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A Study of Human Traffic for Emergency Evacuation at Universiti Tun Hussein Onn Malaysia (UTHM) Pagoh Residential College

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Abstract

High-density residential buildings such as university hostels need effective evacuation strategies during emergencies to protect occupant's lives. The objective of this study is to evaluate and enhance the emergency evacuation efficiency of Block A10 of the Universiti Tun Hussein Onn Malaysia (UTHM) Pagoh Residential College. The study simulated the emergency situation by using movement models to determine the congestion points using Pathfinder program to model the building environment based on site survey and architectural plans. The simulation involved the comparison between existing evacuation routes with better approaches such as low occupancy density, route assignment according to the nearest exits and walking speed. Findings showed that the bottlenecks were narrow walkways and lack of enough exits with the width of the staircases being the main structural limitation. The best approach was to reduce occupant density (load management) to the lowest possible evacuation and the time was at 276 seconds in comparison to the current baseline of 420 seconds. These results indicate that structural constraints cannot be overcome solely by increasing walking speed, highlighting the need for additional measures such as improved signage, corridor clearance and zoning strategies.

1. Introduction

Emergency evacuation serves as an essential disaster management component whereby individuals should evacuate successfully out of the hazardous areas. The additional complexity of emergency evacuation operations is due to the fact that emergency unpredictability enters into the combination with numerous hazards and numerous reactions of the people affected. The transport systems have seen continuous congestion outside peak hours, logically signifying the extreme burden on the evacuation systems that need a better traffic management system (Meyer et al, 2018). Studies have shown that slow evacuation response results into traffic jams in addition to complex traffic control, which often exceeds shelter capacity and increases risks on evacuees (Zhang et al., 2016). To correctly allocate resources, the processes of evacuation traffic must be checked by analysts in time and place, so the evolution of a kinematic wave model allows the optimization of the evacuation routes (Chen & Zhan, 2008).

Advancement in technology plays an emerging vital function in the creation of better emergency evacuation measures. Emergency evacuation strategies are developed and tested on simulation modelling alongside Building Information Modelling (BIM) and artificial intelligence (AI) prior to the real emergencies occurring

(Kuligowski, 2016). These evacuations need the collaboration of the agencies with trained responders and the involvement of communities (Drabek, 2013). Using flexible planning processes, operators will be able to assist disabled individuals and individuals with limited mobility to conduct effective evacuations (FEMA, 2018). Moreover, the realistic simulations should evaluate the human factors since evacuation modeling should account for the individual decisions of human beings as well as collective behaviors.

This study focuses on emergency evacuation at Block A10 of Universiti Tun Hussein Onn Malaysia (UTHM) Pagoh Residential College. The major objective is to help in the rapid and safe evacuation of the occupants to a safe place which in most cases is hampered by poor visibility and inappropriate evacuation paths (Bukowski, 2001). Nevertheless, the current evacuation planning is likely to ignore the needs of the disabled, individuals who need the provision of an evacuation route (Bukowski, 2001). Besides that, staircases as the primary means of exiting the building may cause overcrowding, particularly in high rise buildings where there are many occupants (Bukowski, 2001).

The objective of this study is to determine current traffic patterns during evacuations in case of an emergency and demand better evacuation in the residential building. This study uses Pathfinder software to model different situations to identify the best evacuation methods, specifically load management and route optimization to minimize the total evacuation time (RSET).

2. Literature Review

2.1 Human Behavior in Emergency Evacuation

Response of occupants to an emergency evacuation greatly determines its success and is most often motivated by panic, stress or familiarity with the surrounding (Suparto & Erwandi, 2024). The studies have shown that social influence and leadership are vital factors people often follow the example of others, even in a situation when their actions are not in compliance with recommended safety directions (Wang et al., 2021). Futhermore, building design elements and active systems such as exit signs that are dynamically lit, prove to be more efficient than the fixed signs in directing people to safety in atypical or smoky environments (Bernardini et al., 2023).

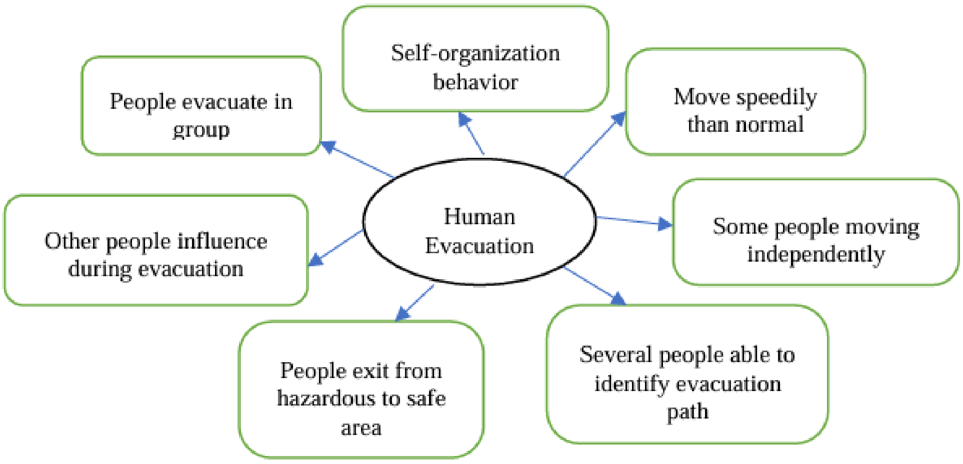

Fig. 1: Type of Human Behavior

2.2 Pedestrian Characteristics and Movement Dynamics

Movement of evacuation is an individual phenomenon brought about by crowd density and geometry of buildings. Dense crowd may cause congestion at small exits, which is also usually simulated in the Social Force Model to understand how panic affects the crowd movement (Zheng et al., 2023). In residential houses, the possibility of bidirectional flow in which opposing traffic streams collide with one another may interfere with movement and create the risk that people can fall on stairways (Garcia-Perciante et al., 2022). These small-scale dynamics must be managed in order to design efficient routes that avoid hazardous crowd levels.

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2.3 Modeling and Simulation Techniques

The developments in the realm of computational tools have turned simulation software into a necessary tool for safety analysis without the risks of physical exercise.

- Pathfinder: The software is an agent-based tool that is employed to model human movement by simulating individual agents with a distinct walking speed and making a decision-making process (J. Liu & Li, 2023). It can be especially useful when it is necessary to determine the points of the bottleneck and the Required Safe Evacuation Time (RSET) under different conditions (Selim et al., 2024).

- PyroSim: It is commonly used with movement models and is a graphical interface to the Fire Dynamics Simulator (FDS), where smoke propagation and heat transfer are directly simulated and have a direct influence on evacuation dynamics (Xu et al., 2020).

2.4 Optimization and Large-Scale Planning

There are optimization models which help in planning large scale evacuations as they determine the optimal method of allocating resources and timing exits. One of the strategies that help to reduce congestion and minimize confusion is zone-based planning that splits an area and allocates certain paths to each section (Romano et al., 2023). Additional usage of real-time data based on Geographic Information Systems (GIS) and traffic modeling will help to improve the choice of assembly points and routes and make adjustments dynamically as the emergency situation evolves (González-Villa et al., 2022).

3. Methodology

The study employs a quantitative design of simulation-based analysis as a method of evaluation and enhancement of evacuation efficiency.

3.1 Study Area and Data Collection

The research took place at the UTHM Pagoh Residential College, Bock A10, which is a five-storey building on which there are about 480 residents (96 people per floor). Comprehensive building plans and architectural layouts were acquired in order to map corridors, stairs and exit points. The data on occupant loads was gathered using residential data, which established that residential houses have four rooms with an average occupancy of 12 individuals per house. It was simulated on Pathfinder software as we can see from Figure 2.

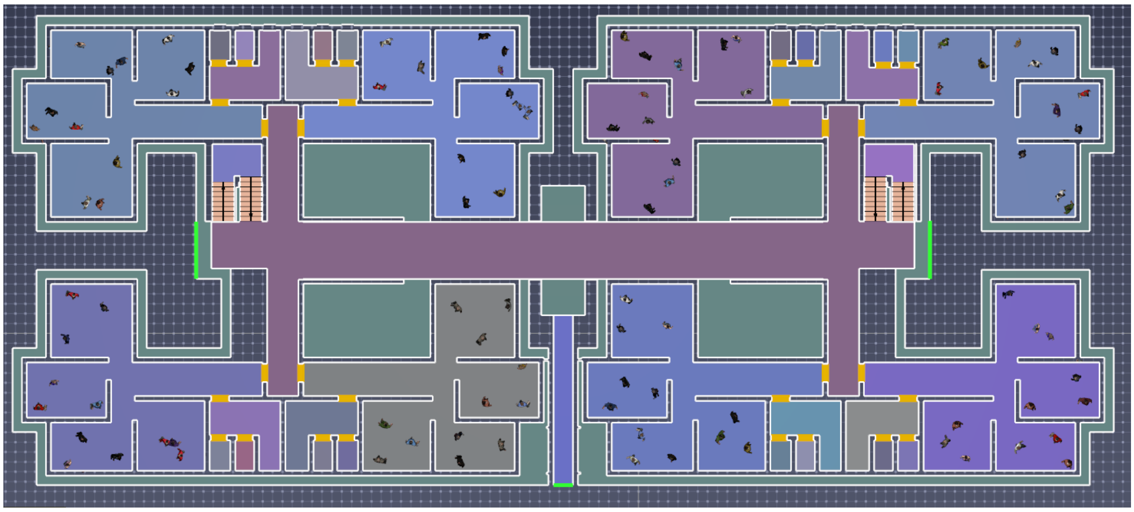

Fig. 2: 3D Residential layout by Pathfinder Software

3.2 Simulation Modelling

Pathfinder software was used to model emergency evacuation situations and is validated to estimate occupant egress times and study occupant behavior. The 3D model of the residential block was developed in the form of a detailed 3D model through Autodesk Revit and taken to Pathfinder. The simulation parameters consisted of the mean escape speed of 1.19 m/s, which is in line with the national standards.

The modeling system is an agent-based system where each of the 480 residents is modeled as an entity with specific path planning abilities. This enables the software to properly follow the behaviors where the agents dynamically move forward through obstacles and other occupants without collision. Through the modeling of these interactions, the model is effective in the identification of critical points of congestion, that is, at the head of the stairwells, which are structurally limited in its throughput capacity. Moreover, the simulation allows us to conduct comparative analysis of various conditions, including the occupant density and walking speed, to identify the influence of the specified conditions on the Required Safe Evacuation Time (RSET). The stability and consistency of the results were verified through comparison with the manual calculation.

Three improvement plans were piloted:

- Scenario 1: A decrease in occupancy density per floor or zone to reduce congestion.
- Scenario 2: Distribution of evacuation routes according to the closest exit to equal the load.
- Scenario 3: Observe maximum flow rates by increasing the occupant walking speed to 1.5 m/s.

Table 1: Description of Evacuation Improvement Scenarios

Scenario	Description
1	This scenario aims to decrease the total numbers of occupants from 480 to 320 to see how the density can have an influence on movement. Through reduction in the number of occupants, it also reduces the clogging effect at the bottom of the stairwells and ensures a smooth flow of people without the development of thick crowds. This situation is aimed at eliminating the source of the delay structural bottlenecks by making sure the physical capacity of the building is filled with the number of people who are trying to exit the building.
2	In this scenario what the simulation does is allocate all the occupants to the closest exit possible instead of using the familiar or conventional path. This is aimed at balancing the load or burden on all the staircases to avoid having one exit overloaded and others underutilized. This explored the ability of improved traffic management to counteract constrained corridors, but it was revealed that the fixed width staircases continued to limit the general flow.
3	This scenario is to test the human walking speed effect by changing the standard value of agent velocity parameter of 1.19 m/s to 1.5 m/s. It tries to find out whether structural delays could be defeated through faster movement. The simulation, however, showed that at higher speeds the pressure in the bottlenecks points increased, which in turn resulted in more serious queuing on the stairs. This demonstrates to the panel that speed is not a solution to evacuation problems when the width of the exit is not adequate.

3.3 Required Safe Evacuation Time (RSET)

The required safe evacuation time (RSET) is the time that should lapse before the occupants can remain in a safe place out of the building. The calculation of RSET is the following:

$$RSET = \mathrm{T}_{\mathrm{alarm}} + \mathrm{T}_{\mathrm{pre}} + \mathrm{T}_{\mathrm{mov}}$$

The Requirement Safe Evacuation Time (RSET) is an important parameter in fire safety engineering indicating the maximum amount of time required to evacuate everything in a building to a safe zone outside of the building. In block A10 study, RSET will serve to measure how the current structural design and evacuation processes can safeguard residents from environmental effects in the form of smoke or heat which is present before the environmental conditions attain life threatening levels.

The RSET is used all over the world to check the safety of buildings by comparing it with the Available Safe Evacuation Time (ASET) a building can only be safe when RSET is far less than that of ASET. This calculation will be necessary to determine structural bottlenecks, including the narrow staircases found in Block A10 and to meet the national standards of residential safety. Also, RSET gives a technical foundation that measures the

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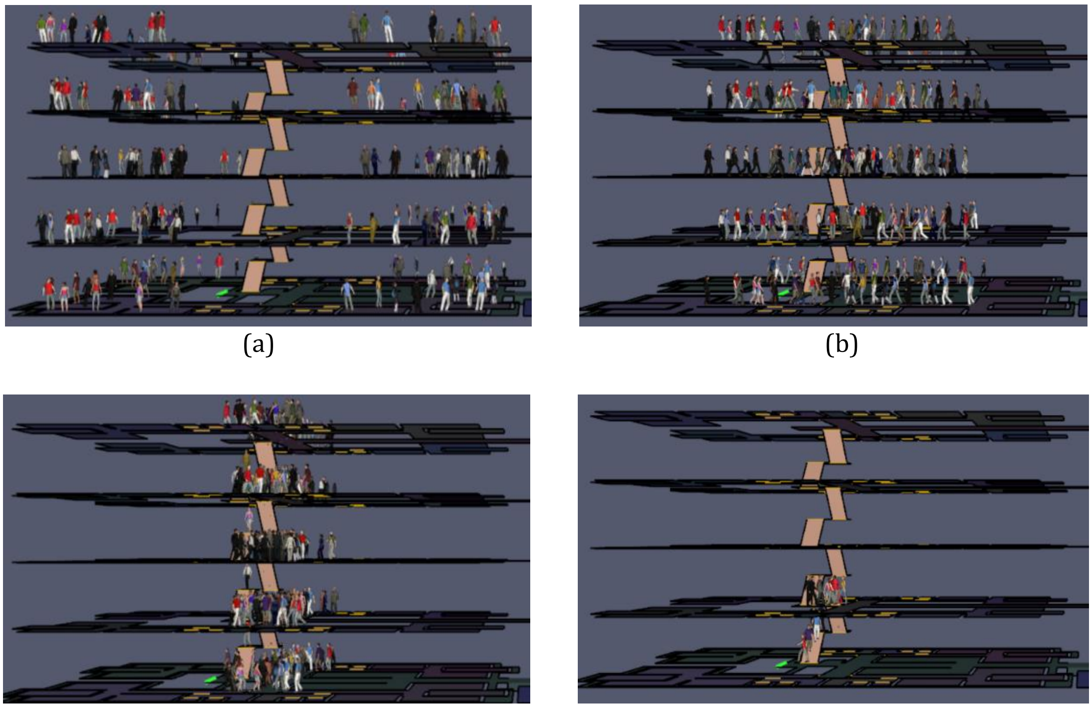
effectiveness of various improvement strategies. The RSET analysis in this study proved that the baseline evacuation time of 420 seconds was inadequate and that the most efficient way of ensuring the RSET was decreased to a more reasonable and safe evacuation time of 276 seconds was through the Load Management (Scenario 1). These ultimately offer RSET data-based recommendations of structural modifications like clearing corridors and more signage to decrease the initial delays that were experienced during the pre-movement stage in the simulation. Where T_{pre} is the response time and T_{mov} is the evacuation time which is obtained because of the simulation where T_{pre} is the alarm time and T_{mov} is the evacuation time.

4. Results and Discussion

This section presents the simulation outcomes obtained from the Pathfinder studies that investigated the patterns of traffic at Block A10. The Autodesk Revit was used to model the 3D laying out of the residential building to get the simulation to present an accurate representation of the real conditions of the building.

4.1 Analysis of Evacuation Flow Stages

There are four phases in the evacuation process. It was demonstrated in the simulation that occupants begin to move and transfer to the main stairwell. A severe bottleneck, formed at the head of the stairwell, occurs as the crowd attempts to exit the stairwell but the structural constraint and the narrowing of the exit passageway create congestion.



(a) (b)

(c) (d)

Fig 3: Simulation of Occupant Evacuation Stages

In Figure 3, the evacuation process is shown and it goes through four different phases. The distribution of occupants in Figure 3(a) gives the baseline density in the upper floor, given that occupants were initially distributed in their respective starting positions before the fire drill began. The evacuation in Figure 3(b) starts with the occupants starting to move and shift to the main stairwell. Figure 3(c) emphasizes how a serious bottleneck is formed at the entrance of the stairwell, the crowd tries to get out, the only reason is the structural limitation and the narrowing of the exit route. Lastly, Figure 3(d) shows the dissipation stage which is in which most of the occupants will have already made it through the vertical route and only few groups near the last exit discharge point signal the end of the evacuation.

4.2 Scenario Analysis

Table 2: Evacuation Time for Scenario 1

Type	Occupant	Time (s)	Average Distance (m)
Existing	480	420	48.5
Simulated	320	276	48.5

Table 3: Evacuation Time for Scenario 2

Type	Occupant	Time (s)	Average Distance (m)
Existing	480	420	48.5
Simulated	480	341.8	48.5

Table 4: Evacuation Time for Scenario 3

Type	Occupant	Time (s)	Average Distance (m)
Existing	480	420	48.5
Simulated	480	300	48.5

The evacuation efficiency analysis of Block A10 was performed based on the comparative analysis of three different improvement plans and the current baseline performance. To start with, the current situation of the 480 occupants led to evacuation time of 420 seconds. Scenario 1 was the best intervention of all with the occupancy density of 480 to 320 residents, the evacuation time reduced to 276 seconds. This underscores the fact that structural bottlenecks that are reported to exist at the stairwells can best be addressed by controlling the number of people in the building.

Scenario 2, on the other hand, was aimed at dispersing occupants to their closest exits, making the traffic load equal. Although this was a slight but significant improvement over the historical reference of 341.8 seconds, it was still not as efficient as density reduction and so it seems that the physical width of the staircases remains one of the main limiting factors no matter the route. Scenario 3 experimented on the effects of accelerating speed of walking to 1.5 m/s, which led to the evacuation time of 300 seconds. Surprisingly, the occupants in this scenario took longer to evacuate, despite travelling at a higher rate than in Scenario 1 as the higher velocity increased the severity of queuing and clogging in the stairwell entrances, which have a fixed width. All these findings prove that although behavioral and routing modifications have certain advantages, structural capacity and occupant density need to be considered in case the safest Required Safe Evacuation Time (RSET) is achieved.

4.3 Model Verification

Simulation results were compared to manual mathematical results to establish reliability. In Scenario 1, the simulation gave out 276 seconds and the manual behind estimate was 270 seconds. In Scenario 3, the simulation result measured 300 seconds versus a manual result of 295.2 seconds. This stability confirms the variables in the model, as well as the credibility of the Pathfinder software in this paper.

4.4 Discussion of Evacuation Time

Scenario 2 was the baseline condition that achieved a time of 341.8 seconds that is lower than the historical reference of 420 seconds yet proves that the existing infrastructure is a cause of delays. Scenario 1 was the one which gave the longest reduction time (276 seconds), as effective reduction of the crowd size is the most practicable one to conquer structural constraints. Interestingly, Scenario 3 (300 seconds) was still lower than Scenario 1 implying that moving faster did not imply faster exit time but increased serious queuing in fixed-width staircases.

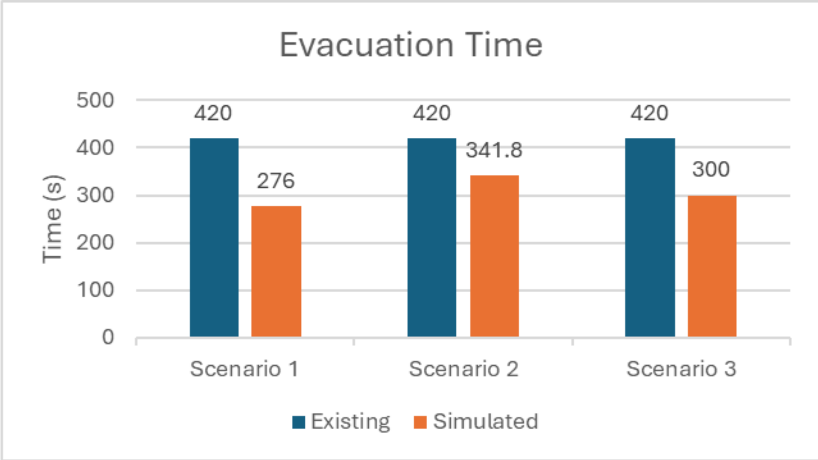


Fig. 4: Graph of Evacuation Time

5. Conclusion

This study successfully identified the emergency evacuation traffic patterns for Block A10 at UTHM Pagoh. The original simulation at the baseline ensured that the bottleneck in rapid egress is based on the inability of the staircases of a fixed width and the adjacent corridors to guarantee throughput capacity. The occupation density in Scenario 1 that was brought down by the improvement plan proved that the best approach to minimizing the total evacuation time is the load management. The findings confirm the hypothesis that there are more displays of exit signs, more the width of the main hall, and the clear escape path would save a lot of time during the evacuation. Further studies are suggested to include the use of Fire Dynamics Simulator (FDS) data to determine the effects of smoke and heat on evacuation behavior.

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