Modeling of Neurotic Personality Trait of Pedestrians in Panic Situation

Mufrah Naveed Sarwar, Syed Waqar Jaffry
mufrah.naveed@pucit.edu.pk, swjaffry@pucit.edu.pk
Artificial Intelligence and Multidisciplinary (AIM) Research Lab
Punjab University College of Information and Technology (PUCIT), University of the Punjab (PU), Lahore, Pakistan

***Abstract*—Pedestrian crowd simulation is an emerging field of study that simulates large number of pedestrian movement in different environmental conditions. In literature, several macroscopic and microscopic models are proposed to simulate pedestrian movement. However, for realistic pedestrian motion, the most widely used and highly cited microscopic model is the Social Force Model (SFM). This model has capability to simulate pedestrian motion in both normal and panic conditions. In literature, it is observed that the incorporation of personality traits in pedestrian models for crowd simulations is almost nonexistent. Whereas, it is believed that pedestrians' personality is a very crucial factor hence it should be modeled to simulate pedestrian's movement realistically. Personality computing is a vast domain, hence in the current study, one of the most relevant personality attribute of the Big Five personality traits known as 'neuroticism' is incorporated in SFM. Exhaustive simulations of several experiments are performed and the results are reported. It is found that if personality trait of pedestrian's neurotic-ness within a crowd is diverse among each other than the evacuation behavior become complex and chaotic. On contrary, if crowd's neurotic diversity is less and crowd is more homogeneous than smooth patterns in the crowd evacuation time are observed. In literature, best evacuation time for SFM is reported for global panic value 0.4 but on incorporating pedestrian's neurotic-ness and performing exhaustive experiments with both homogeneous and heterogeneous crowds, best evacuation time is obtained on global panic value 0.3. This value indicates that on adoption of personality attribute in SFM, relatively more individualistic behavior provides better evacuation time than of herding behavior when compared with SFM.**

Keywords—panic modeling; evacuation; pedestrian motion; social force model; crowd simulation; personality; neuroticism

I. Introduction

The phenomena in which movement of a large number of entities or characters in a particular environment is simulated, is known as crowd simulation [1]. In particular situations such as concerts and sport events, where human pedestrians form a group is called pedestrian crowd. Such crowds can be programed in computer to study their behavior in various situations which is known as pedestrians' crowd simulation.

A. Why pedestrian crowd simulation?

To observe human interactions among each other and their collective behavior in different situations, crowd simulation could be performed. In literature, it has been used for simulating evacuation phenomena in concerts, sport events or passenger's dynamics at transportation centers. Similar techniques are also being used in films, video games and 3D computer graphics.

B. Pedestrian crowd simulation in different situations

Moving entities or pedestrian in crowd exhibit locomotive behavior due to that they try to reach at their desired destination by moving from one place to another by avoiding static and dynamic obstacles on the path. In literature, pedestrian crowd has been modeled and simulated primarily for normal and panic situations.

In normal situation, pedestrians walk with their desired velocity that is most comfortable walking speed. They usually keep a certain distance from each other, walls and obstacles. On the other hand, in panic situation velocity of pedestrians may vary and distance get smaller as pedestrians are in hurry. This may lead to tragic situation as this collective behavior often leads to injuries and deaths [2].

C. Social Force Model

Social force model is a most widely used microscopic model to simulate realistic motion of pedestrian in normal as well as panic situations. It is capable of handling low and high-density crowds. In literature, it has been extended for different scenarios to make more realistic and faithful representation of human behavior. For example in [3] an attempt has been made to model the pedestrian behavior to investigate the mechanism of panic and stress in crowd.

Several simulation based experiments has been conducted, assuming physical and socio-psychological forces that describe the pressure build up in crowd due to panic situation [3]. We have reproduced some of those experiments reported in [3] and [4]. Fig. 1 shows simulation state of pedestrians evacuating from a room in a normal situation while Fig. 2 and Fig. 3 show simulation state of pedestrians evacuating from a room in panic situation.

To illustrate normal situation, Fig. 1 represent a scenario in which 200 pedestrians are trying to evacuate from a room that has a static obstacle (round shape column) in front of exit door. On the left side, information has given about simulation time (**t**) in second, **N** shows the number of pedestrians within room, **N_Injured** shows how many pedestrians are injured due to pushing forces from other pedestrians, **V0** indicate desired velocity for all pedestrians and **FWall_x** shows the wall friction toward pedestrians.

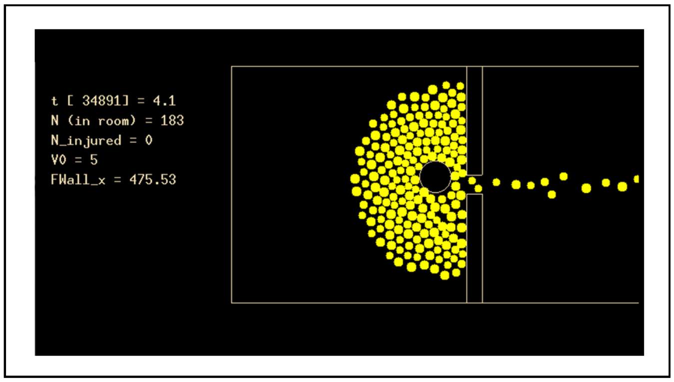

Fig. 1. Social Force Model simulation, pedestrian (200), round shaped obstacle before exit (normal situation)

Moreover, Fig. 2 represent panic situation, in which 90 pedestrians are trying to evacuate from a room where fire (vertical dotted line) start propagating from left side and move toward the exit door. Pedestrians become static and injured as fire touches them. This state of simulation indicates that out of 90 pedestrians, 28 are successfully evacuated, 17 are injured due to fire and 51 are trying to evacuate. Legends on left side, represents similar information as in Fig. 1 except it also indicate count of injured pedestrians as well.

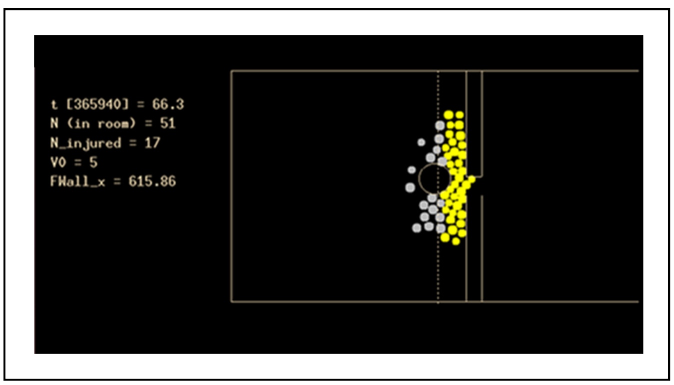

Fig. 2. Social Force Model simulation, pedestrian count 90, round shaped obstacle, panic situation (fire in the room)

a) Global Panic Variable

Fig. 3 represent panic situation, in which 90 pedestrians are trying to evacuate from a smoky room that has two exit doors one on left and other on right side. To control overall panic of all pedestrians, a global panic variable was introduced in existing work [3]. The global panic variable indicates level of panic for all pedestrians. Each pedestrian tries to update his/her desired direction '$\boldsymbol{e_i^o}$' either by choosing individualistic behavior or with herding behavior. Here individualistic behavior expressed as pedestrian i follow his preferred direction '$\boldsymbol{e_i}$' to move forward and herding behavior expressed as pedestrian i choose average direction of his neighbors '$\langle \boldsymbol{e_j^o(t)} \rangle_i$' within a certain radius of i. Panic value dictates which term will contribute more in the final direction of pedestrian i. Direction of a pedestrian i at a certain time point t is expressed in (1):

$$e_i^o(t) = Norm\left[(1-p_i)e_i + p_i\langle e_j^o(t)\rangle_i\right] \tag{1}$$

The panic parameter 'p' resides in the ranges [0.0, 0.8]. Low value of the panic parameter shows less panic and high value shows high panic in the environment. In [3] best evacuation time is reported against panic value 0.4.

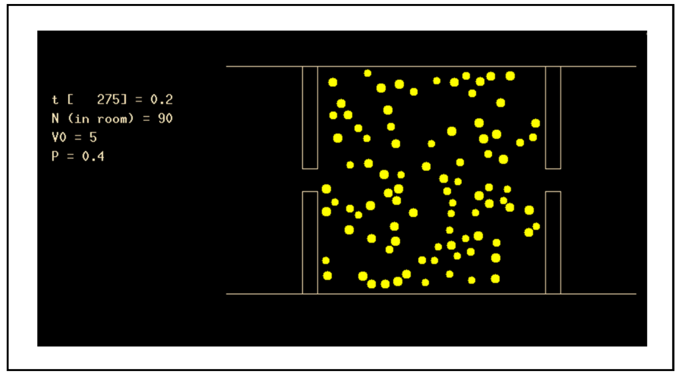

Fig. 3. Social Force Model simulation, pedestrian count 90, smooky room with two exit doors, panic situation (smooky room)

Primary acceleration equation of social force model presented in [3] describes change in the velocity of pedestrian i at time t is given as follows

$$m_i \frac{dv_i}{dt} = m_i \frac{v_i^0(t)e_i^0(t) - v_i(t)}{\tau_i} + \sum_{j(\neq i)} f_{ij} + \sum_{W} f_{iW} \tag{2}$$

here m_i is mass of pedestrian i, $v_i(t)$ is actual velocity of pedestrian i at time t, $v_i^0(t)$ is desired velocity of pedestrian i at time t, $e_i^0(t)$ is desired direction of pedestrian i at time t, τ_i is relaxation time of pedestrian i, f_{ij} is interaction forces between pedestrian i and j, f_{iW} is interaction forces between pedestrian i obstacle W [3]. Equation (2) explains the movement of pedestrian i at certain direction e_i^0 with a desired speed v_i^0. But due to obstacles, pedestrian tends to adapt actual speed v_i with relaxation time τ_i. While moving towards a destination pedestrian tries to maintain a certain distance from obstacles W and other pedestrians j which are repulsive forces. There are also similar interaction forces denoted by f_{ij} & f_{iw} presented in [3].

II. Literature Review

Social Force Model is a highly cited microscopic model to simulate pedestrian movement in both normal and panic situations [3]. For panic situation, model was presented in year 2000. Since the year 2000 till 2017 thousands of research papers have cited this model. Researchers have either modified or extended it to make it more realistic or performed comparison with it or has used it to meet their desired objectives. This model was modified or extended by incorporating different humanistic and environmental factors. Researchers have extended this model in various directions by adding individualistic behavior by incorporating decision making [5], [6], [7], [8], [9], [10], [11], collision avoidance [12], [13], [14], [15], [16], [17], [18], [19], [20], [21] social and cognitive abilities such as altruism [22], emotion impact [23], waiting behavior [24], overtaking behavior [25], pedestrian crossing behavior [26], pedestrians trajectories correction and removing oscillations in position [27], removing pedestrians overlapping [28] etc. Researchers also extended this model by adding group behavior such as crowd turbulence [29], leaderships effects [30], group bonding forces [31] etc. They have modified it for normal situation by introducing self-stopping phenomena [32] and for panic situation by evacuating pedestrians from railway station [33], earthquake evacuation [34], closed room [35], [36], [37], [38], and station hall [39] etc.. After performing a comprehensive literature review, literature gap is identified that the incorporation of personality traits in pedestrians is almost nonexistent in the literature. Whereas, it is believed, that personality traits are very crucial factor in pedestrians' movement.

In order to make SFM more realistic, in current study a personality trait is incorporated in SFM in panic situation. Personality computing is a very vast subject, hence in current study, one of most relevant personality attribute of the Big Five personality traits 'neuroticism' is incorporated in SFM.

III. Methodology

Personality is a very basic aspect of an individual which differentiate him/her from other individuals. Pedestrians of various personalities constitute a heterogeneous crowd, which can help us to measure personality effects on evacuation behavior of pedestrians in panic situation.

A. Personality

Personality can be described as difference between individual characteristics such as patterns of feeling, behaving and thinking [40].

B. Personality Traits

Personality traits are among most significant factors which could capture and predict individual's latent characteristics and observable behaviors. The Big Five personality traits or Five factor model is the most celebrated set of personality trait model used in the literature [41]. This model represent human personality in five different dimensions which include Openness, Conscientiousness, Extraversion, Agreeableness and Neuroticism, alternatively called as OCEAN [42]. In these five dimensions Openness represent imaginative, openness to new ideas ability of the subject, Conscientiousness represents how much organized, efficient, reliable a subject is, Extraversion carries social and enthusiast behavior, Agreeableness represents honesty, trustworthiness, and altruism while Neuroticism captures sensitivity, anxiety, and depression of the subject. To overwhelm the complexity of the system after prospective incorporation of all five traits, in this study it decided to first incorporate the most relevant attribute 'neuroticism' in social force model in panic situation by the simplest possible modeling approach.

C. Neuroticism

Neuroticism expresses anger, anxiety, depression and emotional stability state. People with high neurotic value are emotionally unstable and with low neurotic value are emotionally stable [43]. It indicates that a more neurotic person will have more negative emotions and a less neurotic person will have less negative emotions. Such emotions increase individual level of depression and tension. Due to which it is hypothesized that a high neurotic pedestrian will have high panic value and less neurotic pedestrians will have low panic value in similar conditions. Therefore, a set of values [0, 0.5, 1] were defined to express 'neuroticism'. If a pedestrian has '0', '0.5' and '1' neuroticism, it indicates that s/he feels less, neutral and high depression and anxiety respectively.

D. Pedestrians Delta Panic

A variable DeltaPanic is introduced in SFM model having value 0.1. Purpose of this variable is to allow pedestrians to perceive global panic value as their local panic value based on their neuroticism.

E. Pedestrian Types

In SFM, pedestrians are of similar type (homogeneous). They have same velocity and same global panic value. To incorporate neuroticism in pedestrians, three types of pedestrians are considered namely low neurotic, neutral neurotic and high neurotic having values of neuroticism 0, 0.5 and 1 respectively. Each of these types will have their own local panic value based on their neuroticism and DeltaPanic variable.

1) Low Neurotic Pedestrian

These types of pedestrians will perceive less panic than of global panic value due to their low neurotic personality. For instance, if GlobalPanic is 0.5 than low neurotic pedestrian will feel panic 0.4. It can be expressed as

$$PedestrianPanic[i] = GlobalPanic - DeltaPanic$$
$$PedestrianPanic[i] = 0.5 - 0.1$$
$$PedestrianPanic[i] = 0.4$$

2) Neutral Neurotic Pedestrian

These types of pedestrians will perceive same panic as global panic due to their neutral neurotic personality. For instance, if GlobalPanic is 0.5 than neutral neurotic pedestrian will feel panic 0.5. It can be expressed as

$$PedestrianPanic[i] = GlobalPanic$$
$$PedestrianPanic[i] = 0.5$$

3) High Neurotic Pedestrian

These types of pedestrians will perceive high panic than of global panic due to their high neurotic personality. For instance, if GlobalPanic is 0.5 than high neurotic pedestrian will feel panic 0.6. It can be expressed as

$$PedestrianPanic[i] = GlobalPanic + DeltaPanic$$
$$PedestrianPanic[i] = 0.5 + 0.1$$
$$PedestrianPanic[i] = 0.6$$

A threshold for panic value is defined between the rang 0 and 0.8 as proposed in [3]. For instance, if GlobalPanic is 0 than low neurotic pedestrians will perceive it as 0. Because subtracting DeltaPanic (0.1) from GlobalPanic (0) will result in -0.1 which is not an appropriate panic value. Similarly, if GlobalPanic is 0.8 than high neurotic pedestrian will perceive it as 0.8. Because adding DeltaPanic (0.1) in GlobalPanic (0.8) will result in 0.9 which is not an appropriate panic value.

F. Crowd Combination

For experimental purposes, based on above types of pedestrians, two types of crowds could be generated namely homogenous crowd (having only one type of pedestrians) and heterogeneous crowd (more than one type of pedestrians).

1) Homogeneous Crowd

Homogeneous crowd has same types of pedestrians. For example, either all agents are low neurotic, neutral neurotic or high neurotic. For experimental purposes, homogenous crowds have only three possibilities. For instance, if all pedestrians are low neurotic than in configuration file it is represented as follows.

$$LowNeuroticPedestrian = 1.0$$
$$NuetralNeuroticPedestrian = 0.0$$
$$HighNeuroticPedestrian = 0.0$$

Here minimum and maximum range for all three types of pedestrians is from [0, 1]. Where 0.0 indicates that no pedestrian of particular type exists within crowd and 1.0 mean 100% pedestrians are of a particular type. In above example, $LowNeuroticPedestrian$ is 1 which indicates that all pedestrians in the crowd (100%) are low neurotic and zero percent pedestrians are neutral and high neurotic each.

2) Heterogeneous Crowd

Heterogeneous crowd will have more than one type of pedestrians at a time. For example, if we consider only two types in a crowd at a time, crowd can have combination of low and neutral neurotic pedestrians or neutral and high neurotic pedestrians or low and high neurotic pedestrians. As in heterogeneous crowd density of each population also matters, hence, variation in density of crowd is carefully performed with a factor of 10% which has generated a reasonable number of crowds for experimentation purposes.

For two types of pedestrians within crowd from a set of three possible pedestrian types and having a variation of 10% crowd at a time, total 27 crowds could be generated. For instance, one of such crowd can consist of total 90 pedestrians in which 18 are low neurotic (20% of 90) and 72 are high neurotic (80% of 90). In configuration file, it is represented as:

$$LowNeuroticPedestrian = 0.2$$
$$NuetralNeuroticPedestrian = 0.0$$
$$HighNeuroticPedestrian = 0.8$$

As it is heterogeneous crowd (two type of pedestrians) therefore, neutral neurotic pedestrians are zero in this crowd, only low neurotic and high neurotic pedestrians are present. Accordingly, 27 combination can be generated of such crowd.

IV. EXPERIMENTS

After incorporation of personality attribute 'neuroticism' in pedestrians there is need to perform extensive experiments to collect valuable findings. Experiment shown in Fig. 3 is selected for simulation purposes. As on initialization of each experiment, pedestrians are placed in the room randomly. Hence to deal with randomness total ten simulations are performed against each panic value and average evacuation time is obtained against these simulations for a specific panic value. Against 9 panic values total 90 simulations are performed (10 simulation for each panic value). Homogenous and heterogeneous crowd collectively made 30 combinations of crowd. Therefore, computed counts of total simulations performed against each combination of crowd either it is homogenous (one type of pedestrians) or heterogeneous (two types of pedestrians) is 2700. Details about the total simulations performed are presented in TABLE I.

TABLE I. SIMULATION COUNT FOR ALL PEDESTRIANS COMBINATION

Types of Pedestrians	**Simulation Count for All Pedestrians Combination**		
	Pedestrians Combination	***Simulation count***	***Total***
One type of pedestrians	3	90	270
Two type of pedestrians	27	90	2430
			2700

TABLE I. indicates that for total 30 combinations, 2700 simulations are performed. Evacuation time obtained against each panic value for all crowds is discussed in next section.

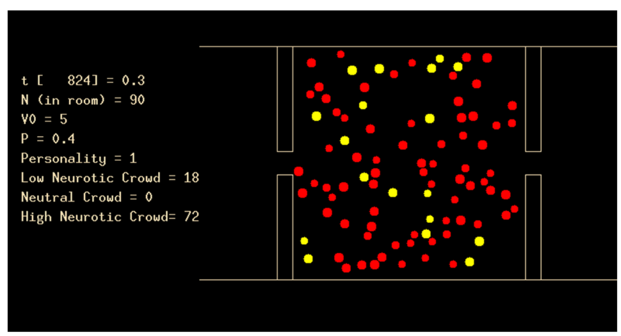

Fig. 4. Neuroticism incorporated pestrians count 90, 18 are low neurotic and 72 are high neurotic, evacuating from a smoky room with two invisible exits door (panic situation)

For better understanding, in Fig. 4, snapshot of initial configuration of heterogeneous crowd consisting of 20% low neurotic pedestrians (represented by yellow color) and 80% high neurotic pedestrians (represented by red color) is shown. Exhaustive simulations experiments are performed for homogenous crowd and heterogeneous crowd in panic situation and evacuation time for each crowd is recorded. Results of these experiments are presented in the following section

V. Results

For brevity, the result presented in this section are combined results for both homogenous (one type pedestrians) and heterogeneous (two type of pedestrians) crowds.

A. Crowd combinations providing minimum evacuation time for each panic value

In TABLE II. , minimum evacuation times against all panic values against all possible crowd combinations (homogenous and heterogeneous) are presented. Maximum simulation time for each simulation is set to 120 seconds. If any crowd simulation does not terminate (minimum 80 pedestrians evacuate) within 120 seconds, then the simulation is terminated automatically. As we can see that for panic value 0.8, all possible crowd combination does not evacuate within 120 seconds. Therefore, last row of TABLE II. have no crowd combination count and evacuation time. This indicates that all 30 crowd combinations will take more than 120 seconds to evacuate from room for panic value 0.8.

TABLE II. Crowd Combination providing minimum evacuation time for each panic value

Panic Value	**Crowd combinations with minimum evacuation time**			
	Low Neurotic Pedestrians	***Neutral Neurotic Pedestrians***	***High Neurotic Pedestrians***	***Minimum Evacuation Time (sec)***
0.0	0	0.2	0.8	43.81
0.1	0	0.4	0.6	41.06
0.2	0.4	0	0.6	39.94
0.3	0.9	0	0.1	38.51
0.4	0.2	0.8	0	38.54
0.5	0	1	0	41.69
0.6	0.5	0.5	0	50.28
0.7	0.8	0.2	0	77.86
0.8	-	-	-	> 120 sec

From TABLE II. it can be noticed that at panic value 0.3 minimum evacuation time is achieved for crowd combination consisting of 90% low neurotic pedestrians and 10% high neurotic pedestrians. Fig. 5 represent the curve obtain after drawing minimum evacuation time against each panic value. We can see that from panic 0.0 to 0.3 evacuation time decreases for crowd, but after panic 0.3 it continuously increases even at panic value 0.7, it has maximum evacuation time. So, we can say that as panic increases after panic 0.3, evacuation time for homogenous (one type of pedestrians) and heterogeneous (two type of pedestrians) crowd exponentially increases. Helbing et al. [3] has reported that best evacuation time was achieved on panic value 0.4 when same type of pedestrians evacuate from a smoky room having two invisible exit doors. Which indicate that 60% individualistic behavior and 40% herding behavior among pedestrians let them to escape in minimum evacuation time.

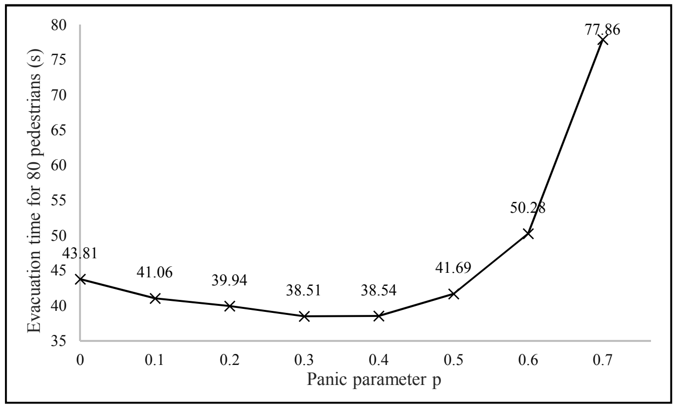

Fig. 5. Minimum evacuation time for each panic value provided by homogenous and heterogeneous crowd combinations

After incorporation of neuroticism in pedestrians we created homogenous as well as heterogeneous crowd. Our results indicate that best evacuation time can be achieved on panic value 0.3 when pedestrians having neurotic personality trait (90% low neurotic and 10% high neurotic). Such crowd combination can evacuate in best evacuation time by having 70% individualistic and 30% herd behavior.

B. Count of crowd combination providing minimum evacuation time against each panic

We have counted crowd combinations for both homogeneous and heterogeneous crowd that provide minimum evacuation time against each panic value. Result of this experiment is represented in Fig. 6, which shows that for panic value 0.0, no crowd combination provides minimum evacuation time. For panic value 0.1, only one crowd combination provides minimum evacuation time. For panic value 0.2, 4 crowd combinations provide minimum evacuation time. For panic value 0.3, 14 crowd combinations provide minimum evacuation time. For panic value 0.4, 10 crowd combinations provide minimum evacuation time. For panic value 0.5, 1 crowd combination provides minimum evacuation time. Accordingly, for panic value 0.6, 0.7 and 0.8 no crowd combination provides minimum evacuation time. Experiment result indicates that mixture of homogenous and heterogeneous crowd provides best evacuation time on panic value 0.3.

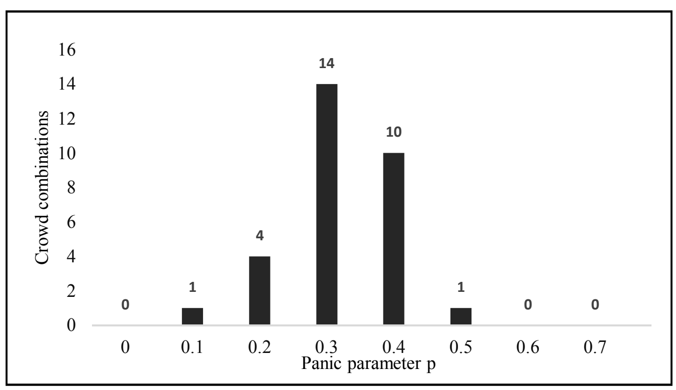

Fig. 6. Count of crowd combinations providing minimum evacuation time for each panic value

C. *Count of crowd combinations whose evacuation time lie in specific range*

Here count of all homogenous and heterogeneous crowds that produces various evacuation times for each panic value are presented. Evacuation time of these crowds lies in specific ranges. As the simulation time start from 0 second and end on 120 seconds (maximum simulation time), hence, if any crowd combination does not evacuate within 120 seconds its simulation is terminated and that crowd combination is added into the category 'above 120 seconds'. In Fig. 7, it could be seen that most of evacuation time generated by all the crowd combinations lies in range of 41 seconds to 50 seconds. The histogram presented in Fig. 7 is bimodal on ranges "41-50" and "above 120" which indicates that either most of the crowds evaluate within 41 to 50 seconds or they failed to evaluate in 120 seconds. This critical finding could help evaluation planners in different life threating crowd evacuation scenarios for better planning.

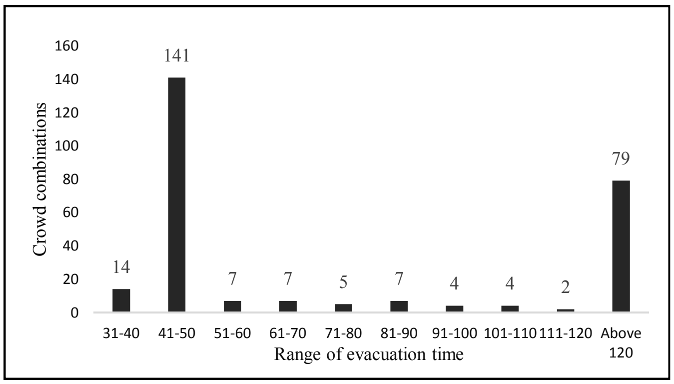

Fig. 7. Count of crowd combinations producing evacuation time that lie in specific range

VI. CONCLUSION

Pedestrian crowd simulation is a process of simulating movement of many entities or characters in environment. In literature pedestrian crowd, has been modeled and simulated primarily for normal and panic situations. In normal situation, pedestrians walk with their desire velocity that is most comfortable walking speed. Whereas in panic situation velocity of pedestrians may vary and distance get smaller as pedestrians are in hurry or their density get increased. Social Force Model (SFM) is a microscopic model which is widely used to simulate realistic motion of pedestrian in normal as well as panic situations. For panic situation, Helbing et al. reported best evacuation time on panic value 0.4. That indicates that if pedestrians have 60% individualistic behavior and 40% herd behavior while evacuating from a room in a panic situation, they will evacuate in less time. The SFM doesn't have provision to simulate personality based heterogeneity in crowd simulation.

Whereas conducting a comprehensive literature review, it is observed that incorporation of personality traits in pedestrians' models is nonexistent. On contrary, it is believed that personality is the representative of human individuality or heterogeneity. Therefore, in this study most relevant personality trait 'neuroticism' is incorporated in pedestrians' model. Through this homogenous crowd (comprises of one type of pedestrians) and heterogeneous (comprises of two type of pedestrians) crowds are formed.

After conducting extensive experiments on these crowds, three results are reported in detail. First result indicates that the crowd combination having 90% low and 10% high neurotic pedestrians exhibits minimum evacuation time on panic value 0.3. Second result indicates counts of crowd combination that provide minimum evacuation time against each panic value. It is observed that total 14 crowd combinations out of 30 provide best evacuation time on panic value 0.3. Third finding is about crowd combinations that provide evacuation time against each panic value. In this it is found that for panic situation (smoky room with two exists) most of crowds either evacuate in the time range of 41 to 50 seconds or does not evaluate at all (in maximum 120 seconds).

VII. FUTURE WORK

In this study, an extension of the SFM is presented by incorporating one of most relevant attribute of personality known as 'neuroticism'. After integrating neuroticism, three types of pedestrians are created namely low, neutral and high neurotic. A comprehensive set of experiments is performed on homogeneous (one type of pedestrians) and heterogeneous (two type of pedestrians) crowds. In future, it is planned to conduct experiments for heterogeneous crowd comprises of three or more types of pedestrians. Secondly, in this study 10 simulations against each panic value for each crowd combination is performed. In future, this simulation count could be increased to a higher number. Through this modification is expected to reduce stochastic effect from the simulation results. Finally, the proposed extension would be validated through benchmarks data sets.

ACKNOWLEDGMENT

Authors are grateful to Gabriele Bernardini for helping in understanding of social force model. They are also heartily thankful to Illés Farkas for his constructive and fruitful discussion in comprehension of social force model experiments. Finally, authors are thankful to Mian Muhammad Mubasher for his careful review of the manuscript and help in programming of proposed extension.

REFERENCES

[1] D. Thalmann, "Crowd Simulation," in Encyclopedia of Computer Graphics and Games, N. Lee, Ed. Springer International Publishing, 2016, pp. 1–8.

[2] I. J. F. D. Helbing, "Simulation of pedestrian crowds in normal and evacuation situations," vol. 21, pp. 21–58, 2002.

[3] D. Helbing, I. Farkas, and T. Vicsek, "Simulating dynamical features of escape panic," *Nature*, vol. 407, no. 6803, pp. 487–490, Sep. 2000.

[4] D. Helbing, I. Farkas, P. Molnàr, and T. Vicsek, "Simulation of pedestrian crowds in normal and evacuation situations," presented at the Pedestrian and Evacuation Dynamics, 2002, pp. 21–58.

[5] D. Sumpter, J. Buhl, D. Biro, and I. Couzin, "Information transfer in moving animal groups," Theory Biosci., vol. 127, no. 2, pp. 177–186, May 2008.

[6] Z. Zainuddin and M. Shuaib, "Incorporating Decision Making Capability into the Social Force Model in Unidirectional Flow," Res. J. Appl. Sci., vol. 5, no. 6, pp. 388–393, Jun. 2010.

[7] Z. Zainuddin and M. Shuaib, "Modification of the Decision-Making Capability in the Social Force Model for the Evacuation Process," *Transp. Theory Stat. Phys.*, vol. 39, no. 1, pp. 47–70, Jan. 2010.

[8] M. M. Shuaib, Z. Zainuddin, and I. M. Abu-Sulyman, "The Characteristics of the Factors That Govern the Preferred Force in the Social Force Model of Pedestrian Movement," *ArXiv10080140 Cs Math*, Jul. 2010.

[9] H. Xi, S. Lee, and Y.-J. Son, "An Integrated Pedestrian Behavior Model Based on Extended Decision Field Theory and Social Force Model," in *Human-in-the-Loop Simulations*, L. Rothrock and S. Narayanan, Eds. Springer London, 2011, pp. 69–95.

[10] Z. Zainuddin, K. Thinakaran, and M. Shuaib, *An Age Based Dynamic Respect Factor for Pedestrian Dynamics*. ASME Press, 2011.

[11] D. R. Parisi, D. Sornette, and D. Helbing, "Financial price dynamics and pedestrian counterflows: A comparison of statistical stylized facts," *Phys. Rev. E*, vol. 87, no. 1, p. 012804, Jan. 2013.

[12] M. Moussaïd, D. Helbing, S. Garnier, A. Johansson, M. Combe, and G. Theraulaz, "Experimental study of the behavioural mechanisms underlying self-organization in human crowds," *Proc. Biol. Sci.*, vol. 276, no. 1668, pp. 2755–2762, Aug. 2009.

[13] LI Shan-shan, L. I. Shan-shan, Q. Da-lin, and W. Jiu-zhou, "Improved social force model considering pedestrian deceleration to avoid collision," 吉林大学学报（医学版）, no. 03, pp. 623–628, 2011.

[14] F. Zanlungo, T. Ikeda, and T. Kanda, "Social force model with explicit collision prediction," *EPL*, vol. 93, no. 6, p. 68005, Mar. 2011.

[15] P. Saboia and S. Goldenstein, "Crowd simulation: applying mobile grids to the social force model," *Vis. Comput.*, vol. 28, no. 10, pp. 1039–1048, May 2012.

[16] Y. Gao, P. B. Luh, H. Zhang, and T. Chen, "A modified social force model considering relative velocity of pedestrians," in *2013 IEEE International Conference on Automation Science and Engineering (CASE)*, 2013, pp. 747–751.

[17] G. Köster, F. Treml, and M. Gödel, "Avoiding numerical pitfalls in social force models," Phys. Rev. E, vol. 87, no. 6, p. 063305, Jun. 2013.

[18] W. Qian-Ling, C. Yao, D. Hai-Rong, Z. Min, and N. Bin, "A new collision avoidance model for pedestrian dynamics*," Chin. Phys. B, vol. 24, no. 3, p. 038901, Mar. 2015.

[19] X. Zhang, X. Zhang, Y. Wang, and H. Yu, "Extended social force model-based mean shift for pedestrian tracking under obstacle avoidance," IET Comput. Vis., Sep. 2016.

[20] J. A. Kirkland and A. A. Maciejewski, "A simulation of attempts to influence crowd dynamics," in IEEE International Conference on Systems, Man and Cybernetics, 2003, 2003, vol. 5, pp. 4328–4333 vol.5.

[21] P. Ratsamee, Y. Mae, K. Ohara, T. Takubo, and T. Arai, "Modified Social Force Model with Face Pose for Human Collision Avoidance," in Proceedings of the Seventh Annual ACM/IEEE International Conference on Human-Robot Interaction, New York, NY, USA, 2012, pp. 215–216.

[22] A. Braun, S. R. Musse, L. P. L. de Oliveira, and B. E. J. Bodmann, "Modeling individual behaviors in crowd simulation," in 16th International Conference on Computer Animation and Social Agents, 2003, 2003, pp. 143–148.

[23] B. Liu, Z. Liu, and Y. Hong, "A Simulation Based on Emotions Model for Virtual Human Crowds," in Fifth International Conference on Image and Graphics, 2009. ICIG '09, 2009, pp. 836–840.

[24] F. Johansson, A. Peterson, and A. Tapani, "Waiting pedestrians in the social force model," Phys. Stat. Mech. Its Appl., vol. 419, pp. 95–107, Feb. 2015.

[25] J. K. K. Yuen and E. W. M. Lee, "The effect of overtaking behavior on unidirectional pedestrian flow," Saf. Sci., vol. 50, no. 8, pp. 1704–1714, Oct. 2012.

[26] 曲昭伟，曹宁博，陈永恒，白乔文，赵利英，康萌, Q. U. Zhao-wei, C. Yong-heng, B. a. I. Qiao-wen, Z. Li-ying, and K. Meng, "A Modified Social Force Model Considering Random Behavior Fluctuations," 交通运输系统工程与信息, vol. 16, no. 5, pp. 192–197, May 2016.

[27] B. Steffen, "A Modification of the Social Force Model by Foresight," ArXiv09120634 Phys., Dec. 2009.

[28] T. I. Lakoba, D. J. Kaup, and N. M. Finkelstein, "Modifications of the Helbing-Molnár-Farkas-Vicsek Social Force Model for Pedestrian Evolution," SIMULATION, vol. 81, no. 5, pp. 339–352, May 2005.

[29] W. Yu and A. Johansson, "Modeling Crowd Turbulence by Many-Particle Simulations," Phys. Rev. E, vol. 76, no. 4, Oct. 2007.

[30] L. Hou, J.-G. Liu, X. Pan, and B.-H. Wang, "A social force evacuation model with the leadership effect," Phys. Stat. Mech. Its Appl., vol. 400, pp. 93–99, Apr. 2014.

[31] S. Xu and H. B. L. Duh, "A Simulation of Bonding Effects and Their Impacts on Pedestrian Dynamics," IEEE Trans. Intell. Transp. Syst., vol. 11, no. 1, pp. 153–161, Mar. 2010.

[32] D. R. Parisi, M. Gilman, and H. Moldovan, "A modification of the Social Force Model can reproduce experimental data of pedestrian flows in normal conditions," Phys. Stat. Mech. Its Appl., vol. 388, no. 17, pp. 3600–3608, Sep. 2009.

[33] X. Yang, H. Dong, Q. Wang, Y. Chen, and X. Hu, "Guided crowd dynamics via modified social force model," *Phys. Stat. Mech. Its Appl.*, vol. 411, pp. 63–73, Oct. 2014.

[34] M. DM. DM., E. Quagliarini, G. Bernardini, and L. Spalazzi, "EPES – Earthquake pedestrians′ evacuation simulator: A tool for predicting earthquake pedestrians′ evacuation in urban outdoor scenarios" *Int. J. Disaster Risk Reduct.*, vol. 10, Part A, pp. 153–177, Aug. 2014.

[35] D. R. Parisi and C. O. Dorso, "Microscopic dynamics of pedestrian evacuation," *Phys. Stat. Mech. Its Appl.*, vol. 354, pp. 606–618, Aug. 2005.

[36] D. R. Parisi and C. O. Dorso, "Morphological and dynamical aspects of the room evacuation process," *Phys. Stat. Mech. Its Appl.*, vol. 385, no. 1, pp. 343–355, Nov. 2007.

[37] P. Ma and B. Wang, "The escape of pedestrians with view radius," *Phys. Stat. Mech. Its Appl.*, vol. 392, no. 1, pp. 215–220, Jan. 2013.

[38] Zhang Hailin, Jin Maojing, and Liu Hao, "A Modified Social Force Model under Different Psychological Conditions for Room Evacuation," *ICTIS 2013*.

[39] L. Wang, Q. Zhang, Y. Cai, J. Zhang, and Q. Ma, "Simulation study of pedestrian flow in a station hall during the Spring Festival travel rush," *Phys. Stat. Mech. Its Appl.*, vol. 392, no. 10, pp. 2470–2478, May 2013.

[40] "Personality," *http://www.apa.org*. [Online]. Available: http://www.apa.org/topics/personality/index.aspx.

[41] A. Vinciarelli and G. Mohammadi, "A Survey of Personality Computing," *IEEE Trans. Affect. Comput.*, vol. 5, no. 3, pp. 273–291, Jul. 2014.

[42] S. Pappas, L. S. C. | November 18, and 2013 11:38pm ET, "Personality Traits & Personality Types: What is Personality?" *Live Science*. [Online]. Available: https://www.livescience.com/41313-personality-traits.html.

[43] "Big Five personality theory." [Online]. Available: https://www.123test.com/big-five-personality-theory/.