

ENHANCED SAFE CONDUCT AND PREPARATION FOR EFFECTIVE EVACUATION (ESCAPEE) USING GAMA

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ABSTRACT: Hospitals are essential structures with the purpose of providing healthcare and assistance especially during disasters. These facilities are also prone to fire due to the presence of electrical equipment, oxygen tanks, chemicals, and other flammable materials. In an event of a fire, the layout of the hospital must be able to provide an effective evacuation. In this paper, the evacuation of ten emergency rooms (ER) was simulated. The simulation for the rooms utilized an agent-based model (ABM) by using GAMA Platform. Varying densities were simulated per ER and a fire simulation was done. The simulations resulted to total evacuation time for the different ERs and the mortality rate considering a fire inside the room. The results show that the number of occupants affected the evacuation time by 10 to 20 seconds. In addition, there is also a weak correlation between the area of the ER and the evacuation time. Based on observation of the simulations, the location of the exits, the number of exits and the layout of the emergency rooms play a significant role in safe evacuation.

Keywords: Evacuation, Fire, Agent based model, Hospitals, GAMA Platform

1. INTRODUCTION

A disaster, according to the International Federation of Red Cross and Red Crescent Societies [1], is a sudden phenomenon that disrupts a unit's functionality. Shaluf [2] stated that disasters can be classified into three types: natural, man-made, and hybrid. Among the various disasters, fire alone accounts for 39.2% of the major disasters worldwide [3]. The Philippines are among those countries that have a tragic and significant record of fire incidents that resulted to numerous casualties. Some incidents are the Ozone Disco Fire in 1996 that resulted to a casualty count of 162, the Valenzuela Factory fire in 2015 that resulted to 74 deaths and the fire in NCCC mall in 2017 that resulted to 39 deaths [4].

Almost any building or structure is vulnerable to fire. This study focuses on hospitals, which are essential structures. Its purpose is to provide healthcare, assistance and accommodation during times of disasters. However, hospitals can be very vulnerable to disasters as well, especially to fire. The presence of volatile substances, extremely flammable materials and equipment with high tendency of overheating make hospitals more susceptible to fire. In the event wherein a fire may occur, hospitals must readily have a proper evacuation plan and layout. This may reduce the likelihood of casualties as a result of the fire.

Evacuation is needed when a hazard poses harm to the health and safety of people inside a facility or structure. This must be observed, practiced and executed especially in unforeseen and urgent instances when fire occurs. To preserve life and

safety, the occupants of the building need to evacuate by following the building's evacuation plan. Accurate and effective evacuation plans are created and improved based on real-time evacuation drills. In the case of hospitals, it may be difficult to commence. Conducting drills may cause commotion, inconvenience and disruption in operations. In this study, evacuation simulation is used instead. It is an alternative quantitative method to determine evacuation times based on the concepts of crowd dynamics and pedestrian motion. This study uses an agent-based model through GAMA Platform, a simulation software that is capable of modelling explicit multi-agent simulations.

Ten hospital emergency room layouts were obtained in this study. The research includes two phases of evacuation simulations. The first set of simulations involve the evacuation of ten hospital emergency layouts, where graphs of evacuation time versus occupancy density are plotted. The second set of simulations involve the evacuation of three representative layouts for small, medium and large areas. The division of the areas are determined by the researchers based on the obtained layouts. The second phase of simulations, fire was introduced at random location with a rate ranging from 0.5 m/s to 2.0 m/s.

2. RELATED LITERATURE

2.1 Allowable Unit Area per Occupant

A facility or structure can only occupy a certain density at a time. According to the National Building Code of the Philippines [5], the allowable unit area

per occupant of a hospital or sanitaria is 8.4 m²/person.

2.2 Evacuation Models

There are many ways to simulate an evacuation model. Such methods include flow-based models, agent-based model (ABM) and cellular automata (CA). A flow-based model is one that considers a continuous flow movement between evacuees, without the consideration of varying human characteristics and direction [6]. The second type of model is the agent-based model, an improvement of the flow model that already considers a number of factors like the building configuration and the evacuees' proximity between each other. The last type of model is the CA model which utilizes cell grids and some rules of movement to come across this area of grids.

This research utilizes agent-based modeling or ABM. Agent interactions in multiplex systems can be simulated through this type of model. Therefore, several factors among agents and the floor layout can be investigated. Ha and Lykotrafitis [7] investigated the effect of the architectural complexity of a building on the crowd motion while commencing an evacuation. In their study, they explored the effects of the evacuees' panic level by varying desired agent speeds. They also explored the effect of the complexity of the floor plan by varying the door sizes. It was found that as the room door size and the desired speed increase, the evacuation time immediately decreased. The study employed a relationship between the size of the egresses having to match the configuration of the room and the speed of the occupants leaving the room.

Kasereka, Kasoro, Kyamakya, Doungmo Goufo, Chokki, & Yengo [8] used ABM to simulate evacuation of people in the case of fire. They were able to explore different factors and establish relationships between these factors. As the number of evacuees are higher, the fatality increases. As the speed of the agents increased, the number of survivors increased. The ABM model allows integration of different factors that influence the model, opening new doors of possibilities in mimicking real life scenarios. The study utilized GAMA to simulate an evacuation of supermarkets in case of fire and they have concluded that the faster the velocity of the occupants in the buildings, the higher the number of people who have evacuated. In addition, the number of deaths had decreased. Addition of exit doors had significantly influenced the model in such a way where the evacuation time of the occupants had significantly decreased and that the number of survivors had increased.

2.3 GAMA Platform

Claridades, Villanueva and Macatulad [9] conducted a simulation of an evacuation using GAMA Platform and they have discovered that several factors regarding human behavior such as original states, panic, eating and studying will hasten the evacuation process while sleeping and going to the bathroom are considered as impedances in the evacuation. Aside from that, the results of the evacuation time suggest that altering the width of the corridor and pathways towards the exit can affect the response time. When the width of the pathways increased, the response time decreased.

Macatulad and Blanco [10] conducted an evacuation simulation of the Melchor Hall building at the University of the Philippines, Diliman. The researchers have incorporated ABM and GIS to model the evacuation of the people and to look at different scenarios for evacuation planning. Simulating the ABM in GAMA allowed the researchers to construct a 3D GIS-BASED model of the structure. The test simulation in GAMA was satisfactory assuming only 6% room capacity. Considering only the first floor, the researchers discovered that the people at the first floor managed to evacuate at 9 seconds on average while the total evacuation time for the five-storey building is 96 seconds.

3. MODEL DESCRIPTION

The model works by first dividing the layout of the ER into square grids size 0.4 m x 0.4 m. An example of the layout being divided into the grids are shown in Fig. 1. The obstructions are determined when they overlap cells. These cells are then obstructions and the agents will not be able to pass through those cells. Agents are also considered to obstacles to other agents, this prevents overlapping of cells.

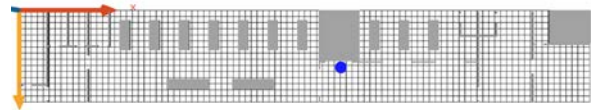


Fig. 1 Sample ER layout divided into square grids

The agents in the model move by utilizing a Moore Neighborhood. This means that an agent can have the option of moving to eight different directions as explained by Brugiére [11]. Figure 2 shows the illustration of the neighborhood. Given an agent in the center shown as a blue circle, the agent will be able to move into any of the eight directions. The agent will choose the shortest path going towards a selected exit. The only time that there will be less than 8 options is when an obstacle is present in the cell.

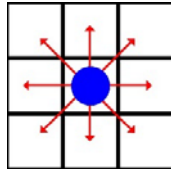


Fig. 2 Agent movement using Moore neighborhood

In choosing the exits, the agents select the closest direct exit. The agents then move towards the exit using the shortest path possible. Once the agent reaches a distance less than or equal to 0.4 m from the location of the exit, they are considered to be safe and have exited the layout. The program records the number of people that have exited at a given time and which exit they used. The independent variables used in the study are occupancy density, velocity of fire, number of people. The dependent variables are evacuation time and casualties. Controlled variables include the ER layout, exit location and fire source. The research determined the amount of time steps and total time to complete the evacuation for 10 different hospital emergency rooms to acquire the evacuation time. In addition to the 10 hospitals, 3 hospitals were selected to be simulated considering a fire within the room. The controlled variables for each setup were the emergency room layout, with the nonstructural components or obstacles, the locations of the exits, and the source of fire. The independent variables in each experimental setup included the density of the occupants and the rate of spread of fire. Five trials of the simulation were done for each density for 11 varying densities of the ten hospitals. Three trials were simulated considering a fire source for three densities for three different hospitals. In total, 658 simulations were done. In the ABM model the layout of each hospital was considered including the obstructions present such as walls, chairs, beds, tables, and other immovable equipment. In order to simulate the most realistic evacuation simulation possible, factors that contribute to the decision-making of the agents such as distance effects and location of exits were also taken into account. The results of the simulation were the evacuation times with corresponding densities and the number of casualties due to fire. These results were analyzed to assess the efficiency and effectiveness of the evacuation, as well as to evaluate and recommend a solution to improve the plan layout

4. DATA AND RESULTS

Prior to simulations, the researchers investigated ten hospital emergency room layouts as shown in Table 2. The smallest of the surveyed hospitals is about 200 m² and the largest about 2000 m². Based on

the values shown in Table 2, there is a weak correlation between the total floor area and the area of the hospital ER. However, it is evident that the area of the ER ranges from 2% to 16% of the total hospital area.

Table 2 Areas of the ten surveyed hospitals

Hospital	ER Area (m ²)	Total Floor Area (m ²)
A	212	1,804
B	241	9,206
C	321	10,644
D	382	8,670
E	393	4,806
F	665	18,964
G	959	6,712
H	1,038	6,404
I	1,071	13,851
J	1,820	96,358

The evacuation time for the varying densities for all the ten hospitals are shown in Fig. 3 and Fig. 4. The hospitals named alphabetically are in increasing order. Hospital A has the least ER area while hospital J has the largest area. It was found that the minimum and maximum evacuation time considering the different densities are shown in Table 3. The change in density effected the evacuation time by about 10 – 20 seconds.

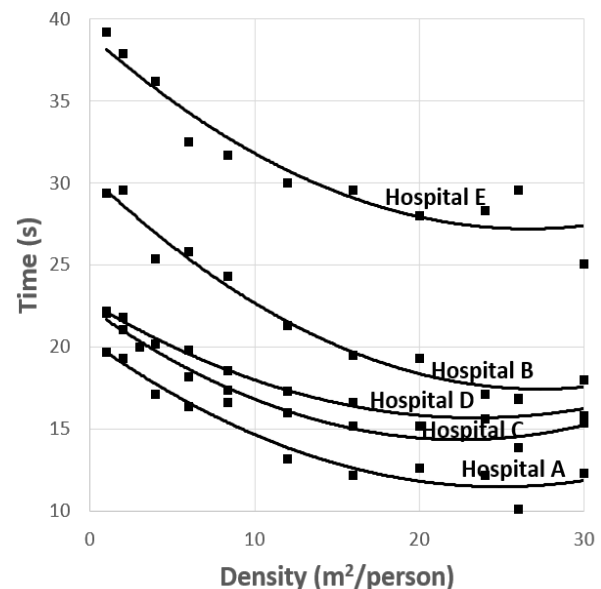


Fig. 3 Density versus time graph for Hospitals A-E

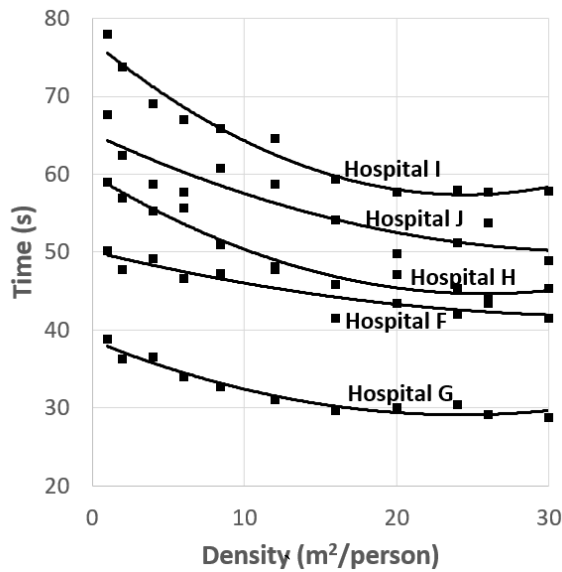


Fig. 4 Density versus time graph for Hospitals F-J

Table 3 Minimum and maximum evacuation times

Hospital	No. of Exits	Min. Evac Time (sec)	Max. Evac Time (sec)
A	2	10.1	19.7
B	1	18	29.6
C	2	15.4	22.2
D	2	15.2	22.1
E	1	25.1	39.2
F	2	50.2	41.5
G	3	28.8	38.9
H	2	45.3	59
I	2	57.8	78
J	3	48.9	67.7

The graph of the area of the ten hospitals versus the evacuation time for three different densities are shown in Fig. 5. the best fit polynomial curve for a high, medium, and low densities using the estimated area from all ten emergency room layouts. It can be observed that the area of the hospital has an effect on the evacuation time, however, there are some points where the evacuation of one room can be faster than that of a smaller room due to other factors such as the locations of the exits and the layout itself which includes the walls and obstacles. The number of exits ranged from one exit to three exits and it was found that there was no correlation with the number of exits.

Fire hazards were simulated by assuming it to start as a circle in the agent-based model with a diameter of 0.4 m. The hazard then continued to expand given varying velocities and the casualties and mortality rates were acquired for Hospital B, G, and J which

were determined as the representative areas for small, medium and large areas for the ten hospitals gathered.

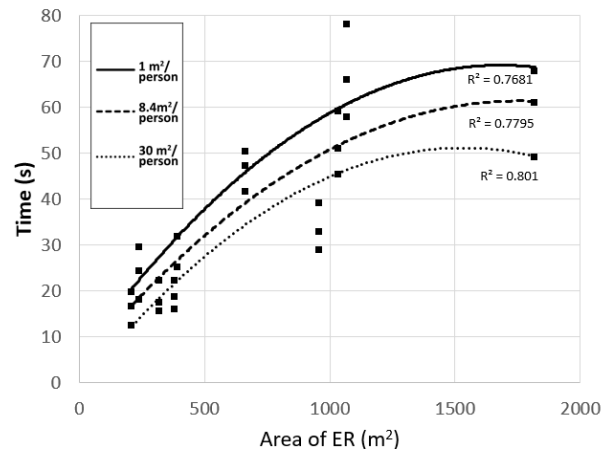


Fig. 5 Effect of ER area on evacuation time

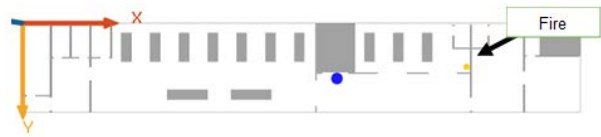


Fig. 6 ER Layout of Hospital B and the fire source

Figure 6 shows the layout of Hospital B and where the fire was assumed to start. The resulting graph of the mortality rate for varying velocities of the hazard is plotted in Fig. 7. The starting location of fire is placed near the oxygen tanks. Upon simulating, the curves produced by introducing fire to the layout of hospital B were steep. This may be due to the single exit located at the center of the layout. As the fire increases in diameter, it slowly spreads towards the exit. Therefore, agents who are travelling from the right side of the layout when engulfed by the growing radius of the fire, were already considered to be casualties. The maximum mortality rate of hospital B ranges from 80% to 90%.

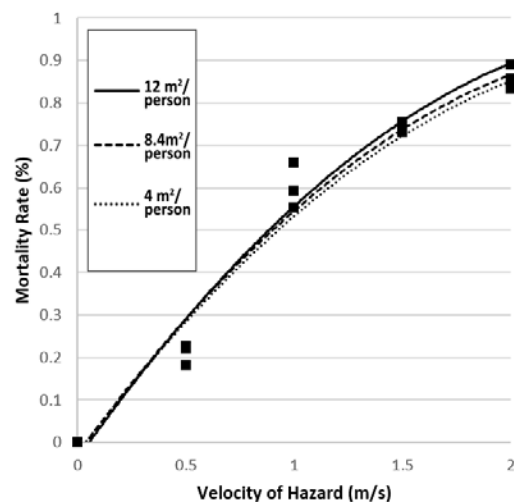


Fig. 7 Velocity of Hazard vs. Mortality Rate

Figure 8 shows the layout of hospital G. It is evident that hospital G has a larger area and has more exits as compared to hospital B. The starting location of the fire is assigned at the equipment room of the layout where fire will most likely to occur.



Fig. 8 ER Layout of Hospital G and the source of fire

The graph of the velocity of fire versus the mortality rate of hospital G shown in Fig. 9. The graph produced flatter slopes compared to the curves produced for hospital B. This implies that hospital G's layout is effective since it produced a flatter slope for the curves showing the relationship of the rate of fire with respect to the mortality rate. The highest speed of fire which is 2 m/s produced a smaller mortality rate for Hospital G as compared to Hospital B. Some of the factors that have contributed to the results are the location and number of exits as well as the presence of obstructions near the exits.

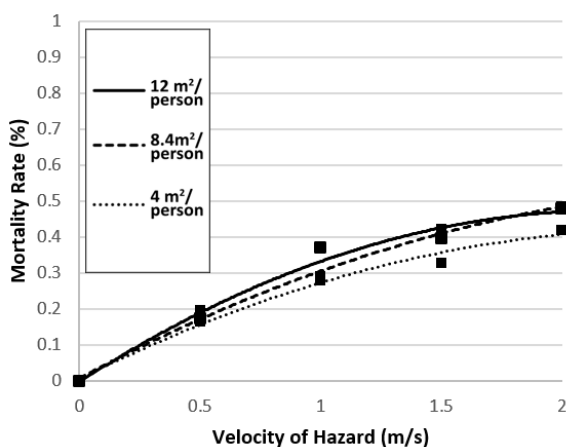


Fig. 9 Velocity of Hazard vs. Mortality Rate (Hospital G)

Figure 10 shows the layout of Hospital J and where the fire was assumed to start. The resulting graph of the mortality rate for varying velocities of the hazard is plotted in Fig. 11. Hospital J has the largest area among the ten hospitals. Fire was introduced in the simulation and was placed near the third exit. Over time, the fire spreads towards the exit, engulfing the area and the agents that chose that specific exit.

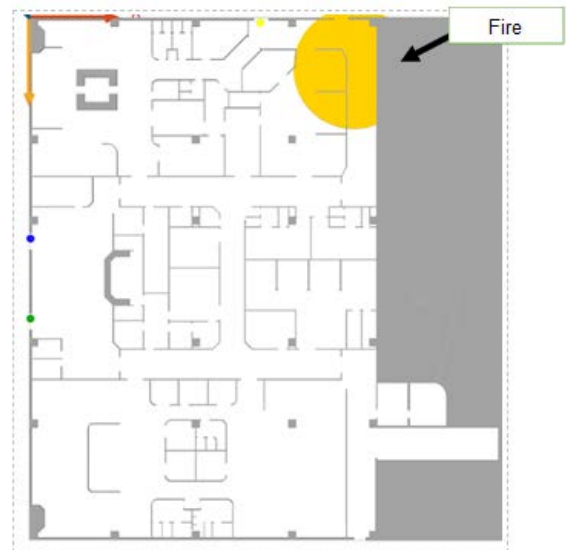


Fig. 10 ER Layout of Hospital J and the source of fire

The graph of Hospital J, as shown in Fig. 11, shows curves that are slightly steeper than hospital G but flatter than hospital B. The implication of this is although fire was initially near the exit, the highest velocity of fire produced a smaller mortality rate as compared to hospital B. The maximum mortality rate of hospital J ranges from values of approximately 58% to 72% took the exit at the rear side of the layout. Its distinct features include three exits: one at the top and two on the side as shown in Fig. 10.

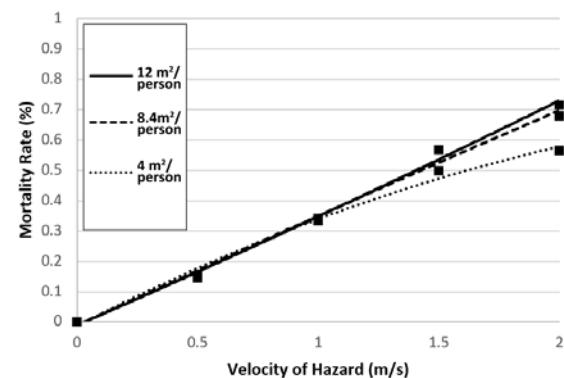


Fig. 11 Velocity of Hazard vs. Mortality Rate (Hospital J)

5. CONCLUSION

Ten emergency rooms were simulated for the evacuation time and fire. The researchers were able to develop an ABM program to simulate the evacuation. Varying the densities of the room effected the time by 10 to 20 seconds, which were graphed. Moreover, it was found that although the area of the hospital has a weak correlation with time, it still has an effect on the evacuation time. Evacuation time becomes faster when the exits are more spread out from one another, and serve equal number of occupants. The mortality rate is also based on how fast the fire is, where the fire source is, and locations of the exits. Obviously having more alternative routes lessens the mortality rate.

6. ACKNOWLEDGMENTS

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