Fast Crowd Evacuation Planning System for Disaster Management

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Abstract

Last few decades witnessed the occurrence of various natural and man-made disasters that were difficult to control, thereby leading to heavy casualties. To overcome these, preventive measures like the design of the building, coordinated pre-planning, etc., needs to be done. To reduce the casualties during fire disaster and to enhance the evacuation efficiency, it is important to consider the impact of factors which influence the evacuation. The effect of human and fire factors depend on strategies used for evacuation in the building architecture. This paper presents a method for fast crowd evacuation and safety management, thereby improving the efficiency of evacuation.

Keywords: evacuation, fire, crowd, sensors, exits

1 Introduction

Growth in population and increase in the occurrence of public events in large scale, such as political events, sports event, family functions and entertainment programs which gather a massive number of people, lead to congestion, because of which control and prediction of crowd becomes difficult and complex [11]. This leads to implementing several real time applications to monitor several activities [5, 10, 9]. Moreover, with the increase in natural or man-made calamities such as a terrorist outbreak, fires, etc. the need of the hour is to find efficient ways for emergency evacuation taking into consideration the architectural designs, topography, etc. The increasing disasters during the few past decades, which were caused due to crowd mismanagement led to heavy casualties. This highlighted the importance of safe crowd evacuation. Exploring and analyzing how the factors influence the process of crowd evacuation is important to eliminate casualties and financial wastage during fire disasters. In this work, fire based evacuation process in different buildings and its structures are discussed. Interactions between building environment, fire and evacuees are taken into consideration for efficient crowd evacuation. After knowing the complexities of prevention and extinction of fire in buildings, especially big and complex public buildings, emergency evacuation has been a crucial method for reducing disasters. Various studies on evacuation strategies have been done on the fire scenarios and human behavior modeling to estimate the time of evacuation and analyze the evacuation processes. [3].

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The most critical factor that leads to several causalities is the lack of control. Some of the recent examples of disasters which occurred are Camp Fire in California, November 2018; Hurricane Michael in Gulf Coast, October 10, 2018; Super Typhoon Mangkhut in the Philippines, and southern China, etc. All these hazards have caused casualties of thousands of living beings and injuries to millions. Evacuations, especially which arise during a situation of emergency can be characterized by increased speed, physical interactions, bottleneck effect, and clogging exits. The readiness of the evacuees to drift towards an exit at the fastest possible speed, which results in clogging, is the bottleneck effect also known as the “human jam” effect [1].

Evacuation planning is another important factor to be considered because immediate route planning is very crucial when a disaster happens. Route information can be made available immediately if the complexity of computation can be reduced. The route-finding algorithms like Dijkstra and A-star, which use heuristics components, can be explored extensively to produce enhanced evacuation result with the integration of evacuation planning approaches [13]. When an emergency arises in front of pedestrians, majority of the normal human behavior disappears. In non-emergency situations too similar effects can be observed, like crowds trying to reach to their preferred seats at a concert or customers running while shopping in a supermarket. It can be inferred from the observations that the patterns made by the crowd during an emergency are the same as that of pedestrians in the above scenarios. When people are in a hurry to leave the building then the intended velocity of crowd increases. As the anxiety builds, individuals are less worried about being in the comfort zone, rather are increasingly worried to locate the most advantageous and briefest approach to move out from catastrophe inclined zone. It is observed that if individuals need to exit from the building at the time of crisis, and if they are not well familiar with the architecture of the building, they would keep running towards the exit utilized as an entrance, regardless of whether different other easy ways are available to reach [8]. Individuals also loose the capability to arrange themselves in their surrounding and consequently show crowding or running conduct, such as pushing or other physical connections. Such non-adaptive behavior of crowd leads to death and damage of most evacuees at the time of calamity. This can result into a low evacuation speed, moreover if one or more people fall down in such a situation then the situation worsens, as the people who fell down will act as an obstacle for remaining crowd. Microscopic, macroscopic and mesoscopic models are proposed to avoid such situation. In Microscopic models, crowd is represented as a discrete and a separate entity whereas in macroscopic model it is characterized through their density and average flow. The mesoscopic models present the relationship between macroscopic and microscopic models [6]. A good evacuation model should consider social human behavior such as herding, queuing, competitiveness behavior. Results inferred from the existing literature on the basis of the previous crowd behavioral evacuation modelling systems are discussed in this section and section The behavioral factors comprises of physical, psychological and environmental factors. Physical factors include speed, wait time, goal, fitness, etc. Psychological factors are instantaneous emotions of person at that moment, like confused, sadness, panic, anger, selfish-minded, stress, etc. Environmental factors comprise of building layout, smoke, smoothness, etc.

Evacuation process, crowd disasters, and traffic management are the key motivation for research in this field. Despite the fact that every individual is distinct, there occurs an underlying coherence that governs crowd behavior. The researchers are developing interest towards a macroscopic model of crowd dynamics, which can be ascribed to crowd’s underlying collective behavior. Models for crowd simulation that have existed a couple of decades incorporate queuing models, transition matrix models, and stochastic models. Prior models applied statistical regression analysis to forecast disasters. A few analysts have displayed crowd in correlation with the conduct of liquids. Despite the fact that this model portrayed aggregate conduct, it needs be rectified to incorporate cooperation between the individuals, which did not relate to energy and momentum conservation laws. Such fluid dynamic models were tried and tested on traffic stream issues and 1-D vehicle stream issues [11].

As opposed to representing the individual interactions and the irritations presented by them, the macroscopic model gives a more extensive picture. There is emphasis now on average velocity, average acceleration and the general direction of motion. Individual behavioral effects and preferences are smoothed out giving a net average effect. Consequently, such modeling methods adapted to an Eulerian approach of analysis involving the center of mass and density concepts, for efficient crowd evacuation. It is relevant to glance the differences that exist between two modeling - the macroscopic and microscopic methods. Microscopic modeling focuses on the individuals establishing the crowd. It considers the interactions among individuals with their surrounding environment and with different people. This design of crowd modelling mainly focuses on the direction of motion, and acceleration of discrete individuals. Aggregate behavior is perceived from the information of the movement of the people. The macroscopic model focuses on collective behavior of crowd, i.e: group behavior on the movement of the single person to the whole crowd in general. The macroscopic model gives a more extensive view with more emphasis on the average velocity, average acceleration and general direction of motion. Individual behavioral impacts and inclinations are smoothed out giving a net normal impact. Thus, such modeling strategies adjusted to an Eulerian approach of analysis include the center of gravity and density concepts, for safe and efficient crowd evacuation [7].

2 Related Works

Y. Hu, X. Wang [3] studied how to improve the efficiency during crowd evacuation from the building on fire. Computational experiments are done to know the impact of several factors on fire evacuation.

Evangelos Boukas, et al [1] proposes an accurate Cellular Automaton model for simulation. It assesses the human mobility and behavior during an emergency situation. A mobile robot is used for simulating and redirecting the evacuees from their originally planned exits i.e-by which people intended to move out, to more passable and lesser crowded exits.

Survey on Crowd Behaviour evacuation during emergency focuses on Crowd behaviour evacuation modeling, crowd behavioral factors and crowd evacuation planning. W. Zakaria and U. Yusof [13] study crowd behaviour evacuation modelling characterized by individual conduct in terms of crowd behavioral factors and methodologies with regard to crisis clearing and route finding, thereby ensuring an efficient emergency evacuation.

To ensure the smooth flow of crowd during evacuation for purpose of safety and fast evacuation, psychological behaviour of crowd needs to be considered. X Xu, L Zhang, et al. [12] presented a paper which stresses on the fast and organized evacuation of large-scale crowd densities from disaster prone area to the nearest shelters. They propose an algorithm for evacuation planning named as Artificial Potential Field with Relationship Attraction (APF-RA) which uses Internet of Things for collection of data and cloud backend is used for storage and analytics.

S. Mukherjee et al. [7] described a method to model crowd dynamics using Lagrangian approach, considering several forces that are present between the individuals which constitute the crowd while they are in motion, which is demonstrated via the energy function known as Lyapunov and variable gradient method.

X. Lu, Peter B. Luh [6] studied how the route planning and other psychological features are impacted by increase in anxiety of people, using virtual reality experiments.

O. Khalid et al. [4] proposes EvacSys, an emergency evacuation system which is based on Cloud computing technology. The drawback of the evacuation process is that the effective information are available to follow through a safe route of the the affected areas.

Paper by Ying Zheng, Bin Jia,et. al [14] examines the influence of fire spreading on the dynamics of pedestrian evacuation. Exit choice model behavior analysis is done by M. Haghani and M. Sarvi

[2] wherein they consider two types of exits: between rooms of building and main exits which lead to outside.

Taking the above factors into consideration, this paper implements a system that consists of a processing unit to redirect evacuees from their originally intended exits, to nearer and less overcrowded ones.

3 Proposed Methodology

This section discusses about the proposed methodology for a crowd evacuation system from a building which is caught by fire. During emergency the sensors of smart watches can be advantageous during crowd evacuation when other signals are not available due to external factors such as power loss, no human guidance and the scenario demanding a dynamic evacuation strategy. Flow diagram of the proposed system is given in Figure 1.

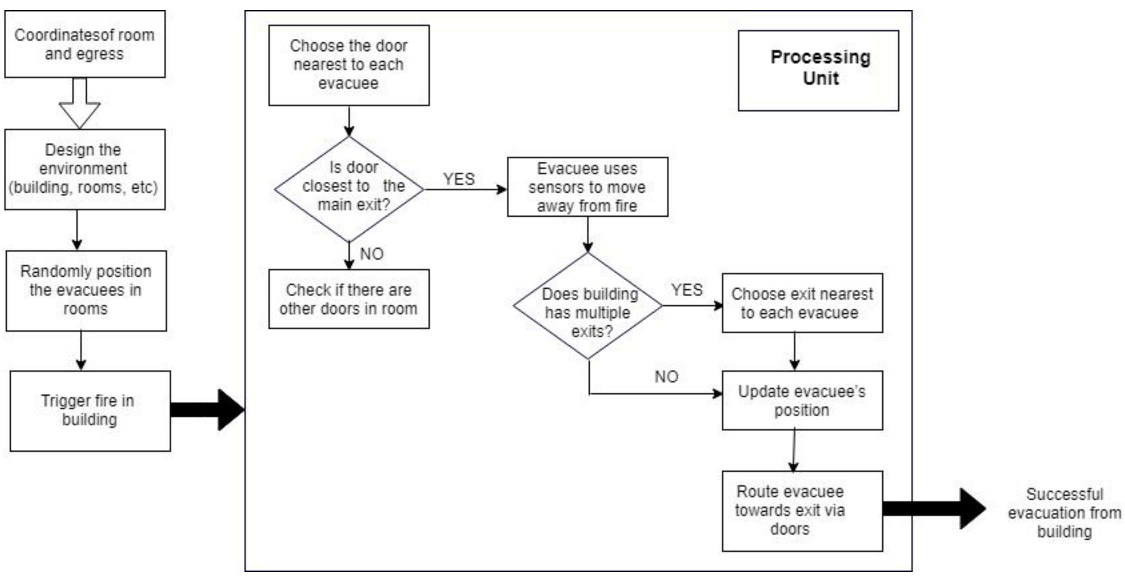


Figure 1: Flow Diagram of Proposed Crowd Evacuation System

The proposed system consists of the following modules:

Input Module: This module is needed for initial setting up of environment for the simulation. It takes input to define the architecture of building. Coordinates of room and egress(door and main exits) is taken to create the layout, then environment is designed like rooms, doors are positioned. Distribution of people is done within several rooms of building followed by triggering of fire.

Processing Unit: The most prominent module of this system is Processing unit, using which evacuees are redirected from their originally intended exits, to more nearer and less crowded exits. Processing unit takes values from input module and does the main task of evacuating people from building, using Euclidean distance to find the door which is nearest to each evacuee and closest door to the main exit. In case the fire is near to a door, and the room has multiple doors, some other door is chosen to move them out from the room. Evacuees use sensors to move away from fire, such that they maintain sufficient distance from it; they also move closer to the main exit of building.

Output Module: This module is needed for successful evacuation of all people from the building, and calculates the total time needed for this.

The proposed system uses a processing unit to redirect evacuees towards main exits via nearest doors in the respective rooms they are present in. Following factors are considered during the design of the proposed system:

- Environment /Architecture of building
- Distribution of the crowd
- Evacuation strategy

Human positioning is done using random distribution, Poisson and Gaussian distributions. Evacuation strategy is based on calculating the Euclidean distances between evacuees, doors and fire, and then selecting a shortest route to the main exit, which passes through the doors and leads through way which is distant from fire.

3.1 Environment

This consists of simulation of building architecture and the positioning of rooms, doors and exits. The doors lead from one room to another whereas exits lead out from the building. Building architecture considered here includes simple and complex designs, with single and multiples exits. Single exits mean simple evacuation is done, i.e. evacuees move out from building one by one, whereas in case of multiple exits parallel evacuation takes place, i.e. simultaneously more than one evacuee can exit from building.

3.2 Distribution of the crowd

Evacuees and fire coordinates are distributed throughout the building to get a real-time and efficient simulation of crowd. Fire coordinates are taken as fixed inputs and positioning of evacuees is decided on basis of following three distributions:

3.2.1 Random Distribution

In this the positions of evacuee varies, but can be restricted to a certain range. Using these for calculation of coordinates of evacuees:

$$initialX = rand(1,1) * 2 + 8 \tag{1}$$

$$initialY = rand(1,1) * 2 + 1 \tag{2}$$

$$initialHead = rand(1,1) * 2 * pi \tag{3}$$

where
initialX is the X-coordinate of evacuee in the beginning of simulation,
initialY is the Y-coordinate of evacuee in the beginning of simulation,
initialHead is the positioning of head of evacuee initially,

3.2.2 Poisson Distribution

The Poisson distribution demonstrates the discrete probability distribution of the number of occasions happening inside given timeframe, known as the number of times the event occurs over that time period on an average.

In this the Poisson values (x,y) are stored in a file and read from there for the number of evacuees to be positioned. Here x is the left and y is the rights coordinate of initial evacuee position. These values are stored in an array A. Now this array 'A' contains required number of Poisson coordinates which are read and is used to position the evacuee within the building.

3.2.3 Gaussian Distribution

Gaussian distribution (or normal distribution) is represented by a bell-shaped curve which is a continuous function that approximates the precise binomial distribution of occasions. If the large number of events need to be considered, then it is assumed that during any measurement values will follow a normal distribution with an equivalent number of measurements above and below the average value.

In this the Gaussian values (x,y) are stored in a file and read from there for the number of evacuees to be positioned. Here x is the left and y is the right coordinates of initial evacuee position. These values are stored in an array A. Now this array 'A' contains required number of Gaussian coordinates which are read and is used to position the evacuee within the building.

4 Evacuation Strategy

Crowd evacuation system is used within a fire triggered building, in which evacuees are already there distributed randomly or by using any mathematical model. Initially, distances are calculated to get the nearest door and exits from the position of evacuee, then evacuee is sent from that door which is farthest from the fire position (in case of multiple doors). Then after each movement of evacuee, positions are updated to get a path farthest from fire and closest to door. This process is repeated until all evacuees exit safely from the building. Evacuation is carried out using following algorithm:

Algorithm 1 Crowd Evacuation Algorithm

```
Input: Coordinates of building, rooms and doors
Output: Total time taken for successful evacuation of whole crowd
Begin
while NOT(success evacuation) do
    Get next state of system
    Update knowledge i.e.- dynamic positions of evacuees
    Deliberates and Commits with an objective
    Get methodology to achieve 100% evacuation
end while
while (successful evacuation) do
    Replan evacuation methodology
    Update knowledge i.e.- dynamic positions of evacuees
    If NOT (reasonable methodology)
    Then get new evacuation methodology
end while
```

Each time there is a movement in evacuee's position, this algorithm is called to update position of each evacuee and also checks if all evacuees are out of building or not and accordingly proceed with other steps. Update knowledge means taking new evacuee's positions coordinates and calculating distances from door, fire positions and other evacuees, thereby to decide which route to choose for safe and fast routing of evacuees from the building.

4.1 Room Having Multiple Doors

In case the room has more than one door, then evacuee chooses a door which is nearest to him/her and also away from fire position. If there are two doors and both lead to rooms having fire, then it is seen which door is farther from fire, and that path is chosen for evacuation.

4.2 Building Having Multiple Exits

This case holds importance when there are multiple evacuees scattered throughout the building. To avoid chaos situation evacuees can move out from building via different exits depending on which exit is closer to them.

5 Results and Performance Evaluation

Simulation is done for several architecture and positioning of crowd using MATLAB software. The algorithm used considers that each evacuee has a smart watch having two thermal sensors, which directs the person in a direction away from fire source, i.e. if fire is towards right side, then right sensor will sense it and the evacuee will be moved towards left.

Our simulation model builds up the environment for indoor evacuation by taking several input parameters like room and building coordinates, positions the evacuees using different distributions which is followed by triggering of power. All these inputs are passed to Processing unit, which does the main task of evacuating people from building. The nearest door to each evacuee and closest door to the main exit is found out using Euclidean distance. In case the fire is near to a door, and the room has multiple doors , some other door is chosen to move out from the room. Evacuees use sensors to move away from fire, such that they maintain sufficient distance from it, also moving closer to the main exit of building. Parallel evacuation can be done in case building has multiple main exits to direct people out of building. For each evacuee, an exit nearest to him is chosen thereby reducing the overall evacuation time of every evacuee and also letting several people evacuate simultaneously from the building.

5.1 Simulation Environment

Table 1 gives the system configuration used for the experimental purpose has following specifications:

Table 1: System Configuration

Processor	Intel(R) Core(TM) i3-4005U CPU @ 1.70 GHz
RAM	4GB
System Type	64-bit
Operating System	Windows 8.1
IDE used	MATLAB R2017a

5.2 Different Scenarios

Several scenarios have been considered by varying the complexity of building architecture and number of exits from the building. When there are multiple exits, then parallel evacuation strategy is used. The scenarios considered are as follows:

- Simple architecture with single exit
- Simple architecture with multiple exits
- Complex architecture with single exit
- Complex architecture with multiple exits

Scenario 1: Simple Architecture with Single Exit Here 10 evacuees, single exit and simple building architecture is considered. Initial, intermediate and final positioning of evacuees using random distribution, with fire positions, doors and single exit from building is shown in Figure 2.

Scenario 2: Simple Architecture with Multiple Exits Here 10 evacuees, several exits and simple building architecture is considered. Initial, intermediate and final positioning of evacuees using random distribution, with fire positions, doors and various exits from building is shown in Figure 3.

Scenario 3: Complex Architecture with Single Exit Here 10 evacuees, single exit and complex building architecture is considered. Initial, intermediate and final positioning of evacuees using random distribution, with fire positions, doors and various exits from building is shown in Figure 4.

Scenario 4: Complex Architecture with Multiple Exit Here 10 evacuees, multiple exits and complex building architecture is considered. Initial, intermediate and final positioning of evacuees using random distribution, with fire positions, doors and various exits from building is shown in Figure 5.

5.3 Different Mathematical Models for Evacuee Distribution

For positioning people within the building Random, Poisson and Gaussian distributions are used. The optimal positions of people (X and Y coordinates) for Poisson and Gaussian distributions is given in Tables 2 and Table 3. Table 2 is the sample database for Gaussian distribution, which is used to decide the initial evacuee positions within the building. The proposed Crowd Evacuation Algorithm is executed for various scenarios and different distributions and the results are given in Figures 6, 7, 8, 9, 10 and 11.

Graph depicting the comparison for random distribution of evacuees for Scenario 1(simple building architecture), considering both single and multiple exit scenarios is shown in Figure 6.

Graph depicting the comparison for random distribution of evacuees Scenario 2 (complex building architecture), considering both single and multiple exit scenarios is shown in Figure 7.

From the graphs in Figure 6 and Figure 7 it can be referred that in Scenario 1 of simple building architecture (having single exit) takes more time than parallel evacuation as various exit are present so it avoids chaos situation, because evacuees get distributed to move out from several exits, whereas in Scenario 2 of complex building architecture (having multiple exits) there are some cases when parallel exit takes more time. This is because building architecture is complicated and all evacuees might be in same area and hence take same exit for evacuation. Further for an increase in the number of evacuees, parallel execution takes less evacuation time, in both the scenarios.

Graph depicting no of evacuees vs Evacuation Time for Poisson distribution of evacuees considering both simple and complex building architectures for single exit is shown in Figure 8.

Graph for no of evacuees vs Evacuation Time for Gaussian distribution of evacuees considering both simple and complex building architectures is shown in Figure 9.

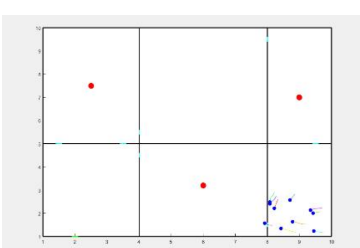
Table 2: The input database of Evacuee position using Poisson distribution

X Coordinate	Y Coordinate
478	111.627
480	121.3759
484	139.9677
544	26.05447
500	178.3827
518	127.2397
563	3.71561
492	168.6202
485	144.2966
499	178.3827

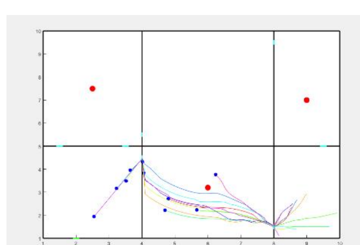
Table 3: The input database of Evacuee position using Poisson distribution

X Coordinate	Y Coordinate
1864.665	769.186
1402.86	391.0406
2426.033	554.9927
1761.856	712.3284
1441.703	427.7648
2578.066	408.9709
2405.973	573.8311
2839.682	194.7726
1561.517	543.1734
1964.916	795.9227

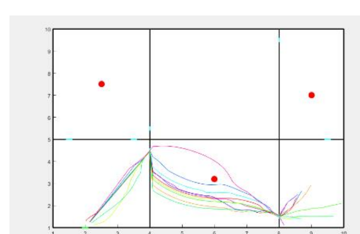
From the graphs in Figure 8 and Figure 9, it is inferred that parallel crowd evacuation takes less evacuation time for both Poisson and Gaussian distribution, as several evacuees can move out of building simultaneously from several exits.



(a) Initial positions,

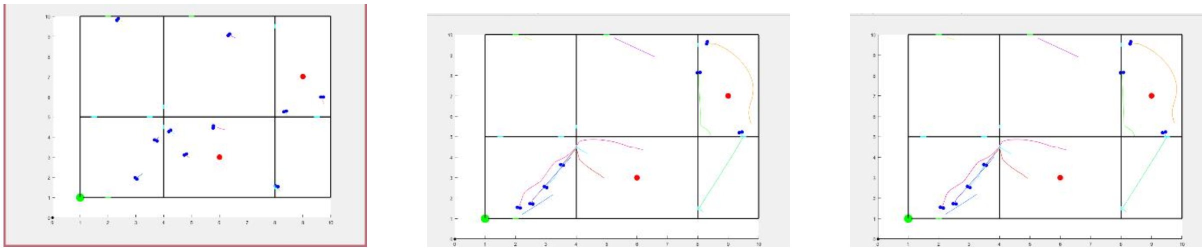


(b) Intermediate positions



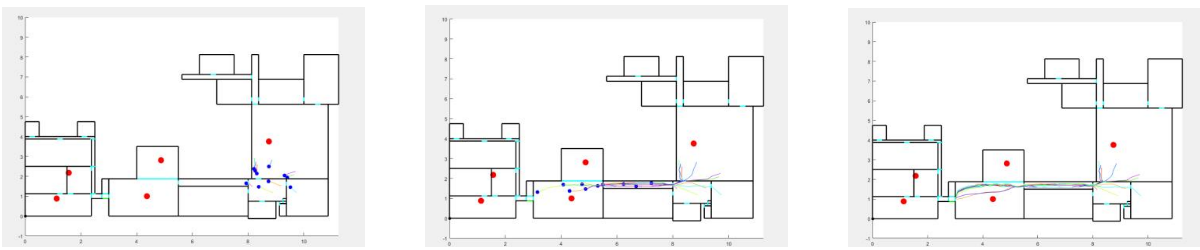
(c) Final positions of evacuees

Figure 2: Simple architecture, single exit from building- ,



(a) Initial positions, (b) Intermediate positions (c) Final positions of evacuees

Figure 3: Simple architecture, multple exits from building



(a) Initial positions, (b) Intermediate positions (c) Final positions of evacuees

Figure 4: Complex architecture, single exit from building

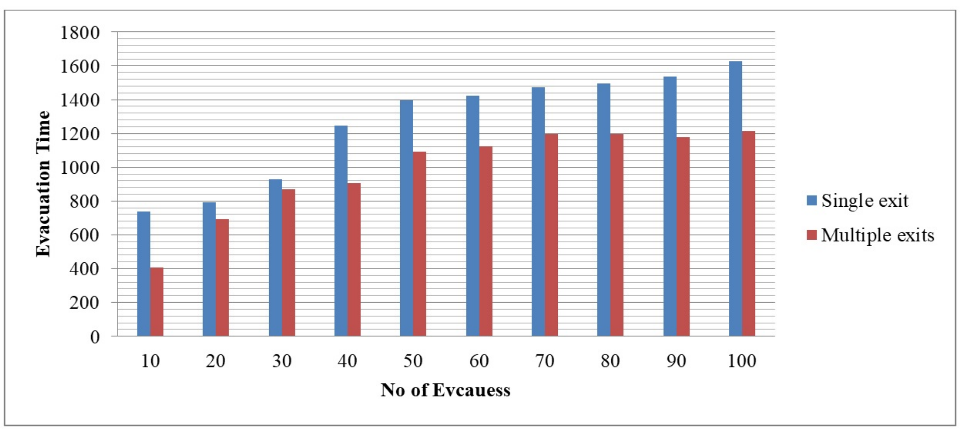
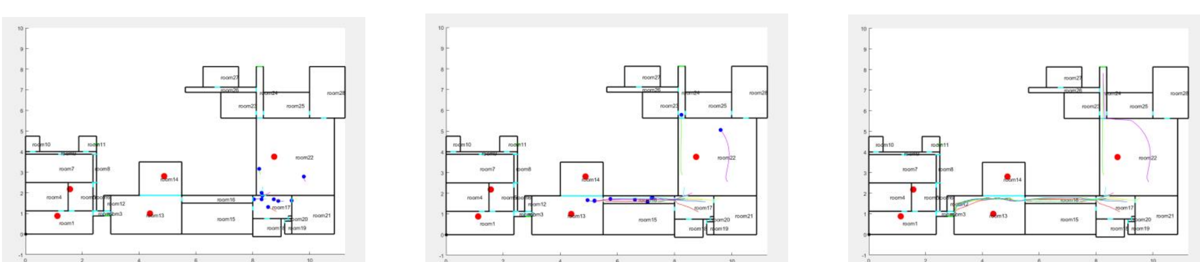


Figure 6: No of Evacuees vs Evacuation Time for Random Distribution (Scenario 1)



(a) Initial positions, (b) Intermediate positions (c) Final positions of evacuees

Figure 5: Complex architecture, multiple exits from building

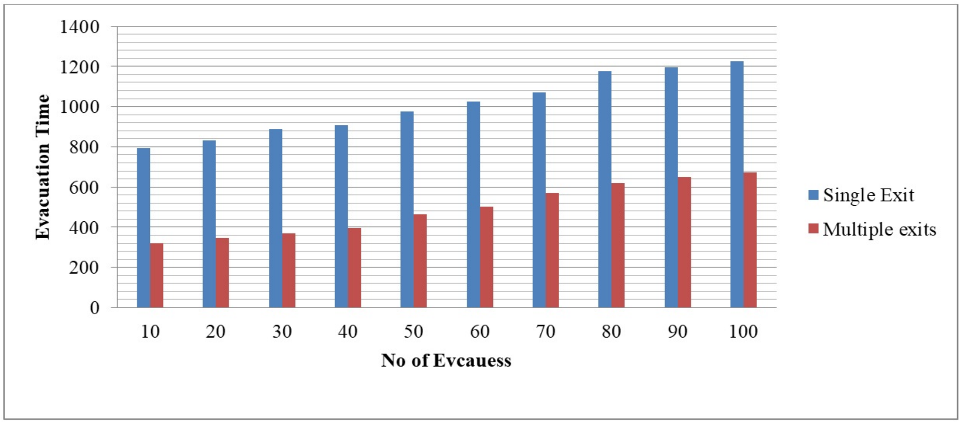


Figure 7: No of Evacuees vs Evacuation Time for Random Distribution (Scenario 2)

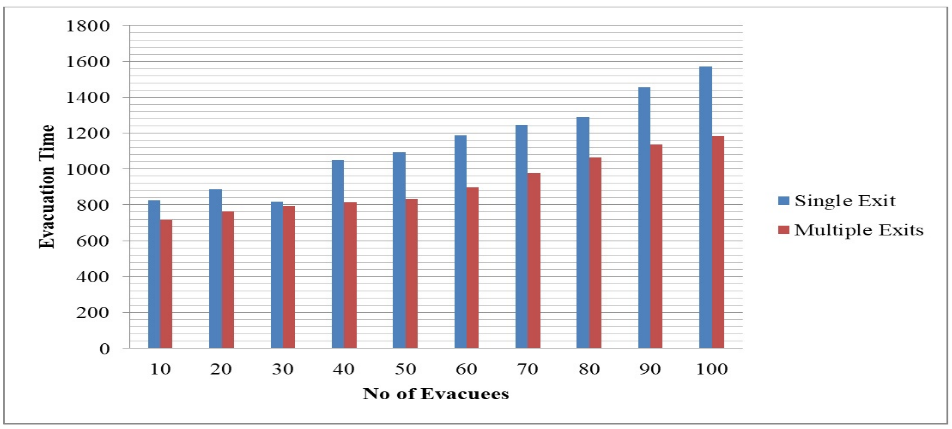


Figure 8: No of Evacuees vs Evacuation Time for Poisson Distribution (Scenario 1)

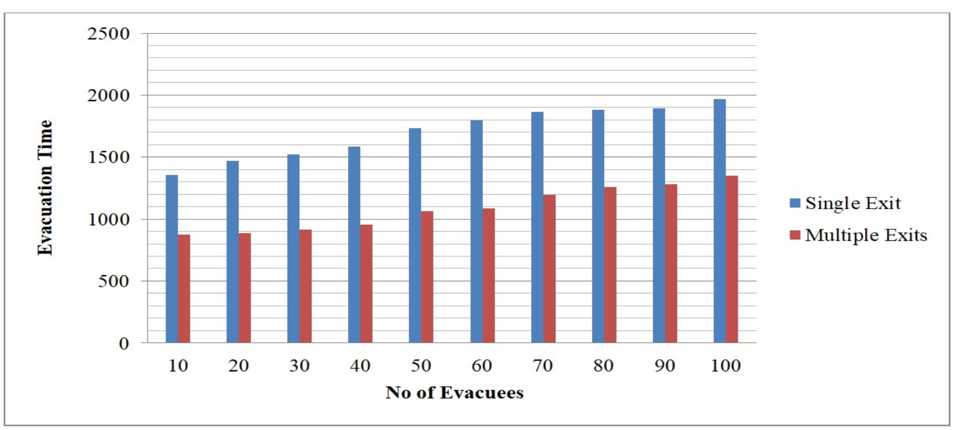


Figure 9: No of Evacuees vs Evacuation Time for Gaussian Distribution (Scenario 1)

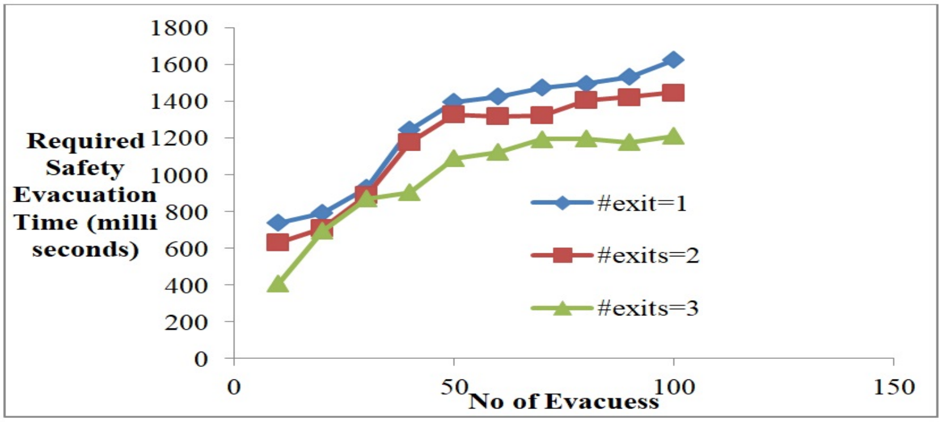


Figure 10: No of Evacuees vs RSET for varying no of exits (Simple Architecture)

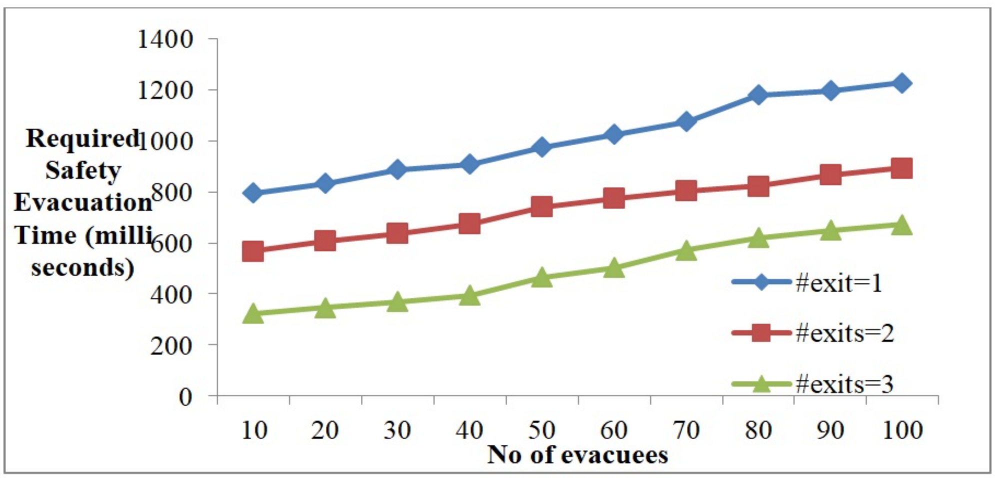


Figure 11: No of Evacuees vs RSET for varying no of exits (Complex Architecture)

5.4 Evaluation Metric

The evacuation time can be compared as per the number of exits used using Required Safety Evacuation Time (RSET) which represents the time from starting of evacuation till the time last evacuee comes out of the building. Graph depicting the comparison of Required Safety Evacuation Time of evacuees, considering simple building architectures for single exit, two exits and three exits is shown in Figure 10.

Graph depicting the comparison of Required Safety Evacuation Time of evacuees, considering complex building architectures for single exit, two exits and three exits is shown in Figure 11.

From the graphs in Figure 10 and 11, it is inferred that as number of exits in the building increases, Required Safety Evacuation Time (RSET) reduces, keeping no of evacuees as constant, in both simple and complex building architecture.

6 CONCLUSION

Fire scenarios and evacuees have a great significance on evacuation strategy and escaping efficiency. The work in this paper considers several building architectural scenarios and different evacuee compositions to explore influence of these factors on evacuation strategies. The proposed crowd evacuation system has been simulated for simple and complex building architectures, considering several mathematical models for evacuee distribution within the space. From the results it can be inferred that the proposed system performs better than the existing systems. Further it is also observed that parallel crowd evacuation takes less evacuation time for all mathematical crowd distributions, as several evacuees can move out of building simultaneously from different exits.

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