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An Improved Simulation Model for Pedestrian Crowd Evacuation

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Abstract: This paper works on one of the most recent pedestrian crowd evacuation models—i.e., "a simulation model for pedestrian crowd evacuation based on various AI techniques"—which was developed in late 2019. This study adds a new feature to the developed model by proposing a new method and integrating it into the model. This method enables the developed model to find a more appropriate evacuation area design regarding safety due to selecting the best exit door location among many suggested locations. This method is completely dependent on the selected model's output—i.e., the evacuation time for each individual within the evacuation process. The new method finds an average of the evacuees' evacuation times of each exit door location; then, based on the average evacuation time, it decides which exit door location would be the best exit door to be used for evacuation by the evacuees. To validate the method, various designs for the evacuation area with various written scenarios were used. The results showed that the model with this new method could predict a proper exit door location among many suggested locations. Lastly, from the results of this research using the integration of this newly proposed method, a new capability for the selected model in terms of safety allowed the right decision in selecting the finest design for the evacuation area among other designs.

Keywords: evacuation models; simulation; exit locations; evacuation area design; evacuation time; management; improved pedestrian crowd evacuation

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1. Introduction

Currently, population size is intensely increasing, demand for space is inevitable, and new styles of buildings are built extensively due to the quick advancement in economics and its continuity [1,2]. The various structures of these buildings affect the duration of evacuation within the evacuation process [3]. Therefore, considering an operative evacuation system for these buildings is crucial when an emergency state occurs, such as terrorist threats, bombs, fires, and venomous gas [4].

All parties involved, such as residents, governments, and designers, face a problem when an emergency evacuation occurs inside these buildings [2]. Researchers are dependent on modeling to define the communication's rules and conditions between the environment and evacuees when there are deficiencies in the evacuation's realistic data [5]. Accordingly, crowd simulation allows dealing with an emergency, and it is precise, convenient, and supportive [6,7]. In the last two decades, regarding the limitations of using homogeneous people in various simulation models [8], there have been some simulation models proposed for evacuation, such as Simulex [9], BGRAF is acyually a simulation model [10], and Exodus [11]. In 2019, one of the most recent models for simulating pedestrian crowd evacuation using different AI methods was built, incorporating homogeneous people to simulate the pedestrian evacuation crowd [12]. However, this new model has a limitation that does not allow the best exit door location to be specified for the evacuation area according to the evacuee's efficiency. Moreover, it cannot choose the finest design among several existing designs for the evacuation area.

The main aims of this research are as follows: (1) focus on the methodology of this new model and try and find a method to determine the best exit location for the evacuation area and the best evacuation area design from a safety perspective, and (2) design and implement the method and integrate it with the existing model. Evacuation is a commonly researched field that remains an issue among scientists. There were various research papers on the evacuation process which tackled different conditions.

The main goal of this paper was to address the increasing demands of using pedestrian crowd simulation models. For safety purposes, governments and architects aim to design buildings properly. Consequently, various evacuation methods appear, such as protective, preventive, rescue, and reconstructive evacuations [13]. The evacuation problem is not solely the physical movement of evacuees; it is multifaceted and related to the physical and social circumstances, such as the high possibility for hazard, great stage of pressure, and inadequate data. These circumstances illustrate robust communication among the environment, danger, egress process, population demographics, and participant behavior [14]. Evacuees' communication in a building environment can influence the evacuation system. Therefore, the objective of this work was to offer a methodical technique based on a crowd simulation model to indicate the best exit door location and create a design with more safety. Hence, this paper adds a new environmental ability to the most recent pedestrian evacuation crowd simulation model developed in late 2019. The ability involves determining the best exit door location for evacuation, based on the model's evacuation process results, and selecting a more appropriate design for evacuation.

This paper is organized as follows: Section 2 presents a literature review. Section 3 describes the research method of the selected developed model and the methodology of this study. Section 4 shows the proposed method with the ability to determine the best exit location for evacuation within an area and presents the simulation results describing the selection of the best exit door locations and indicating a suitable design from the evacuation perspective. Lastly, Section 5 provides the final clarifications and recommends some information for future research work.

2. Literature Work

This section reviews several evacuation crowd models that considered the environment, speed, and behavior.

In 2016, S. Nirajan et al., using the collected responses for a questionnaire review of 1127 travelers, constructed and theoretically and mathematically proved a model allowing directors of the train station to find a suitable approach to deal with an emergency via an emergency controller while considering and assessing the locations of emergency exit signs during normal situations and emergencies in a train station [15]. In 2018, C. Shuchao, et al. offered an extended multi-grid model to examine evacuation within a room with two exit doors under the fire condition. The proposed model could guess the evacuees' movement and exit choice and act as a guider by providing recommendations to the evacuees when a fire emergency exists [16]. In 2018, Kontou et al. used cellular automata (CA) parallel computing tools to develop a model of crowd evacuation, then used them within the area of evacuation to mimic and assess the different appearances and manners of the individuals, including disabilities. To conduct the simulation process, a secondary school in the region of Xanthi was selected, which included disabled children. The school's safety training was well-ordered, with observing and existing earthquake. The evacuation time was recorded entirely. Finally, the realistic data validated the suggested model, and there was an expediency implication for the particular area [17].

In 2018, Kaserekaa et al. offered an intelligent agent-based model to simulate and model evacuees leaving a building under fire emergency. To assess the suggested model, four factors were used: the average time taken to exit (MT), the average fitness of the alive people (MP), total deaths (TM), and the total number of people alive (TV). When the simulation was executed, fire spreading, speed, some evacuating people, and other factors appeared that could influence the model. Moreover, emotional and physical properties with some other properties such as stress, disability, speed, wind, gender, and age are severely considered by this model and they may considerably affect the decision making of people who need to evacuate; the author of the proposed model wished to involve these factors due to fuzzy logic [18]. In 2019, M. Danial et al. developed a simulation model for pedestrian crowd evacuation based on the idea of fuzzy logic techniques, the idea of the KNN algorithm, and some statistical equations. The model defined various speeds for each participant based on different properties such as physical, psychological, and emotional properties and indicated individuals' evacuation time with their behaviors that appeared during the emergency evacuation process. Finally, the model confirmed that a combination of various properties, environments, distributions, and familiarities of the individuals with the environment led to a significant change in the behaviors that appeared for the participants and their evacuation efficiency during the emergency evacuation [12].

The authors' contributions to these existing literature works are shown in Table 1 based on this reference [19]. Table 1 shows the authors' contributions from the perspective of the methods they used to build their simulation models, the situation of evacuations, agents who participated in the evacuation process, and appearances that were achieved from the results of the evacuation processes.

Table 1. Shows the contributions of the authors.

Authors	Methods	Situations		Agents		Appearances
		Normal	Emergency	Disable	Not Disable	
Nirajan, et al. (2016)	Conduct a model theoretically and mathematically	✔	✔		✔	focus on emergency controller and evaluating emergency exit signs' locations
C. Shuchao, et al. (2018)	An extended multi-grid model		✔		✔	predict the movement of the evacuees, exit choice, and act as a guider
Kontou et al. (2018)	A model with Cellular automata (CA) parallel computing tools		✔	✔	✔	Recording evacuation time
Kaserekaa et al. (2018)	An intelligent Agent-Based Model with for factors		✔		✔	Appeared some factors affect the decision making of people to evacuate
M. Danial et al. (2019)	Cellular Automata (CA) with fuzzy logic, KNN, and some statistical equations		✔		✔	Records evacuation time and emergency behaviors during the evacuation process
This paper	An Integration simulation model		✔		✔	Best design choice among numerous designs

3. Research Method

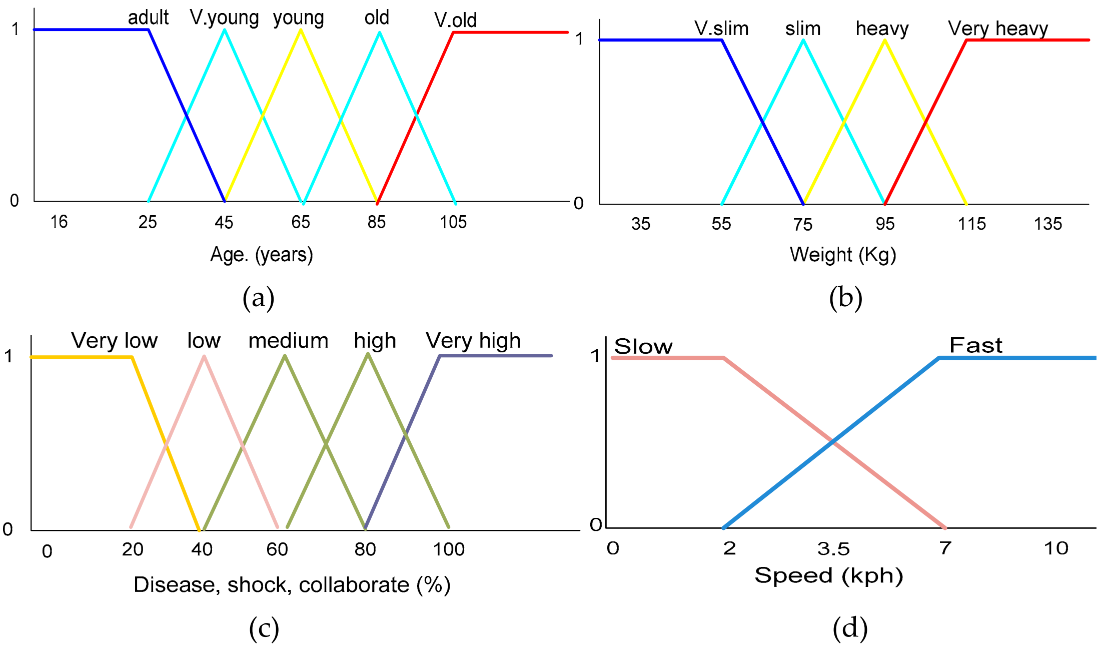
This section can be divided by subheadings. It provides a concise and precise description of the developed simulation model and the improvement in the developed model.

3.1. The Developed Simulation Model for Pedestrian Crowd Evacuation

This section presents the methodology of the most recent simulation model for pedestrian crowd evacuation. It is divided into three main parts: (1) the idea of fuzzy logic that was used to manipulate the individuals' properties via designing various membership functions and then prepared to be used in defining various individuals' speeds; (2) the idea of the kth nearest neighbors (kNN), which was used to help the evacuees find the nearest exit door; (3) some statistical equations were used to determine the desired speed for each individual through the evacuation process by benefiting from the individuals' properties that were prepared by the idea of fuzzy logic, as mentioned.

3.1.1. Idea of Fuzzy Logic in the Developed Model

Inside this developed model, various properties for each individual were collected—for example, physical, emotional, and biological properties—and then these properties were manipulated via the idea of the fuzzy logic technique. This manipulation was used for the fuzziness of each property and then helped the developed model to reach a realistic solution. From the fuzziness of each property, the model signified a specific range of qualities spanning to create a linguistic variable—for instance, "disease {very low, low, medium, high, very high}, weight {very slim, slim, heavy, very heavy}, age {adult, very young, young, old, very old}, collaboration {very low, low, medium, high, very high} and shock {very low, low, medium, high, very high}" [12]. Then, for each range, a membership function was designed by the model. The membership functions of the age, weight, disease, shock, and collaboration are distinctly illustrated in Figure 1a–d [12]. Consequently, these membership functions were utilized in defining the individuals' desired speed.



(a) (b)

(c) (d)

Figure 1. Model definition: (**a**) age membership function; (**b**) weight membership function; (**c**) fisease, shock, collaborate membership function; (**d**) speed membership function [12].

3.1.2. Idea of the K-th Nearest Neighbors (KNN) in the Developed Model

K-th Nearest Neighbors (KNN) use the training set and select features in the training set as different dimensions in an area. Using KNN to manage the number of points in the area determines the observation value for each dimension. Hereafter, it measures two points based on their similarity via the distance between them. Some suitable metrics include measures such as Euclidean, Manhattan, and others [20]. Equation (1) in the following is the Euclidian distance used by the developed model to measure two points.

$$\mathrm{dist}((a_1,b_1),\ (a_2,b_2)) = \sqrt{(a_2-a_1)^2+(b_2-b_1)^2}, \tag{1}$$

where a_2 and b_2 present the coordinate of the exit door location, and a_1 and b_1 present the coordinate of the pedestrian's location.

Therefore, the algorithm decides to select the new observation's adjacent data points to select the right class among numerous classes [21]. This study works on improving this developed model by adding a new feature to find the best design among numerous designs based on evacuees' evacuation times for each of the designs. Thus, this method was not compared with other methods, such as K means and others, while the developed model already used KNN.

Inside the developed model, individuals participating in the evacuation process were categorized according to the environment's familiarity property through the evacuation area. Their familiarities were determined during the collection of data about the individuals participating in the evacuation process. Some participants had no information about the exit door of the evacuation area from the gathered data, whereas some others had. The developed model utilized the K-Nearest Neighbor (KNN) technique to implement the familiar agents by introducing familiar properties for agents; checking the distance of each exit Ei inside the classes A, B, and C; and then choosing the nearest one to evacuate. Figure 2 shows how the evacuees check the distances between the exit door location and him/herself.

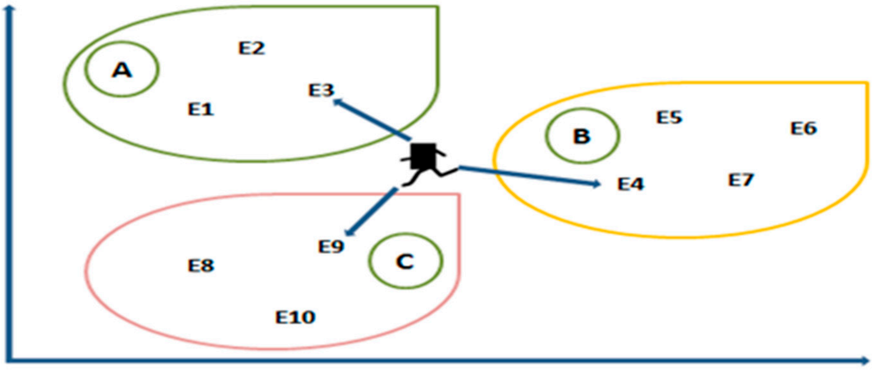


Figure 2. Illustration of how the agent checks the distance of each exit Ei inside the classes A, B, and C based on the K-Nearest Neighbor (KNN) technique and then chooses the nearest one to evacuate from.

3.1.3. Statistical Equations Used in the Developed Model

When the participating individuals' properties were gathered and examined, membership functions were created, as mentioned in Section 3.1. These functions were utilized in determining the weighted degree of the properties, while the property according to the idea of fuzzy logic consists of two values; a lower value and upper value. Figure 1 shows how the weight degrees of each property values are specified to participate in the speed of the agent.

From Figure 3 it appears that an agent has an age, and the age ranges from 16 to 105; this range is partitioned into some class intervals. Each class interval is indicated with a specified name—for example, 16–25 is adult, 25–45 is very young, 45–65 is young, 65–85 is old, and 85–105 is very old. Based on the fuzzy logic idea, some equations are proposed by the author to find the weights of the properties' values—for instance, if rgw age value equals 57 its weight is specified by Equation (2) [2] after specifying the lower value and upper value of the property via age membership functions. See Figure 3.

$$weightprop = \frac{\sum_{i=1}^{n} wp_i * srd_i}{\sum_{i=1}^{n} wp_i}. \tag{2}$$

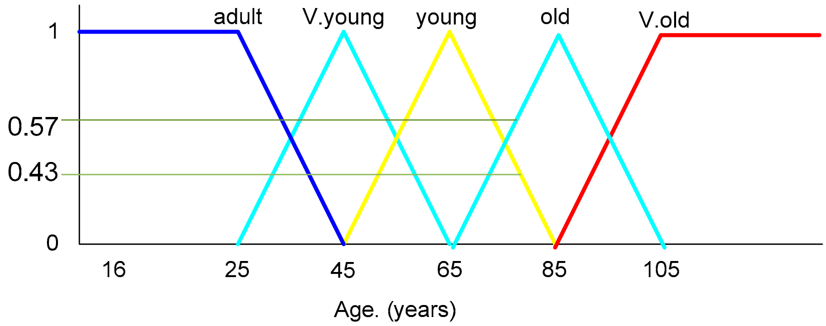


Figure 3. Shows how the weight degrees of each property value are identified to participate in the speed of the agent [12].

wp_i denotes the weighted degree for the given property and *srdi* denotes the degree's speed range. This model was developed to create heterogeneity inside a single class interval, and various forms for Equation (2) were suggested (see Equations (3) and (4)). The agent's degree of weights' property is defined separately by applying Equations (3) and (4) [12].

$$weightprop = weightedmean = \ (lov * minisrd + upv * maxisrd)\,/\,(lov + upv), \tag{3}$$

$$weightprop = weightedmean = \frac{(upv * minisrd + lov * maxisrd)}{(lov + upv)}. \tag{4}$$

lov denotes the lower value, *upv* denotes the upper value, *minisrd* denotes the minimum interval speed range, and *maxisrd* denotes the maximum interval speed range of the mentioned properties. Because these weights participate in specifying the desired speed for an agent, the range of the speed must be identified. The speed range is assumed to be a minimum of 2 k/h to a maximum of 7 k/h, as shown in Figure 1. Each property has its range, as mentioned above, and for each property there is a value given randomly between its ranges or that could be chosen by the user of the simulation model. Moreover, this model created several class intervals for the speed range to keep a balance between the property value and the speed. For example, when an agent is 57 years old, this agent, according to designed age membership function 0.57 is young and 0.43 is very young, and its speed range is between 4 and 5 k/h. See Figure 4. The logical reason behind this separation in speed range was that older agents are slower than younger agents. Furthermore, Equation (5) (Midvale) [12] was used to find the middle of the class interval chosen by the age membership function.

$$\text{Midvalue} = lov + upv/2. \tag{5}$$

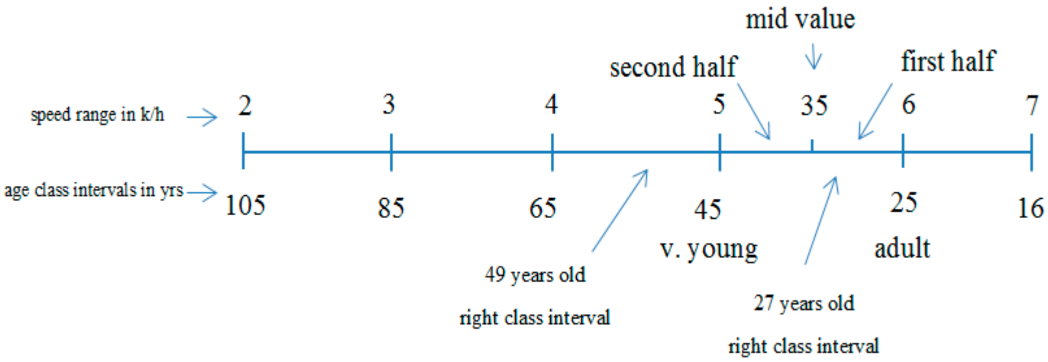


Figure 4. How the weights of an agent's properties are identified [12].

This midvalue aims to keep diversity in both distinct parts of a chosen class interval and avoid weight redundancy. Consequently, the result of Equation (5) and the value of the property decide on the use of Equation (3) or (4). However, when the given property value was equal to the midvalue result, there is no difference in Equation (3) or (4). When an agent has more than one property, such as age, weight, disease, and so on, the same operations used to find the weight of age would be used to determine the weight for other properties. Finally, Equation (6) [12] would be used to find the desired speed of each agent from the results of Equations (3) and (4) after amalgamation with both emergency factor em_i and gender factor gen_i. Readers who are interested in knowing more about these equations should look at this paper [12].

$$\mathrm{desiredSpeed} = \left(\frac{\sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{wp}_I}{\mathrm{n}}\right) * gen_i * em_i. \tag{6}$$

3.2. Improvement in the Developed Model

This section illustrates a proposed method for one of the most recently developed simulation models for pedestrian crowd evacuation. The previous subsection mentions efforts to improve the model's ability to find the best exit door location among various suggested exit door locations through the area of evacuation and selecting a more suitable design among other designs of the evacuation area. Figure 5 presents the proposed method.

Step 1: Specify lower bound and upper bound of the side of the evacuation area, which the designer wants to place the exit door location.

Step 2: Identify the number of exit door location, which the designer wants to be tried for the selected side of the evacuation area.

Step 3: Get exit door locations randomly between the lower bound and the upper bound as mentioned in step 1.

Step 4: Select one of the random exit door locations as mentioned in step 3.

Step 5: Start evacuation process for that exit door location from step 4, and then find evacuation time of each individual.

Step 6: Find average of individuals' evacuation time which was found by step 5.

Step 7: Check if there is still a random exit door location to be tried, if there exists return to step 4, otherwise go to next step.

Step 8: Compare averages of the evacuation times for exit door locations.

Step 9: Select the exit door locations with the minimum average as the best exit door location to be

Figure 5. Shows a proposed method to integrate with the most recently developed simulation models.

This proposed method was integrated with the created simulation model to increase the performance of the simulation model, and involved a new capacity of that model via simulating an evacuation area with various exit doors locations with the hope of identifying the best location for the exit door among them and also choosing the best design for the evacuation area. To confirm this method's possibility, various experiments were performed in Section 4 and then discussed.

4. Results and Analysis

To improve this method and integrate it with the developed model, several scenarios have been written which have been used to improve the model through different experiments. Since the developed model worked on the area of a cafeteria and sufficient data were collected about the individuals that participated in the evacuation process and analyzed, this research also studied the same area and used the same data of the selected model; interested readers can look at this paper [12]. From there, the written scenarios mentioned above were tested for five various prominent exit door locations with the same distribution of the individuals through the area of the cafeteria, and the plans could be described in these points: (1) Only one exit door for each student part, employee part, and staff part. (2) Two exit doors for the student's part, only one exit door for each employee and staff part. (3) Two exit doors for the student part, two exit doors for the employee part, and one exit door for the staff part. The above-mentioned points are described in Table 2. For more details, Table 3 shows the importance of some parameters in the final result of the evacuation time.

Table 2. Shows several scenarios used to execute the model through different experiments.

Experimentations	Scenarios
#A	Each of the employee part, student part, and staff part has one exit door; evacuees were not familiar with the exits
#B	Two exit doors for the student part and each of the employee parts, and the staff part has one exit door; evacuees were not familiar with the exits.
#C	Two exit doors for each of the student part and employee part, and one exit door for the staff part; the evacuees were not familiar with the exits

Table 3. Shows the importance of some parameters in the final result of evacuation time.

No	Parameters	Importance
1	Individuals distribution	Individuals' distribution within a small area of the evacuation leads to more collisions among evacuees and decreases the evacuees' speed; thus, the evacuation time will increase. On the other hand, when they are distributed within a large area, the numbers of collisions among the evacuees will decrease. The evacuees can move toward the exits at their desired speeds; therefore, the evacuation time will decrease. An individual takes more time to evacuate when the individual from the distribution is far from the exit door.
2	Number of each part exit doors within the area of evacuation	The evacuation time is minimized with an increasing number of exit doors for each part within the evacuation area. However, the individuals who choose the wrong exit door to evacuate by without having familiarity with the evacuation area may take a long time.
3	Familiarity	Individuals' familiarity with the area evacuation will help them to evacuate in a shorter time from the evacuation area. However, this familiarity causes congestion on the way to the exit door. At this time, the evacuation time will increase.

All the scenarios mentioned in Table 2 have been tested for 20 evacuees, and each scenario was tried for 20 not familiar evacuees. All the evacuees involved in the different scenarios had the same attributes, such as evacuees' ages between 20 and 57, and evacuees' weights between 57 and 102 kg. Moreover, the developed model defined the evacuees' desired speed based on their properties, as mentioned in Section 3.1.3.

4.1. Result and Experimentation #A

Inside the model, the evacuation area was designed and managed according to scenario number #A mentioned in Table 2. The design was tested, as shown in Figure 6, and the results of 20 nonfamiliar evacuees for five exit door locations are shown in Table 4.

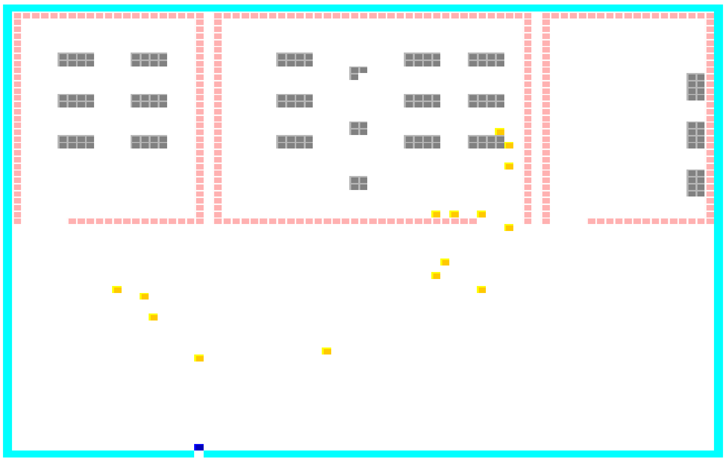


Figure 6. Shows the area of evacuation with one exit door for each part of the evacuation area.

Table 4. Result of scenario #A for 20 nonfamiliar evacuees for 5 exit door locations.

	Exit 1 At Location (70,47)	**Exit 2 At Location (70,57)**	**Exit 3 At Location (70,73)**	**Exit 4 At Location (70,83)**	**Exit 5 At Location (70,35)**
Individuals			**Durations**		
1	0:18:225	0:18:158	0:19:346	0:18:162	0:18:203
2	0:11:834	0:14:579	0:19:330	0:22:362	0:11:763
3	0:13:990	0:12:905	0:13:732	0:14:260	0:16:495
4	0:14:310	0:14:752	0:15:387	0:15:27	0:15:851
5	0:13:903	0:16:437	0:20:197	0:26:246	0:13:474
6	0:9:289	0:9:114	0:9:551	0:9:686	0:10:205
7	0:15:902	0:14:552	0:15:352	0:15:777	0:14:585
8	0:13:946	0:14:44	0:14:819	0:15:3	0:15:621
9	0:15:469	0:15:333	0:15:595	0:15:637	0:15:894
10	0:17:786	0:18:444	0:16:792	0:16:730	0:18:307
11	0:10:766	0:11:427	0:17:157	0:19:650	0:10:881
12	0:13:192	0:15:532	0:21:815	0:25:356	0:13:26
13	0:8:77	0:8:969	0:13:285	0:14:679	0:8:496
14	0:19:680	0:19:677	0:20:238	0:20:59	0:20:669
15	0:18:526	0:18:438	0:17:846	0:18:839	0:19:328
16	0:17:319	0:18:365	0:17:852	0:18:526	0:19:231
17	0:15:454	0:14:762	0:15:431	0:14:798	0:15:670
18	0:18:773	0:18:960	0:18:620	0:19:264	0:19:235
19	0:21:643	0:21:811	0:21:688	0:21:856	0:22:118
20	0:22:740	0:22:221	0:22:534	0:22:668	0:22:549
Average Durations	15.541	15.924	17.328	18.229	16.08

4.2. Result and Experimentation #B

Inside the model, the evacuation area was designed and managed according to scenario number #B mentioned in Table 2. The design was tested, as shown in Figure 7, and the results of 20 nonfamiliar evacuees for five exit door locations are described in Table 5.

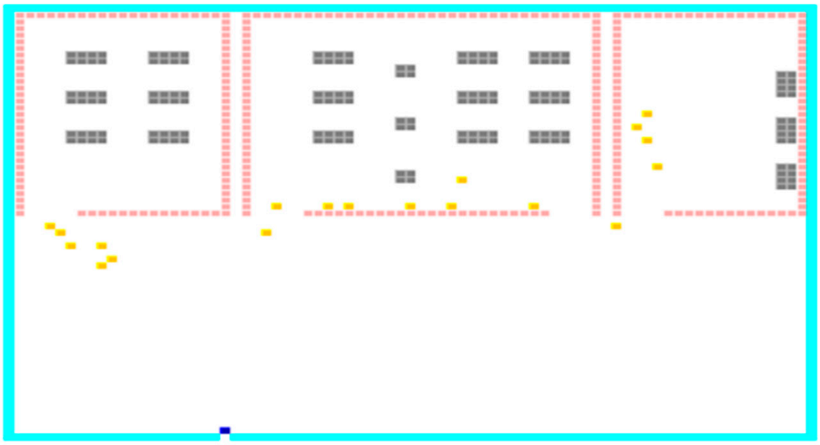


Figure 7. Shows the area of evacuation with two exit doors for the student part of the cafeteria.

Table 5. Result of scenario #B for 20 nonfamiliar evacuees for 5 exit door locations.

	Exit 1 At Location (70,47)	**Exit 2 At Location (70,57)**	**Exit 3 At Location (70,73)**	**Exit 4 At Location (70,83)**	**Exit 5 At Location (70,35)**
Individuals	**Durations**				
1	0:18:753	0:18:661	0:18:613	0:19:78	0:17:41
2	0:12:606	0:14:111	0:19:264	0:22:504	0:12:354
3	0:13:462	0:13:362	0:13:661	0:13:751	0:16:409
4	0:10:578	0:15:691	0:9:974	0:15:464	0:15:770
5	0:12:967	0:17:264	0:21:40	0:23:75	0:13:135
6	0:9:384	0:14:676	0:9:567	0:9:907	0:10:183
7	0:14:784	0:20:895	0:21:692	0:25:475	0:14:575
8	0:14:233	0:15:794	0:14:105	0:18:645	0:14:345
9	0:16:361	0:14:649	0:15:314	0:18:279	0:15:859
10	0:17:858	0:18:396	0:14:854	0:17:200	0:13:450
11	0:11:603	0:12:982	0:17:131	0:20:522	0:10:110
12	0:14:300	0:16:321	0:22:623	0:24:119	0:14:481
13	0:8:547	0:9:425	0:12:264	0:14:723	0:7:918
14	0:20:462	0:14:224	0:16:56	0:19:720	0:13:792
15	0:13:569	0:18:425	0:18:809	0:18:183	0:18:763
16	0:17:383	0:17:615	0:18:314	0:18:615	0:19:220
17	0:14:677	0:14:525	0:14:273	0:14:498	0:16:816
18	0:17:787	0:17:345	0:17:362	0:17:665	0:19:941
19	0:18:597	0:18:829	0:18:526	0:18:842	0:21:487
20	0:21:237	0:21:482	0:21:551	0:21:459	0:24:884
Average Durations	14.957	16.233	16.749	18.229	15.526

4.3. Result and Experimentation #C

In the model, the evacuation area was designed and managed according to scenario number #C mentioned in Table 2. The design was tested, as shown in Figure 8, and the results of 20 nonfamiliar evacuees for five exit door locations are shown in Table 6.

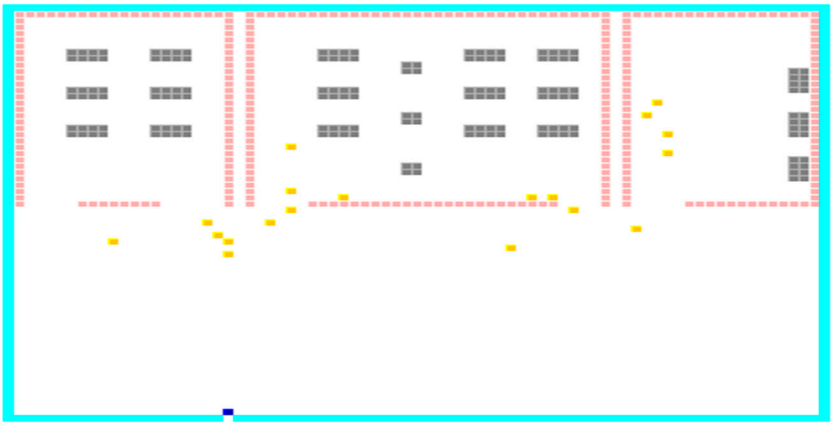


Figure 8. Shows the area of evacuation with two exit doors for the student part of the cafeteria.

Table 6. Result of scenario #C for 20 nonfamiliar evacuees for five exit door locations.

	Exit 1 At Location (70,47)	**Exit 2 At Location (70,57)**	**Exit 3 At Location (70,73)**	**Exit 4 At Location (70,83)**	**Exit 5 At Location (70,35)**
Individuals			**Durations**		
1	0:17:694	0:18:230	0:18:618	0:19:5	0:17:437
2	0:14:820	0:14:669	0:16:970	0:23:706	0:14:939
3	0:13:755	0:13:632	0:14:32	0:14:375	0:16:418
4	0:15:68	0:10:235	0:10:2	0:12:559	0:14:261
5	0:14:2	0:12:882	0:16:171	0:19:442	0:13:492
6	0:9:421	0:9:515	0:15:487	0:16:449	0:14:126
7	0:15:905	0:15:63	0:19:834	0:25:400	0:19:386
8	0:14:871	0:14:766	0:15:729	0:14:806	0:15:654
9	0:16:387	0:15:307	0:15:994	0:18:213	0:15:554
10	0:14:968	0:13:871	0:18:92	0:17:464	0:14:119
11	0:11:84	0:12:1	0:12:801	0:15:343	0:10:892
12	0:14:671	0:14:933	0:18:79	0:21:573	0:13:78
13	0:8:113	0:9:43	0:10:55	0:16:31	0:8:739
14	0:15:74	0:19:632	0:19:909	0:20:736	0:14:188
15	0:18:35	0:17:903	0:18:720	0:18:848	0:17:543
16	0:17:412	0:16:937	0:18:222	0:18:669	0:16:903
17	0:14:368	0:14:545	0:14:193	0:14:566	0:16:880
18	0:17:793	0:17:353	0:17:295	0:17:720	0:20:607
19	0:18:609	0:18:841	0:18:430	0:18:882	0:21:462
20	0:21:77	0:21:139	0:21:460	0:21:548	0:24:899
Average Durations	15.156	15.024	16.504	18.266	16.028

From this integrated model's experimentations' results, it appeared the method proposed in Section 3.2 worked properly. The method made the developed model significantly improve in finding the evacuees' evacuation times' averages for various exit door locations and then used them to select the best exit door location among them. Moreover, the written scenarios, as mentioned above, made the model create different designs for the area of evacuation to be tested by the improved model. Consequently, the proposed method worked as a new capability of the developed model after it compared the evacuees' evacuation times' average for the suggested exit doors' locations. It indicated the best exit door location among many others via the selection of minimum average durations that all evacuees took to evacuate from the evacuation area's exit door locations. The green color in Tables 4–6 shows the minimum average duration belonging to the best exit door location.

When change occurs in the evacuation area's design, it changes the evacuees' evacuation time within the evacuation process. Thus, it changes decision making to select the best exit door location for evacuation, among others. For instance, in Figures 6–8, an evacuation area contains three different parts. As mentioned in the model developed in paper [12], the first part is the employees' part, the second part is the student part, and the third part is the staff part. As shown in Figure 6, each part has one exit door. From the results shown in Table 4, the best exit door location was (70,47), with an average duration of 15 s and 541 milliseconds. Moreover, as shown in Figure 7, the students' part has two exit doors, while the employees' part and the staff's part have one exit door. From the results presented in Table 5, the evacuation duration was significantly improved. However, the best exit door location remains the same (70,47), with 14 s and 957 milliseconds. Furthermore, as shown in Figure 8, the employees' part and students' part have two exit doors, while the staff's part has one exit door. From the results obtained in Table 6, the evacuation duration was slightly increased and the best exit door location changed to (70,57), with a duration of 15 s and 024 milliseconds. Finally, the designer can choose the best design for the evacuees from the three tested designs. The design shown in Figure 7 was safer than other designs shown in Figures 6 and 8, while it takes only 14 s and 957 milliseconds for the evacuees to evacuate from the evacuation area. See Figure 9.

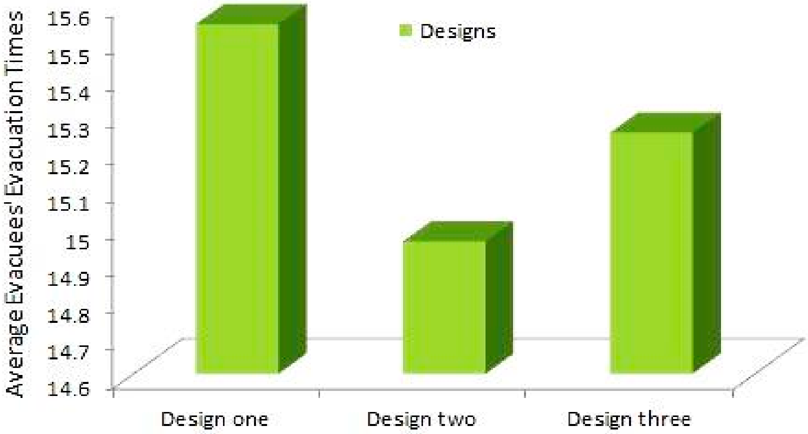


Figure 9. Evacuation times for three different designs of the evacuation areas.

5. Conclusions

Even though identifying the evacuation time and behaviors that appear during emergency evacuations for evacuees is vital, it is still crucial to build methods for these models to simulate various circumstances to enlarge the models' capabilities carefully. From there, in this study a new method was proposed and integrated with one of the most recent simulation models for pedestrian crowd evacuation published in late 2019. This integration was conducted to improve the ability of the developed model and cause the model to simulate the effect of the different exit door locations on pedestrians' evacuation times and choose the best exit door location among them. This method was dependent on the developed model's output. In contrast, it used the evacuees' evacuation times to specify the best exit door location, among other things.

Furthermore, to confirm this proposed method's ability, several scenarios were written and tried by the integrated model. From the results, it appeared that the developed model was more capable than before, whereas, with the proposed method, the average evacuees' evacuation times could be found and then used to determine the best exit door location among many others. From there, the designers made a decision regarding which design is the best for an evacuation area in terms of safety. Finally, it is recommended as future work to focus on adding a new feature to the proposed method to determine which exit door had more congestion and collision between the evacuees and determine how the congestion and collision influenced the evacuation process.

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