Identify The Individuals Status During Crowds Movement

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ABSTRACT

Crowds form for a variety of reasons and crowd control must be considered in order to provide a safe and enjoyable experience when a massive gathering of people forms a moving crowd. Providing for public safety is an important matter for authorities in order to provide civilians with the ability to proceed with their routine life and work. However, authorities face complex and costly processes when controlling large events, especially when crowds start moving. Authorities face many challenges when organizing a crowd in order to provide successful crowd management to prevent an unwanted catastrophe. We examine the two major types of crowd behavior, the movement of a structured crowd where people head in one direction with the same goal or destination, and the movement of unstructured crowds where people head in different directions with different goals or destinations.

This proposal develops an alert system for crowd control to keep the crowd away from dangerous situations. The main idea of behind the alert system is monitoring the individuals' locations by scrutinizing the position status of the individuals in the crowd at a particular moment in order to inform the authorities about unusual individuals' behavior. A Fuzzy Logic algorithm was developed for the alert system; it makes decisions regarding the critical density spots that might obstruct smooth crowd motion. We created a system of crowd monitoring that analyzes every individual in the crowd by scrutinizing their position's status to allow the fuzzy logic system to identify the critical density spots in order to point out these potentially obstructive locations to authorities who would then be able to intervene.

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DEDICATION

I would like to dedicate this dissertation to praising Allah and asking for his peace and blessing on all of those who contributed to completing this research and making it useful knowledge. This work is also dedicated to: My father, Adnan Edris, my mother, Nawal Halal, my wife, Rawan Mursi, my brothers Amar, Amer, Amro my sisters Nora, Nada, Najod, my kids, Rakan and Rayan, my Friend Abdullah AlAjlan. who have been a constant source of support and encouragement during the challenges of studying and life. I am truly thankful for having you in my life.

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CHAPTER 1

INTRODUCTION

For many years authorities have tried to develop crowd control techniques that can be applied when, for different reasons, thousands or millions of people gather, and techniques to best avoid unexpected crowd dynamics or movement. Our focus for analyzing dynamic crowd behavior is based on the two major types of crowds: the structured crowd that moves in one direction with a specific goal, such as occurs in the Islamic practice Hajj or the Hindu Kumbh Mela; and, the unstructured crowd where people have different directions and goals, such as in a town square or in a shopping mall. Delayed or unstable movement, caused by a need for medical attention or by panicking individuals, for instance, have created difficulties for the authorities charged with crowd control. Keeping public property safe is another challenge for authorities when a crowd is present.

When the people in a high-density crowd move as a herd, their individual behavior is influenced by those surrounding them. Their decision-making is affected by others and they are less conscious of their personal decisions; their more unconscious movements can lead them to restricted areas and/or create the conditions for a stampede. This prevents the authorities from controlling rescue operations and puts everyone at high risk. We want to contribute to the urgent need for crowd control in a reliable and authentic way by approaching crowd movement using a different set of measures. The alert system we propose can be used to inform the authorities about critical density spots (CDS) caused by abnormal crowd movement that might put individuals in unintended and unwanted situations, such as losing their sense of direction or panicking. Understanding individuals' pace and distance from others allows the prediction of each individual's next location, which has produced the potential for advanced planning and greater public safety.

1.1 PRELIMINARY RESEARCH BACKGROUND

Increasing the ability of authorities to make effective decisions regarding crowd control by using different approaches to contribute to crowd control is an urgent issue. Many models for control have been presented. For example, Wijermans *et al*. (2016) shows an INCROWD model that helps in crowd control by developing architectural levels for a decisions-support system. To direct the motion of a crowd via kinetic energy, Cao *et al*. (2009) used a method based on detecting abnormal crowd motion flow by combining data on the kinetic energy of the crowd with different motions and directions of individuals in the crowd. Kumar and Bhatnagar (2017) presented a technique to analyze high-density crowd scenes in public areas by deploying a crowd behavior detection system based on a hybrid tracking module that integrated with a Neural Network algorithm. To prevent injuries and damage, Xiong *et al*. (2016) experimented with controlling crowds in an evacuation caused by a gas leak by proposing the use of an unmanned aerial vehicle (UAV) once the poison gas was detected. The UAV control support system provided a correct route for flight to help people avoid the poisonous gas while evacuating the area.

1.2 RESEARCH MOTIVATION AND OBJECTIVE

By understanding the movements in these two types of crowds, structured crowd and unstructured crowd, from different points of view, our approach is intended to help authorities with the process of crowd control by creating an alert system that finds the critical density spots (CDS) in a crowd. To achieve this goal the research attempts to answer the following questions:

1. Can a Fuzzy Logic system be used to successfully identify the Critical Density Spots within a crowd?

2. Does measuring and using the individuals' movement features such as (avg speed, direction, opposite directed individuals) improve CDS detection for *structured* crowds?

3. Does measuring and using the individuals' movement features such as (avg speed, direction, opposite directed individuals) improve CDS detection for *unstructured* crowds?

4. Does the Fuzzy Logic system detect CDS that can be used by authorities controlling crowd motions?

1.3 SCOPE OF THE RESEARCH

The research was constrained by the following limitations:

• Only considers the movement of Agent-based models from a NetLogo model;

• Focuses on the two major type of crowds: structured and unstructured;

• Uses only two crowd behavior models: Social Forces Model (SFM) and Flocking Model (FM);

• Only considers six specific scenarios.

1.4 RESEARCH CONTRIBUTION

The main contribution of this dissertation is a novel approach to the detection of Critical Density Spots (CDS) using fuzzy logic and individuals location data. The overall goal is to help the decision makers who control crowds to prevent potentially lethal accidents that might result from unwanted crowd motions. We implemented two agent-based models of crowd behavior, SFM and FM, with different scenarios to test an alert system that has the ability to detect the critical density spots that could cause abnormal crowd behavior or motion potentially leading to fatal incidents.

We tested the system's ability to find the CDS in a variety of scenarios that can challenge the alert system, based on the Fuzzy Logic machine learning by counting the number of CDS detected for each scenario. Crowd behavior was chosen as a means to demonstrate the intelligence among individuals as a way to avoid collision with others and obstacles.

1.5 AUTHOR'S RELATED PUBLICATIONS

1. Edris, A., Alajlan, A., Sheldon, F., Soule, T., and Heckndorn, R., 2020: "An Alert System: Using Fuzzy Logic for Controlling Crowd Movement by Detecting Critical Density Spots." In: Proceedings of the 2020 International Conference on Computational Science and Computational Intelligence. (Accepted).

2. Edris, A., Alajlan, and Soule, T "A Contribution to Crowd Control by Detecting CriticalDensity Spots." 2021 International Conference on Computational Science and Computational Intelligence (CSCE), Las Vegas, NV, USA (Accepted at IEEE CSCE conference)

3. Edris, A., Alajlan, A., and Soule, T "A Survey of the Literature on Human Movement for Crowd Control". (Processing of submitting).

4. Alajlan, A., Edris, A., Heckendorn, R. B., & Soule, T. (2021). Using Neural Networks and Genetic Algorithms for Predicting Human Movement in Crowds. In Advances in Artificial Intelligence and Applied Cognitive Computing (pp. 353-368). Springer, Cham.

5. Alajlan, A., Edris, A., Sheldon, F., & Soule, T. (2020, December). Machine Learning for Dense Crowd Direction Prediction Using Long Short-Term Memory. In 2020 International Conference on Computational Science and Computational Intelligence (CSCI) (pp. 686-689). IEEE.

6. Alajlan, A, Edris, A., and Soule, T "Literature Review for Predicating Next location for individuals". (Processing of submitting).

1.6 DISSERTATION ORGANIZATION

The remainder of the dissertation is organized as follows: Chapter 2 discusses the research background; chapters 3 and 4 present the alert system approaches used for feature extraction implementations in experiments. Chapters 5 and 6 provides the prediction for individuals' next location, and Chapter 7 includes the conclusions and suggestions for future work.

CHAPTER 2

BACK GROUND AND RELATED WORK

One of the main responsibilities for law enforcement when engaging with people forming a crowd is the people's safety. Crowds form for various reasons, such as sports, political rallies, and religious gatherings. There is always a chance that an out-of-control crowd might create dangerous, even lethal, injuries to people. Analyzing the types of crowd movement and crowd behavior led to distinguishing two main types of crowds: structured and unstructured crowds. When people travel with a single, shared destination or goal, it is called a structured crowd, and can be seen in situations such as religious gatherings or when evacuation plans for emergencies are in effect. In general, the individuals adopt and maintain a specific speed relative to the speed of others walking in the crowd. Due to the speed being influenced from others in the crowd, these crowds become herd-like and large waves can form, causing unwanted consequences, especially when speeds or directional flows change.

An example of an unstructured crowd, when people gather without a common destination or goal, can be seen in a downtown setting, where people pass each other in different directions with very different purposes. Damage and casualties can occur in this situation if there is panicked behavior and people begin a disturbance among the others surrounding them or start running into each other.

In this review, we identified different approaches for controlling crowds, the challenges for these various approaches in both structured or unstructured crowds, and summarized the results in a table to make them more easily available for interested researchers.

2.1 INTRODUCTION

Preventing unwanted injury to people and property is the most important reason for crowd control, no matter what the type of gathering may be. It is a major obligation of law enforcement to keep crowds under control to prevent unintended and clearly unwanted incidents from occurring. In order to understand crowds and crowd behavior, we scrutinized the dynamic movement of people when they gathered for different events so that it might help prevent crowd movements

FIGURE 2.1: Example of an unstructured crowd. Image from Ozturk *et al*. (2010).

FIGURE 2.2: Example of structured crowd. Image is a screen capture from videos in 2019 from Ministry of Hajj, Kingdom of Saudi Arabia, https://www.haj.gov.sa/en

that might lead to injuries or lethal consequences. The two major types of crowds that can be distinguished based on their dynamic movement are the structured crowd and the unstructured crowd. An example of a structured crowd is when people gather with intentional movement toward a specific direction or with a specific goal; this occurs, for instance, at the Islamic Hajj or the Hindu Kumbh Mela. When people move without a common intention or direction and pass one another, such as in town squares, shopping malls, or train stations, these are examples of unstructured crowds Edris *et al*. (2020) and Alajlan *et al*. (2020). Figures 2.1 2.1 illustrate these two major types of crowds.

Authorities face some common problems when controlling crowds. For instance, a slight delay in crowd movement can produce the unexpected result of crowd motion developing into a stampede. Protecting property is an equally important reason for crowd control. Basically, crowds are made of individuals who gather for various reasons and whose individual movements and behaviors are influenced by those around them; they begin to "share" ideas and motions and become less individual and less autonomous in their decision-making. This leads to a group consciousness, which can lead to behavior that might not occur in individual decision-making Bolia (2015). This can be the result of massive numbers of people in a crowded area. A massive crowd can also be challenging to the limitations of a location's infrastructure. Stampeding can occur creating an extremely high density in a crowd, especially when there is poor event management, where safety precautions, competitive advantage, and system failures are problems Bolia (2015) Table 2.1 shows incidents of past stampedes in different locations and their causes. These incidents show how vital it is to understand crowd behavior and movement in order to improve crowd control processes for large events, such as at large sports or religious events, or during evacuations.

2.2 BACKGROUND

Certain skills are necessary for crowd control practices; these include competency in the observation of, making sense of, anticipation of, and action taken regarding crowd movement. In research on crowd control there are a few models for controlling crowds. Wijermans *et al*. (2016) presented INCROWD, which models a specific level of architecture for the decisions of

TABLE 2.1: Table 1 explain the places of incident with number of casualties Bolia (2015)

The year	**The Location**	**The Cause**	**Casualties**
1883	Victoria Hall (Britain).	Free toys distribution causes stampede.	180
1989	Hillsborough Stadium (Britain).	Local police decided to open the stadium gates when the stadium was already full.	249
1990	Hajj (Mina, Mecca).	Overcrowding.	1426
2008	Chamunda devi temple, Jodhpur, Rajasthan (India).	Stampede due to false rumors of bomb.	249
2010	Phnom Penh (Cambodia).	Suspension bridge went way over capacity.	450
2013	Ratangarh temple (India).	Stampede at bridge.	89
2015	Hajj (Mina, Mecca).	Overcrowding.	1859

support systems for the modelling of crowd development and crowd control. INCROWD also provides a framework for the classification of crowds.

Surveillance of crowds is one of the main tools for public security and crowd scene analysis has become essential for crowd control in public areas. Cao *et al*. (2009) presented a method to use surveillance to identify abnormal crowd motion. It is based on the crowd's kinetic energy and the motion and direction of crowd flow. Basically, it combines the crowd's kinetic energy with various metrics of motion in order to detect abnormal behaviour in any crowd scene. Despite the challenges, such as low-quality video and very high crowd densities at crowd scenes, Kumar and Bhatnagar (2017) their detection system can uses a hybrid tracking module enabling features that can be integrated with a Neural Network.

The detection of abnormal trajectories comparing to other collected trajectory of walking motion toward desired location as part of the analysis of crowd behaviour is an important subject for researchers when unravelling scenes where a surveillance camera is used. A framework was proposed by Liu *et al*. (2017) for evaluating the behaviour of a crowd and finding abnormal trajectories in structured scenes. To cluster the trajectories, the LDA (Latent Dirichlet Allocation) algorithm was used along with the LOF (Local Outlier Factor) algorithm to detect abnormal trajectories based on the sample trajectory points. The results showed that the framework could learn to detect patterns associated with abnormal trajectories.

There has been a significant increase in the number of surveillance cameras in public areas for monitoring and safety. This has led to increased interest in learning crowd behaviour and movement leading researchers to focus on identifying trajectories using intelligent video surveillance technology. Cui *et al*. (2014) presented a FCM (Fuzzy c-means) algorithm that can cluster the trajectories' points by considering the critical points to be detected in them in order to discover crowd behaviour. Khan *et al*. (2019) summarized the current literature on intelligent methods of crowd analysis and strategies, based on the source of media and requirements needs. The article aims to understand the present concentrations in those fields and how the criteria specifics can be unveiled by artificial intelligence techniques in order for involving crowds activities design requirements. This article's benefit provides research questions and a research map that directs us to future trends in solving crowd intelligence limitations, i.e., the feedback metric relies only on the user without considering other stakeholders, such as analysts and/or developers.

The main concept in the design of public infrastructure is consideration of the capacities of spaces such as staircases or other bottlenecks. A major event, leading to a massive crowd and overcrowding in such spaces, must be regulated to prevent an unwanted accident. Seer *et al*. (2008) presented an assessment for capacity efficiency in bottleneck scenarios that used an experiment from a 2008 real-world dataset of pedestrians walking through subway stations toward the main soccer stadium in Vienna. The results were collected during the European Soccer Championship (UEFA EURO 2008). Another important topic in crowd behaviour studies is detecting the influences that can have an impact on pedestrian interactions when in motion, that can lead to either improved crowd movement or obstruction of crowd flow.

Johansson *et al*. (2008) discusses how many studies are based on video data for high density crowds and presented the example of Saudi Arabian pilgrim flows at different locations for ritual practices. They presented results on the formation of unexpected crowd behaviours and showed the average speed of every individual and detected the density position with ten (10) persons for every square meter. When considering overcrowding, checking the number of people per square meter versus the capacities of various facilities is vital for improving crowd safety. Gao *et al*. (2021) proposed a framework that provides crowd control by releasing the high-density pressure of people on a road network, based on a hybrid crowd dynamic model. The road network monitored changes in the direction of individuals and their continuous dynamic movement, which is the novelty of the approach. The simulation involved manual control commands to replicate a real-world high-density outdoor crowd event with activity authorities in order to test their framework. They have shown in their results that the performance of the framework kept the road network free from risk by distributing the overall crowds to maintain them in a balanced state. When designing buildings for emergencies, the evacuation of people is a necessary step to guarantee safety.

To some extent, studying evacuation drills does not fit with the realistic behaviour when crowd dynamics begin in a real emergency. However, crowd simulation can be modified to meet various emergency situations by adding more complex behaviours for dynamic crowd movement. Gutierrez-Milla *et al*. (2014) demonstrates a distributed simulator for crowd evacuation. They introduced a two-framework model. One framework uses Netlogo, and the other uses MPI. Both models relied on data from the real-case environment in Fira de Barcelona building, Pavilion 2, which is capable of hosting thousands of people.

TABLE 2.2: The Table 2 explain the overall cases of crowd control

Source	**The case**	**Scenarios of crowd motion**	**Type of crowd**	**The crowd control method**
Edris *et al*. (2021)	Control crowd at high density events.	Simulating different crowds' motion using NetLogo machine.	Structured and unstructured crowds.	Finding the critical density spots to inform authorities by using Fuzzy logic.
Xiong *et al*. (2016)	Evacuation disaster in case of leaking gas.	A simulation crowd-based UAV Control Architecture.	Forming a structured crowd since people are heading in one direction.	A decision support system for guiding individuals in case of evacuation.
Chang and Li (2008)	Controlling crowds.	Agent-Based model based on social science studies modeling a Vancouver Stanley Cup Riot 2011.	Unstructured crowd motion.	A decision support system for testing different tactics called SIM Crowd Control.
Schubert *et al*. (2008)	Controlling riots.	Agent based model for locations of rioting.	Unstructured crowd motion.	Using GA for optimizing pre-stored situations to choose the fit strategy for controlling riots.

Wijermans *et al*. (2016)	Controlling crowd movement.	Hajj crowd motion.	Structured crowd.	A hybridization system that involves several techniques, including fuzzy logic and tactical research in decision support systems to operate and enable the device controllers to handle the large Hajji crowds' movement.
Johansson *et al*. (2008)	Controlling crowd movement.	Hajj crowd motion of Arafat to Muzdalifah routes.	Structured crowd.	A decision support system that designs for controlling the crowd motion by deploying thermal cameras and sensors that have been installed and linked to the module system for analyzing the crowd density in real time.

Blanke *et al.* (2014)	Controlling the crowd's mobility process.	Controlling crowds' motion at Zuri Fascht 2013, a large festival event for three days in Switzerland.	Unstructured crowd motion.	An app offers various information and features about the festival while in the background it collects the attendances at different positions.
Bolia (2015)	Crowd management.	Human movement in an evacuation case.	Structured and unstructured crowds.	Two modules: the first module focuses on assessing crowding conditions and a plan of action; the second module determines how to decide the shortest possible evacuation route.

Ma *et al.* (2013)	Controlling crowd movement.	Hajj crowd motion.	Structured crowd.	A proposed method of detecting crowd recognition from segmenting images in a case of the overcrowding of a place to determine an assessment of stampeding in order to alert authorities.
Prasun and Dixit (2015)	Optimizing crowd control strategies.	A Vancouver Stanley Cup Riot, 2011.	Unstructured crowd motion.	A framework of simulating the rioting, police forces for responding to the rioting, and the transit system in a 3D agent-based model; the main object for this study is specific crowd control strategies.

Gao *et al.* (2021)	Sensitivity analysis for agent-based crowd injury.	Crowd injury modeling.	Unstructured crowd motion.	A crowd simulation based on the fuzzy logic for multi-agent crowd injury was developed; it performs the simulation focused on agents, which can be the perfect way to forecast crowd activity in emergency situations.
Alajlan *et al.* (2021)	Predicting human movement in crowds.	Simulating different crowds' motion using NetLogo machine.	Structured and unstructured crowds.	Combining GA and NN for the process of learning crowds' motion by looking at two major behaviors, structured crowd and unstructured crowd, to predict next individuals' location.

Alajlan *et al*. (2020)	Dense crowd direction prediction.	Simulating different crowds motion using the NetLogo machine.	Structured and unstructured crowds.	A prediction of individuals behavioral movement for controlling crowds that depends on the learning machine of RNN (Recurrent Neural Network) and LSTM (Long Short-Term Memory); it was able to handle the sequence of individual's positions dataset for the next location.

The strength of this model is that it performed in linear time, which led to speeding up the procedure effectively in the distributed environment. In other models limitations arose when dealing with a large number of agents that reduced performance.

Simulating interactive crowd movement is a major aim for controlling massive crowds in different scenarios. Most of the crowd navigation research in these simulations considers the trajectory of individuals with various goals or positions, or the interaction among the individuals. Jin *et al*. (2008), proposed a model in which each individual has his/her own personality and makes decisions based on an autonomous movement component of the model. Their simulation is useful because that level of detail in crowd models is valuable for creating modifiable differences in the behaviour or movement of every individual.

These strategies for simulating individuals in a crowd can be effective because they provide information about the configurations of building environments that suggest architectural design changes necessary for safe, efficient pedestrians' paths and add to the system optimal routing for evacuations. Feng *et al*. (2014) proposed an investigation into using mathematical formulation and computational solutions to choose among assessed strategies based on the total travel time. The quality of the command-and-control strategies will be an improvement in understanding for crowd movement.

Panicking is a major factor causing unwanted accidents and triggering competitive crowd behaviour, especially in the case of emergency building evacuations. Considering this kind of serious situation, there is an urgent need to develop a crowd control process with reliable solutions for the safety of people. Luh *et al*. (2012) presents an approach to optimize complicated group behaviour in panic situations that reflects the psychological state of individuals in order to simulate crowd movement in cases where individuals are seeking a desirable escape route.

Zhou *et al*. (2016) presented four kinds of logic models that focused on the diverse purposes of pedestrians and their surroundings. These models considered obstacle avoidance behaviour, route quest, and objective search activity, first separately, and then in combination using a weighted average process. Their model can predict and forecast crowd evacuation actions realistically, taking into account human experience and the expertise of modelling processes. In the search for exploring new patterns of unusual crowd movement, recording videos were analysed of different events, such as the Love Parade disaster, to find clues about the causes of crowd disasters.

Ma *et al*. (2013) explained movement turbulence by identifying the pattern of pedestrian crowd movement when there might be concern about the unintentional pushing of others that could lead to fluctuations of speed or velocity of the crowd. Therefore, the turbulence of a crowd pattern can be displayed as it relates to crowd density; the state of turbulence caused in different gatherings of people produces different features of velocity. The pedestrian crowd-quake model was created based on the observed crowd patterns in order to simulate crowd movement. Bolia designed a plan for risk aversion in a real-case environment in India Bolia (2015). The suggested techniques successfully managed crowd control by evaluating the suitability of the venue for an event and identifying the pinch points (high risk points). The advantage of this strategy is that it can ably simulate real pedestrian activities; several scenarios were able to be predicted according to the rules of the crowd management system. Chang and Li (2008) provide a simulation for crowd motion by operating in two stages: the global form on the template movement planner and the shape restriction controller by the fuzzy controller.

The simulating system first produces a rough track for a target shape that is partly in conflict with the environment with a motion planner. A floating controller is then used to transfer agents into a group to accommodate the appropriate form on the basis of many parameters. The intensity of the proposed framework allows deformable shape paths to be created online. It also has the ability to design a set of fuzzy rules to verify that the agents inside the crowd move to the target position in a mutual, collision-free, and compliant way. However, it takes time to manage the crowd movement in the behaviour model. Prasun and Dixit (2015) studies cases of dangerous events at religious gatherings. Two case studies of stampedes are illustrated; the first, Sri Kalubai Yatra Mandhadi at Wai, Maharashtra in 2005, and the second, the Dussehra Festival Stampede at Patna, Bihar in 2014. Both cases were studied from the management perspective that included several factors, including permissible crowd capacity, visitors' database, and architectural changes. The advantage of this study is that analysed the area of the crowd density by determining the size of the allowable crowd and the emergency exit plan requirements based on the crowd volume.

Severiukhina *et al*. (2017) studied the influence of obstacles on crowd dynamics by showing four base scenarios of crowd interactions, such as unidirectional flow, bidirectional flow, merging flows, and interactions. In addition, they demonstrated that from the environment simulation to layout of different combining obstacles can have an impact on a crowd's dynamic. Moussaïd *et al*. (2010) presented a framework for human crowd motion that is focused on the interactions among individual pedestrians. They calculated the movement of the pedestrians depending on the size of the groups. The first case dealt with a low-density group where the movement frequently was walking in pairs, walking side-by-side in a nearly straight path. However, as the density of the groups increased, the linear formation of the walk bends forward, producing a V-like formation. In the second case, when it dealt with increased crowd density, the crowd density output is group organization in which walking speed is exchanged for social interaction. The advantage of this study is that it indicates that the total efficiency of a pedestrian group has a significant impact on the efficiency of total traffic. However, a downside emerges when the pedestrian group divides into another group, which makes the simulation performance low and leads to an increase in evaluation time.

2.2.1 *Crowd Control*

When considering the possibility of unexpected, harmful accidents, general public safety, and the desire for a good public experience, large gatherings of people at different events need to be under control. Distinguishing the type of crowd helps with the understanding of how to deal with crowd control. Thus, Edris *et al*. (2020) proposed an alert system for crowd control to detect the critical density spots in crowd movements. The alert system determines these spots by analyzing information about every single individual in the moving crowd, scrutinizing and monitoring their locations and looking for variations in the individuals' behaviour. The results detected critical density spots for individuals that was generated by the NetLogo machine; but the results also demonstrated a limitation based on the capacity of the machine to handle larger populations of individuals. Very large crowds, over a thousand individuals would require a more powerful machine.

Xiong *et al*. (2016) considered the matter of evacuation in the case of a gas leak incident and what might cause casualties and damages during an evacuation. They proposed using an Unmanned Aerial Vehicle (UAV) to help with the evacuation of people, after the detection of toxic gas when a precise evacuation route is required. A control support system, based on UAVs for crowd evacuation, indicates the need for a fleet management module of UAVs, a trajectory UAV planning module, and a crowd simulation module. For the proposed architecture, the result demonstrated an effective, safe evacuation path to help people avoid poisonous gas.

Using an agent-based model and simulation (ABMS) for controlling crowds, Park *et al*. (2015) has suggested a decision support system for testing different tactics called SIMCrowd-Control. The system was built based on reliable social science studies modelling a Vancouver Stanley Cup Riot, that happened in 2011, and deployed different tactics to search for an optimal decision. Based on the number of officers who were lined up to block the rioters it shows a high number of police officers were able to blocks most of the rioters.

Schubert *et al*. (2008) presented a decision support system for crowd control for a different specific strategy in active riot situations. The system consists of control strategies for using multiple police barriers in various locations and various barriers strengths to control riots. The previous set of control strategies for rioting situations was stored, and because it is driven by the Genetic Algorithm (GA), it can select the right strategy for evaluation using stochastic agent-based simulation. The system looks for the best linear version of a control strategy that is a pre-stored example and compares it with current situation; this strategy will be selected based on the relative fitness values of the strategies.

Khozium (2012) presented a framework to manage the large volumes of Hajji worshippers. They introduced a hybridization system that involves several techniques, including fuzzy logic and tactical research in decision support systems to operate and enable the device controllers to handle the large Hajji crowds' movement, it can thus ensure protection and preserve the traditions of the Hajjis with time constraints when the groups pass. The strength of this framework is that it is able to perform during the Hajjis campaign. The technique also reveals strong generations of decisions that reduce operating expenses. However, it relies on matrix based approaches, which are time-consuming.

In Saudi Arabia, there are annual gatherings, considered major overcrowding events, that take place in order to practice Islamic rituals; due to these events, many improvements have been applied for various public services. There are many challenges to taking precautions when seeking the pilgrims' safety and developing different approaches for crowd control and the assessment of crowd density. Khozium *et al*. (2012) presented a decision support system, designed to control crowd motion by deploying thermal cameras around the route of Arafat to Muzdalifah, which is a difficult point to be managed. Sensors have also been installed that are linked to the module system to analyse crowd density in real time; once the crowd reaches maximum density, the system triggers alarms according to the level of crowding.

There are many different attractions at large events with highly dense crowds, such as stages and food stands, which can make a difficult to design controls for a mobile crowd; a lack of preparation during the planning stage can result in unwanted accidents. Blanke *et al*. (2014) presented an app for Zuri Fascht 2013, a large, three day, festival event in Switzerland. The app offers various information and features about the festival, while in the background it collects information about attendance from different locations. The collected data is then provided to capture the dynamic crowd movement in order to discover the relevant parameters that can contribute to the planning and design phases.

Deshpande and Gupta (2010) concentrated on a computerized framework to track crowding and provide warnings to manage a crowd. Their framework process includes two approaches. The first approach is to prepare for catastrophe by pre-disaster planning; it involves identifying sensitive locations and space utilization, evacuation routes, and other administration-related plans. The second approach relies on real-time monitoring by two modules: the first module focuses on assessing crowding conditions based on plans of action; and the second module determines the shortest possible evacuation route. Fuzzy-logic is applied in the first module, while the second module uses the G.I.S framework to find paths. The advantage of this framework is that it can detect the areas of human movements. However, when faced with a large dataset, it needs a long processing time.

Determining the capacity of places where individuals gather is becoming an important subject as a way of preventing overcrowding at one location, as happened in Hajj stampede in 2015. Musa *et al*. (2017) proposed a method of for detecting crowd density from segmented images in the case of overcrowding of a place, in order to determine potential stampedes and alert the authorities. A real-life image from surveillance cameras at Hajj was used for this purpose to demonstrate the method's accuracy when seeking a reliable outcome.

Sporting events are considered an attraction for crowds with the chance for the violent emotions of team fans to trigger crowd flows, which can potentially cause damage to public properties and/or accidents. To maintain public order and safety, an important duty for the police forces is to keep crowds from rioting. Park *et al*. (2019) presented a framework of simulating riots, police forces response to riots, and the transit system in a 3D agent-based model. The main object for this study was to evaluate specific crowd control strategies. The Vancouver Stanley Cup Riot of 2011 was used as the simulation for this case study, in which the police formed a line that pushed the crowd toward public transit as they sought to disperse the crowds by forcing them from the public area scattering them around various place.

Kugu *et al*. (2014) designed a crowd simulation based on fuzzy logic for multi-agent crowd injury detection. The simulation focused on crowd agents, which can be the perfect way to forecast crowd activity in emergency situations. The simulations must accompany well-built models in order to produce the most acceptable, consistent, and realistic effects. The advantage of applying the fuzzy logic is that it can overcome the mathematics paradigm by simple interpretation, versatility, and the natural representation of languages. The drawback of this simulation is that it relied on expert experience. If the domain knowledge is incomplete, the success of the fuzzy logic model is not insured.

Alajlan *et al*. (2021) presented a prediction method for human movement in a crowd to be used for crowd control. The authors emphasized how important it is to accurately and reliably simulate crowd behaviour. They simulated crowd motion in a NetLogo model where they deployed various scenarios of crowd motion. They combined a GA and NN for the process of learning the crowds' motion and considered two major scenarios: structured crowds and unstructured crowds. They used the NN trained GA to predict individuals' next locations. The results compared the error rate of the actual position and predicted position. The result presents promising result comparing the prediction location with the actual individuals location.

Advance detection of issues in crowd behaviour can be effective for determining actions and responses at appropriate times in order to prevent accidents. Working with simulations that allow a variety of scenarios can help a system learn to predict reliable behaviours of crowds, as can working with different pedestrian models, such as the FM (Flocking Model) and the SFM (Social Forces Model). Alajlan *et al*. (2020) presented a study on the prediction of individual's behavioural movements in crowds using a RNN (Recurrent Neural Network) and an LSTM (Long Short-Term Memory) network; their method was able to use the sequence of the individuals' positions to predict the individual's next location. The study compared the prediction resulted in high- and low-density populations within two major types of crowds, structured and unstructured.

2.3 CONCLUSION

Methods to predict and control crowds at large events is an important topic that has attracted a lot of researchers working to discover the means of preventing lethal incidents and promote the public safety. Different approaches have been presented for handling crowds with different approaches to predicting and/or controlling a crowd's motion in a variety of scenarios. Crowd safety is the shared ambition of this research, the table 2.2 shows a brief overview of the crowd control research discussed in this chapter. It's aim is to make it easier for researchers to understand the scope of the field in order to contribute to the area/study of safe crowd control.

CHAPTER 3

AN ALERT SYSTEM: USING FUZZY LOGIC FOR CONTROLLING CROWD MOVEMENT BY DETECTING CRITICAL DENSITY SPOTS

When people form crowds without an orderly arrangement, we need to consider how to best control their movement to provide safety and maximize their experience. Controlling a large crowd is a complicated and costly operation, but it is important to prevent risky situations that can lead to trampling and crushing, and to provide general public safety. Crowd control forces must be able to organize people to provide successful crowd management. In this paper we examine two types of crowds: structured crowds, where people are heading towards the same goal and in generally the same direction, as happens in religious gatherings like the Islamic Hajj or the Hindu Kumbh Mela; and unstructured crowds, where people walk in different directions, as occurs in train stations and in the centers of towns and cities. By identifying the locations of each individual in a crowd, many potential problems of controlling crowds can be detected and avoided, since we will able to identify the direction and speed of each individual and compare it to the surrounding crowd. We propose an alert system as a way of keeping crowds safe in risky situations. The alert system focuses on scrutinizing the status of individuals in order to inform the authorities in case of risk behavior. Fuzzy logic is proposed as the basis for the alert system for deciding if the locations of individuals are considered critical spots causing obstruction of crowd motion. The aim of this paper is to establish a system that is able to process and analyze the individuals' locations according to their current locations status. The system is using the fuzzy logic, as the machine starts to learn the critical density spots by pointing these locations.

3.1 INTRODUCTION

In large gatherings, crowds, which can reach up to thousands or millions of people, there is a risk of unexpected dynamic movement that can cause injuries and/or death. There are two major types of crowds that are well known: structured crowds, where people move in deliberate specific directions, such as in the Islamic Hajj or the Hindu Kumbh Mela; and

FIGURE 3.1: An unstructured crowd motions. Image from Ozturk *et al*. (2010).

unstructured crowds, where people move randomly, as in town squares, shopping malls, and train stations, as shown in Figure 3.1 and Figure 3.2. There are some common difficulties that authorities controlling crowds face, such as the delay of momentum, perhaps caused by one person's medical incident, or disorderly behavior, perhaps caused by someone running through a crowd. These behaviors change the local behavior and density of the crowd. We refer to these as "critical density spots" (CDS). These spots are going to be defined by alert system that scrutinizes some crowd motion factors such as speed, direction, and opposite directed people. When this occurs, the alert system reports each individual's current location and defines creates its location status wither this spot is critical or not. Our objective here is to determine how an alert system can identify these CDS so that organizers can deal with dangerous situations. In order to manage the mobility of crowds in a controlled manner, we propose an alert system that detects the average speed of the crowd, detects individuals' direction of movement, and detects the directions of those who move in the opposite direction. This alert system is proposed in order to prevent unexpected crowd dynamics that lead to stampedes with lethal consequences such as Islamic Hajj Ganjeh and Einollahi (2016) and Hindu India Prasun and Dixit (2015).

FIGURE 3.2: A structured crowd motions. Image is a screen capture from videos in 2019 from Ministry of Hajj, Kingdom of Saudi Arabia, https://www.haj.gov.sa/en

3.2 BACKGROUND

In terms of controlling crowd motions, we need to understand the crowd motion or behavior. Rodriguez *et al*. (2009) distinguishes two types of crowds with regard to their formation and direction; the structured crowd where people are close to each other and have one destination and direction, and the unstructured crowd where people pass one another in seemingly random directions. Crowd motion analysis can be effective in order to control a crowd. One method is presented by Cao *et al*. (2009) to detect abnormal crowd motion. Khan *et al*. (2019) reported finding requirement engineering to help understand the achievement of recent research on the enhancement of crowd intelligence. Moussaïd *et al*. (2010) studied the walking behavior of pedestrian social groups and its impact on crowd dynamics by analyzing 1500 pedestrians under normal conditions and showed the interactions socially between the group members regarding walking behavior. In Zurich, Switzerland, there is a large festival that takes place for three days; Blanke *et al*. (2014) captured the dynamics of crowd motion and behavior using an app based on participatory gps-localization.

To monitor crowd motion for the avoidance of safety-critical crowd events, a design of a computer-based system was shown by Deshpande and Gupta (2010) using Fuzzy Logic and G.I.S in two studies: open air theatre and an auditorium. The purpose was to determine speed, displacement, and the usability of the overall space. Containing riots with non-lethal weapons (NLWs) is a means used by police and the military; Kugu *et al*. (2014) presented a sensitivity analysis for crowd motion agent-based crowd injury modeling by using the Fuzzy Logic approach. Zhou *et al*. (2016) presented a detailed case of crowd evacuation behavior, adding assailant's effects, by using Fuzzy Logic. For motion planning to shape a template, Chang and Li (2008) proposed a technique for simulation that worked by using Fuzzy Logic; there were two steps: global motion planning and controlling for shape constraints. Alajlan *et al*. (2021) have shown crowd motion by Using Neural Networks and Genetic Algorithms for predicting human movement to help of crowd control motion.

A lethal incident happened in 2015 at the Hajj (an Islamic ritual) where a structured crowd of pilgrims stampeded; Musa *et al*. (2017) proposed a method for crowd-head calculation to prevent any future stampeding. Bolia (2015) suggested strategies for better crowd motion control and for risk management to avoid stampedes at mass gatherings, such as in religious places, railway stations, or social events. Prasun and Dixit (2015) focused on stampedes at religious events in India, such as Sri Kalubai Yatra Mandhardev at Wai, Maharashtra (in 2005) and the event Dussehra Festival Stampede at Patna, Bihar (in 2014), by analyzing the causes and flaws in crowd motion control.

3.3 FRAMEWORK OVERVIEW

3.3.1 *Problem statement overview*

Learning the behavior of a crowd's movement can be useful to improve the control process of people at large events, such as sport events, religious gatherings, and evacuations. Structured and unstructured crowds are two ways of distinguishing crowds by presenting the motile behavior of crowd movement. The structured crowd motion can behave like wave movement, since the individuals are at high density and close to each other, one large mass of people. This wave of people comes with the risk of casualties in the event of chaos or confusion, when individuals changed their speed or direction significantly with the current speed heading and relative to the speed average for the crowd. This is unlike the unstructured crowd, where individuals are scattered in different places and are able to swiftly change paths and move in between other individuals in a problem situation. By observing crowd motion and distinguishing in terms of the aforementioned measures, we will illustrate some major factors that will be beneficial for crowd control processes to prevent accidents.

3.3.2 *Factors of Fuzzy logic*

We want to focus on an individual's location status via an alert system to scrutinize whether that status needs to be controlled in the case that the authorities are needed to intervene. The alert system will define various individuals' location status by monitoring factors, such as detecting the average speed of intervene, a factor that has a high impact on crowd motion. If there is a fluctuation in the average speed, affected by an individual's motile behavior, it can lead to disrupting crowd movement. People tend to walk in groups of families, friends, or couples; these groups can impact the average speed of crowds when intervene speed is inconsistent Fang *et al*. (2003).

By monitoring the direction of individuals, a way to control crowd motion will be possible. People pay attention to the area of vision in front of themselves in order to make a decision about

TABLE 3.1: Variables and membership functions

Variables	**Membership Functions**
The average speed	CDS, need attention, safe
The direction of individuals	CDS, need attention, safe
The number of opposite directed individuals	CDS, need attention, safe

a desired direction or to avoid collisions with others; this has been demonstrated in different techniques by simulating the direction of individuals. Therefore, we have chosen to detect the direction of individuals as a major factor for our alert system. The direction of people has become an important subject for many researchers; they have presented different approaches and methods to crowd control based on Cao *et al*. (2009); Alajlan *et al*. (2021); Blanke *et al*. (2014); Chang and Li (2008) for the cases of abnormal behavior, or behavior near emergency exits.

The last factor to be monitored by the alert system is the forewarning of most dangerous case, namely the opposite directed individuals who are head or starting to head in the wrong direction; most crushing and stampeding happens by the collision of two crowds. In 2015 this scenario took place in Mina, Saudi Arabia during the Hajj and caused more than two thousand deaths among pilgrims. Due to people who were misdirected and going against the correct direction, a collision occurred between these highly dense crowds Ganjeh and Einollahi (2016).

These factors are going to be the essential variables for the alert system as shown on table 3.1 . In the case when the CDS alert goes off, it will point to the spots of every affected individual and will save time and effort for the authorities resolving any problem.

3.3.3 *Alert System Framework Overview*

The alert system is going to report the location status of every individual continuously to determine if the location status is a CDS or not. In other words, the system will ask about the location status of every individual by monitoring the factors of the average of crowd speed,

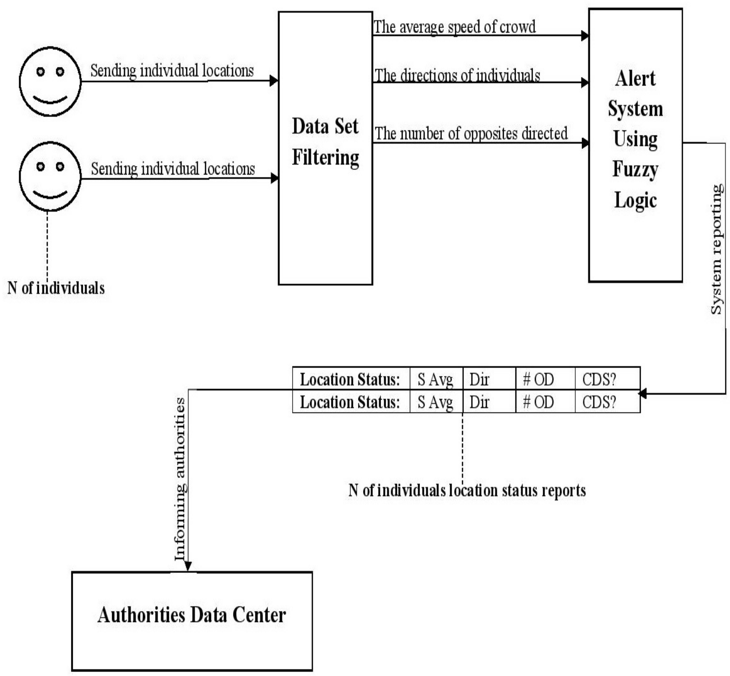


FIGURE 3.3: This shows the workflow for alert system. Collecting the individuals locations as an inputs for alert system to produce reports status about each individuals.

individuals' directions, and the detection opposite-directed individuals in order for the alert system based on Fuzzy Logic to report to the authorities.

Our system will be able to monitor the high-density structured crowd motion to identify the potential areas of threat, based on the CDS location status for every individual, and inform the authorities ahead of actual danger. However, we believe our model will be dependent on the features of the unstructured crowd because these determinations are based on some reliable factors of crowd motion and behavior. figure 3.3 explains the workflow of alert system by collecting the individuals current location due to extracting the speed average of crowd, the direction of individuals, and the opposite directed individuals. Therefore, this information will be feed to alert system that uses fuzzy logic for informing authorities about the critical density spots.

3.4 CONCLUSION

In this paper, we have presented the basic model of an alert system for controlling crowds by detecting the critical density spots in order to inform the authorities who make decisions about crowd control. Two types of crowds, structured and unstructured, are going to be studied by collecting every individual's location. The identification of these potential critical density spots can lead to greater safety in large crowd conditions. In the future, the framework will be implemented and tested by simulated crowd's motion.

CHAPTER 4

A Contribution to Crowd Control by Detecting Critical Density Spots

Crowd control is a complicated process and a highly costly operation, but it is essential when a large number of people gather and create herd movement in which there is a high chance of casualties from trampling and crushing. People's safety is critical in order to enhance their experience when attending large events or religious gatherings; the public's overall safety must be guaranteed. A crowd control process can help organizers make decisions in order to save manpower and create time for preventing fatal accidents in crowds that lack guidance or leadership. By focusing on the two main crowd types, structured and unstructured crowd behaviors, it is possible to contribute to the crowd control process with logic. Monitoring individuals' location and status in a crowd is necessary for crowd control. Our method is based on major factors such as an individual's speed, direction, and detecting the direction of other individuals. The proposed model in this paper is based on Edris *et al*. (2020), an alert system that can inform authorities by flagging individuals who are in a situation of risk when a crowd is being formed and while events are taking place. The alert system scrutinizes individual's location status using fuzzy logic to identify the critical density spots that can obstruct crowd motion. Crowd simulations were built using Netlogo to generate datasets of individuals' locations based on the flocking model and the social forces model. We compared the crowd behavior in different situations to detect the critical density spots distinguishing the levels of risks among individuals.

4.1 Introduction

Steering crowds and governing human dynamic behaviors are two main goals for crowd simulation. Crowd behavior simulation can provide data to help the design of public spaces for large events like religious gatherings and concerts. These large events can potentially cause lethal consequences, such as trampling and crushing; however, simulating a crowd's behavior

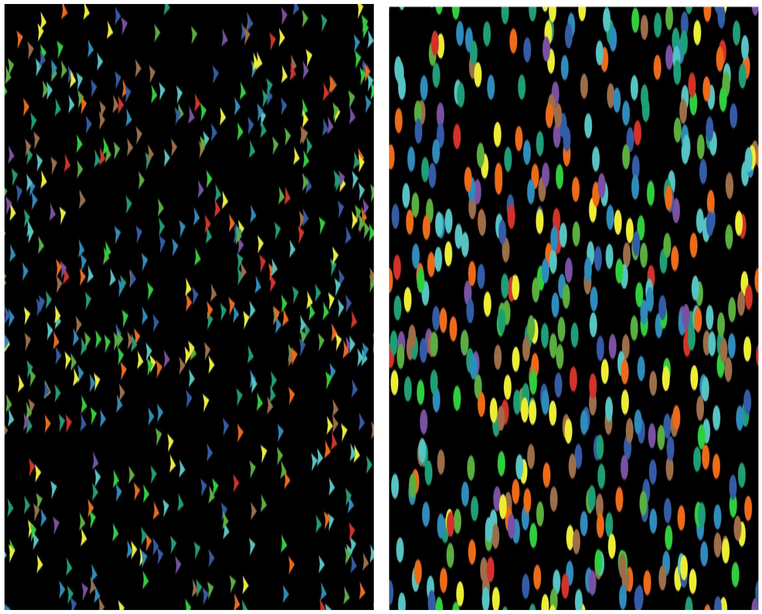


FIGURE 4.1: A screen shot from Netlogo machine for simulating structured crowd presenting FM and SFM

can improve public safety in such a space and improve the experience of attendance through increased safety. To characterize the agent behavior in a crowd simulation, each individual in the same simulation has a degree of intelligence he/she displays when responding to each situation they confront. Hence, we used a flocking model (FM) and a social force model (SFM) to represent individual agent intelligence in crowd motion to create experiments that produce reliable results for a variety of agent behaviors. We focused on two main types of crowds: a structured crowd, which forms when people share the same destination, or goal, such as the religious gatherings of the Islamic Hajj or the Hindu Kumbh Mela; and an unstructured crowd, where people scatter in different directions without common goals, such as in rail stations or city centers. Our approach contributes to crowd control because it makes it possible to provide information to authorities regarding critical density spots (CDS); in Edris *et al*. (2020) we used fuzzy logic rules to determine the status of every individual and identify the individuals in special situations of potential danger in order to save manpower and effort and prevent avoidable accidents. We propose an alert system run by the fuzzy logic system. Tracing the individual's direction, monitoring the individual's speed, and detecting individuals whose movement and speed is in the opposing direction are the main inputs for the alert system.

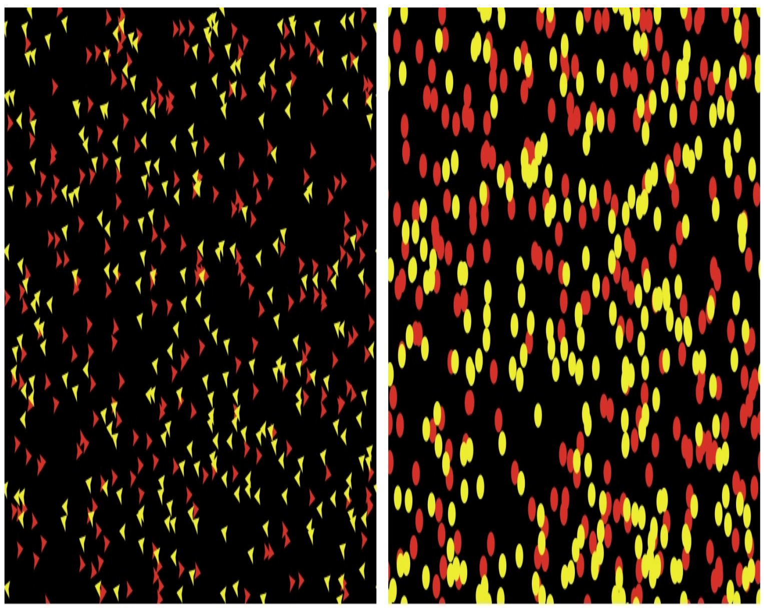


FIGURE 4.2: A screen shot from Netlogo machine for simulating unstructured crowd presenting FM and SFM

4.2 BACKGROUND

The urgent need for crowd control is an important research topic worldwide and has led to new and different solutions. Cao *et al*. (2009) analyzed abnormal crowd motion using surveillance cameras on a crowded scene to determine the crowd's characteristics by assessing the crowd's kinetic energy and the directions of motion. Using a GPS-Localization algorithm, Blanke *et al*. (2014) were able to catch crowd dynamics at a large event at Zuri Fascht in Zurich, Switzerland in 2013 to help the crowd control process. In order to understand crowd intelligence for identifying the current and future crowd direction, Khan *et al*. (2019) presented a survey paper to help engineers with crowd-based requirements. Rodriguez *et al*. (2011) detected a particular person in a crowd scene by using video for density awareness in the crowd and exposed some constraints for crowd density self-awareness. Crowd evacuation was modeled by Zhou *et al*. (2016), with attacking individuals by using a fuzzy logic approach for controlling a crowd. Human crowd movement can be influenced by the crowd dynamics of a group of pedestrians; Moussaïd *et al*. (2010) concluded that 70 percent of people in a crowd move in groups. The indication of crowd motion in Dee and Caplier (2010), based on crowd direction, was determined by using histograms that analyzed crowd behavior. Shen *et al*. (2018) presented crowd motion control based on model gestures based on the element of speed.

For anomaly crowd motion detection, Marsden *et al*. (2016) used a scene-level holistic approach with two main features, motion speed and crowd density. Crowd motion predictions were made by Dal Bianco *et al*. (2017); with indications of the agent's desirable speed, an evaluation of statistical information was possible regarding a crowd's behavior, a new approach. An unforgettable accident took place in Saudi Arabia at the Hajj in 2015, as reported in Fang *et al*. (2003); Alrajhi *et al*. (2018); Salamati and Rahimi-Movaghar (2016); Ganjeh and Einollahi (2016) that caused a stampede between two colliding crowds. A proposed approach to preventing what happened in the 2015 incident was developed byMusa *et al*. (2017); this consisted of a technique for calculating crowd capacity for medium-sized places. Bolia (2015), the authors proposed a risk management approaches to prevent stampedes at mass gatherings by simulating pedestrians' behaviors in order to study different crowd control strategies in India. In another approach for preventing stampedes, which have taken place in India at religious events, Prasun and Dixit (2015) posed different considerations from different perspectives for such cases. A flocking model was used by Van Den Hurk and Watson (2010) to simulate crowd movement for people and animals.

Motsch and Tadmor (2011) introduced a self-organized dynamic for the flocking model by taking the relative distance between agents and considering the spaces between agents. Pelechano and Malkawi (2008) built a flocking-based model to test evacuation plans from high-rise buildings. A simulation of robot movement in a flocking model was proposed in Dewi *et al.* (2011) and was used for avoiding collisions in crowds and to avoid crashing into obstacles. By creating a multi-agent computer game from black dots moving on a virtual playground, the flocking model in Belz *et al.* (2013) presented behaviors of groups of people lacking self-organization. Crowd motion behavior was simulated in Mehran *et al.* (2009) based on the social force model for predicting abnormal crowd motion based on images at the University of Minnesota. In Luber *et al.* (2010), simulated tracking people using the SFM in populated environments to keep track of the current and future status of crowd motion. In Yuan *et al.* (2019), a separation behavior within a crowd at a T-shape channel was simulated based on a SFM to improve a pedestrian's desirable speed during the separation process. Helbing and Molnar (1995) was the founder of the SFM in which agents make their decisions based on forces between them when they form a crowd.

The founder of fuzzy logic was Zadeh (1988) to avoid crowd disasters, Deshpande and Gupta (2010) implemented a computer-based system using fuzzy logic and G.I.S to monitor a crowd system via pre-disaster planning and real-time analysis. In Kugu *et al.* (2014), proposed an agent-based model of crowd injuries using the fuzzy logic approach for the purpose of providing the government with information about crowd activities in case a decision would be needed as to whether to implement crowd control or not. An early use of fuzzy logic, in 1990, was proposed by Lee (1990) to be deployed for the control system and it benefitted from human-like thinking for decision making. For the planning of the template-shape motion of crowd simulation, Chang and Li (2008) presented a mechanism that used fuzzy logic as a control for shape constraints when planning the crowd motion template shape. Informing the authorities via an alert system based on fuzzy logic for crowd was proposed by Edris *et al.* (2020).

Year	Location	Scale of the incident	Failure Elements
2012	Port Said, Egypt	74 dead, over 1,000 Injured (Overcrowding + rioting)	Design (Throughput + Riot)
2012	Cairo (copic), Egypt	3 dead, dozens injured (Overcrowding)	Design (Throughput)
2013	Abidjan, Ivory Coast	62 dead, dozens injured (Overcrowding)	Design (Capacity + Crazing)
2013	Allahabab, Northern India	36 dead, 31 injured (Overcrowding, railway platform)	Design (Capacity + Crowd management)
2013	Hubei, China	4 Dead, 14 injured (Overcrowding on stairs - school)	Crowd Management
2013	Datia, India	50 dead, 100+ injured (Overcrowding)	Design (Capacity + Crowd management)
2013	Anambra, Nigeria	28 dead, 200+ injured (Overreaction/Design - call of "fire")	Design (Capacity and crazing)
2014	Ningxia, China	14 Dead, 10 Injured (Design/Overcrowding- food handouts)	Design (Crowd flow, Crowd management)
2014	Mumbai, India	20 dead, 40 injured (Overcrowding, narrow streets)	Design (Capacity, Crowd Flow)
2015	Shanghaii, China	36 dead, 46 injured - crowd crushing (overcrowding)	Design (Capacity, Crowd Flow)
2015	Mina Valley, Saudi Arabia	1500+ dead, thousands injured (overcrowding)	Design (Capacity, Crowd Flow)
2016	Lucknow, India	24 dead, 20 injured (overcrowding on bridge)	Design (Capacity, Crowd Flow)
2016	Falls festival, Australia	60 injured on egress (slope, scheduling, overcapacity)	Design (Capacity, Crowd Flow)
2017	Uíge, Angola	17 dead, 61 injured (ingress, overcapacity)	Design (Capacity, Crowd Flow)
2017	Lusaka, Zambia	8 dead, 28 injured (food aid, queueing)	Design (Capacity, Crowd Flow)
2017	Tegucigalpa, Honduras	4 dead, 25 injured (ingress, overcapacity)	Design (Capacity, Crowd Flow)
2017	Turin, Italy	2 dead, 1527 injured (firework mistaken for bomb, robbery)	False alarm (Information)
2017	Lilongwe, Malawi	8 dead, 40 injured (ingress, overcapacity)	Design (Capacity, Crowd Flow)
2017	Dakar, Senegal	8 dead, 40 injured (tear gas, management)	Management (police - tear gas)
2017	Mbour, Senegal	8 dead, 60 injured (ingress, overcapacity)	Design (Capacity, Crowd Flow)
2017	Johannesburg, South Africa	2 dead, 17 injured (ingress, overcapacity)	Design (Capacity, Crowd Flow)
2017	Mumbai, India	22 dead, 39 injured (overcapacity, bridge)	Overcrowding, Information
2017	Sidi Boulaalam, Morocco.	15 dead, 40 injured (queueing)	Design (Capacity, Crowd Flow)
2018	Caracas, Venezuela	17 dead, dozens injured (tear gas - management)	Management (Tear gas)
2018	Nice, France	30 injured (firework mistaken for bomb)	False alarm (Information)
2018	Celtic Park, Scotland	5 injured (design, management)	Management (Crowd Flow/design)
2018	Madascar	1 dead, 40 injured (Design, Management)	Design (ingress crush)
2018	Luanda, Angola	5 dead, 7 injured	Management (gates shut)
2018	Corinaldo, Italy	6 dead, 59 injured	Design (bridge/barrier collapse)
2019	Port Harcourt, Nigeria	15 dead, 12 injured	Design (locked gate)
2019	Kuala Lumpur, Malaysia	2 dead (elderly)	Design (queueing system)
2019	Cookstown, Ireland	3 dead, dozens injured	Design (queueing system)
2019	Antananarivo, Madagascar	16 dead, 101 injured (Design, Mangement)	Design (Doors closed)

FIGURE 4.3: The figure shows the number of incidents during the last ten years that involved factors such as crowd management or crowd flow https://www.gkstill.com/ExpertWitness/CrowdRisks.html

4.3 PROBLEM STATEMENT

Accidents can occur when people gather in high densities, are very close together, and become confused and suddenly change direction or the speed with which they move. The data in figure 4.3 was collected by Prof. G. Keith Still and shows the number of incidents during the last ten years that involved factors such as crowd management or crowd flow. The figure 4.3 helps us understand the scale of causalities of these accidents. Our role is to help prevent these types of incidents by monitoring crowd motion and differentiating among crowd formations.

4.4 MODEL

The authorities face common difficulties regarding the organization of a large event where people form as a crowd; these difficulties include a sudden speed change, change of direction, or individuals facing others in opposite directions, any of which can cause serious accidents. Understanding crowd behavior led to improving the abilities of the control process of large events where people gather and can be useful for evacuations plans as well. The two main types of crowds are structured and unstructured crowds, which are our subjects for seeking a variation in the individual's location status for the purpose of informing the organizers, and thus, hopefully, to contribute to the crowd control process.

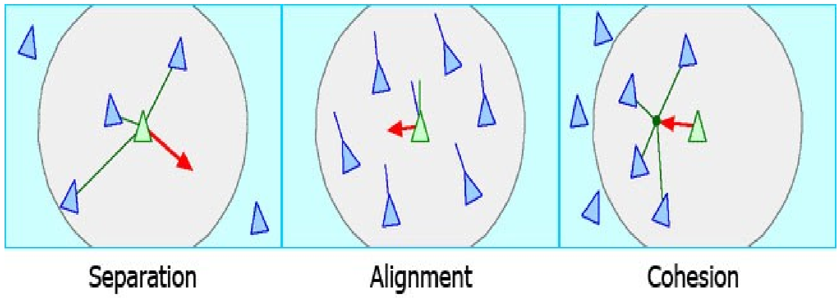


FIGURE 4.4: **Separation:** steer to avoid crowding local flock mates. **Alignment:** steer towards the average heading of local flock mates. **Cohesion:** steer to move towards the average position (center of mass) of local flock mates. "https://towardsdatascience.com/optimising-boids-algorithm-with-unsupervised-learning-ba464891bdba"

4.4.1 *Agent Model Behavior*

For this project, we used a Netlogo simulation that has been used to generate a crowd dataset Edris *et al*. (2020) in order to handle the massive adjustable number of individuals presented by structured and unstructured crowds; the simulation was used before in Alajlan *et al*. (2021); Edris *et al*. (2020). Individuals can affect interactions within crowds; thus, studying the intelligence of an individual's behavior can help reveal important aspects of crowd behavior. We used the FM and SFM models for simulating crowd motion to seek the variations of crowd motion behavior in structured and unstructured crowded areas.

The FM can be used to show the motion of a crowd and it is based on three elements, separation, alignment, and cohesion, for forming crowd behavior; however, there are some editable rules. This is illustrated by figure 4.4. The FM model shows perfect crowd behavior when a flock mate deals with others and stimulates crowd motion and can be used as the subject for a crowd control test Pelechano and Malkawi (2008); Dewi *et al*. (2011). The FM has been edited for the purpose of simulating people's crowd behavior by setting the following: a variable speed for every individual, an ability to avoid collision, a field of view, and a boundary with others.

Another crowd behavior was implemented for this research using the SFM Mehran *et al*. (2009); Luber *et al*. (2010); Yuan *et al*. (2019); Helbing and Molnar (1995); the model simulated the individual's interaction with others and the environment. The force of impact has been shown in the formal 4.1; it lets the individuals deal with others in order to avoid collisions. The same concept can be applied regarding static obstacles that might be impacted in order to avoid

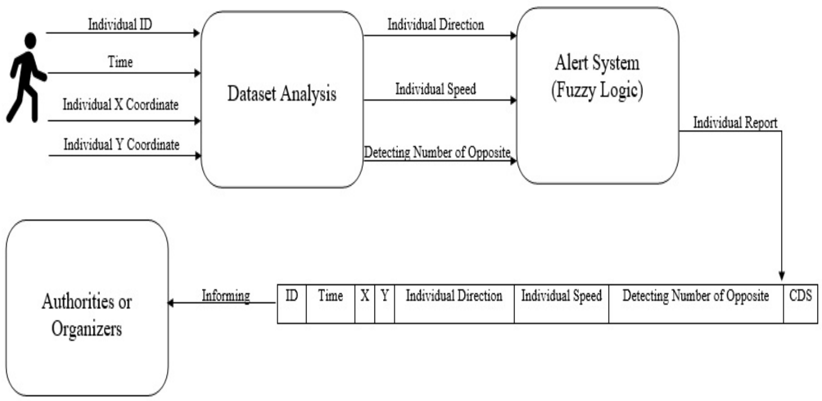


FIGURE 4.5: The illustration of the system work flow for contributing control process for informing authorities

collisions. Also, the last force describes an impact on individuals moving toward their desired destination, which affects the outcome.

$$F_i^{SOC} = \sum_{j \in Pi} f_{i,j}^{SOC} + \sum_{O \in Pi} f_{i,o}^{SOC} +_i \tag{4.1}$$

4.4.2 *Alert System*

The idea proposed in this paper uses fuzzy logic as the main logic for the alert system, which considers the individual's location status for detecting the critical density spots (CDS) Edris *et al*. (2020). Major factors were monitored by the alert system to distinguish the individual's location status based on the individual's direction, the individual's speed, and detecting the number of individuals moving in the opposite direction. A drift in each individual's location status was named as a critical density spot and flagged by the system to inform authorities about it. In other words, each individual location status is checked by the system at all times to count the CDSs in order to provide the authorities with needed information. The workflow of the overall system is explained in figure 4.5.

4.4.3 *Fuzzy Control Systems Inputs*

Input: the individual's direction. The alert system scrutinizes the individual's location status and flags the CDS when monitoring the individual's direction, speed, and the detection of individuals moving in the opposite direction via fuzzy logic. One of the important factors that was chosen as an input for the fuzzy logic is the individual's direction since it is considered a subject of research that has an impact on crowd behavior Khan *et al*. (2019); Zhou *et al*. (2016). People tend to look forward in their zone of vision to decide about their direction or to avoid colliding with others; simulated directions in various approaches and techniques are essential for interpreting an individual's crowd behavior.

Input: the individual's speed. Speed has been defined for the alert system as an important factor since it is involved in the motion of crowd behavior as a fluctuation of motile behavior Dee and Caplier (2010); Marsden *et al*. (2016). In addition, people form groups when they walk; these groups consist of families, friends, or couples; a crowd's speed will be tempered based on the speed of individuals in these groups Marsden *et al*. (2016); Dal Bianco *et al*. (2017).

Input: the number of people moving in the opposite direction. The alert system counts the number of people moving in the opposite direction within a particular distance because there could be the danger of a collision of crowds and the possibility of a stampede, as happened at the Hajj in 2015 Salamati and Rahimi-Movaghar (2016); Ganjeh and Einollahi (2016); Alrajhi *et al*. (2018); **?**.

The inputs for the fuzzy logic control system is presented as:

The direction of individuals:

· The angle (value range); how the individual's direction is, a measured while approaching the goal, on scale of 0 to 1?

· Fuzzy set (fuzzy value range): Wrong direction, In between, Right direction.

The individual's speed:

· The speed (value range): what the individual's speed is, on scale of 0 to 1?

· Fuzzy set (fuzzy value range): Too fast, Good, Too slow.

The number of people moving in the opposite direction:

· Count (value range): how many individuals are counted who face this individual within distance range of five steps, from a count of 0 to 5?

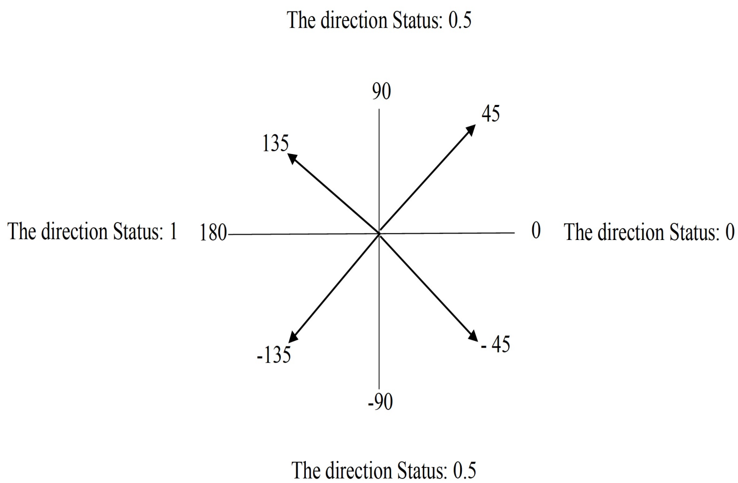


FIGURE 4.6: The direction will be assigned for every individual based on the angel toward the desirable direction in order to define their direction status. An assigned value of 1 for the individual means he is headed in the wrong direction, 0.5 means the individual is in between the right and wrong directions, and 0 means the individual is headed in the right direction.

· Fuzzy set (fuzzy value range): None, Some, Lots.

The system is going to check every individual for his/her location status to detect CDSs in case they may be needed for alerting authorities; Table 4.1 explains the inputs of the fuzzy logic control system. Figure 4.6 shows how the direction value was assigned for everyone. The system can scrutinize every individual in both structured or unstructured crowds with high densities and flag CDSs.

To help explain the fuzzy logic rules, some examples of cases follow:

· IF the individual speed was **Too Slow** and the number of individuals moving in the opposite direction was **Lots**, and individual direction was the **Wrong Direction**, THEN the CDS outcome will be **High-Risk**.

· IF the individual speed was **Too fast** and the number of individuals moving in the opposite direction was **None**, and individual direction was **In between**, THEN the CDS outcome will be **Mid-Risk**.

· IF the individual speed was **Good** and the number of individuals moving in the opposite direction was **None**, and individual direction was **Right Direction**, THEN the CDS outcome will be **Low-Risk**.

TABLE 4.1: The table presents the variables for the alert system that helps in the control crowd process and explains the membership functions with meaning signed values for the fuzzy logic control system.

Variables	Membership Functions	The meaning	Value
The direction of individuals	Wrong direction	The direction going opposite from the goal	1
	In between	The direction in between goal and wrong direction	0.5
	Right direction	The direction on the right way	0
The individuals speed	Too fast	The speed is too fast	1 max speed
	Good	The speed average	Between 0 &1
	Too slow	The speed is too slow	0
The number of opposites directed individuals	Lots	The individuals facing high number of people	Max 5
	Some	The individuals facing some number of people	Between 0 to 5
	None	The individuals facing no number of people	0 people

4.5 RESULT

To study the crowd control process, we placed the emphasis on two main types of crowds that can form when people gather (structured and unstructured crowds) with the implantation of agent behavior to stimulate crowd motion. The agent's behavior applied a logic that made others react when they were forming crowd motion; they behaved as the agent who was placed in the crowd by following editable rules, those for the FM and SFM. This crowd agent behavior is impacted by different decision-making rules, as in the SFM, where the compulsion for a desirable location forces the agent to walk in the direction of the correct goal.

Also, avoiding others and/or obstacles influences the agent's movement by allowing him to hesitate and consider the correct path; this is a special feature of the SFM simulation. However, the FM is influenced by the three elements of separation, alignment, and cohesion and affects the agent's choice of direction, which will be adopted by the others in the crowd. The SFM is only impacted by forces such as the force of avoiding collision with obstacles or other agents, and the force of a desirable location; SFM agents are presented as round shapes unlike the FM agents that are presented as arrow-headed shapes and appear in figure 4.1 and 4.2.

As said above, three scenarios were utilized for our test: a structured crowd where people walk toward a shared goal or location; an unstructured crowd where people do not share the goal of a particular location; and a merging route where people walk in routes that will merge. We were looking for the diversity of crowd behaviors that could provoke the alert system to determine the agents' locations who would be flagged as CDSs. A specific time frame was extracted to collect the individual's location dataset; there is a ten-step difference between every sample for clear results for crowd motion. Table 4.2 4.3shows the diversity of CDSs that detected the number of individuals by the fuzzy logic of the alert system in the different scenarios with two different populations of 500 and 1000. By comparing these different populations of individuals, we discovered that the alert system worked for both the low-density population and the high-density population when the system looked for CDS individuals' locations.

The alert system detected the number of CDSs in the structured crowd in the FM, which appears at step 0; individuals were forming in motion toward the same direction with populations of 500 and 1000. The system identified most of the individuals as having mid-risk status, and a few at high-risk. In this case individuals are close to each other and are forming and in motion with a shared goal, which allowed the alert system to flag the individuals at that moment. As long as the crowd is moving, since they are forming as a structured crowd that understands the crowded conditions, the fuzzy logic system points to only those who are misdirected, demonstrate a fluctuation in speed, or face a certain number of individuals moving in the opposite direction. At the next step 10, the individuals have been paying attention to their destination and walking as a herd, based on the number of detected CDSs, and were determined to be low-risk and mid-risk for the populations 500 and 1000. At the final step 20, the herd started to move with smooth motion; the individuals had gotten used to this kind of motion, as indicated by the high number of detected CDSs; and the system determined that they had low-risk status.

The SFM behavior has a redundancy of hesitation motion since the force of the impacts influences the individual's decision-making by targeting one shared goal of location among the individuals; this led to a queue of individuals trying to avoid stepping into each other. However, a desired location randomly assigned to each one of individuals on the right side of the screen in order to prevent this kind of queuing motion by forcing the individuals toward the desired location. This rational decision by the SFM shows that the alert system did detect the number of CDSs; the system detected a higher number of individuals at low-risk and high-risk when the populations were 500 and 1000 when they gathered as a structured crowd for all the steps.

For the unstructured crowded area with FM behavior, the alert system detected that the number of CDS individuals were almost half of the population since the two groups were facing each other and crossing paths; the system indicated that the individuals were high-risk when walking in the wrong direction. In the unstructured crowd with the SFM, the back and forth bouncing movement affected the individual's decision-making; the individual's behavior was impacted by the forces of interaction. Therefore, the alert system detected that most of the individuals' statuses were at high-risk at certain times because of the fluctuation in change of direction toward the wrong direction. However, the opposite was also true; when the fluctuation in change of direction was toward the right direction, the alert system detected CDS individual statuses as low-risk.

The alert system expanded its efficiency via the different scenarios of crowd motion, especially with the merging routes with the agents walking in paths that eventually merged, leading agents to cross each other. For the agents with FM behavior, the alert system detected the number of CDS individuals' statuses as, mid-risk because the route is narrow; however, because

TABLE 4.2: The approaches of counting the number of CDSs in different simulation types and different scenarios. This illustrates the level of alert for each step 0, step 10, and step 20 as low-risk, mid-risk, and high-risk (L, M, H). The first three rows represent the scenarios, the agent behavior, and the agent population, respectively.

Scenarios:			**Structured**				**Unstructured**			
Agent Behavior:			FM		SFM		FM		SFM	
Population:			500	1000	500	1000	500	1000	500	1000
The Number of Detecting CDS	Step 0	L	0	0	223	320	0	0	488	165
		M	499	998	3	13	213	376	8	9
		H	1	2	270	660	287	624	0	812
	Step 10	L	33	50	263	260	0	0	81	104
		M	466	948	1	11	204	344	1	5
		H	1	2	209	687	296	656	396	835
	Step 20	L	299	324	304	259	1	2	104	849
		M	199	672	5	17	176	274	1	45
		H	2	4	141	634	323	724	336	1

in the end the routes combined into one large route, the agents had freer space. Since the agents experienced a narrow route where they were very close to each other, the alert system flagged most of them with mid-risk and high-risk status.

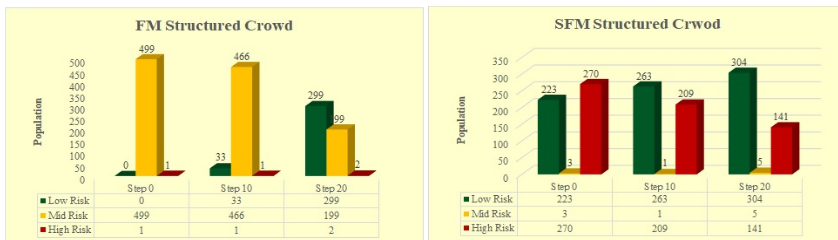
Eventually, the routes merged, which meant the two crowds crossed each other; the alert system detected that the number of CDSs of high-risk status had increased for the population 1000*2 for the combination of the two crowds at certain times periods. Regarding the SFM behavior for the merging routes, because of an undetermined bouncing of movement caused by the force of impacts, this led the alert system to detect the number of CDS agents when they walked in the right direction, did not face agents moving in the opposite direction, and maintained their speed; the system flagged them as low-risk. By contrast, the system flagged agents as high-risk when they walked in the wrong direction, did not maintain agent speed, and faced agents moving in the opposite direction. Hence, there was increasing instability in the numbers of detected CDSs among all statuses at the different steps. Below is a graph explaining the relationship between the scenarios regards to the different steps **??** and **??**.

4.6 THE SYSTEM OVERVIEW

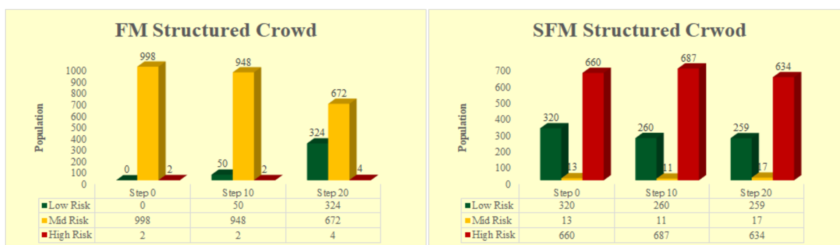
Our contribution for crowd control will provide the authorities with individuals' locations statuses that determine the CDSs using fuzzy logic; we implemented an alert system by checking

TABLE 4.3: The approaches of counting the number of CDSs in different simulation types and different scenarios. This illustrates the level of alert for each step 0, step 10, and step 20 as low-risk, mid-risk, and high-risk (L, M, H). The first three rows represent the scenarios, the agent behavior, and the agent population, respectively.

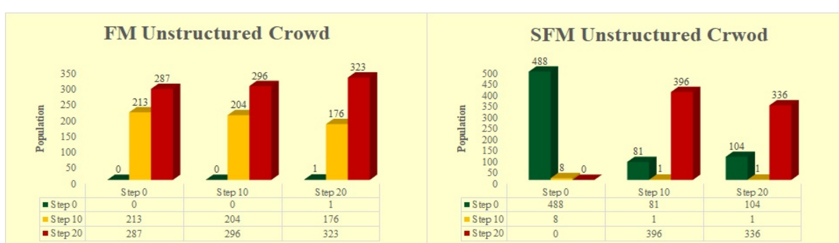
Scenarios:			**Merging**			
Agent Behavior:			FM		SFM	
Population:			500*2	1000*2	500*2	1000*2
The Number of Detecting CDS	Step 0	L	41	21	394	512
		M	715	1534	115	110
		H	74	240	431	443
	Step 10	L	42	22	410	691
		M	712	1522	104	360
		H	68	245	427	1
	Step 20	L	37	15	372	497
		M	710	1510	112	103
		H	66	254	457	441



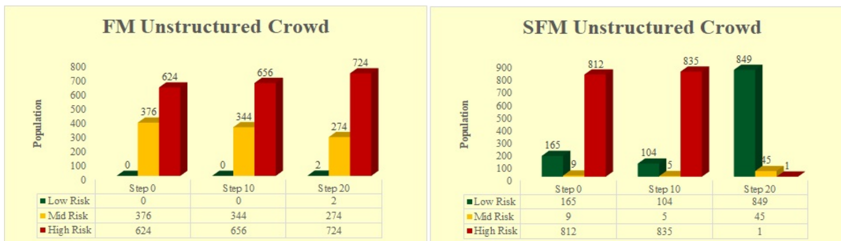
(a) An illustration of variation in steps between the FM and SFM for structured crowd with population of 500 individuals



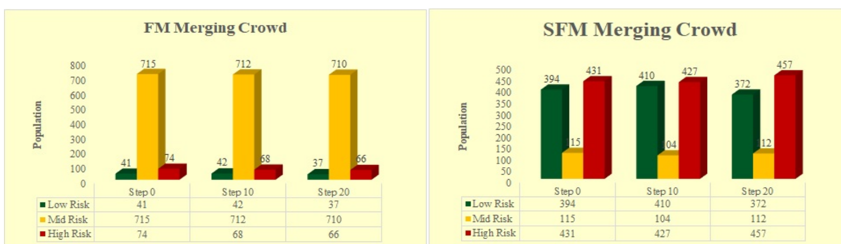
(b) An illustration of variation in steps between the FM and SFM for structured crowd with population of 1000 individuals



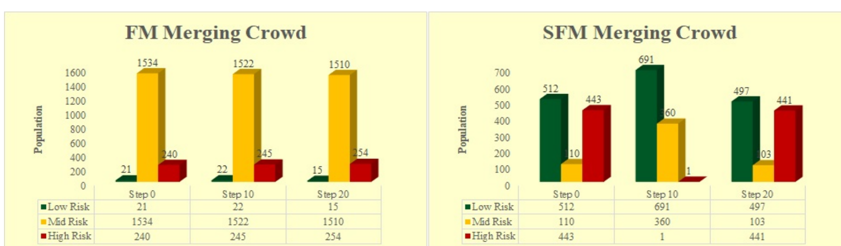
(c) An illustration of variation in steps between the FM and SFM for Unstructured crowd with population of 500 individuals



(d) An illustration of variation in steps between the FM and SFM for Unstructured crowd with population of 1000 individuals



(e) An illustration of variation in steps between the FM and SFM for Merging route with population of 500 individuals



(f) An illustration of variation in steps between the FM and SFM for Merging route with population of 1000 individuals the individual's direction, speed, and counting individuals moving in the opposite direction to detect the CDSs. We believe testing different crowd behaviors, such as by the FM and SFM with some scenarios with structured and unstructured crowds and merging routes can lead us to explore variations of crowd behavior. Our alert system extracted the individual's dataset as time, X coordinate, Y coordinate, and individuals IDs as inputs for dataset analysis, where the individual's direction, speed, and the counting of individuals moving in the opposite direction were all calculated.

CHAPTER 5

MORE IMPLEMENTATION WITH DIFFERENT SCENARIOS

Here we present the results from more scenarios testing the alert system by detecting the individuals' status during the crowd movement with the agents' behavior defined with the SFM. We are testing the alert system the new results are shown in Table 5.1. The individuals' cone of vision has been set at a 90 degree arc.

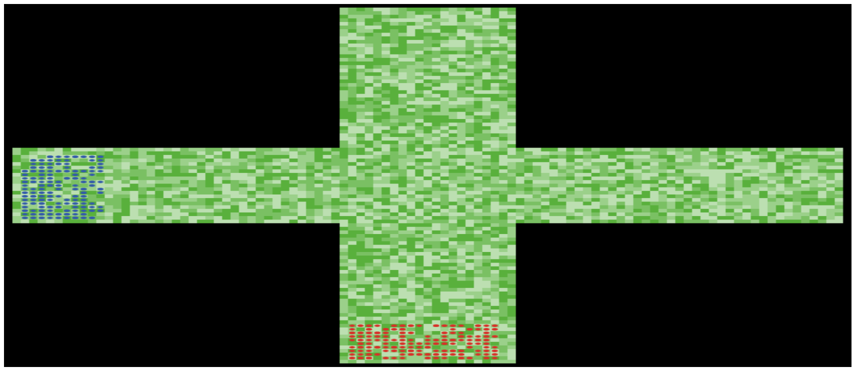
The first new scenario is an intersection where individuals with a perpendicular heading meet at an intersection with one group heading from the North to South and the other one heading from West to East as shown in Figure 5.1(a). The agent behavior was based on the SFM. The green color defines the main routes for pedestrians and block color is off the route and agents allowed in that area. We collected data from three phases of the the intersection scenario: Before reaching the intersection, Inside the intersection, and After the intersection.

The intersection experiment helps us to understand the dynamic flow of crowds and the fuzzy logic system's ability to detect the level of risk for each individual. The results shown in table 5.2 count the number of individuals in each status for the three measured stages: Before, Inside, and After. The Figures 5.1(b), 5.1(c), 5.1(d) show the status of the individuals.

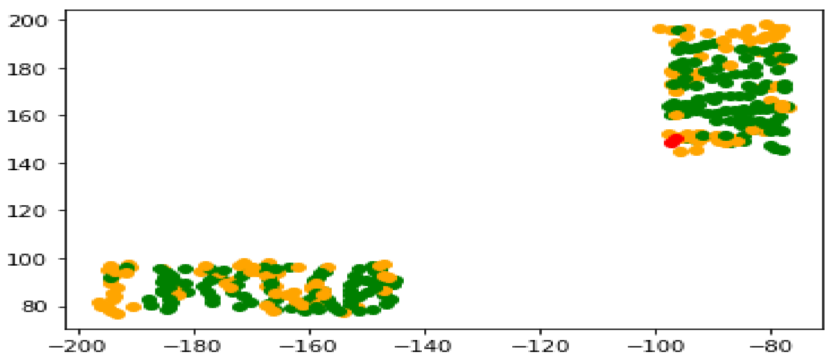
The merging route has been designed to model a real route were two group of people heading from the west side toward the east side and merging at some point in the middle as shown in figures 5.1(e). We want to understand how this kind of behavior may provoke the alert system. The results have been collected at two stages: before merging and after merging. Figure 5.1(f) shows the results before the two groups merge. It shows that alert system has detected a number of individuals with medium and high risk levels. Interestingly, after merging they formed a smooth moving group and the alert system spotted few medium or high risk individuals (figure

TABLE 5.1: The fuzzy values for the fuzzy logic system.

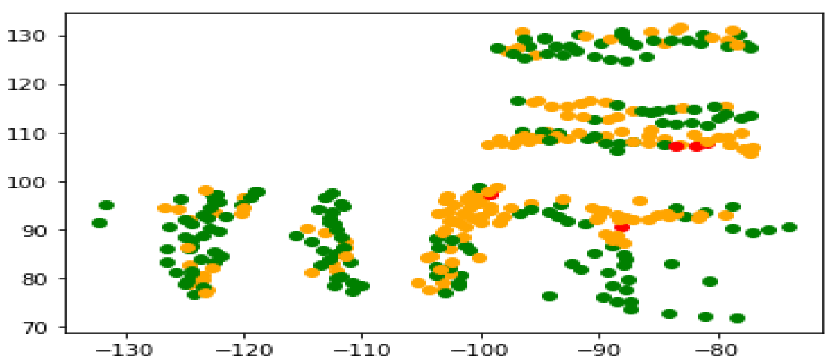
The Fuzzy Logic Variables	**Membership Functions**
The Individual speed	Low-Risk, Mid-Risk, High-Risk
The number of opposite people	Low-Risk, Mid-Risk, High-Risk



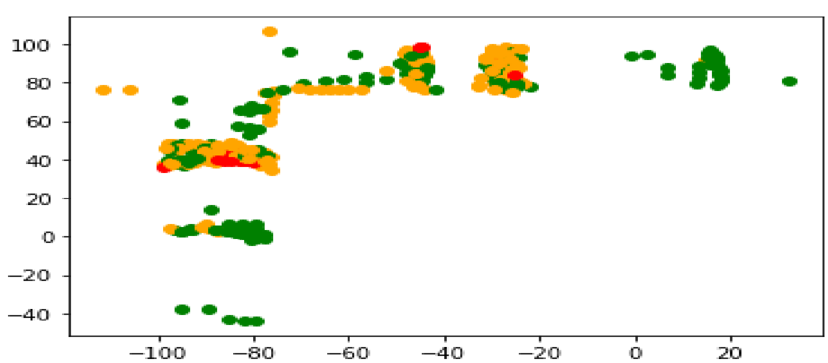
(a) The Intersection scenario from NetLogo machine.



(b) The individuals in the intersection scenario at the Before stage.



(c) The individuals in the Intersection scenario at the Inside stage.



(d) The individuals in the Intersection scenario at the After stage.

TABLE 5.2: The results for the intersection scenario. The number of medium and high risk individuals increases in the intersection, and interestingly, remains high even after the pedestrians have passed through the intersection. Suggesting that the intersection has a lasting disruptive affect on the pedestrian flow.

The Intersection Stages/Individual's Status	**Low-Risk**	**Mid-Risk**	**High-Risk**
Before	199	130	2
Inside	173	153	5
After	160	148	23

TABLE 5.3: The results for the merging scenario. Interestingly, there are more mid and high risk individuals before the marge than after it. We hypothesize that this is because the route become much wider after the merge.

Merging Stages/Individual's Status	**Low-Risk**	**Mid-Risk**	**High-Risk**
Before	51	223	56
After	218	112	0

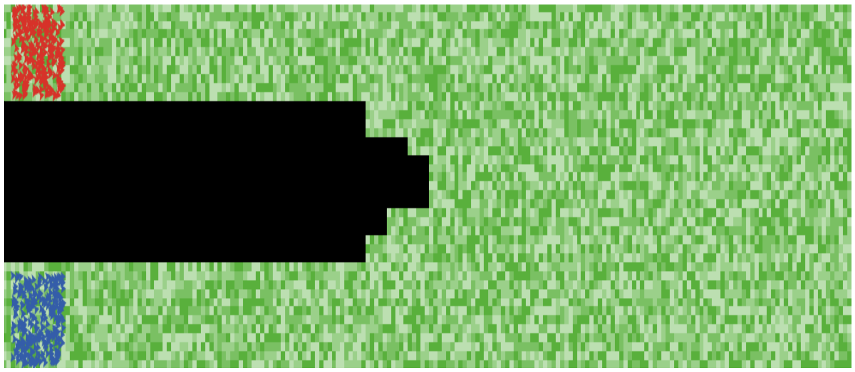
TABLE 5.4: Results for the Unstructured1 scenario. The most mid and high risk cases occur, as expected, when the two groups meet.

The Unstructured1 Stages/Individual's Status	**Low-Risk**	**Mid-Risk**	**High-Risk**
Before interfering	138	193	0
Inside interfering	95	148	88
After interfering	203	95	33

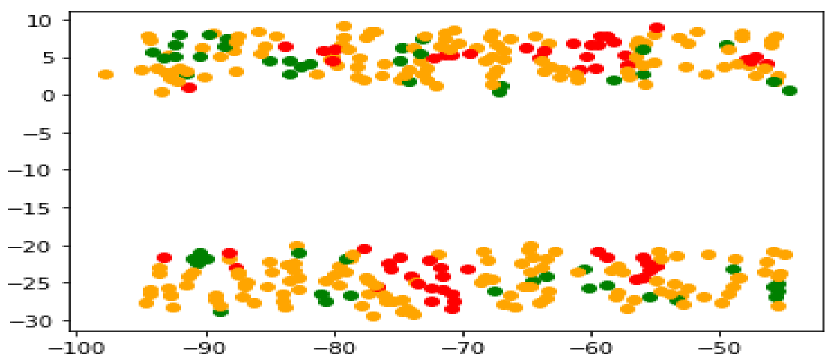
5.1(g)). Table 5.3 presents the number of individuals in the low, medium, and high risk groups before and after merging.

Next we tested two unstructured scenarios. The first scenario, referred to as Unstructured1, had two groups of people starting on opposite sides of a space, they then each walk across the space, with destinations on the opposite side of the space; essentially trading places. The two crowds were measured at three points: Before any group interference, then when they met, referred to as Inside, and finally After they passed each other. The results are shown in 5.4. The alert system detected the most individuals in the high risk category during the Inside stage, whereas the Before and After stages showed fewer high and mid risk individuals, showing that the alert system does detect the potential for collisions and disruptions when the two groups meet. The three stages are illustrated in figures 5.1(h), 5.1(i), 5.1(j), and 5.1(k).

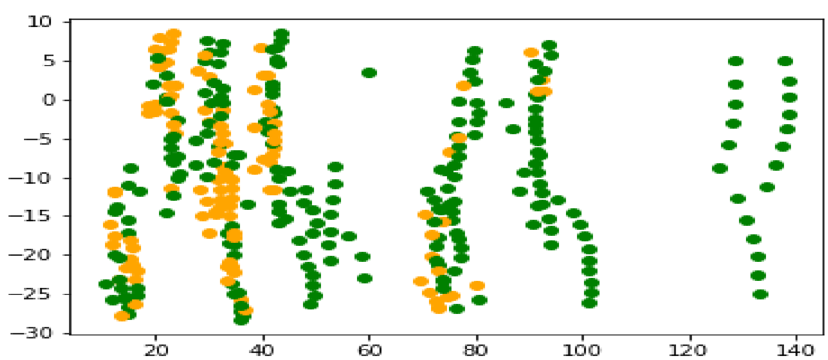
In the second unstructured crowd motion, called Unstructured2, pedestrians move around without shared directions. Each pedestrian has a randomly chosen goal point to move to, when a goal is reached a new randomly chosen goal point is chosen. This scenario is illustrated in Figure 5.1(l). This kind of behavior very roughly approximates movement in a shopping center,



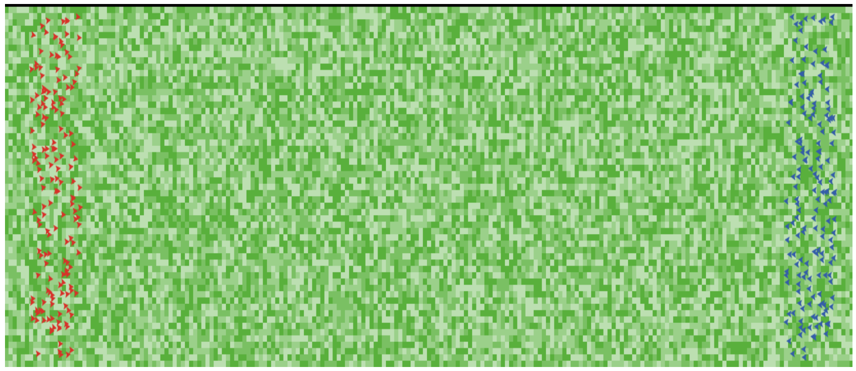
(e) Illustration of the merging scenario.



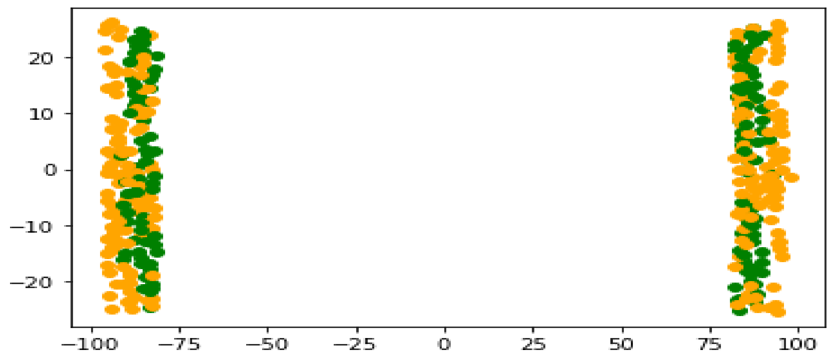
(f) The results from the merging scenario, before merging.



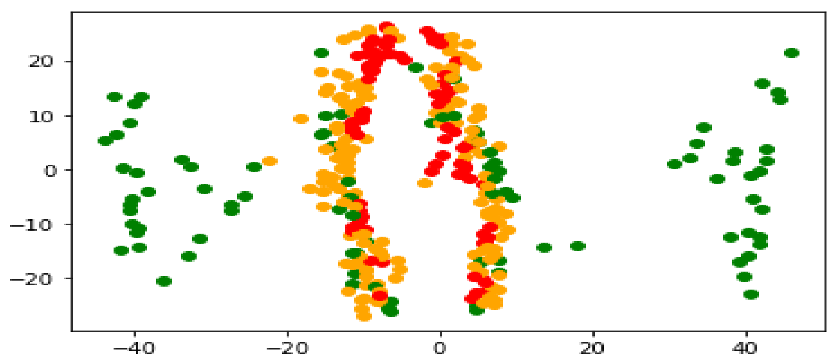
(g) The results from the merging scenario, after merging.



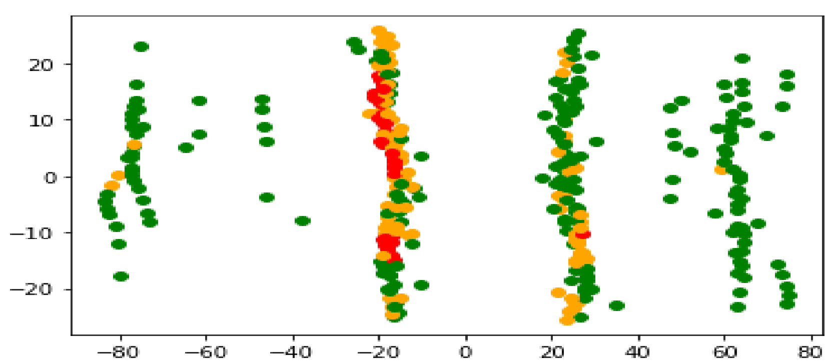
(h) The Unstructured1 scenario.



(i) The Unstructured1 scenario at the Before interference stage.



(j) The Unstructured1 scenario at the Inside interference stage.



(k) The Unstructured1 scenario at the After interference stage.

TABLE 5.5: The results for the Unstructured2 scenario. There are very few mid or high risk cases, which we hypothesize is because individuals' movement is rarely directly opposed and there is little coherent motion, making it easier for individuals to move around each other.

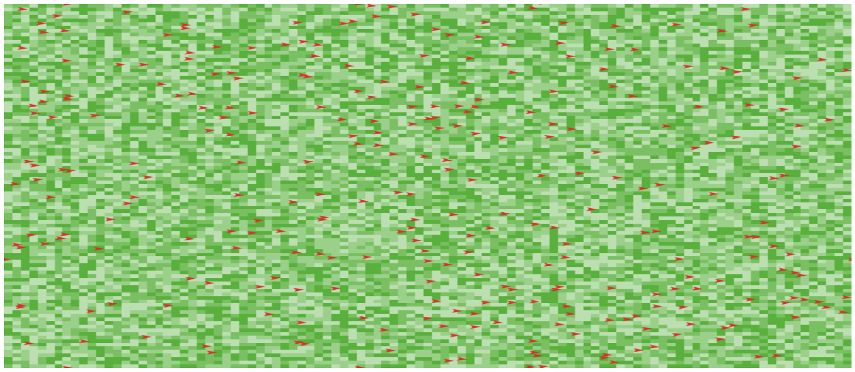
The Unstructured2 Step/Individual's Status	Low-Risk	Mid-Risk	High-Risk
Step 1	324	7	0
Step 5	331	0	0
Step 10	329	2	0

downtown, or fair, where people move from goal to goal. Data was collected after 1, 5, and 10 steps, shown in figures 5.1(m), 5.1(n), and 5.1(o). The results show that there is not that much change the number of mid and high risk individuals in Unstructured2 due to the movement of agent behavior, which rarely directly face one another. The count of individuals is shown in 5.5.

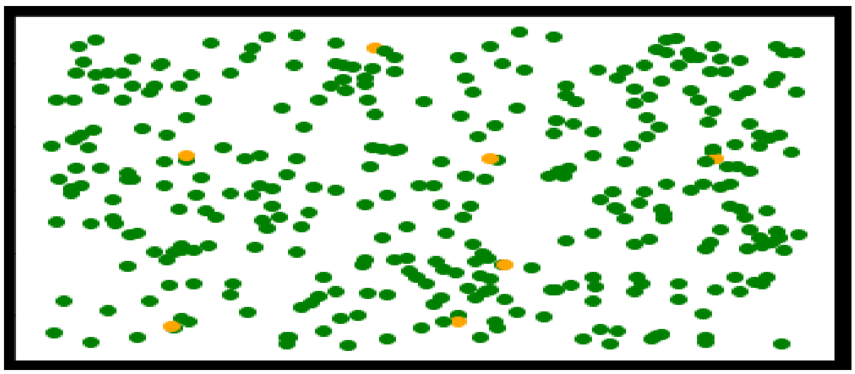
The last scenario simulated was Waypoint 5.1(p). In this scenario pedestrians generally move from a common starting area (left side) to a common goal area (right side), but they may randomly chose to divert to one or more of three waypoints along the edge of the space. These waypoints simulate facilities, photo points, or other points that pedestrians may chose to move to. The data was collected after five and ten steps to seek times when there was more interactions between agents. The alert system clearly detected the convergence of individuals at the Waypoint, illustrated in figures 5.1(q), and 5.1(r); 5.6 presents the Waypoint results for detecting CDS status.

5.1 SUMMARY

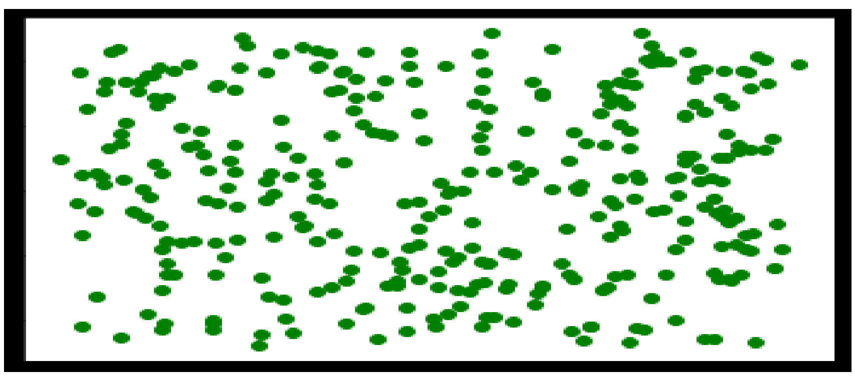
Different scenarios were applied in order to detect the CDS, captured at various times, by using the alert system based on the Fuzzy Logic algorithm; this approach provoked the system's abilities to detect the individual's speed and the number of individuals who moved in the opposite direction. Because historically most lethal incidents have occurred during the movement of structured crowds Table 2.2 going in the same direction, we emphasized structured crowd scenarios. The contribution of our research is to provide the authorities with the location status



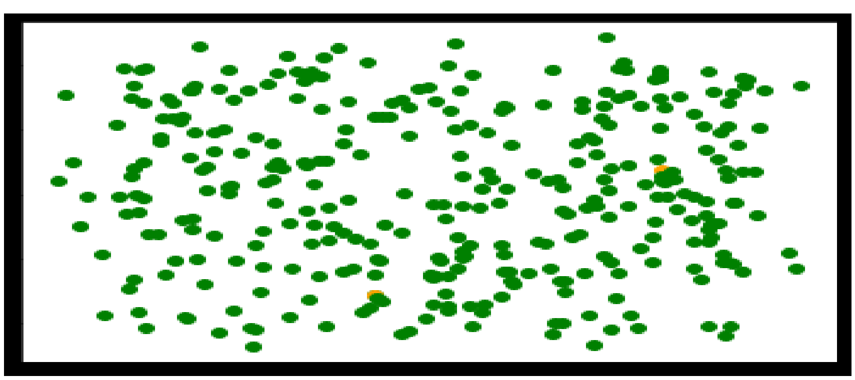
(l) The Unstructured2 scenario.



(m) The Unstructured2 scenario after 1 step.



(n) The Unstructured2 scenario after 5 steps.

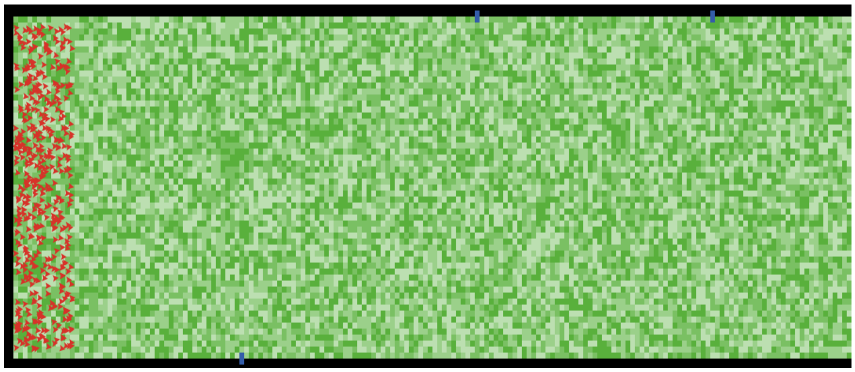


(o) The Unstructured2 scenario after 10 steps.

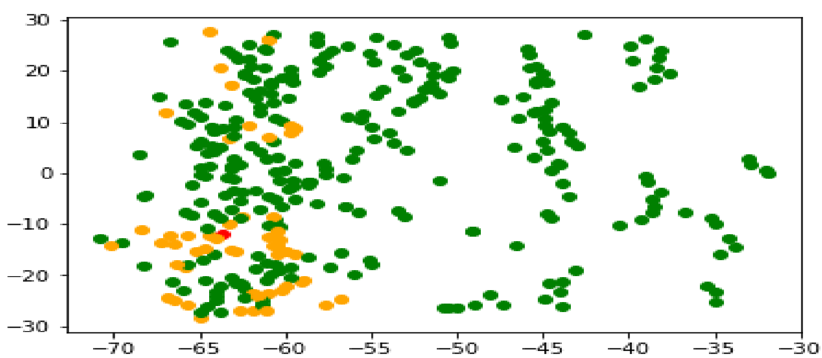
TABLE 5.6: Results for the Waypoint scenario.

The Way-points Steps/Individual's Status	**Low-Risk**	**Mid-Risk**	**High-Risk**
Step 5	286	43	1
Step 10	224	59	47

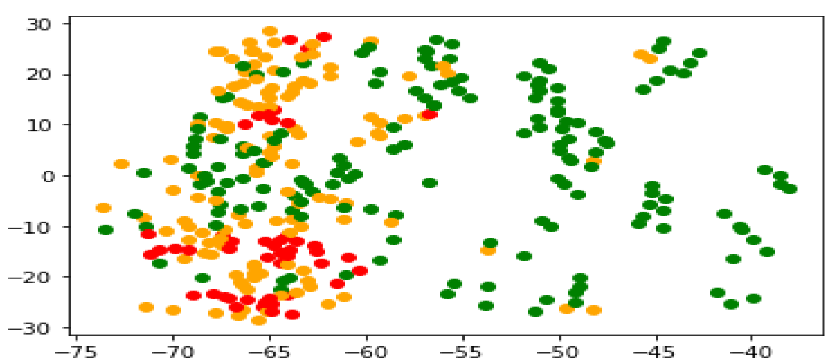
of every individual in these environments in order to improve crowd safety and reduce the manpower and effort required when intervention is needed in different situations.



(p) The Waypoint scenario.



(q) The waypoint scenario at step 5.



(r) THe waypoint scenario at step 10.

CHAPTER 6

CONCLUSION AND FUTURE WORKS

6.1 CONCLUSION

The main objective for conducting this research was to develop a system that can be used to inform authorities about high risk areas - Critical Density spots (CDS) - in a crowd. To achieve this objective, four research objectives were addressed.

First, we demonstrated that Fuzzy Logic can be used as a successful and suitable algorithm to identify the Critical Density spots (CDS) in a crowd, making it possible to inform authorities about these high risk areas. To demonstrate this, we studied a variety of crowd scenarios, focusing on the structured and unstructured crowd motions. We implemented agent behavior using both a social forces model (SFM) and a flocking model (FM). Our results show that the Fuzzy Logic allows for the presence of ambiguous human judgments in computer problems. Our results show that using computing methods based on Fuzzy Logic decision systems can improve the performance of our systems for identification of high risk areas in crowds.

Next, we identified several useful features for determining individuals' status with the Fuzzy Logic algorithm, the critical features were average speed, direction, and number of oppositely directed individuals. We showed that this approach improves the identification of CDS for both structured and unstructured crowds. Focusing on the individual's behavior led us to use SFM and FM for the agent simulations. We wanted to understand crowd movement by analyzing each individual's status from their speed, direction, and what they faced from their point of view (i.e. what was within their cone of vision). Our results showed that the speed factor for the Fuzzy Logic system was important because fluctuations in an individual's movement can cause a delay of momentum in the overall crowd motion.

Our results show that the other two important features for the Fuzzy Logic system are an individual's direction of motion relative to their desired destination and the direction they are facing. Monitoring the direction of individuals allows the system to focus on the zone each individual pays the most attention to, their cone of vision, which is normally in front of the individual. This is important to the CDS detection system because it is specifically interruptions in this zone by another individual or an obstacle can lead to unstable crowd movement. It is vital to keep this one factor for Fuzzy Logic input to avoid repeating what happened in Saudi Arabia in 2015 at the Hajj Islamic practice when two crowds collided and caused deadly results for the pilgrims Ganjeh and Einollahi (2016). The last input factor our research identified as being useful to detect CDS is the number of opposite directed individuals, i.e. individuals who might cause collisions. Counting the umber of oppositely directed individuals within a specific distance was critical in ascertain an individual's risk status. Using these inputs for the alert system, which used a Fuzzy Logic algorithm to make decisions, was very effective at indicating CDS with both structured and unstructured crowds.

Lastly, our results show that the Fuzzy Logic features used in the alert system improved the detection system across a variety of scenarios. Because these features successfully activated the alert system. That is the alert system spotted individuals with particular verifiable levels of risky status that, in a real world situation, could be used to inform of the authorities of the risky areas.

6.2 FUTURE FOR CROWD CONTROL RESEARCH

We have contributed to the ever-important and growing field of crowd control by developing an alert system that can reliably give the authorities information regarding at-risk individuals in dense crowds. Our purpose has been to help save lives and protect property. Based on the Fuzzy Logic algorithm, our system monitored individuals' speed, their direction, and the number of opposite directed individuals, and used these features to assign risk categories to pedestrians in the crowd. Using crowd movement scenarios from both structured and unstructured crowds and agent behavior simulated with both FM and SFM, we tested various scenarios each of which are important in practical crowd control situations to demonstrate the effectiveness of the proposed system.

Future work for improving the alert system should include modeling group behaviors, e.g. families, and how groups might affect crowd motion. For example, if a family group member became detached from the group, it might cause a disruption of crowd motion, which should trigger a warning in the system. Possibly groups of individuals could be treated as single individuals and kept under watch in order to prevent unintended consequences if the group began to separate.

Another factor that should be explored in future research is other data sources, such as monitoring of individuals' heart rates in crowds. Once a structured crowd begins dangerous movement, a fluctuation in heart rate could be an indication of trouble and be used to help alert the system to potential disruption. Comparing heart rates with individuals' speed might also allow the monitoring of individual's health status to alert a medical response if there is a problem. Medical issues with one member of a crowd can trigger larger and dangerous disruptions. Consideration of additional factors that contribute to the effectiveness of the alert system is valuable and may improve the detection of situations of unwanted risk thereby leading to better crowd control.

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