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Modelling and Simulation of Crowd Evacuation with Cognitive Behaviour using Fuzzy Logic

Wahida Zakaria[1], Umi Kalsom Yusof[1], and Syibrah Naim[1]

[1]School of Computer Science, Universiti Sains Malaysia
e-mail: wahidazakaria@yahoo.com, umiyusof@usm.my, syibrah@usm.my

Abstract

Emotions are the common properties involved during emergencies. Various emotions are observed during emergency such as panic, fear, sad and anxiety which will lead to the behaviour and trajectories during the evacuation. Even there are many studies of computational simulation model which focus on crowd behavioural, yet there are still gaps of real evacuation due to the scarcity of real data and mostly assumption is made on the simulated model. In this paper, investigation on how the key emotions turn into behaviour are studied from the real emergency video. The key emotions extracted are panic and confuse which is observed from the real emergency video. These emotions are then map to psychological theories adopt from Lazarus Theory of emotions and stress. Due to the uncertainties in human behaviour, fuzzy approach is chosen to map linguistic value to speed (numerical) which will then lead to behavioural results. The simulation results show that the inclusion of emotions via fuzzy rules has resulted 63.14% accuracy compare to non-fuzzy 56.01% to real emergency trajectories data.

***Keywords**: Crowd Behaviour, Emotions, Emergencies Evacuation*

1 Introduction

Gathering trend in current society in celebrating event has become a universal phenomenon. Crowd gathering consists of peoples from small to large scales [1]. In a big event, a tiny misconception can easily get many people to be out of control [2]. Emergency often creates emotions such as panic and stress in the crowd. As stated in the study of General Adaptation Syndrome (GAS) by [3], the transition of human emotional state from normal to panic is due to the life-threatening event which is out of the individual control. Crowds easily losses the irrational behaviours in emergency evacuation when emotions such as anger, anxiety spirals and develop to high level [4],[5]. Due to this reason, understanding the key emotions involved and behavioural actions during the evacuation is critical to minimize loss in tragedies that have grown rapidly.

In recent years, there have been many studies attempt to investigate and improve crowd emergency evacuations [6],[7]. The crowd safety in public assembly places can be improved with the understanding of human and social behaviours during emergencies [5],[8]. Past studies of emergency evacuation have revealed that there are three crowd behavioural factors that can influence evacuation results namely psychological, environment and perception factors [9],[10],[11]. Psychology is the study of the individual which tend to get a general understanding of society, stress, trends in mental illness, human behaviour and problems. Meanwhile, sociology study the culture and pattern of social relationship and the interaction. Each of these perspective is important on the society.

At a high level view, crowd behaviours are governed by human emotions (psychology) and the surrounding environment (sociology). Psychology and sociology studies go hand in hand, however in our study we will focus more on human psychological factors without neglecting sociology factors such as environment and other that are able to influence human mind during emergency evacuation process.

The understanding of human behaviours in the perspective of psychology is utmost crucial which is being ignored by most of the existing models [12],[13],[14]. Most of these models are based on assumptions on reality observation which are expected to be useful in analyzing the parameters [15]. Those models also make assumptions on the capability of the evacuation facilities and design. According to [16], these observations can be either from real life or experiments. Experiments observations result may give different result especially during emergency evacuation. Both type of the observation is classified as qualitative.

Anderson [17] in his research mentioned that there is a wide research conducted in the field of pedestrian involving many community, however there is no linkage on the studies between these sub-communities in producing a consistent theory. They focus on different set of issue but mostly is leading towards understanding human complex behaviour, crowd safety, facilities design and to give some insight before emergency evacuation [7]. Existing models have been trying to incorporate realistic pedestrian behaviour into the model by learning mechanism such as from the researcher observation [16] or virtual reality [18]. However, due to scarcity of the real behaviour data, many computational tools for the emergency simulation rely on assumptions that is inconsistent and unrealistic [5]. The growing need for a realistic crowd simulation has been described by Smith et al. [19] in his study which focused on the design of large venues such as stadium and concert halls [6].

Therefore, this has explain the need of incorporating a realistic human behaviour involving psychological and perceptions of human into the evacuation models in imitating the real behaviour of human as it is crucial [20].

This paper aims to investigate the impact of emotions towards the behaviour and trajectories of crowd during emergency evacuation to be as close as real evacuation video via fuzzy logic to handle uncertainty and Boids Theory [21] for steering and obstacles avoidance using simulation in continuous space. The behaviour of the crowd is translated based on psychological factors consider from previous work [22] which is adopted from Lazarus emotions and stress theory [23] with two key emotions from real video are extracted and input as fuzzy parameters.

In addition, it is natural that under emergency conditions, individual reactions towards stressor is unpredictable. In such scenarios of uncertainty, emotions play big role in how would the crowd behave. According to [24], the emotions evolvement can affect the movements of each individual in the crowd. Hence, this work intend to investigate how would emotions trigger based on distance from stressor in the fuzzy model that would impact on walk, wait, fast walk and run behaviour during emergency evacuation in order to better understand the crowd behaviour during emergency scenarios.

2 Related Work

Past studies of crowd emergency evacuation involved aircraft evacuation [9] consider stress and a multi-agent framework of human and social behaviours [5] [25],[26] with emergent behaviour of the crowd such as queuing, herding and following and arc shape at bottleneck. Meanwhile, Soumya [27] in her study of emotional ant based has considers emotions of crowd such as anger, selfish minded, sad and confused. In behaviour based real time evacuation [14], he used mixed geometrical model with ant colony algorithm to describe biological behaviours of crowd during evacuation. All the study is related to the realistic crowd behaviour that potentially lead to emergency evacuation.

The most common approach used in past studies of crowd modelling and simulation are agent-based model. This approach has become popular in crowd simulation and computer graphics application such as gaming due to its graphics and high visualization and its capability to build in with identity as a whole or individual depending on crowd modelling chosen.

Prior to the construction of a computational simulation framework, understanding the emergence and nature of crowd behaviours in emergency situations is crucial [5]. There are three different level of complexity in crowd behaviours that we need to understand which are individual (microscopic), group (macroscopic) or interaction among individuals and group (mesoscopic). Most of the studies on crowd modelling during an emergency event assumed simplistic of crowd behaviour during emergency evacuation [10]. This is meant by focusing the crowd simulation as whole (group) and limiting individual influence towards evacuation such as in studies of [28].

The trend of adopting realistic behaviours in the existing studies through features such as collision avoidance, following, herding and queuing are meant to imitate reality evacuation behaviours [29],[30],[31]. However, during emergencies, the crowd will behave according to the level of stress and emotions that they encountered. There are also models which tried to simulate realistic emergency scenario by comparing side by side with the real emergency video on what is perceived through the questionnaires [29],[30],[31]. Another recent study which still compared qualitatively to the real video pattern with the simulated one has been conducted using Wundt’s 3d emotion model for the real emotion evolution [43]. Reviewing this method, one can conclude that this method is much depending on the user perception to judge it as real or unreal. In general, crowd evacuation are conducted in two ways, one is through control experiment which is perceived as real and another is by simulation of the model.

The trend of considering reality aspects into the crowd evacuation have grown widely. This can be seen in studies which perceived realistic aspect of crowd such as in [16],[35], artificial intelligent approaches such as [9],[11],[27],[35], crowd abnormal behaviours detection [33],[34],[35] and modelling crowd with the consideration of human reasoning [36].

Current models have considered realistic aspect of the crowd behaviours by fusing the observed human behaviours into their models for simulations [29],[35]. Fuzzy logic has been applied in previous study such as [9] to model human behaviours in the aircraft and [11], which is to overcome the behaviours uncertainty under a stressful situation. These models have produced pattern in the evacuation behaviours such as herding, competitive and queuing by mapping the stress and panic level the individual possessed.

Another work by [11], has explored on the emotions, personality and the perception impact on the crowd behaviour. However, the link between the emotions changes towards the sudden changes in the environment are not elaborated. The future aim of this study is to apply a qualitative method by comparing the simulation work to CCTV video to produce more realistic behaviours in the crowd simulation.

Hence, there are two main contribution identified in this work. Firstly, a crowd emergency model with the integration of individual cognitive behaviour based on psychology theory of Lazarus [37] is proposed. This is due to the importance of integration of human reasoning in the perspective of psychology which has been discussed earlier. Secondly, the proposed fuzzy model combines various techniques such as agent ahead detection within certain radius and fuzzy logic on psychological behaviours considering distance from the stressor. The fairly complex system is modelled with the consideration of the three input aspects namely panic, confuse and the distance from the stressor.

3 The Proposed Evacuation Model Integrate with Key Emotions Learn from Real Emergency

The proposed model was aim to obtain a human-like evacuation model which adopt key emotions as observed from real video into our approach. Without neglecting the most important attribute during emergency which is stress, Lazarus theory [37] of cognitive and appraisal in stressful situation are chosen to be included in the proposed model. The stage that being focus in this model is emotion-focused coping. Fig.1 show Transactional Model of Emotions, Stress and Coping by Lazarus [37] map to the proposed model.

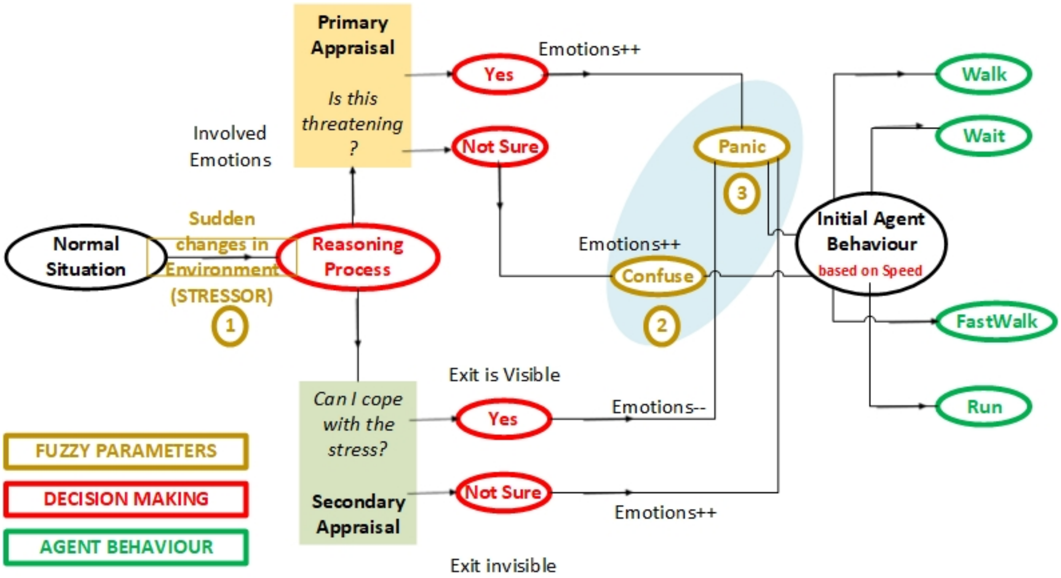


Fig.1 The Proposed Transactional Model of Emotions, Stress and Coping (Adopted from [37])

Comparing our model to Lazarus as in Fig.1, our model is in agreement with Lazarus' theory of stress [37], where primary and secondary appraisal stage is being consider not only at the initial point but throughout the simulation process.

(1) In the Primary Appraisal stage, individual evaluation of the situation whether the situation is threatening has match to our proposed Fuzzy model by assessing the distance of stressor from the individual which will trigger a rise in panic emotion if it is dangerous situation. If the situation is unsure, it will lead to confuse emotion in fuzzy rules.

(2) In the Secondary Appraisal stage, individual evaluation of coping with the stress is being reassessed to make the situation less stress and more acceptable by changing goals (emotion-focused coping) which in our model it is the consideration of the nearest exit selection. This has also match to our model, where if exit is still far, panic will increase tremendously and if within the certain set radius to the exit, panic will gradually decreased.

The detail framework of this study can be found in the work by [22] which elaborate the extraction of key emotions from real emergency video. Our study extends the framework by giving comparison and simulation results on the proposed model.

3.1 Integration of Fuzzy Rules

Fuzzy Rules is proposed in this model to handle uncertainty in human behaviour which is difficult to measure with exact calculation, thus we have proposed fuzzy logic in predicting crowd behaviour during evacuation. Fuzzy Logic is initiated by Lotfi A.Zadeh [38] to handle uncertainties and different view of individual which is in form of linguistic values and quantitative description of a complex system rather than numerical values. Due to this, analyzing human behaviours using linguistic information (words) is preferred over the quantitative values.

The incorporation of fuzzy logic in computer models has shown promising results where intuition, emotions and judgment play an important role. From the history, fuzzy logic is successful in process of human reasoning, perception, decision making and in very complex models where understanding is judgmental. For this reasons, the proposed model incorporate human reasoning and environmental changes via fuzzy rules to simulate behaviour of crowd during evacuation. Zadeh [38] has proposed the idea of decision-making and uncertainty by suggesting the set of membership which is the key to decision making.

Fuzzy sets have a mathematical way of representation in a humanistic system. Fuzzy sets consists of a universe of discourse and a membership function that maps every element in the universe of discourse to a membership value between 0 and 1. The Membership function in our work is to represent distance, panic and confuse level of an agent in the fuzzy set. The membership function *qA(i) (Xi)* is the measure of how much the crisp input *Xi* belongs to a fuzzy set *A(k).*

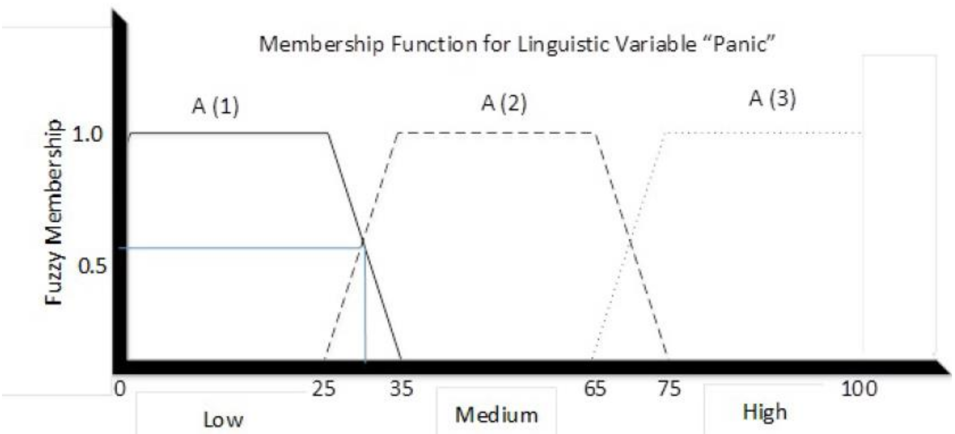


Fig.2 Membership function variation of Panic as Low, Medium and High

For example, the typical membership functions for a linguistic variable panic are given in Fig.2. The input *Xi* = 30 belongs to a membership degree *qA(1) (Xi)* = 0.5, to the fuzzy set *A(1).* Linguistic variable panic can be characterized as having 0.5 memberships in the fuzzy set "low", "medium" and "high" as shown in Fig.2. The membership functions shaped for our variable is trapezoidal. The proposed model uses input parameter ranges between 0 to 100 to represent the intensity of each variable. Examples of fuzzy rules used in one of the variables as follows:

IF Distance = VeryNear AND Panic = Low THEN Speed = FastWalk
IF Distance = Near AND Panic = Low THEN Speed = Walk
IF Distance = Far AND Panic = Low THEN Speed = Wait

The aggregation of the three input namely panic, confuse and distance will produce an output namely stress. Mamdani's model [39] with centroid defuzzification is applied in determining the stress level which eventually converted to an individual speed as the output. The proposed model has applied a maximum aggregation method to calculate for the speed outcome which is defined in Equation 1.

$$Maximum\ (x') = max\ \{\mu\_{A}\ (x), \mu\_{B}\ (x)\} \quad (1)$$

The details of fuzzy model can be found in [22]. The total stress value computed, is assigned to an agent as an initial speed value. The fuzzy rules proposed are used to explain under emergency evacuation mode, mixture of emotions can lead to behavioural actions of the agents such as wait, walk, fastwalk or even run. These four behaviours are studied in the proposed model.

3.2 Modelling Crowd from Real Emergency Data

Within this paper, the evacuation case in Dam Square, Amsterdam on 4th of May 2010 is analyzed and compared to previous work by [3]. In this real video, the gathering of large crowd was in placed for the national remembrance of the dead people. Within two minutes of the silence period, out of sudden a person start shouting and followed by a loud "BANG" due to fence collapse and the panic has spread very fast.

Observing the above panic video, information on emotions is extracted. We can see there are 2 types of behaviour in the emergency evacuation which is wait or minor action. This emotion is assume as confuse. Another types of behaviour is run very fast due to panic. The emotion panic is define as P while Confuse as C. Based on these observation, the 2 key emotions is consider to be part of reaction when stressor is imposed. The key emotions is control by the distance of the person to the affected point which we define the stressor as S.

3.3 Model Scene and Target

In this work, we consider analyzing the trajectories of crowd during evacuation to be as real as the evacuation video. A rectangular screen of size 600 X 800 is chosen based on the real evacuation video data. 35 individual are being traced by [3] in his study of crowd evacuation in Dam Square which the gathering event turn to chaos. The There are 20,000 peoples in the gathering and the plot of tracked individual are taken from different densities to represent the whole crowd.

In this predefined setup, all agent move to the desired direction according to the principles governed by the well known Boids Theory [21]. Furthermore, we assume the moving space and moving time in this predefined setup to be continuous. All agent initial position are set to be the same as the real video data position which the position and trajectories are represented by a series of vectors:

Definition 3.1 *Agent*

$$\text{Agent} = A_1, A_2, \ldots A_n$$

Definition 3.2 *Agent position*

$$\text{Position} = (X_1,Y_1,t_1), (X_2,Y_2,t_2), \ldots (X_n,Y_n,t_n)$$

where $\mathbf{A_i = (X_i, Y_i, t_i)}$ represents the position (X_i,Y_i) of the *i-th* point of trajectory at time, t_i, and n represents the total number of point belonging to the trajectory.

When the simulation started, agent flee within 50 radius which is equal to 10metres of those near to stressor. It is natural, under emergency people will react to run away from the stressor without much thinking and only later on the assessment will begin. The same scenario is set in our proposed model which is the vision assessment will come on later and the agent will assess on the shortest exit or known exit. Due to the uncertainty of human behaviour, fuzzy logic approach is chosen to map the emotions and distance to stress value which will eventually converted to initial movement (speed) of the agents.

When simulation started, the speed of the agent are based on Boid's Theory [21], where the forces imposed in steering every step taken towards the exit. The forces are adopt from Boid's Theory [21] by Craig Reynold which uses steering forces. In our work, we have adopted three forces from his theory which is flee forces, the most threatening obstacle avoidance and agent movement towards target.

Each Agent will have below values assigned:

- mass - scalar
- position - vector
- velocity - vector
- max_force - scalar

- max_speed - scalar

Adoption of Craig Reynold Boid's Theory [21] for agent movement is as in Equation 2,3,4 and 5.

$$steering\_force = truncate\ (steering\_direction, max\_force) \tag{2}$$

$$acceleration = steering\_force\ /\ mass \tag{3}$$

$$velocity = truncate\ (velocity + acceleration, max\_speed) \tag{4}$$

$$position = position + velocity \tag{5}$$

Combination of all the forces discuss above will produce one steering force for each of the agent.

$$\sum Steering\_Forces = \sum Ahead + \sum Seek\ Force + \sum Avoidance\ Force \tag{6}$$

In our simulation, we have compare emotions simulation on non-fuzzy and fuzzy model. The accuracy of each model trajectories compared to real video are calculated. The next section explained the simulation results in detailed.

4 Simulation Results

Validation of the model is done by comparing the trajectories accuracy during the evacuation in the simulation with the real emergency video data. The simulation position results of each agent at each time step are compared using Euclidean Distance formula as in Equation 7 to get the differences of value compared to the original evacuation data.

Euclidean Distance of Real Data to Simulation Data.

$$\sum_{agent=A} \sum_{timepoint=t} = \sqrt{\frac{(x(a,t,sim) - x(a,t,data))^2 + (y(a,t,sim) - y(a,t,data))^2}{numberofA * numberoftimepoints}} \tag{7}$$

The average error per time step for all agent is calculated and resulting for the accuracy percentage of 35 agents which will be showed in further discussion.

Firstly, the comparison is made on non-fuzzy model without emotion and non-fuzzy nodel with different combination of emotions at the initial point to get the best trajectories accuracy. Then we compare the best non-fuzzy model with our proposed fuzzy model, and previous models which one of it is with mirroring emotions using neuroscience with discrete navigation [3] and another model of Social Force by Helbing's [25]. The comparison is made upon 35 agents position which were track for 49 time steps. As for the fuzzy model, all the agent has the value of panic, confuse, speed and target. But as for non-fuzzy with emotion, the initial speed is based on proportionate of panic and confuse value with the same target as fuzzy. Table 1 show accuracy of each model.

Table 1: Comparison of Model Average Error

Model	**Average Error in Meter (Accuracy %)**
Fuzzy	0.3686 (63.1%)
T.bosse [2]	0.5416 (45.4%)
Helbing [20]	0.5854 (41.5%)
The Best Non-Fuzzy	0.4399 (56.0%)

4.1 Simulation Results on Non-Fuzzy Model With and Without Emotions

In this subsection, we perform simulations on non-fuzzy model with and without emotions to find for the best possible trajectories of the agent compare to the real video and to study the behaviour outcomes of agents viz. wait, walk, fast walk and running behaviour. In these experiments, the agent initial speed are proportionate based on the combination of emotion and assumption of panic will increase the velocity and confuse will slow down the velocity. The initial speed and maximum speed are as set as in Table 2.

Table 2: Specification of Non-Fuzzy Model with and without Emotions

Panic	Confuse	Initial Speed	Max Speed	Accuracy (%)
0	100	0.1	1	56.0
25	75	0.285	1	51.9
50	50	0.3333	1	42.8

75	25	0.5888	1	43.1
100	0	0.679	1	41.5
NA	NA	Random	1	53.4

In these experiments, the behaviour of the agents will keep on changing depending on the stress level which the stress values are then converted to speed. Based on Thayer's Emotions Model [40], energy is equivalent to stress level which means that, at a lower stress level, the energy encounter is also at the lower level and vice versa. This aids us to better study the link of trajectories for each agent with the behavioural changes under emergency evacuation and subsequently how this emotions affects the crowd during the evacuation. The best accuracy on these models is the combination of 0% panic and 100% confuse which is at 43.99% average error per meter. In these models, emotions is consider unchanged throughout the simulation.

Referring to Table 2, the accuracy of Non-Fuzzy without emotion model has also been compared. The result has shown that Non-Fuzzy model with emotions has better accuracy than without the emotions even though the combination may not be correct. From this study, we can understand that, emotions somehow have impact towards the crowd trajectories and evacuation. However, to get to the best value of emotions combination with stressor distance, fuzzy logic model is proposed to handle the uncertainty and to eliminate unnecessary effect.

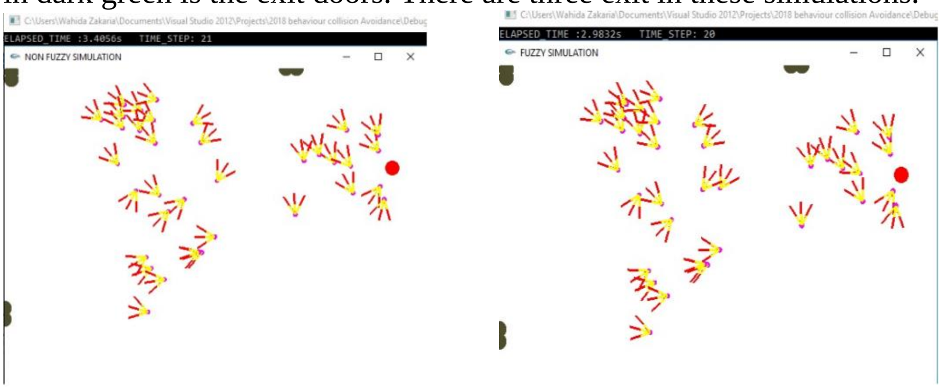
4.2 Simulation Results Comparison on the Best Non-Fuzzy Model with Fuzzy Model

The non-fuzzy model in this simulation has the same flow of fuzzy model except for emotions influenced. The agents position in proposed fuzzy model have the same starting point but may differ to the last time steps as in below screenshot:

(a) A Non-Fuzzy Model (b) Fuzzy Model

Fig.3. Time Step = 1 Comparison for Non-Fuzzy and Fuzzy Model

The red circle is the stressor where the crowd fleeing from and the two big dot in dark green is the exit doors. There are three exit in these simulations.



(a) A Non-Fuzzy Model (b) Fuzzy Model

Fig.4. Time Step = 20 Comparison for Non-Fuzzy and Fuzzy Model

(a) A Non-Fuzzy Model (b) Fuzzy Model

Fig.5. Time Step = 49 Comparison for Non-Fuzzy and Fuzzy Model

In Fig.4 and Fig.5 scene, the lines for each agent represent visibility area. During initial state, non-fuzzy model has shown 53% of the agent are at the position of waiting and 46% of them are just start to walk. Meanwhile, fuzzy model has shown that 22% of the agents already started to run and 61% are still fast walking during the initial time of evacuation. In the middle of the simulation, non-fuzzy model still shown most of the agent still fast walking and in fuzzy model has shown increasing agent are panic and running. Towards the end of the simulation, there are still fast walking behaviour seen on non-fuzzy model and as for fuzzy model most of the agents are panic and in running state.

In the last time step of simulation as in Fig.5, different pattern of crowd behaviour are circles to show fuzzy model behave more natural during emergency as influence is possible in this model. As for non-fuzzy model, throughout the simulation, influence by other agent cannot be traced clearly event the initial value set for all agent are the same and coming from fuzzy value. Fuzzy model has shown some influence of emotions in the neighbouring agent and the exit visibility of each agent thus changing the direction of the original 3 agents to the opposite direction. The difference of fuzzy and non-fuzzy model are explained in detail as shown in Table 3

Table 3: Behaviour Comparison at 6 Selected Time Step on Fuzzy and Non-Fuzzy Model

Time Step	**Run Behaviour**		**Fast Walk Behaviour**		**Walk Behaviour**		**Wait Behaviour**	
	Fuzzy	*Non-Fuzzy*	*Fuzzy*	*Non-Fuzzy*	*Fuzzy*	*Non-Fuzzy*	*Fuzzy*	*Non-Fuzzy*
T1	6	0	22	0	8	17	0	19
T10	3	0	26	34	7	1	0	0
T20	14	8	22	26	0	1	0	0
T30	33	29	2	5	0	1	0	0
T40	33	32	2	1	0	2	0	0
T50	33	30	1	4	1	1	0	0

In the fuzzy model, we can conclude that during emergency, they will be continuous rising of panic emotions until situation is settle down. Meanwhile, confuse emotion is reflected mostly in waiting behaviour followed by walking behaviour. This is also seen on the agent which change heading direction.

6 Conclusion

In conclusion, the proposed model have shown the need of human-like integration into the crowd evacuation simulation to mimic real evacuation scenario. The framework set can be easily used by the management and safety authorities of any temporary set up event to test on the evacuation process in case of emergency arise. The parameters of each agent and the setup such as the area size can be easily changed to show the behaviour of the agents towards the exit. The study has shown the need of fuzzy logic integration into the model in imitating human behaviour during real evacuation. In future work, consideration of optimization in the current proposed fuzzy model to obtained lesser average rate and better accuracy.

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