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ESCAPE: EVACUATION SIMULATION USING COGNITIVE AGENT-BASED MODELING ON POSSIBLE EARTHQUAKE IN GAMA PLATFORM FOR THE CASE OF KALAYAAN RESIDENCE HALL

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ABSTRACT:

Agent-based modeling (ABM) is a valuable tool for assessing the life-safety capacity of buildings during evacuations. This study focuses on the Kalayaan Residence Hall (KRH), a university dormitory, using Evacuation Simulation using Cognitive Agent-based modeling on Possible Earthquake (ESCAPE). ESCAPE integrates cognitive behavior, addressing the oversight in traditional ABM by considering human aspects. The 3D GIS-based model of KRH includes floors, rooms, exits, and path networks. Occupants involved in the model comprise residents, maintenance, office staff, and guards. The simulations, featuring eight scenarios, vary in agent numbers, locations, and time-based behaviors derived from survey responses. In 800 simulation runs, 79 exceeded the recommended evacuation time of 150 seconds. Analysis reveals evacuation time is influenced by the evacuee count, with over 500 occupants causing inefficiencies. The study suggests increasing occupants' knowledge about evacuation protocols and conducting regular drills to reduce panic. Recommendations include enhancing unused exits' serviceability to improve the evacuation scheme. This comprehensive approach aims to optimize KRH's evacuation efficiency by addressing cognitive aspects and refining protocols.

1. INTRODUCTION

1.1 Background

Emergency evacuation demands swift movement to open areas to avert hazards like falling debris, secondary incidents, and potential explosions or fires. However, devising effective evacuation management plans sometimes poses challenges (Federal Emergency Management Agency, 1990; Yan et al., 2018). Traditional evacuation planning methods typically involve resource-intensive drills, which might be impractical due to diverse situations in varying environments.

To improve this, employing simulation methods, like Agent-Based Modeling Simulation (ABMS), can offer insights without the need for physical drills (Claridades et al., 2016), simulating evacuations and computing the Available Safety Egress Time (ASET), representing the time it takes for evacuees to reach safety. ASET must surpass the Required Safety Egress Time (RSET), which denotes the recommended duration for all evacuees to reach safety, with the difference known as the margin of safety (Cuesta et al., 2016).

Kalayaan Residence Hall is a dormitory in UP Diliman and is the subject chosen for this study. This dormitory serves as the home of around 500 first-year students every year. It is a 4-story building that was established in 1975. With the building being around for more than four decades, it can be expected that some parts have deteriorated. One of these is their evacuation exits.

After an inspection, it was found to have highly elevated and rusty emergency pull-down ladders. With this, its management only uses 6 out of 16 exits, whereas 3 of 8 exits at the front of the building are only utilized. The locations of these are shown in Figure 1. The same goes for the exits at the back of the building, where 3 of 8 are only serviceable, as shown in Figure 2.

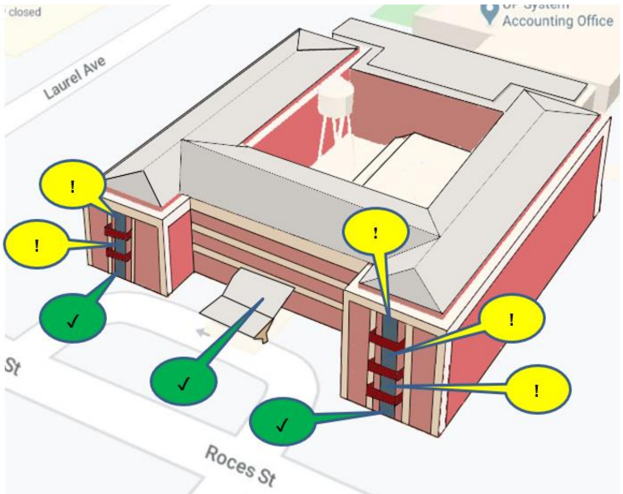

Figure 1. Locations of Exits at the Front of KRH

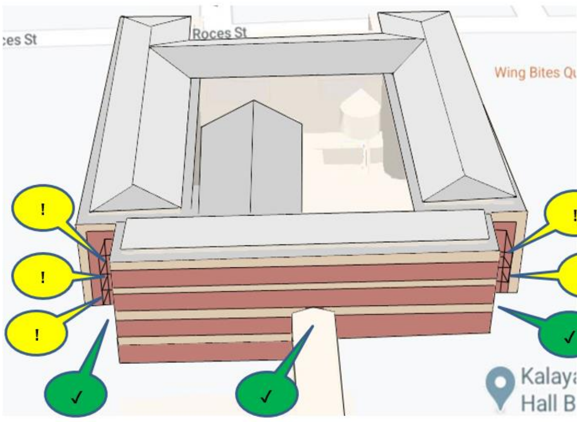

Figure 2. Locations of Exits at the Back of KRH

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1.2 Rationale

This study employs Agent-Based Modeling Simulation to evaluate the effectiveness of the evacuation plan at KRH. This approach complements existing evacuation schemes and route planning methods, allowing planners to explore multiple scenarios and analyze potential factors influencing evacuation time. The method addresses challenges related to resource constraints and the logistical difficulty of involving all stakeholders in evacuation drills. Overall, it provides a comprehensive and efficient way to assess and improve evacuation strategies.

By analyzing evacuation scenarios, identifying critical factors for effective evacuation, and proposing improvements, this study hopes to contribute to the creation of safer and more resilient urban environments, which can support efforts to address related targets of the Sustainable Development Goal 11 (SDG 11) of the United Nations (2015) by enhancing the safety, efficiency, and resilience of evacuation procedures.

1.3 Research objectives

With the issue of the efficiency of the dormitory's evacuation scheme, this study was conducted to seek answers to these specific research questions: i) Is the existing evacuation scheme in Kalayaan Residence Hall efficient for its residents to have an ample amount of time to evacuate in the event of an emergency (earthquake)? and ii) What factors (e.g., human behavior, location variables, etc.) affect evacuation?

Considering these questions, the general objective is to assess the efficiency of KRH's evacuation scheme using cognitive agent-based modeling simulation. Specifically, this will be done by doing the following:

- Create a 3D GIS model of KRH that represents its building and evacuation scheme,
- Create a simple ABMS model of the evacuation of KRH, incorporating cognition to its agents in the GAMA platform, named ESCAPE, and
- Assess the efficiency of the evacuation scheme by analyzing the simulated evacuation time and comparing it to the prescribed RSET.

1.3 Scope and limitations

1.3.1 Scope and study area: The building of interest for this research is the Kalayaan Residence Hall, a dormitory in the University of the Philippines Diliman (UPD) campus in Quezon City. It is located along A. Roces Street, at the corner of Laurel Avenue. It is surrounded by other dormitories such as Yakal Residence Hall, Acacia Residence Hall, and others. The area of study was limited to the building only.

Additionally, it was assumed that a person was already marked safe once they passed through an exit since it was deemed that the evacuation areas were enough for all the evacuees. Moreover, the gathered dataset represents the residents of batch 2019-2020 and the evacuation scheme of their time.

1.3.2 Assumptions and limitations: Due to the complexity of simulating evacuations, some limitations and assumptions are set to simplify the study. One major assumption made was that no secondary hazards would occur as these are hard to predict and model. Also, validation was not conducted for this study, as no actual evacuation drill was conducted in the dormitory. The accuracy of the results may be assessed once the evacuation time from an earthquake drill is ready or if there will be new standards for measuring accuracy in the future.

2. REVIEW OF RELATED LITERATURE

2.1 Basis for modelling simulations

One of the main references used was the Book by Cuesta et al. in 2016 entitled Evacuation Modeling Trends. It was used as a guide in evacuation simulation modeling in general, as it provided insights into published practices and guidelines in modeling simulations. Another is GAMA's documentation on their website (Taillandier, P. et al, 2019) which was consulted as a reference for the syntax, examples, functions usage, and other software's capabilities.

Investigating the case of KRH, it was found that Claridades et al. (2016) conducted a similar process to explore ABM's usage for modeling evacuations. Their study suggested improving the model by including human behavior aspects and cognition to represent real-life evacuation scenarios and to be able to study what behavior affects the evacuation process.

2.2 Basis for human behavior aspects

For the human behavior aspects, the study by Trivedi and Rao in 2018 was consulted, where the concept of using boids rules in describing human crowd behavior was adopted. Another one was from the study of Macatulad & Blanco in 2014, where panic stress effects were seen to multiply the speed of some evacuees by a factor of 1.5 than the average. This basis was complemented by the study of Pelechano et al. in 2005, where panic stress tolerance was related to how much a person was trained for evacuation practices and protocols.

2.3 Basis for prescribed RSET

It was mentioned that the efficiency of an evacuation scheme is achieved by checking if it is within a prescribed RSET. In this study, the metric used was 150 seconds or 2.5 minutes from various references such as Cuesta et al. (2016), and Macatulad and Blanco (2014).

3. METHODOLOGY

3.1 Creation of the evacuation model environment

The first stage involved the gathering of needed datasets requested from respective sources, as well as surveying the dormitory residents to obtain the relevant information to incorporate cognitive behavior into the ABMS.

3.1.1 Setting up the 3DGIS dataset: For the building dataset, request letters were sent to their offices, with the approval of the Office of Student Housing and KRH administration. The gathered datasets are cleaned, consolidated, and synthesized in preparation to be used as inputs into the agent-based model. In this stage, the set-up 3D GIS dataset of KRH must be able to display the correct description of the building as reflected in the available KRH building floorplan (Figure 3).

3.1.2 KRH evacuation scheme: The 3DGIS dataset should also be able to represent the current evacuation scheme of the dormitory (e.g., closed fire exits, closed rooms, etc.).

A dialogue between the dormitory managers was conducted to obtain the evacuation scheme of KRH, described as follows:

- Residents are advised to take the nearest exits to their location,
- Taking the elevated emergency exits is discouraged,
- Do Duck-Cover-Hold during an earthquake,
- Evacuate as soon as the shaking stops, and
- Proceed to evacuation areas:
    - Basketball Court, and
    - Front Driveway.

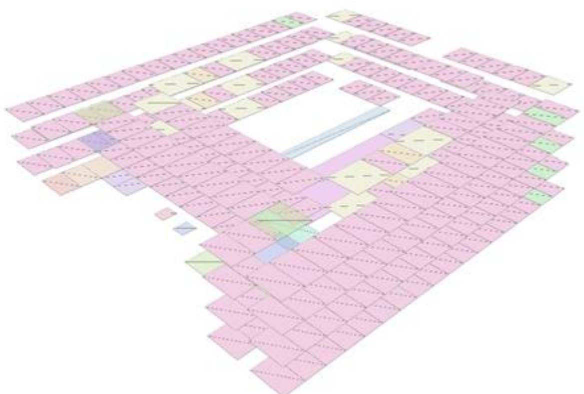

Figure 3. 3DGIS dataset of the KRH building showing the room layout

Translating this into the model, agents will have a pre-evacuation stage which corresponds to the duration of the earthquake. In cleaning the building datasets, some of the exits – denoted by the green points – are removed to reflect the situation of the evacuation scheme. The same is done for the path network (Figure 4) to show the available paths for the agents. Vector files for the room are also modified by adding areas such as the guards' posts and the maintenance staff quarters. Used and unused rooms are updated such that each shape has the correct attribution of the number of residents per room.

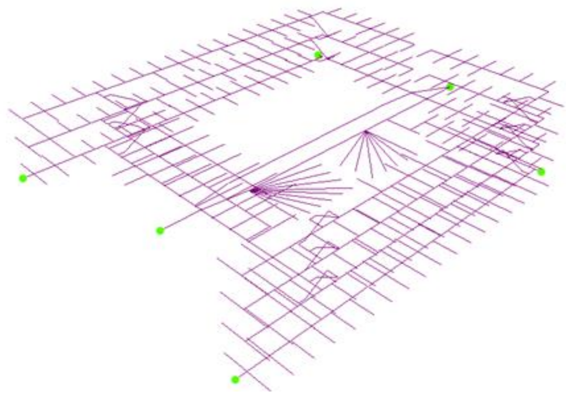

Figure 4. 3D visualization of the path network and exit points of the KRH building

3.1.3 Modeling the agents and agent rules: A survey was conducted to derive behavior and spatial dynamics information for the agents representing dormitory residents. Questions were asked to respondents to describe their familiarity with the evacuation scheme and protocols. Their answers were generalized to "familiar" or "not familiar" with the evacuation scheme.

When translated into the model, an agent will have a 74% chance of being spawned with the knowledge of the exits; the opposite goes for the remaining 26%. The same was done for panic stress handling, where an agent will have a 38% chance of being spawned with the attribute of panic, and the opposite goes for the remaining 62%.

The schedule of the dormitory staff is described in Table 1. Translating this into the model, these schedules were used to determine at which times and locations staff agents are spawned in the building.

Staff	Location		Times of Duty	
	On-Duty	Off-Duty	Day Type	Time
KRH Guard	Guard Post	Outside	Weekdays & Weekends	Present All Time (Morning to Night)
Other office's Guard	Guard Post	Outside	Weekdays	8am-5pm (Morning & Afternoon)
Office Staff	RA Office	Outside	Weekdays	8am-5pm (Morning & Afternoon)
Maintenance Staff	Roaming to assigned floors	Outside	Weekdays	8am-5pm (Morning & Afternoon)
Stay-in Dormitory Manager	RA Office	Room	Weekdays	8am-5pm (Morning & Afternoon)
Stay-Out Dormitory Manager	DM Office	Outside	Weekdays	8am-5pm (Morning & Afternoon)
Resident Assistants	RA Office (25%)	Outside (50%), Room (25%)	Weekdays	8am-5pm (Morning & Afternoon)

Table 1. Summary of Schedule of Staff in KRH

The schedules and locations of the residents are also obtained, and the summary of all the variables to be used in the model for the weekdays is shown in Table 2.

	Outside Dormitory	Room	Study Area	Room Hopping
Morning	0.99	0.01	0	0
Afternoon	0.99	0.01	0	0
Evening	0.07	0.82	0.10	0.01
Night	0	1	0	0

Table 2. Summary of Variables of Chances for the Locations of the Residents for the Weekday

The residents who leave the dormitory and travel to their home residence during the weekend are also investigated. The output of which, when translated to the model's code, means that a resident agent has a 56% chance of not spawning in the building for the possibility that they went home.

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For those that remained in the dormitory, their location and schedules were again asked for their weekend. Furthermore, these were the computed chances of where they are usually for weekends. The summary of all the variables used in the model for the weekends is shown in Table 3.

	Outside Dormitory	Room	Study Area	Room Hopping
Morning	6 %	88 %	4 %	2 %
Afternoon	18 %	74 %	8 %	0 %
Evening	2 %	76 %	18 %	4 %
Night	0 %	100 %	0 %	0 %

Table 3. Summary of Variables of Percent Chances for the Locations of the Residents for the Weekend

3.2 Development of the ESCAPE model in GAMA

The previously synthesized datasets were then used as inputs for the rules on agents' movements and the evacuation simulation environment for the ESCAPE model created in the GAMA simulation platform (Taillandier, P. et al, 2019). An agent is represented as a box whose dimensions are the shoulder span, waist diameter, and standing height, based on information from the survey where: 65% answered for average type, 18% for slim type, and 17% for round type. The percent distribution of the body types is used as the chance of spawning in the model, in which, when assigned, their dimensions are denoted in Table 4, based on the study of Del Prado-Lu (2007). The height is randomized based on the distribution of the measured heights from the study, where the values for heights range from 1.43 m to 1.78 m.

	Waist Diameter (m)	Shoulder Span (m)
Slim	0.305577	0.210085
Average	0.339541	0.252802
Round	0.381972	0.299211

Table 4. Body Dimensions Used for the Body Types

In general, ESCAPE follows the simulation process shown in Figure 5. The program's interface lets users input the day type and daytime parameters.

Upon execution, it imports and displays building shapefiles, placing people agents in rooms. Agents gain panic attributes by chance, with a possibility of not spawning if absent from the dormitory (e.g., residents outside, staff off-duty) based on the values derived from the survey as described in section 3.1.3.

The 'earthquake' triggers a time-varying pre-evacuation phase with agents performing the 'duck-cover-hold'. The evacuation process follows, with agents exiting to the nearest point. Evacuation time is recorded and saved in a text file for each simulation, concluding the process.

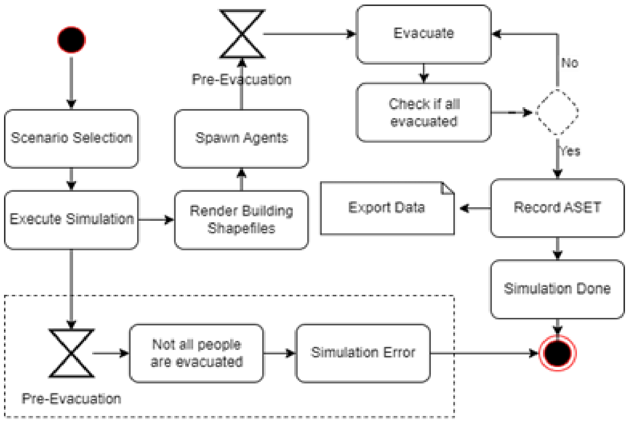

Figure 5. The conceptual model in creating the model

3.3 Running the model and assessing evacuation efficiency

The model's accuracy was assessed using intermediate output values and visual animations displayed within the GAMA software, as shown in Figure 6. The created model was run for 100 times each for the 8 different scenarios: the morning, afternoon, evening, and night for the weekdays and the weekends.

The outputs were analyzed to describe the evacuation scheme's efficiency compared to a prescribed RSET and checked if they were within the prescribed RSET value of 2.5 minutes, from which statistical inferences were drawn. In addition, a correlation analysis was done to draw inferences about the correlations between the evacuation time and variables in the model.

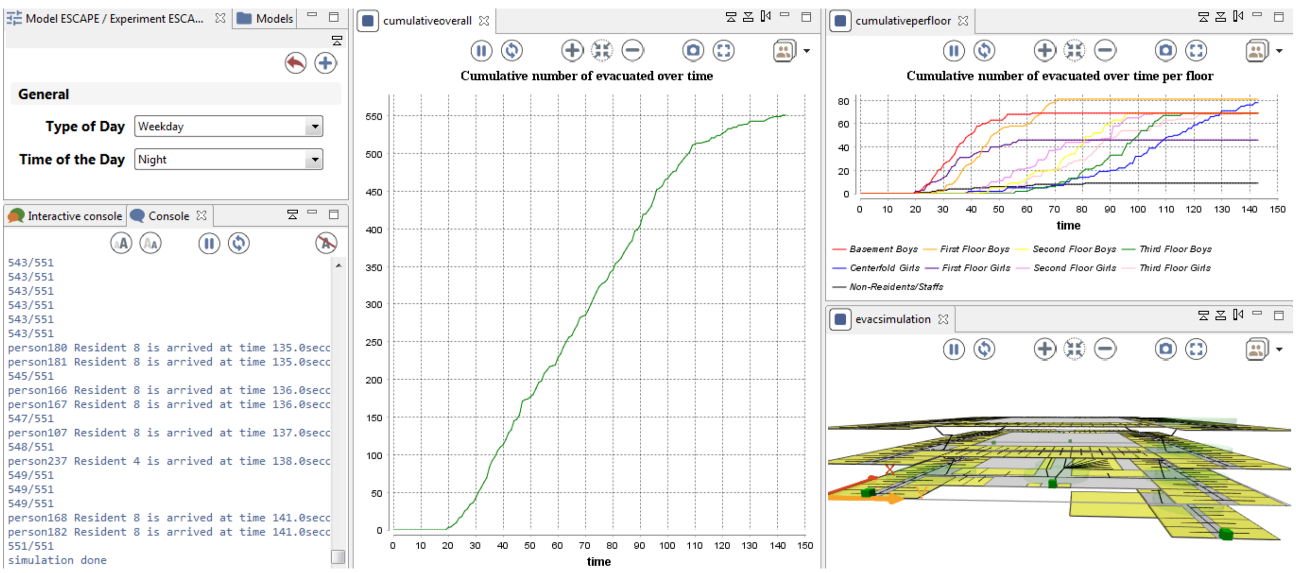

Figure 6. Sample output in monitors of the software

4. RESULTS AND DISCUSSIONS

4.1 Evacuation scenarios simulation time vs. RSET

The distribution of the evacuation times for all the simulation runs was graphed, in which there are scenarios for the cases that are not within the prescribed RSET, indicated by the red line, as shown in Figure 7.

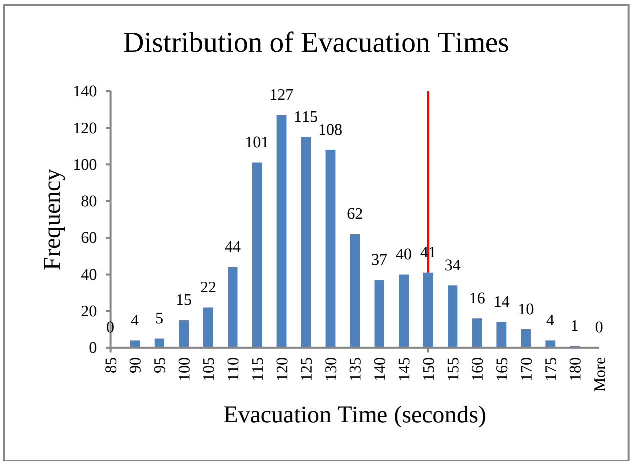

Figure 7. Histogram Plot of Evacuation Times for all the Simulation Runs

The distribution of the evacuation times for each scenario was also plotted in a graph (in Figure 8) to see how the evacuation times varied across the different scenarios. It can be observed that most of them are well distributed away from the 150-second mark, except for two scenarios, which are the Weekday Evening and Weekday Night.

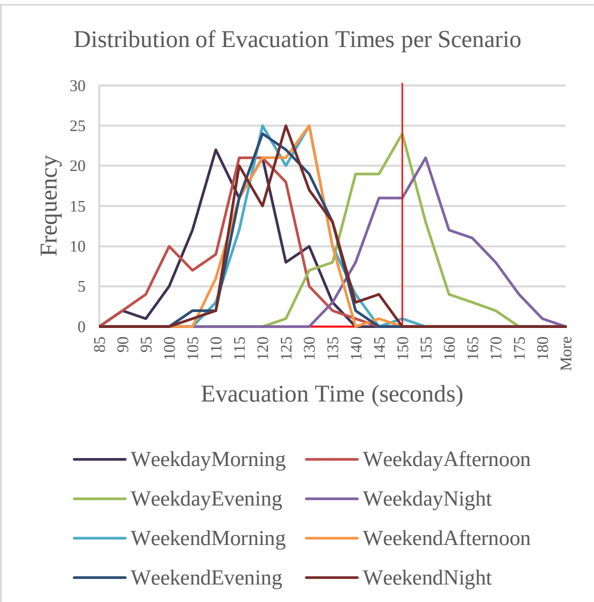

Figure 8. Histogram Plot of Evacuation Times for Each Scenario

In the same graph, it was observed that 57 out of 100 runs for the weekday night and 22 out of 100 runs for the weekday evening. 79 out of the 800 simulation runs resulted in an evacuation time greater than the prescribed RSET of 150 seconds.

It is seen that inefficient evacuation times are prone to occur on the weekday night, followed by the weekday evening. With this, it might be a good idea to focus on improvements in evacuation planning, especially for these schedules.

4.2. Assessment of variables concerning evacuation efficiency

4.2.1 Critical values for inefficient scenarios. A correlation analysis was conducted to determine which variables had a relationship with the evacuation time. It was found out that the number of evacuees, the number of experiencing panic, the number of knowledgeable with the exits, the number of people that are just staying in their rooms, and the number of people in the basement, 1st floor, 2nd floor, 3rd floor all had a relatively high and positive correlation coefficient. On the other hand, the number of leaving the dormitory had a relatively high negative correlation coefficient.

More importantly, it should be of greater concern to know at which variables' values inefficient scenarios occur. Thus, the inefficient scenarios are profiled to understand which criteria inefficient scenarios typically fall into. The values of the critical scenarios for these variables are tabulated as shown in Table 5.

Factors	Count Range	
	Critical Values	Values Modeled
No. of Evacuating People	496 - 551	24 - 551*
No. of Panicking Evacuees	158 - 235	-
No. of Knowledgeable with Exits	359 - 429	-
No. of Absent in the Dormitory	0 - 51	-
No. of Staying in Own Rooms	423 - 542	-
No. of Evacuees from Basement	49 - 69	1 - 69*
No. of Evacuees from_1st floor	130 - 183	15 - 183*
No. of Evacuees from_2nd floor	135 - 176	2 - 176*
No. of Evacuees from 3rd floor	132 - 176	3 - 176*
No. of Staff Present	3 - 9	3 - 27*

Table 5. Critical values for inefficient scenarios vs. the general scenario (*Values vary depending on the day type and daytime)

It was observed that inefficient scenarios tend to occur when the number of evacuees at the dormitory reaches around 500 or more, which is 90% and above the count of the occupants. The inverse of this is observed with the number of residents leaving the dormitory.

It was also seen that critical scenarios are also categorized by having high numbers of panicking, with a high correlation factor of 0.8097 against the evacuation time. The same goes for the number of knowledgeable with the exits, with a high correlation factor of 0.8129 against the evacuation time.

On the other hand, it can be observed that critical scenarios tend to occur at low numbers of room hopping and going to the study area, as compared to the values they are modeled to. The same goes for the number of staff in the building. However, these variables showed a low correlation factor of 0.0224, 0.2271, and -0.5328 to the evacuation time, respectively. So, it is inconclusive to say that these variables affect the evacuation time.

Additionally, critical scenarios are observed when the number of those in the basement, 1st floor, 2nd floor, and 3rd floor are at high values. It can also be observed that some of the previously mentioned variables have high correlation factors with the number of evacuees. So, to speak, these variables may relate to the evacuation time but may only be so just because they are just a factor of the number of evacuees, to begin with. This explains why the number of panicking and knowledgeable on the exits is highly related to the evacuation time. However, as it turns out, they do because the high numbers of evacuees bring their high numbers.

4.2.2 Weekday evening vs. weekday night scenarios: To further investigate, values for these variables are also explored for the weekday evening and weekday night scenarios. Moreover, for the weekday evening, it can be seen that the previous findings agree with the values. The same goes for the weekday night scenarios.

One thing to note is that it was also observed that critical scenarios for the weekday evening and weekday night slightly varied on the pre-evacuation time. It can be seen that critical scenarios occur when the pre-evacuation times are 18 to 30 seconds in the weekday evening scenario. In comparison, this occurs in the weekday night scenario when the pre-evacuation time is 12 to 30 seconds.

The pre-evacuation time assumes that evacuees should wait until the shaking stops before moving toward an exit. However, knowing that this factor affects the evacuation time, the dormitory's management can advise its residents to evacuate immediately as soon as possible, even when the shaking has not stopped yet. With this, in the event of an earthquake that lasts around 10 to 30 seconds, it can be inferred that the weekday evening scenario has more chance of having an evacuation time within the prescribed RSET compared to the weekday night scenario.

4.2.3 Effect of panic and knowledge of exits. As mentioned earlier, critical scenarios are also categorized by having high numbers of panicking and the number of knowledgeable with the exits. Separate batch simulation runs were conducted to see if these variables directly affect evacuation times, specifically for the Weekday Evening Scenario, with the results illustrated in Figure 9 and Figure 10.

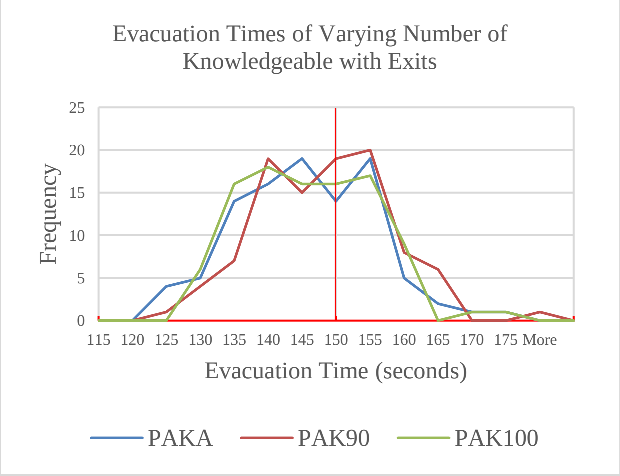

Figure 9. Evacuation Times for Increasing Values of Knowledgeable with the Exits

As illustrated in Figure 9, while the number of panicking is constant, evacuation times are graphed for increasing number values in knowledgeable with the exits. From the actual factor of 0.74159, values of evacuation times are also calculated when the factor is 0.9 (labeled as PAK90, where 90% of the occupants are familiar with the exits) and 1.0 (labeled as PAK100, where all are familiar with the exits). It can also be observed that the number of inefficient scenarios decreases. From the 28 inefficient scenarios, it decreases to 15 inefficient scenarios when the factor is 0.9. It further goes down to 11 inefficient scenarios when the factor is 1.0. With this, increasing the number of knowledgeable with the exits can be suggested to the dormitory management to decrease the possibility of inefficient scenarios.

As illustrated in Figure 10, while the number of knowledgeable exits is held constant, evacuation times are graphed for increasing values of the number of panicking.

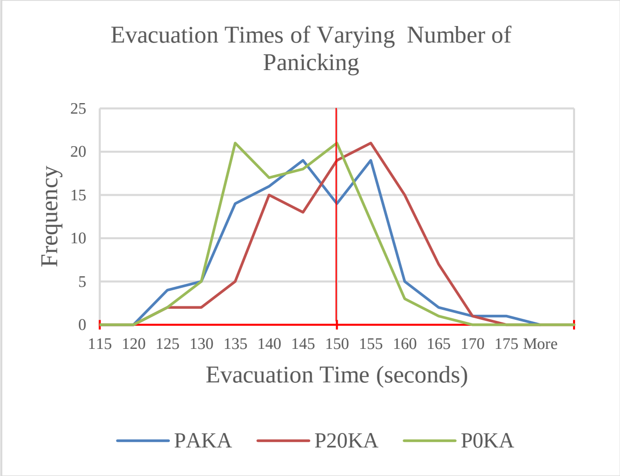

Figure 10. Evacuation Times for Decreasing Values of Number of Panicking

From the actual factor of 0.37699, values of evacuation times are also simulated when the factor is 0.2 (labeled as PA20KA, where only 20% of the occupants are panicking) and 0.0 (labeled as P0KA, where no occupant is panicking).

From Figure 10, it can be observed that the number of inefficient scenarios decreases. From the 28 inefficient scenarios, it decreases to 23 inefficient scenarios when the factor is 0.2. It further goes to 4 inefficient scenarios for when the factor is 0. With this, decreasing the number of panicking can be suggested to the dormitory management to decrease the possibility of inefficient scenarios.

5. CONCLUSIONS

In summary, 79 out of the 800 simulation runs conducted in this study were not within the prescribed RSET of 150 seconds. With this, it can be said that the evacuation scheme of KRH is not efficient as it may not always provide its occupants enough time for evacuation, specifically for the weekday evening and weekday night scenarios.

After investigating some of the variables that contribute to the evacuation time, it is generally observed that evacuation time is highly influenced by the number of evacuees, obtained from a high correlation factor of 0.8164, which also extends to the variables that are dependent on the evacuees' count such as the number of panicking, and the number of knowledgeable with exits. After all, it was found that inefficient scenarios are highly influenced by the number of evacuees, specifically when the count of the evacuees is at around 500 or more, or 90% and above of the occupants.

With this information, it is suggested that the management of KRH can work on lowering the evacuation time by either improving their evacuation scheme or limiting the number of building occupants. Though this suggestion is not guaranteed, this is something that can be investigated for future studies.

Some other recommendations for future studies include validating the model when an actual evacuation time is available to measure the accuracy of the outputs. Another is exploring continuous environment representation instead of representing the paths as lines to describe real-life scenarios better. Lastly, the methods in this study are tested on their applicability to assessing buildings' life-safety capacity before they are built.

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