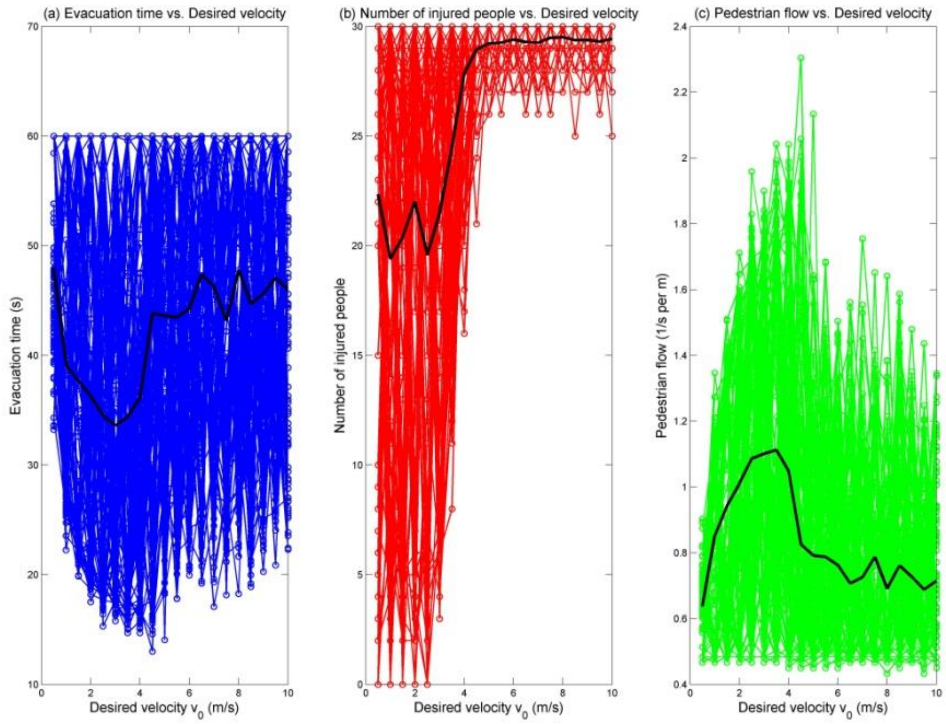

Figure 2.
Evacuation performance metrics from 100 simulation runs of a 30-person classroom evacuation.

The figure plots (a) total evacuation time, (b) injury count, and (c) pedestrian flow rate as functions of the desired speed (v_0) under fixed panic conditions. The black curve represents the average over 100 runs. Notably, the results indicate that when v_0 is approximately 3 m/s, both evacuation time and flow rate are optimized while the number of injuries remains low. These findings underscore the importance of balancing speed and crowd psychology to achieve a safe and efficient evacuation.

Several noteworthy phenomena can be observed from the three graphs (evacuation time, number of injuries, and pedestrian flow concerning the desired speed v_0). There are four primary points discussed as follows. The first one is the evacuation time in Figure 2(a), which does not necessarily decrease monotonically with increasing desired velocity v_0. The evacuation time shown in Figure 2(a) varies significantly with changes in v_0, indicating that even if people desire to move faster (higher v_0), the overall evacuation time does not consistently increase. In some cases, it may even become longer. This fact is common in crowded environments: excessive pushing or clogging cancels out the benefits of increased speed, potentially leading to longer evacuation times or high variability in outcomes. The second point is that injuries fluctuate sharply with speed increases.

The red distribution in the middle panel shows that higher speeds are associated with increased risks of collisions or pushing, resulting in large fluctuations in injury numbers. In specific speed ranges, injuries spike sharply, suggesting that high-speed movement combined with panic can intensify the frequency and severity of collisions without proper guidance. The dense scatter of data points implies that even under the same speed, factors such as initial pedestrian layout, individual reactions, and path choices significantly impact the final injury outcomes. This situation underscores the need for practical crowd psychological guidance and optimized spatial planning for emergency management to reduce collision risks. The third point is that pedestrian flow exhibits complex variations. The green distribution in the right panel reveals that the relationship between speed and flow rate is not linear. While moderate speeds tend to maintain stable and efficient pedestrian flow, high speeds may lead to severe congestion, reducing the throughput efficiency of exits. From this, it can be inferred that evacuation efficiency is poor at very low speeds, but excessively high speeds increase injury risks without necessarily improving flow, highlighting an apparent dilemma. The final point includes recommendations and practical implications based on the simulation of Figure 2. At first, increasing movement speed alone does not necessarily shorten evacuation time. It may, instead, cause serious collisions due to many people moving quickly at once. Evacuation training should promote "moderate and steady speeds" supported by effective crowd flow control measures. The high degree of dispersion in results shows that minor variations, such as initial positions or local bottlenecks, can cause significant differences. Architectural design should optimize both the number and placement of exits and ensure that people can disperse and evacuate in an orderly manner during disasters. High desired speeds are often accompanied by high panic levels, significantly increasing injury numbers. Broadcasting systems, on-site personnel guidance, and pre-drills can help reduce blind rushing and pushing behavior.

In summary, Figure 2 highlights that in disaster scenarios, simply pursuing faster speeds does not ensure safer or more efficient evacuations. Instead, operating within an optimal speed range that suits the environment and crowd psychology, combined with thoughtful spatial configuration and guidance, offers a more effective approach to minimizing injuries and shortening evacuation time. Operating within an optimal speed range that aligns with the environment and crowd psychology, combined with careful spatial configuration and clear guidance, provides a more effective way to minimize injuries and reduce evacuation time. When the desired speed v0 is approximately 3 m/s, a relatively optimal balance is achieved between evacuation time, pedestrian flow, and injury count. This fact suggests that individuals can evacuate efficiently at this speed without causing excessive crowding or high collision risks, thereby reducing the likelihood of injuries, which coincides with previous studies [15, 16]. From the perspective of emergency management and architectural design, this finding holds significant practical value for shaping evacuation strategies: it highlights the importance of promoting evacuation at a moderate speed rather than unthinkingly pursuing maximum speed. Such an approach helps achieve both efficiency and safety during emergency evacuations.

3.1. A Classroom with Obstacles

This section focuses on a classroom layout featuring two entrance/exit doors, desks, and a teacher's podium, as illustrated in Figure 3.

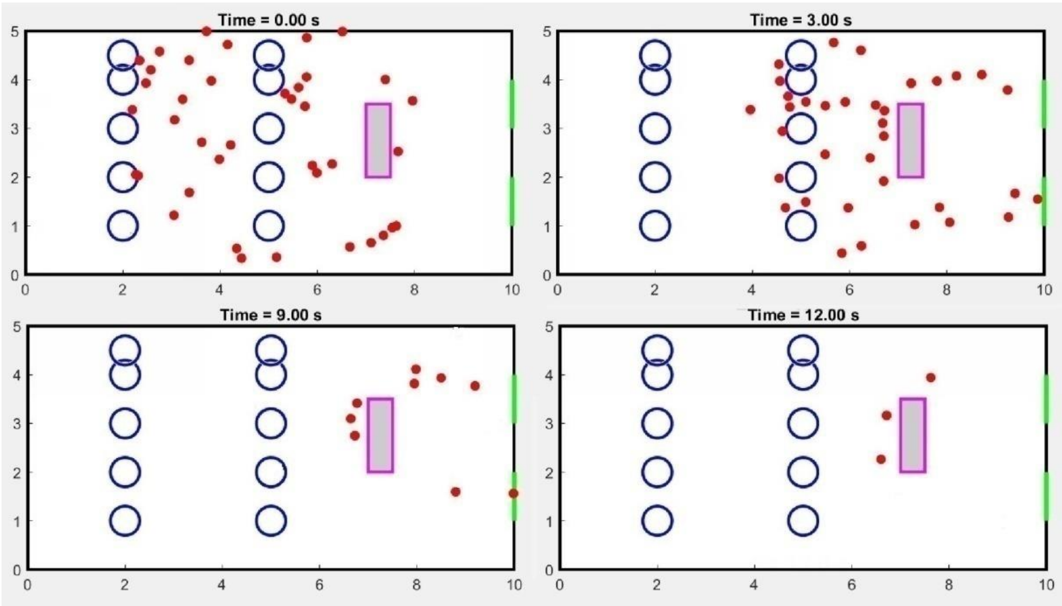

Figure 3.
Snapshots of the classroom evacuation at *t=0.0* s, 3.0 s, 9.0 s, and 12.0 s.

Each panel shows the simulated room layout (10 m × 5 m) with desks depicted as blue circles and a lectern drawn as a pink rectangle. Red circles represent pedestrians who have not yet evacuated, while the exit is indicated by the green boundary on the right. As time progresses, the pedestrians navigate around obstacles toward the exit, highlighting the evolving crowd distribution and interactions with the desks and lectern.

These elements act as physical obstacles during the evacuation, creating additional challenges for students' movements. Therefore, the social force model combines the enhanced local avoidance and queueing mechanism to predict students' behaviors when evacuating from the classroom. Figure 4 demonstrates a typical elementary school classroom setup and the scene of students practicing earthquake evacuation drills in elementary schools.

Figure 4.
A real-life elementary school classroom during an earthquake evacuation drill. Students are shown taking protective cover under their desks, highlighting how the actual arrangement of furniture and personal items can influence safety measures and crowd movement in a real-world setting.

This study, which assesses the impact of varying desired speeds, provides significant findings. It calculates four key parameters: total evacuation time, the potential number of injuries, and pedestrian flow through both the front and rear doors. For each desired speed, we conducted 100 simulation runs. The results, which were then averaged and plotted in Figure 5, illustrate the computed outcomes and their importance in emergency management and safety engineering.

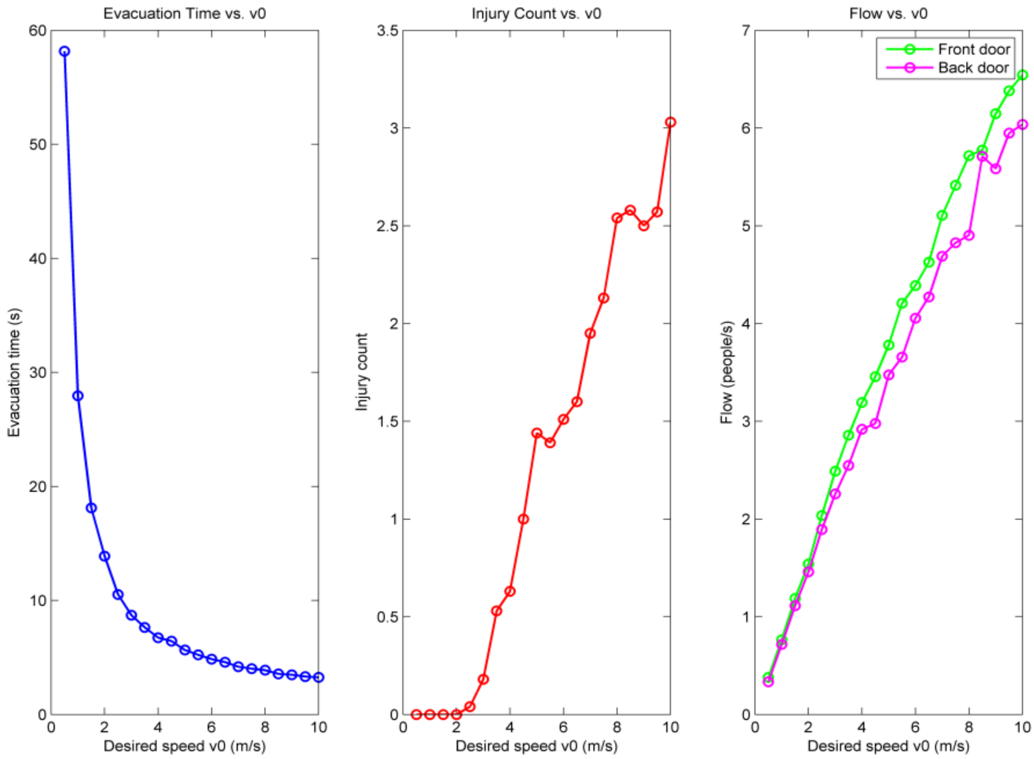

Figure 5.
Evacuation Performance Metrics as a Function of Desired Speed (v_0).

This figure presents the simulation results from a classroom evacuation model incorporating two doors, multiple desk obstacles, and a lectern. The left panel displays the total evacuation time, the middle panel shows the injury count, and the right panel compares the average flow rates at the front and rear doors. The trends illustrate a nonlinear relationship: while increasing v_0 initially reduces evacuation time, overly high desired speeds lead to increased collisions and injuries, demonstrating the "faster-is-slower" phenomenon. These results underscore the critical balance between rapid evacuation and maintaining low injury risks.

The left graph in Figure 5 shows that evacuation time decreases with increasing desired speed (v0) up to a specific range, after which the curve flattens. There are indications that it may start approaching a saturation point, suggesting that evacuation efficiency suffers when the desired walking speed is too low. However, if the speed is too high, factors such as crowding and pushing may cause local blockages, preventing further reduction in evacuation time. This result reflects the "faster-is-slower" phenomenon, where rushing leads to slower evacuation. In emergencies, frantic running may not be the optimal strategy. The middle graph in Figure 5 indicates a sharp rise in injuries once v0 exceeds a critical threshold of 2.5m/s. As people move faster without a proportional increase in space, extreme crowding occurs, especially near exits or narrow areas, leading to more collisions and friction, thereby increasing injury rates. While slightly higher speeds might reduce evacuation time, they also increase the risk of injuries, potentially creating chaos and introducing new safety concerns. The right graph shows a near-linear increase in the number of people passing through both front and rear doors per unit of time as v0 increases. However, this growth may slow down or plateau due to local congestion at higher speeds. This situation illustrates that differences in flow between doors may reveal user preferences or spatial asymmetries in the layout. A significant imbalance suggests that one door may be more accessible or more likely to become a bottleneck. If either door has significantly lower flow, it may be underutilized due to narrow passageways or poor placement. This fact calls for auxiliary exits or adjustments in interior furniture arrangements.

Based on the above findings, here are some valuable insights. At first, in drills, participants should be guided to move at a moderate pace, avoiding excessive rushing and overly slow movement. Secondly, when planning building layouts and crowd flow, consider balancing flow rates and injury risks to avoid irreversible blockages at narrow or single exits. Thirdly, based on the precise simulation, it is possible to estimate injury counts at different speeds, which supports setting speed limits or implementing flow control mechanisms in safety plans. Finally, the desired speed v0 significantly affects evacuation time, injury count, and doorway flow. For emergency managers, the key is to balance minimizing evacuation time with limiting injury risk. Effective strategies include multiple exits and well-designed flow guidance mechanisms to achieve optimal safety and efficiency during evacuation.

3.2. Considering Panic Effects

In this section, we incorporate panic levels into the simulation by introducing a panic coefficient defined in Equations (11)–(12). The panic effects are significant for people escaping from the building when a disaster occurs suddenly or unexpectedly. Panic escape behavior and crowd disasters have the characteristic that, despite the low incidence rate, they may cause many casualties once they happen [22]. In this simulation, the panic coefficient varies from 0 to 0.9 in increments of 0.3, combined with desired speeds ranging from 0.5 to 5 m/s in increments of 0.5. The classroom scenario remains consistent with the setting described in Section 3.2. For each combination of the desired speed and panic coefficient, 100 simulation runs were conducted. We calculate the average parameters: total evacuation time, estimated number of injuries, and the combined average pedestrian flow through the front and rear doors. The results are presented in Figure 6 and further illustrated in Figure 7, which is demonstrated with a 3-dimensional form.

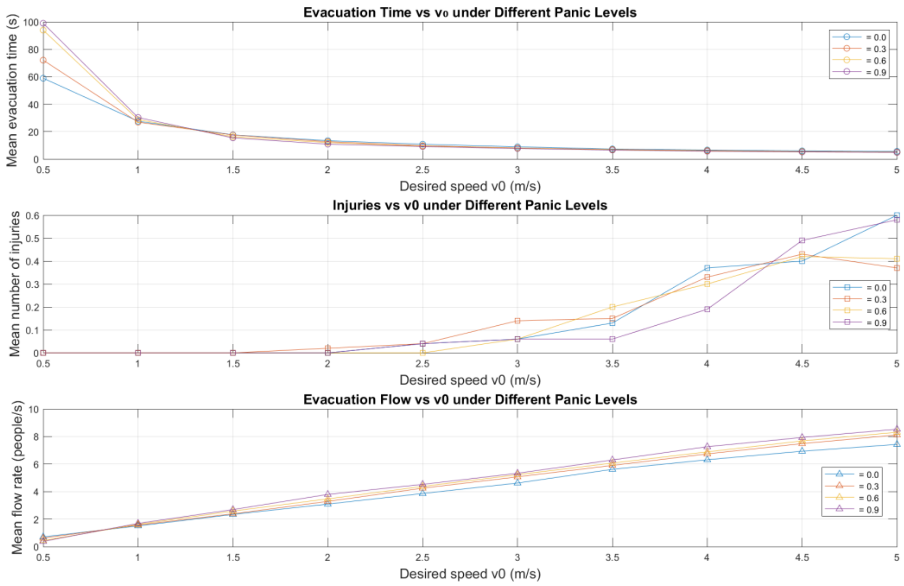

Figure 6.
This figure presents the impact of different panic levels (a = 0.0, 0.3, 0.6, 0.9) on three key evacuation metrics as a function of the desired speed v0 he top subplot displays the mean evacuation time: although increasing v0 generally shortens evacuation time at lower panic levels, higher panic coefficients can trigger more congestion and collisions, making the time reduction less pronounced. The middle subplot shows the mean number of injuries, revealing that moderate speeds at low panic remain relatively safe, while larger v0 values combined with high panic levels lead to a significant increase in injuries. The bottom subplot illustrates the mean evacuation flow (people/s): flow consistently improves as v0 rises, but high panic levels may induce chaotic movement and collisions, offsetting some of the benefits of higher speed. Overall, the results highlight the importance of balancing evacuation speed with psychological stress to ensure both efficiency and safety.

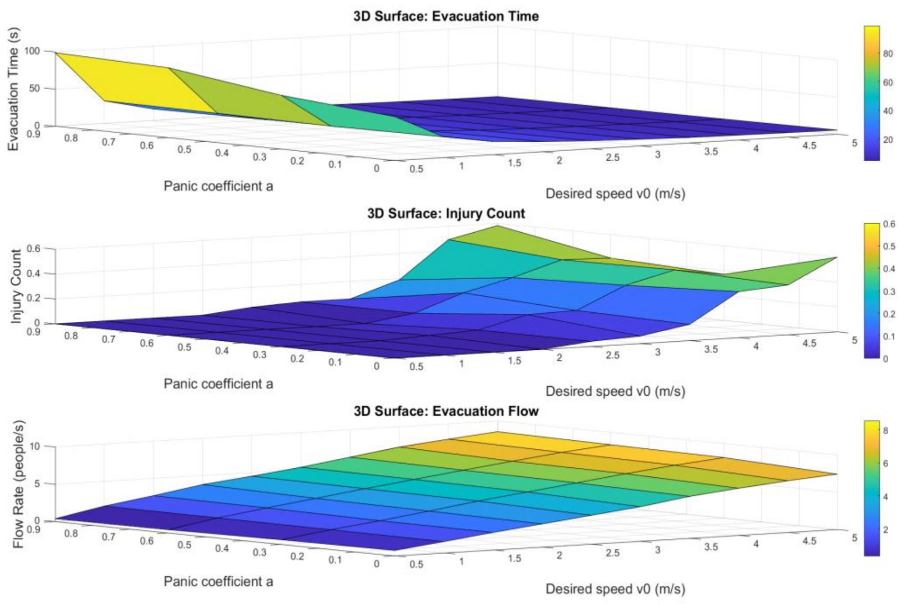

Figure 7.
3D Surface Plots Depicting Evacuation Performance under Varying Panic Coefficients (a) and Desired Speeds (v_0).

The top panel illustrates how increasing v0 and a influences the total evacuation time, with moderate values of both parameters yielding faster evacuations, while extremely high speeds or panic levels lead to congestion and longer times. The middle panel shows that as either v0 or a rises, the injury count grows significantly, indicative of more frequent collisions or chaotic crowd movements. Finally, the bottom panel reveals that the evacuation flow (people/s) generally improves with higher speed but can plateau or decrease at excessive panic or speed levels due to congestion. These 3D surfaces highlight the importance of balancing speed and psychological stress in emergency management: a moderate panic coefficient and speed combination tends to offer an optimal trade-off between reducing evacuation time and limiting the risk of injuries.

Figure 6 shows several key insights that are crucial for emergency management discussions. The top panel shows that increasing v0 generally shortens the mean evacuation time, but the effect diminishes at higher speeds. Moreover, higher panic coefficients partially negate the speed benefit by causing local congestion and uncoordinated rushing, illustrating a “faster-is-slower” phenomenon under extreme stress, which is agreeable to the results of Uesten et al. [23]. In contrast, under low-panic conditions, pedestrians tend to move in a more orderly manner, allowing smoother progress along intended paths and thus reducing overall evacuation time. In the middle panel, injury counts remain low at moderate speeds and low panic. However, as speed and panic increase beyond certain thresholds (2.5m/s), collisions and chaotic crowd behavior drive injuries upward. This result underscores that pushing for maximum speed can lead to significant safety risks, especially under intense psychological pressure. Under low-panic conditions, although the speed remains the same, the more orderly behavior of pedestrians reduces friction and collision intensity, resulting in relatively safer evacuation. The bottom panel indicates that the flow rate (people/s) steadily climbs at higher speeds, yet the improvements can be tempered by congestion and collisions at high panic levels. Low panic conditions yield more stable increases in flow, emphasizing the value of calm, orderly movement in emergencies.

These findings highlight the delicate trade-off between speed and safety. While moderate speeds under low panic levels foster shorter evacuation times and lower injury rates, extreme speeds paired with high panic can cause bottlenecks and injuries. Consequently, protocols that balance speed with psychological stress management, such as providing clear guidance, training to avoid frantic rushing, and optimizing facility layouts can enhance evacuation efficiency and public safety during emergencies, which is well corresponding to the previous result of Alexander [24].

According to Figure 7, the top panel reveals that moderate desired speeds and lower panic coefficients yield shorter evacuation times. However, at very high speeds or high panic levels, congestion effects become pronounced, leading to longer evacuation times a clear manifestation of the “faster-is-slower” phenomenon when crowd stress is excessive. The middle panel shows injury rates rising sharply in the region with high panic and speed. This state corresponds to erratic crowd behaviors and intense collisions under heightened psychological pressure. Conversely, lower panic levels mitigate injuries, even at moderate speeds. Finally, while flow generally improves with increasing speed, high panic can cause chaotic movement that reduces throughput gains, limiting overall efficiency. This effect agrees with one of the conclusions in Mo et al. [25]. The surface of the bottom panel highlights that low to moderate panic fosters steadier increases in flow, reinforcing the advantage of calmer evacuations.

4. Conclusion

This study presents a refined application of the Social Force Model to simulate emergency classroom evacuations, offering novel insights into the interplay between pedestrian desired speed, panic intensity, and evacuation outcomes. The model effectively reproduces key dynamics observed in high-density evacuation scenarios by incorporating realistic features such as physical obstacles (desks and a central podium), dual-exit configurations, and a collision-based injury mechanism. The findings highlight a nonlinear relationship between pedestrian speed and evacuation efficiency, revealing that moderate increases in desired speed reduce evacuation time. In contrast, excessive speed leads to congestion and diminished gains—an embodiment of the “faster-is-slower” phenomenon. Furthermore, introducing a panic coefficient reveals its critical influence on safety: elevated panic intensifies collision frequency and force, significantly raising injury risks even at moderate speeds. Notably, when both speed and panic are high, instantaneous contact forces often exceed the injury threshold, suggesting that panic-induced behaviors substantially compromise overall safety.

Additionally, the study underscores the role of architectural design in evacuation dynamics. An observation is that while overall flow tends to increase with speed, substantial imbalances between front and rear exit usage are driven by spatial configuration and crowd movement constraints. This phenomenon implies that well-considered exit placement and guidance strategies are essential for optimizing flow distribution and enhancing evacuation performance. These results collectively indicate that maximizing evacuation speed alone is insufficient and potentially counterproductive. Instead, a balanced strategy—moderate desired speed, effective panic mitigation, and thoughtful architectural planning—emerges as the optimal path to ensure efficiency and safety. The model thus provides a scientifically grounded framework for multi-objective evacuation planning, contributing not only to theoretical development in pedestrian dynamics but also to practical applications in seismic safety design, emergency preparedness, and risk-informed architectural layout. Future research may extend this approach by incorporating heterogeneous pedestrian behaviors, real-time decision-making processes, and multi-dimensional injury risk assessments, aiming toward increasingly realistic and predictive evacuation models under complex disaster conditions.

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