Crowd Evacuation Control for Public Spaces

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Abstract - *This paper demonstrates a simulated solution for evacuating people from a public place using the Coulomb laws. In an emergency, a plan to guide people away from danger in the shortest and safest possible ways is essential. We employed the Coulomb laws to divide the public space into safe boundaries, based on the number of people inside. This is a dynamic solution, which means, it will change the safety boundaries of a public space based on dynamic crowd movements. Security personnel will use the latest patterns of safety boundaries to assist people to evacuate through exit doors more efficiently.*

Keywords: Social network, virtual team, virtual organization, non-traditional organization, spontaneous and networked organization.

1 INTRODUCTION

It is important to understand crowd control in order to prevent unsafe behaviors, especially in emergency situations that may lead to injury or death. When an emergency occurs, occupants often panic and will attempt to exit using the nearest doors. According to Canada's NRC scientist Guylene Proulx, the activities and the interactions among the occupants in a building before the occurrence of an emergency are relevant to understanding the nature of panic, which can be used to mitigate hysterical or irrational behaviors as stated in the crowd definition and supported in literature.

In normal circumstances, people behave rationally. For example, people who arrive together will also tend to depart together. Family members will remain together before making the decision to exit [14], [8], [2]. A few people depending on their role (e.g. owners and employees) may decide to leave the building first, but at some points will return to retrieve items left behind (e.g., documents, money, and people in danger). The irrationality of their actions is evident only in a retrospective view, but at the time of the action it was determined to be perfectly rational. Evacuees are assumed to be rational, so after realizing that they need to escape, they should make decisions that would lead them to exit as quickly as possible [15]. According to the information gathered, people have to select the exit that can guarantee them the greatest opportunity to escape from the threat as fast as possible [1]. Exit selection has a great influence in the outcome of an evacuation strategy. How people choose exits is a complex process. Generally, they make their decision based on their familiarity with the exit and its visibility [11]. The attributes affecting the exit selections include the distance to the exit, the behavior of other agents, the exit's visibility, and the familiarity of the exits. A building generally consists of enclosed areas with one or more doors. Many theories and researches have attempted to explain and model the problem of finding a way with the main goal to select a way out. Different methods are used to model it. Among those, Cellular automata models consider the variety in the environment (e.g., exit width and obstacles) to have an impact in the exit dynamics of evacuees [18], [13]. Evacuees tend to prefer familiar alternatives, because they feel that unknown alternatives increase the threat. The visibility of exits also influences their decisions. According to personality trait theory [14], [8], [3], [17], [6], these models demonstrate the influence of evacuees' personalities (e.g., shy, aggressive, collaborative) in the outcome of evacuation. A shy person would reluctantly make decisions but he would act as a "follower", an aggressive person would exhibit "selfish behavior", and a collaborative person would try to cooperate with others to come out with a suitable solution for all Agent-based models [5]. In these models, evacuees act as "rational" agents whose objectives are to find the best set of actions that will maximize their progress toward the exit doors, relying on partners that will help them reach safe places in a minimum amount of time. Finally, the choice of an exit door will depend on the interaction between evacuees and their environment. An evacuee will pre-select a route based on his knowledge of the environment, and that initial route may change depending on his estimation of queuing time, traveling time to that particular exit, and sometimes his response to group decisions [16].

An evacuation crowd consists of individuals that interact with each other [8]. Occupants have to escape from the danger as quickly as possible, and by doing so they may have to collaborate with others. Evacuees are assumed to be rational. They pursue their own interests [7]. Evacuees will tend to cooperate with another one if they estimate that they can have a good payoff (maximum chance of being safe), or in contrary will avoid cooperating or associating with another one if their safety is decreased. They might have to be collaborative with others, or try to develop skills (e.g., exploring and visual memory). The urgency theory is used to explain some behaviour of occupants, for instance blockage at exit doors, stampeding or trampling [4]. Three attributes essential to understanding the concept of urgency are [12].

1. The nature of the emergency
2. The consequence of not exiting quickly
3. The time available to exit

By and large simulations of crowds are either macroscopic by modelling environmental parameters that affect a group of agents simultaneously, or microscopic by modelling interaction rules for each agent. A meso-level modelling is offered in [9], and [10] where movement fields are composed of external inputs that influence agents combined by their own local reasoning. In this paper, we demonstrate a strategy to repeatedly divide the environment into distinctly safe boundaries around each exit door. Boundaries are subject to change based on the location of each agent at any moment using a crowd evacuation model. We will also focus on the relationships between locations of exit doors and agent movements in the environment to develop our strategy accordingly. In the following section, we will outline pertinent environmental attributes.

2 ENVIRONMENTAL ATTRIBUTES

Generally, each environment will consist of many different groups of objects such as obstacles (e.g., a row of chairs or trash cans), the agents and the exit doors. Agents can be any type of living beings such as pets or human. In this paper, we assume that only human agents will exist in the environment. The two most important attributes in the environment for us are the agents (i.e., simulating individuals) and exit doors (i.e., evacuation points). These attributes affect each other and are used to determine safe boundaries. In this paper we considered each environment generally having one or more convex zones corresponding to the map. Each of the convex zones is composed of a collection of α zones, which are the spheres belonging to each exit door, with β zones and θ angles for each. Each convex zone must have at least a single exit door inside. If there are no exit doors available for a convex zone, we have to merge it with its adjacent convex zone, which has at least one exit door. Section 3 and section 4 offer remarks about exit door attributes. In section 5 we outline the application of Coulomb's Law.

3 EXIT DOOR ATTRIBUTES

We considered three general attributes for each exit door: zones, boundaries, and θ angles. We assumed three different zones for each exit door. The first zone is the area nearest to the exit door we call α zone. This is determined by each exit door's width. Figure 1 shows two exit doors of different widths and their proportionally sized α zones. This zone is always the same in size and never changes during the movement of each agent. The only way that an α zone could change would be if it is completely blocked or the door width is partially blocked (for instance, by some obstacle that might be a fallen agent, or debris in the environment). In such cases, due to the change in width of the exit door, the α zone will change. Each environment may contain several α zones, one for each exit door. The second zone is called β zone (see Figure 1). The β zones are the areas that are bound by the walls, and each contains a single α zone. Areas between several α zones are divided into the same number of β zones. The third attribute is the θ angle, which is the largest angle that contains a corresponding β zone within each quadrant. Boundaries separate β zones. The θ angle varies based on the locations of agents in each moment. For example, the angle can be reduced if the number of people around a certain exit door increases. Figure 1, shows an environment consisting of three exit doors with corresponding zones and angles.

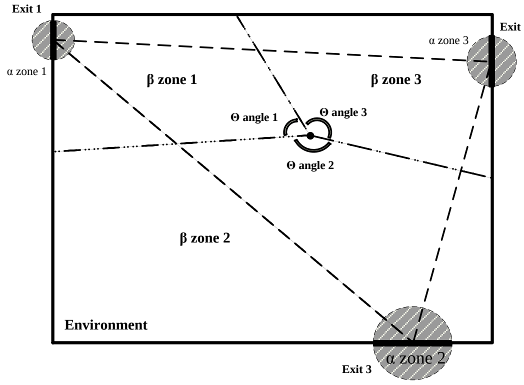

Figure 1: The α and β zones and θ angles related to exit door 1 and 2.

4 COMBINATIONS OF EXIT DOORS

As a matter of standard, each building should have at least one exit door located at a place that is visible to the public. In the case of a single exit door in the environment, the only way to evacuate people will be to guide them to the exit door and through it, and hence there is only one α zone and the rest of the environment belongs to one β zone. There will be no θ angle, which means that there are no safe boundaries available. Our solution is applicable only if we have more than two exit doors at each convex zone. If there are two or more exit doors, there will be a corresponding number of α zones, β zones, and θ angles respectively.

5 APPLICATION OF CUSTOMIZED COULOMB'S LAW

In this section, we demonstrate and apply the customized coulomb's law to exit doors based on the current locations of agents at each moment in time. We divided the process of dividing the environment and decision making of each boundary into four different phases. Initialization is the process of determining locations and status for each exit door to form the initial safety boundaries. Detection of boundaries is another phase. There is a phase for gathering data from sensors. The sensors and detectors sense and detect the locations of agents and their physical specifications and movements by cameras and send information to the processing unit. Another phase is updating the boundaries and decision making, which entails updating and redrawing the safe boundaries based on the latest information gathered by the detector devices installed in the environment. Each phase consists of many other sub-steps. We use different techniques for each phase. The phases and relative steps are described next.

5.1 Initialization

This phase starts by detecting the location of each exit door and also measures the width of each exit door. We consider each exit door as a sphere with the diameter equal to the exit door width. We assume an abstract line drawn from each sphere's centre point to other sphere's centre points in such a manner as to form the largest enclosing polyhedral configuration. This configuration must meet each sphere only once. Because the goal of this step is to only determine the initial values and measures of locations and specifications for each exit door in the environment, to calculate and draw the initiate safe boundaries, we consider our environment to be empty; i.e., devoid of agents.

5.1.1 Initializing the exit doors

At this level, all exit doors located inside the environment will have been detected possibly using a raster map. We need to have two different measures for each. The width and the central point of each exit door are placed on the central straight line that connects two edges of exit doors. This can be done by the cameras and detectors that are installed in the environment. We may use some techniques to increase the speed of detecting and measuring locations of exit doors, such as using a wire frame viewing of the environment.

5.2 Determining the sphere of charges

We assumed that each exit door behaves as a sphere of charge with the diameter equal of the width called α zone. The α zone may be considered to have a simple 2D circular shape or a complete 3D spherical shape. In this paper we considered the α zones as a complete 3D shape. The amount of charge for each α zone is equal to the relevant exit door charge. If an exit door is blocked for any reason during monitoring the environment, we must consider its sphere, and hence its charge, to be 0.

5.3 Determining zones

At this level, we divide our environment into different convex zones. To do this, we use convexity concepts and rules that have previously been used in the neural networks. On the other hand, the environment must be divided into convex shapes such that each default line must meet the edges of the shape only two times. Each convex area must have at least one simple exit door inside; otherwise, we have to join this zone with the adjacent convex zone which has at least a single exit door.

5.3.1 Determining the exit doors boundary

This point consists of determining the largest simple non directed cycle graph of length m where m is total number of exit doors located in each zone. This graph has m vertices and m edges. Every vertex has a degree of 2. We label this graph C_m. For example, in case of 5 exit doors among the convex zone, the largest simple, non-directed cycle graph has the length equal to 5, and also we have 5 different pairs of adjacent charges.

5.3.2 Determining the amount of charge for each exit door

We considered each exit door as a sphere with the diameter equal to the width of each exit door. Based on the metric measurement, the amount of positive charge for each exit door is given by the following equation 1:

$$Q_{ED_i} = \lceil W_{ED_i} \times 100 \rceil \qquad (1)$$

Where Q_{ED_i} is the charge of i^{th} exit door and $W_{ED_i}$is the width of i^{th} exit door. For instance, in case of an exit door with the width of 1 meter, the charge of the mentioned exit door would be 100.

5.4 Detection of Boundaries

At this phase, the process will determine the initial boundaries for each exit door using the initial values gathered in the previous phase. To determine the initial boundaries, this phase will find the point which is located on the line that connects the centres of each pair of exit doors (as charges). The location of this point obtained by considering the width of each exit door, then drawing a virtual vertical page crossing that point. This phase bisects the intersectional boundaries between different vertical pages to reach β zones.

5.4.1 Computing the charge for each adjacent pair of exit doors

At this step, we will calculate the amount of charge between each adjacent pair of exit doors. To do this, we assumed a straight line between each pair of adjacent exit doors. We also assume that the locations of all exit doors are fixed and that the charges for each exit door are positive. We will put a positive charge on the straight line between each adjacent exit door. The amount of the positive charge is given by the following equation 2:

$$Q_t = \left| \frac{Q_{ED_i} + Q_{ED_j}}{2} \right| \qquad (2)$$

Where Q_t is the amount of charge between two charges Q_{ED_i} and $Q_{ED_j}$is located at the adjacent pair on the mentioned straight line. We assumed that the positive charge used between each pair is the average value for them; using this strategy guarantees that the positive charge will stay somewhere between the two fixed charges and not go beyond them.

5.5 Determining equilibrium point

At this step, the process will find the equilibrium location for each positive charge that is placed on the straight line between each pair of positive charges. All exit doors as positive charges are fixed. The positive charge will be located on the straight line and closer to the smaller positive charge. Since the two charges around the positive charge are positive, they will push the positive charge away from themselves. In such a case, the positive charge will stay closer to the smaller positive charge because the grater positive charge has a larger exert force than the smaller one. The equations demonstrated in the three electric charges in equilibrium are used to determine the location of the mentioned positive charges.

5.6 Finding the centroid point for each shape

At this step, the process finds that the geometric centre (i.e., centroid point) for each shape that contains related exit doors. The centre of mass, or centroid of a 2D shape, is the intersection point of all straight lines that divide the shape into two areas with equal movement about the line. The centroid point is the arithmetic mean of all intersection points. The next step is to draw a line from that location to all positive charges and continue that line until it reaches an environment. This line separates the environment into two different areas such that each of them belongs to a different exit door.

5.7 Determining and binding β zones

Each exit door has a θ angle that belongs to it, which is drawn from the centroid point to the equilibrium points of the straight lines crossing from the relative adjacent charges. At the next point, we bind the largest θ angle which includes only a single exit door as the β zone of the relative exit door.The process continues until all β zones are specified for each exit door.

5.8 Data Gathering and Analysis

There should be several sensors, cameras, and detectors installed at different locations in the environment in order to be able to determine the location of each exit door, especially the location of the agents at each moment. These facilities estimate the status of each exit door in each instant in terms of evacuation ability rate. These devices will send pertinent data for agents in terms of their size and an estimate of their movement speeds to the central unit in order to classify analyses and makes decisions. This phase generally gathers and analyses the data obtain by different sensors and detectors installed inside the environment.

5.8.1 Determining the agent locations

The crowd is dynamic and changes locations consistently. The rate of movement is more unpredictable when agents are faced with emergency situations. The process at this step will be to detect each individual's position in the environment. One way to determine the positions is by using a grid. In order to make decisions about the boundaries in real time, the sensors should be fast enough to determine individual locations and this information to the central processing unit for analysis.

5.8.2 Determining each agent's charge

The sensors and detectors should be able to determine the specifications of each individual, such as body sizes and individual movement rates. Having these measures we are able to assign an accurate value as a charge to each agent. At this step, the process will determine the amount of charge for each individual located in the environment based on physical specifications. Each general convex zone consists of a collection of distinct α zones, β zones, and θ angles. Each β zone has its distinct α zone and θ angle belonging to it. Furthermore, α and β zones and θ angles are non-overlapping among zones and angles.

The environment may consist of a number of general convex zones inside. Each general convex zone must consist of at least a single exit door. In case of having a convex area without an exit door, we will join it to its neighbouring zone that contains at least a single exit door.

Each zone has its own set of agents. Each agent may have a different situation in terms of the physical status.

Of all the agents available in each general convex zone, each β zone and exit door, depending upon their situations and locations, support a number of them.

We assumed that each agent has a negative charge based on the specifications that he/she possesses. The considered key features in this paper were age, sex, and health status. The amount of charge for each agent is given by the following equation 3:

$$Q_{Ag_i} = A_i \times G_i \times HS_i < 0 \qquad (3)$$

Where Q_{Ag_i} is the amount of negative charge for the i^{th} agent, A_i is the age of the i^{th} agent and the HS_i is the health status for the i^{th} agent. Because all given values of the equation are negative, the final result of Q_{Ag_i} is always smaller than zero. In the case that there are no agents in any β zones, the total amount of charge for the mentioned zone will be considered to be 0. In order to have agents, the amount of charge in the β zone is relative to the amount of charge for the number of agents, and it is always smaller than 0.

The ranges of ages vary from place to place and depend on the usage of the environment and can be determined based on the average age of the majority of people inside. We consider the normal value to be (-1) and in order to have a reasonable result, we have to bind this value to the majority of people with the same range of age. For example, the usage of values in a kindergarten is different from a conference room because in a kindergarten the majority of people are children, so we may bind the normal value to the group of ages below 10 years old whereas in a conference room, because the average range of age is between 20 and 40, we need to bind the normal value to this group of age.

The other key feature in terms of calculation of agent charges is the gender of individuals. The consideration values for each gender are different from situation to situation. In this paper, we divided agent charges into two categories of males and females. Males have a default value of (-1) and females have a default value of (-1.5).

The third physical key feature that we considered in this paper is health status. The health status may vary from place to place, depend on the environment usage, and is determined based on the health status of majority of the people inside. In this paper we considered having only two options: normal and disabled. In some places, like hospitals or elder houses, there should be other options available in order to have a better estimate of the charges for each agent. We considered a default value of (-1) for healthy status and (-2) for disable agents.

Apart from the physical specifications of each agent, focusing on the status of each exit doors is essential. We determine the amount of charge for each single exit door based on its situation at each time instant.

In different situations, considerations about the specifications for each exit door may vary. We always used the default rate for the best situation of exit doors when it is usable, reliable and can evacuate people to its full capacity. In this paper we assumed three status for each exit, including 'Still open and ready to use' with default value of (-1), 'Not stable' with value of (-1.5), and 'Partly blocked' with the value of (-2).

To obtain the new values for charges of exit doors, we have to consider the previous amount of charges and the latest safety status for each exit door. The total amount of positive charge is shown by the following equation 4:

$$Q_{ED_i} = \left|\frac{Q'_{ED_i}}{SR_{ED_i}}\right| \qquad (4)$$

Where $Q_{ED_i}$the total positive is charge of the i^{th} exit door, Q_{ED_i} is the initial charge of the same exit door and SR_{ED_i} is the safety rate for the i^{th} exit door. If the exit door is completely blocked or not usable, we have to consider its charge as 0.

The cameras and detectors will determine the safety rates of each exit door and send their status to the processing unit. In such situations we have to remove the exit door from our environment and reassign its zone to other ones that are still usable. The exit door will not be considered in forming the largest non-directed simple graph.

5.8.3 Determining the new charge for each exit door

After all agent's amount of charge is determined, the process will calculate the new amount of positive charges for each exit door based on the results obtained in the previous step. In order to determine the new value of each exit door charges, we need to consider all agents that are belonging to that exit door at the moment. The new amount of charge for each exit door is shown by the following equation 5:

$$Q'_{ED_i} = \left|Q_{Z_i} + Q_{ED_i}\right| \qquad (5)$$

Where Q'_{ED_i} is the new positive charge for i^{th} exit door, Q_{Z_i} is the initial positive amount of charge for the i^{th} zone which belongs to the i^{th} exit door and Q_{ED_i} is the previous positive amount of charge for the i^{th} exit door. Determining charges of each exit door is based on the number of people in each zone as well as the status of each exit door. For example, assume having an exit door with 10 people in its zone and the adjacent exit door with the smaller width with only 3 people in its zone, leads us to expand the area of the exit door with the smaller number of people. For the next round of processing we might consider many of the people that belong to the bigger exit door for the smaller one.

5.8.4 Determining the new status for each exit door

Regardless of the already mentioned features, there are many other features that may exist in the environment that should be mentioned while determining each zone and boundary. Determining exit door status is necessary, especially in emergency situations. In the case of blocked exit doors for such reasons as smashed walls or people who block the exit door by pushing or shoving each other, the reliability of the exit door can be significantly decreased. In such cases the amount of positive charge of the exit door will reduce if its reliability decreases. We called the reliability factor for each exit door the safety rate of that exit door. At the initialization phase, the safety rate for each exit door that is ready to use is set to (+1). This rate will change based on the new environmental information gathered by sensors based on each exit door's status. The safety rate is shown by the following equation 6:

$$SR_{Ed_i} = \left|SR_{(ED_i)_{t-1}} \times SR_{(ED_i)_t}\right| \qquad (6)$$

Where $SR_{(ED_i)_t}$ is the safety rate for the i^{th} exit door at the t moment.

5.9 Decision making and updating the boundaries

To make the decision and update the safe boundaries for each of the general convex zones, having the values described in the previous third phases is essential. Based on the new values for each β zone in each moment, the value of charges for each exit door and hence the safe boundaries of the general convex zones will change. The process of determining the boundaries for each exit door should continue and be updated by gathering new data from different sensors at each moment. Having reliable and real time hardware in order to detect and determine the different physical status of the exit doors, people, and locations is essential for forming the safe boundaries in a reasonable time. The process refreshes the results all the time to redirect to the second phase after reaching and completing the third phase.

Having the safe boundaries, which is the result of the 4th phase, helps people to make better decisions. This produces lower risk and hence better results in terms of evacuating people out of danger in emergency situations.

6 IMPLEMENTATION AND EVALUATION

In this section we apply the optimized Coulomb's Law to a sample environment and compare the results as a step towards validating our model. We selected the Station nightclub environment. On Thursday, February 20, 2003, at The Station nightclub located at 211 Cowesett Avenue in West Warwick, Rhode Island, a fire accident occurred, which was the fourth deadliest nightclub fire in American history. More than 100 people lost their lives because of it. The tour manager of the evening's headlining band used pyrotechnics during the show that were the main cause of the fire. In the beginning, the fire ignited flammable sound insulation foam in the walls and then spread to ceilings surrounding the stage. Initially, there were about 132 people inside before the fire incident. Some of them were injured and about 32 escaped uninjured. The cameras and sensors that were installed inside the environment recorded growing billowing smoke and that one exit door was blocked. This made escape impossible because of limiting the vision people at the site. In our approach, we first divide the area into convex zones. We then form the bidirectional cycle crossing all exit doors, and, based on the centroid location of the formed shape, we form the α zones, β zones and θ angles. Based on some assumptions about the percentage of people who were spread in the environment and their physical specifications, we form the new zones. To apply our strategy, we consider only the map of empty buildings as a first step to form the zones. Then, regarding the crowd distribution, we form the new safe boundaries. A general view of the building shown in Figure 2.

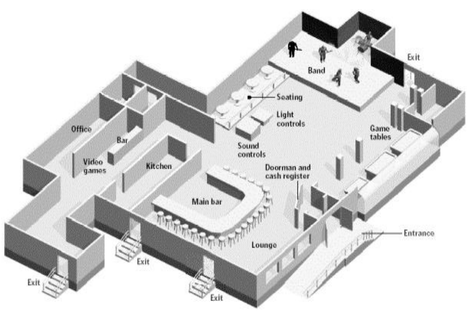

Figure 2.General view of the environment.

At this level, in order to determine the initial safe boundaries, we only focus on exit doors. In order to apply our strategy, at the first step we have to determine the exact locations of each exit door as well as the width of each. This task will be done by using a raster technology that will send raster information to the processing unit by detectors and cameras that are installed in the environment. We also need to determine the general convex zones. Based on the environment map, we have generally two convex zones as shown by equation 7.

$$Z = \{Z_1, Z_2\} \quad (7)$$

The first general convex zone consists of four exit doors and the second zone consists of a single exit door as shown by equations 8 and 9.

$$Z_1 = \{ED_1, ED_2, ED_3, ED_4\} \quad (8)$$

$$Z_2 = \{ED_5\} \quad (9)$$

Since we have more than one exit door in the first zone, there are α zones, β zones, and θ angles for each exit door, whereas the second zone only has a single α zone related to its exit door. There are no β zones or θ angles for the second zone because it consists of only a single exit door, and hence all area of the second zone belongs to its only exit door (ED_5).

We used the metric measurement herein and therefore of five exit doors available in the environment, the width of exit doors 1, 3, 4 and 5 are 1 meter and exit door 2 is 2 meters. Based on the width of each exit door, we are able to compute α zones and the charge of each one as they shown in Table 1.

Table 1. The α zones and the amount of charges for each exit doors based on their width.

Exit doors		
No	Width (m)	Charge
1	1	100
2	2	200
3	1	100
4	1	100

We consider each α zone related to each exit door as a sphere of charge which has a center equal the central width location of each exit door. Figure 3 shows the result of dividing the area into convex zones and α zone related to each exit door.

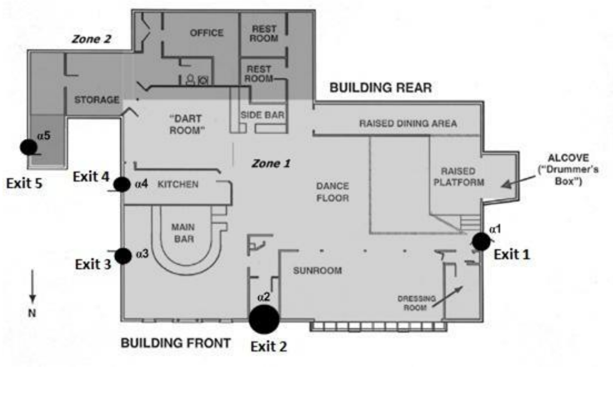

Figure 3: Convex zones of the area and α zones for each exit door.

Because the second zone doesn't have any β zones or θ angles, we only focus on the first zone. We have four exit doors in this zone; hence the largest simple non directed cycle graph has the length of 4. To form the mentioned graph, we need to connect the central points of each exit doors together through straight lines. This diagram must meet each exit door only once. Figure 4 shows the largest simple non-directed cycle graph of length 4 crossing all exit doors in the first convex zone.

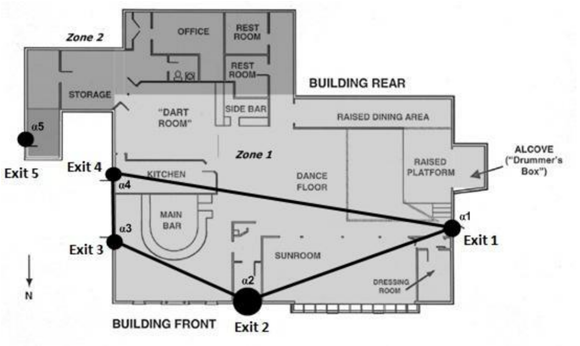

Figure 4. The largest simple non directed cycle graph of length 4 crossing exit doors in the first convex zone.

For the next step, we need to find the centroid point of the 2D shape formed by the mentioned graph. We also need to find the equilibrium points between each adjacent pairs of charges. To do this, we need to have the values of the adjacent pairs of charges. Based on our strategy, we assumed all exit doors have positive charges and are fixed in their places. To find the equilibrium position, we use a positive charge that is equal to the average of the adjacent pairs of charges. The mentioned positive charge is placed on the straight line between the pairs of charges and is closer to the smaller charge. In case of having a same amount of charges, the positive charge will locate in the middle of pairs of charges. To form β zones and θ angles, we have to connect from the centroid point to each equilibrium point and continue the line to the environment. The following Figure 5 shows the centroid location of the 2D shape for the mentioned graph, the equilibrium locations, the β zones and θ angles related to the exit doors of the first zone:

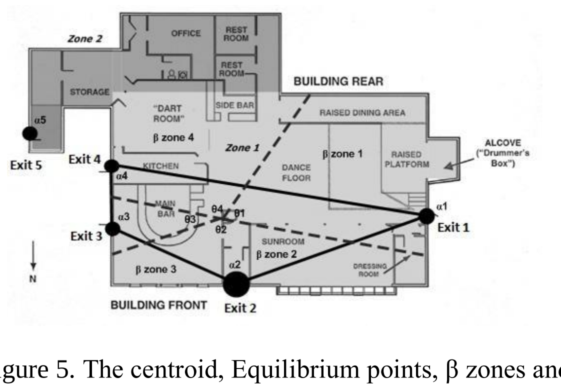

Figure 5. The centroid, Equilibrium points, β zones and θ angles for the first zone.

Figure 5 shows all areas needed for the first zone when there is not any individual available in the environment. At this step we will calculate the charges of the agents available in the environment and will update the safe boundaries based on their distribution in the environment. The process of gathering information about the physical specifications of the agents and their locations is done by sensors and detectors that are installed in the environment. This data will then be processed by our method. Of 230 people that we assumed are available in the environment, we consider 200 people are located in the first zone and 30 people are placed in the second zone. We also assumed that in each area, half of the people are male and the other half are female. We considered all people in our environment to have normal health statuses. We consider in each zone, the ages range is between 20 and 40 years old. We assumed that all exit doors are open all the time and safe to use with their full evacuation capacity, which means blocking will not happen in the environment during the experiment. We apply our strategy in two different modes. When the distribution is the same and when it's not. The following equations 10 and 11, show the collections of the agents in each zones:

$$Z_1 = \{Ag_1, Ag_2, Ag_3, \ldots, Ag_{200}\} \qquad (10)$$

$$Z_2 = \{Ag_1, Ag_2, Ag_3, \ldots, Ag_{30}\} \qquad (11)$$

We assumed to have a same crowd distribution in our experiment. We also assumed there are 100 males and 100 females available in the first zone. All of them have normal health status and between 20 and 40 years old. The gender percentage for each β zone is the same as 50 percent. Hence for each β zone in the general convex zone, we have 25 people consists of 50 percent male (13 people) and 50 percent female (12 people). The table 2 shows the β zones, initial α zone charges, and new α zone charges.

Table 2. β zones, initial α zones charges and new α zones charges.

β Zone	Init α zone	New αzone
1	100	75
2	200	175
3	100	75
4	100	75

Based on our assumption, we observed to have slight changes for the safe boundaries after applying the charges of agents in each β zone. There are four β zones, and thus each zone is assumed to support a quarter of the people in it. We also considered having 13 males and 12 females in each β zone. Figure 6 shows the new safe boundaries based on the crowd distribution we assumed in our experiment.

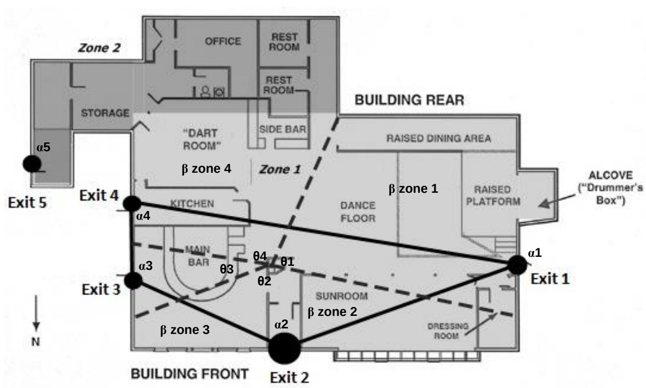

Figure 6. New safe boundaries based on the normal crowd distribution.

The illustrated crowd distribution can be used in many places such as theater saloons or conferences rooms. In such places, because of the kind of usage of environment, the distribution of the crowd is equal for all areas inside.

7 CONCLUSIONS

This paper explored a powerful mechanism for guiding the crowd out of danger using Coulomb's Law, as well as graph theory, and convex and centroid concepts in order to form safe and reliable boundaries around each exit door in the environment in order to provide a decision aid for supervisory control personnel. This yields strategies for people who are trapped in an indoor public space at a dangerous location to be most rapidly evacuated. Using this mechanism can decrease errors committed by exiting individuals in the shortest time period, especially when the circumstances in the environment are obscured due to calamities that change layouts, such as fallen walls. We have fully implemented our algorithm and demonstrated it on a real world scenario.

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