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# IMPROVED CROWD PSYCHOLOGICAL MODEL AND CONTROL

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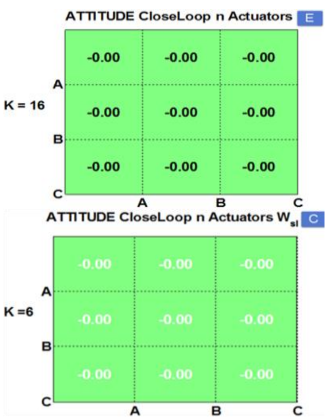



**Abstract**

The behavior of human crowd is an interesting phenomenon in which individuals are set as a collection that comprises of a highly dynamic social group. The crowd behaviors have been investigated by researchers over the years. Recent works include the study in modeling and controlling of the dynamic psychological behavior of crowds such as students' behavior in a classroom or people's behavior in a one-dimensional queue. In this paper, an improved version of the psychological crowd model has been proposed, where the social interaction between two individuals in a crowd is represented by a weightage, called the weight of social interaction. It has been shown that the inclusion of the social interaction weight has allowed social interactions between individuals to be included and results in a more accurate representation of the crowd's psychological factors propagations. Since the psychological dynamics of crowd is naturally unstable, this paper also discusses the application of two nonlinear control approaches to stabilise the crowd to make it calm. Results show that for a crowd of n number of agents, the single-agent controller gives similar performance with the n-agent controller but with much less resources. The simulation results also show that it takes less amount of time to stabilise a crowd when the crowd model includes social interaction weights.

*Keywords*: Crowd psychological behavior; weight of social interaction; Gustav LeBon's theory; nonlinear controllers



## 1.0 INTRODUCTION

Human behavior and human mental functions are categorized as the study of psychology in science. Some researchers focus on interpersonal psychological phenomena [1-4], which is related to topics such as leadership, conflict, conformity and social learning. Thus, an interpersonal psychological phenomenon is a very important area of study as it directly deals with significant world issues and classes [2,5-6].

There are many instances where the behavior of groups has considerable influence on the economic, political or social interests [7]. The mathematical model of a crowd's psychological dynamics have been proposed by Bergey, Speiser and Davison in [8, 9, 10, 11, 12-14]. The mathematical model is inspired by Le Bon's observations of crowd's psychological behavior [15], in which the 'herd mentality' was observed and recorded. The non-linear psychological model for the $i^{th}$ individual in a crowd is given as follows:

$$p_i(k+1) = c_p p_i(k) + \mu_{pa,i}|a_i(k)| \quad (1)$$

$$a_i(k+1) = c_a a_i(k) + \mu_{apa,i} s_i^2(k) \textstyle\sum_{o_j\in N(o_i)} d_{i,j} p_j(k) a_j(k) \quad (2)$$

$$b_i(k+1) = a_i(k) \quad (3)$$

$$s_i(k+1) = \mu_{s,i} S_{def} \alpha^{c_s \beta_i[k]} \quad (4)$$

$$\beta_i(k) = \mu_{sa,i}\big(a_i(k) - b_i(k)\big)^2 + \mu_{sap} \textstyle\sum_{o_j\in N(o_i)} d_{i,j}\, p_j(k) \quad (5)$$

$$|a_j(k)| + \mu_{ssp} \sum_{o_j\in N(o_i)} d_{i,j} p_j(k) s_j(k)(1 - s_i(k))$$

where $p_i$, $a_i$, $b_i$ and $s_i$ are the prestige, attitude, delayed attitude and suggestibility of the $i^{th}$ individual in the crowd respectively, known as the psychological factors of individuals in a crowd. $k$ is the discrete-time index. $N(O_i)$ is the neighbouring individuals who have social interactions with individual $i$.

Prestige (in Eq. 1) has a positive value and it indicates the level of influence that an individual has on other individuals in the crowd, where greater influence is resulted by higher value of prestige. Suggestibility (in Eq. 2) is a positive quantity. The value of suggestibility indicates the individual's tendency to imitate the attitude or actions of others. It can occur by associating the behavior of neighboring individuals into their own behavior. Zero suggestibility value means total disassociation with the behavior of its neighboring individuals. As shown in Eq. 2, suggestibility is an exponential function of $\beta_i$, where $\beta_i$ is given by Eq. 5. The first term of the equation that describes $\beta_i$ indicates that changes in one's attitude value $(a_i)$ tends to make an individual more suggestible. The second term reflects the idea that interaction with prestigious persons tend to make an individual more suggestible. The third term reflects LeBon's idea that, if the neighboring $j$-th individual is more suggestible, the suggestibility of the $i$-th individual increases; otherwise, it decreases. The propagation of prestige and suggestibility are dependent upon the action or attitude of people in a crowd. The value of attitude $(a_i)$ can be positive or negative, indicating a bad or good action of an individual, respectively. The propagation of one's attitude in the crowd depends on the suggestibility of the other individuals in the crowd and the prestige of the affecting source. Extreme attitude of the crowd indicates larger absolute value of the attitude, which is undesirable. The delayed attitude value at time $k+1$ is equal to the value of the attitude at time $k$, showing the dynamics state of people's behaviors. $c_a$, $c_p$, $c_s$ are the constants of the psychological factors – attitude, prestige and suggestibility respectively. Their values are between 0 and 1, and affects the diminishing speed of the attitude, prestige and suggestibility values towards zero. The default value of suggestibility is $S_{def}$. $\alpha$ is greater than one that illustrates a constant growth of suggestibility [3,6-9,11].

In [11], the dynamic psychological behavior of 100 students in a classroom ($n$ = 100) have been illustrated. The states of the psychological factors of all students/individuals were shown on a (10 x 10) grid. The values of remote factors ($\mu$) used for all students are the same where $\mu_{pa,i}$ = 0.02295, $\mu_{apa,i}$ =0.00553, $\mu_{s,i}$=1.07062, $\mu_{ssp,i}$=0.04064, $\mu_{sap,i}$=0.04796, $\mu_{sa,i}$=0.04346. The nominal suggestibility and decay factors are assumed to be $c_p$=0.95, $c_a$=0.55, $c_s$=0.75, $S_{def}$=20, and $\alpha$=1.2 [1,4,8,10-12]. Simulation results have shown that the interaction between attitude and suggestibility of people in Eqs. (2) and (4) reveal an unstable crowd character, which is consistent with Le Bon's observation [15]. In [8], an observer-based pole-placement control approach was used to stabilize the attitude of the crowd based on a linearized crowd psychological model. Results showed that the controller managed to regulate the attitudes of the crowd, but the transient performance was weak. Furthermore, it depends on forcing the disturbed components of different prestige signals toward negative values. The Luenberger observer used was also sensitive to measurement noise and the linear controller approach was not suitable for the nonlinear dynamics of the crowd psychology. Therefore, the following nonlinear controller [11] was then applied:

$$u_i(k) = -a_i(k) \qquad i = 1 \dots n \tag{6}$$

The control signal applied to each individual in the crowd is chosen to be having the negative value of the attitudes of the individuals. The idea is to make the attitude of each student to be zero at each time instant. From the stabilization time (the time it takes for the attitude of the crowd to be stabilized) viewpoint, the performance of this controller was better than the Luenberger observer controller [7]. However, this approach requires a control agent for every individual in the crowd, which is very resource consuming. Therefore, another nonlinear control scheme was suggested [11] in which the controller only control the most 'problematic' individual in the crowd i.e. the one with the largest absolute value of the attitude i.e.

$$u_i(k) = \begin{cases} 0 & if \quad i \neq m(k) \\ -a_i(k) & if \quad i = m(k) \end{cases} \tag{7}$$

$$\text{Where } m(k) = \min\{\arg max_i |a_i(k)|\} \tag{8}$$

Simulation results of this control scheme showed that it worked as well as the previous nonlinear control scheme [11] but with much less amount of resources. For better control of the crowd's attitude, a more accurate dynamical model of the crowd's psychology is needed. As a highly interacting system, neighboring individuals have direct social interaction (such as conversation, gesture and other social exchanges) with each individual in the crowd. However, in existing works [8,10-12] the interactions between two individuals in the crowd are assumed to be unaffected by these social interactions. In this paper, a modified model is proposed where the social interactions between individuals in the crowd is included in the model and represented by certain values of weights.

There are a number of articles that have investigated the movement of agents in crowd [16-18].

The following section describes the derivation of the modified crowd psychological model, followed by the application of the two nonlinear controllers to control a crowd in a (3 x 3) dimension.

## 2.0 MODIFIED PSYCHOLOGICAL MODEL

### 2.1 Crowd Psychological Model with Social Interaction

If the propagation of people's attitude is irrational in the crowd, this crowd is called an 'irrational crowd'. The work described in this paper aims to improve the existing model of the irrational spread of people's attitude and use nonlinear controllers to make an irrational crowd calm. The social interaction weight between two individuals in the crowd, $O_i$ and $O_j$, is denoted by $w_{ij}$ and $w_{ji}$. Therefore, Eqs. 3 and 5 can be written as follows:

$$a_i(k+1) = c_a a_i(k)\mu_{apa,i} s_i^2(k) + \cdots \sum_{o_j \in N(o_i)} w_{ij}(k) d_{ij}(k) p_j(k) a_j(k) \quad (9)$$

$$\beta_i(k) = \mu_{sa,i}\left(a_i(k) - b_i(k)\right)^2 + \mu_{sap} \sum_{o_{j \in N(o_i)}} w_{ij}(k) \ldots \quad (10)$$
$$d_{i,j}\, p_j(k)\left|a_j(k)\right| + \mu_{ssp} \sum_{o_{j \in N(o_i)}} w_{ij}(k) d_{ij}(k) p_j(k) s_j(k)(1 - s_i(k)).$$

In Eqs. 9 and 10, weight, $w_{ij}$, that represents the effects of social interaction is multiplied with the terms that involve the neighboring individual $j$. This weight is dependent upon conversation, gesturing or other social exchanges between individuals in the crowd, which has not been considered in previous works [3,6-9,11], which considered the effect of distance between two individuals only. In this paper, the distance between individuals in the crowd, $d_{ij}(k)$, are multiplied by the weighting factor representing the social interactions between the individuals, $w_{ij}$, for a more accurate representation of the crowd's psychology and its propagation. Note that the distance is inversely proportional to the psychological factors in the crowd, as seen in Eq. 11.

$$d_{ij}(k) = \frac{1}{|\alpha_i - \alpha_j|} \quad (11)$$

where $\alpha_i$ and $\alpha_j$ the positions of individual $i$ and $j$. In fact, with an increasing $d_{ij}$, the amplitude of the attitude decreases. This distance plays an important role in terms of controlling the dynamic psychological factors [7]. For example, normal conversations between two individuals sitting next to each other needs sounds of about 60 dB to be audible [12-13]. However, two individuals sitting across two corners of a classroom may need to speak louder to hear each other. Therefore, in normal cases such as this, the weight of social interaction between the two individuals in the former case is lower than that of the latter. Also, there exists times in which individuals do not follow this assumption, for example, two individuals in small distance between each other but talking rather louder than necessary. Thus, the social interaction parameter can be used to handle such situation. In normal cases, $w_{ij}$ can be assumed to be between 0 and 1. Otherwise, the values can be between 1 and 2.

Consider a crowd of 9 individuals in a classroom sitting in a (3x 3) seating grid as shown in Figs. 1 and 2 where it shows that, except for individuals sitting at the corners and edges of the grid, each individual can interact with 8 adjacent individuals around him. Individuals at the corner grid can interact with 3 adjacent individuals and those at the edges of the grid can interact with 5 adjacent individuals. These interactions among individuals are assumed with different $w_{ij}$ that are only dependent upon conversations and gestures between two individuals. The horizontal and vertical distance between two individuals is assumed to be 1 meter. Thus, diagonal distance is a square root of two meters. The distance of the positions of the nine individuals can then be calculated.

| | | |
|---|---|---|
| 1st S | 2nd S | 3rd S |
| 4th S | 5th S | 6th S |
| 7th S | 8th S | 9th S |

**Figure 1** Student positions in a static crowd of (3 x 3) individuals. 'S' indicates the student

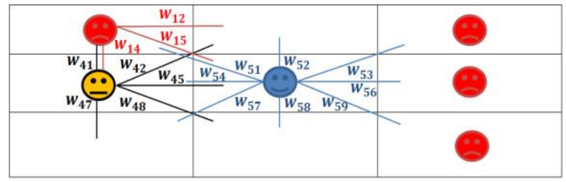



**Figure 2** Interactions between individuals in the (3 x 3) seating grid

As will be shown later, the attitude of the crowd in the classroom is unstable. Therefore, two nonlinear controllers have been applied to both the existing and modified crowd psychological model to stabilize its attitude.

## 2.2 Nonlinear Control of Crowd's Attitude

In the first nonlinear control approach, a control signal is applied to every individual in the crowd and the value of the control signal, is given by Eq. 12, where the controller aims to make the attitude of each individual to decay to zero at each time instant. In other words, a control agent is assigned to each agent in the crowd where it prevents the behavior of the agent to spread to the entire crowd. For example, a crowd with 9 individuals would require 9 control agents for this approach.

$$u_i(k) = -K_a a_i(k), \qquad i = 1 \ldots n \quad (12)$$

The value of $K_a$ is taken to be the average of the initial attitude values between (0,1)of the individuals in the crowd.

$$K_a = \frac{\sum_i^n |a_i(0)|}{number\ of\ numbers} + 0.02 \qquad i = 1 \ldots n \quad (13)$$

For the second nonlinear control approach, only one agent is needed to stabilise the attitude of the whole crowd, where the action of the controller only considers the most problematic individual in the crowd i.e the one with the largest absolute value of attitude as follows:

$$u_i(k) = \begin{cases} 0 & if \quad i \neq m(k) \\ -K_a a_i(k) & if \quad i = m(k) \end{cases} \quad (14)$$

where

$$m(k) = \min\{\arg max_i |a_i(k)|\} \quad (15)$$

If there are more than one individual having the largest attitude value, the one nearer to the control agent will be chosen.

The work in this paper was simulated using MATLAB version 2014a. It considered a crowd with 9 agents, who are assumed to have similar cultural background, age and level of education.

## 3.0 RESULTS AND DISCUSSION

Simulation works are conducted based on the (3 x 3) individuals in the classroom scenario to investigate the effects of the proposed social interaction weights in the modified model and the effectiveness of the nonlinear controllers described above. In all the figures in this section, the dark red colour indicates the large positive value and the dark blue colour shows the large negative value of psychological factors. The ranges of these values are dependent upon the saturation numbers used. The saturation numbers for prestige, attitude, and suggestibility are correspondingly assumed to be between '[-0.2 +0.2]', '[-2 +2]', [-2 +2] and [-50 +50] [3,8-9]. The saturation numbers for attitude and control signal in control simulation part are assumed [-0.2 +0.2]. The light green color indicates zero value of the psychological factors. In some figures, the values of the psychological factors cannot be represented as they have extremely large negative or positive values indicating unstable situations. $w_{SI}$ is assumed to be between 0 and 2.

### 3.1 Comparisons Between Existing and Modified Models – No controller included

The first part of the simulation works compares the two nonlinear models – existing model in [1, 4, 5, 11, 13-15] and the proposed model with the social factor weights. Figs. 3 and 4 show the propagations of the crowd's prestige, attitude and suggestibility for the existing and proposed models respectively. As predicted by LeBon's observation, Figs. 3 and 4 show that, without any form of controller/control agent, the attitude and suggestibility propagation of the crowd are naturally unstable.

For the existing model, in Figure 3, the attitudes of the individuals in the crowd became unstable after $k = 9$, whereas for the proposed model in Fig. 4, the attitudes of all the individuals became unstable a bit late, after $k = 25$.

### 3.2 Comparisons Between The Use Of Two Nonlinear Controllers

In this section, the two nonlinear controllers described in Eqs. 12 and 13 are applied to both the existing and proposed crowd models. Recall that for the first control approach that utilizes Eq. 12, each individual is controlled by one control agent. Hence, for the simulation work conducted in this paper, there will be a total of 9 control agents for the 9 individuals in the crowd. However, for the second control approach that uses Eq. 14, there is only one control agent for the whole 9-individual crowd, and the control agent applies the control signal only to the individual with the highest absolute value of attitude.

Figs. 5 and 6 show the propagation of the crowd's attitude and control signal when the first type of controller was used on both the existing and proposed crowd models respectively.

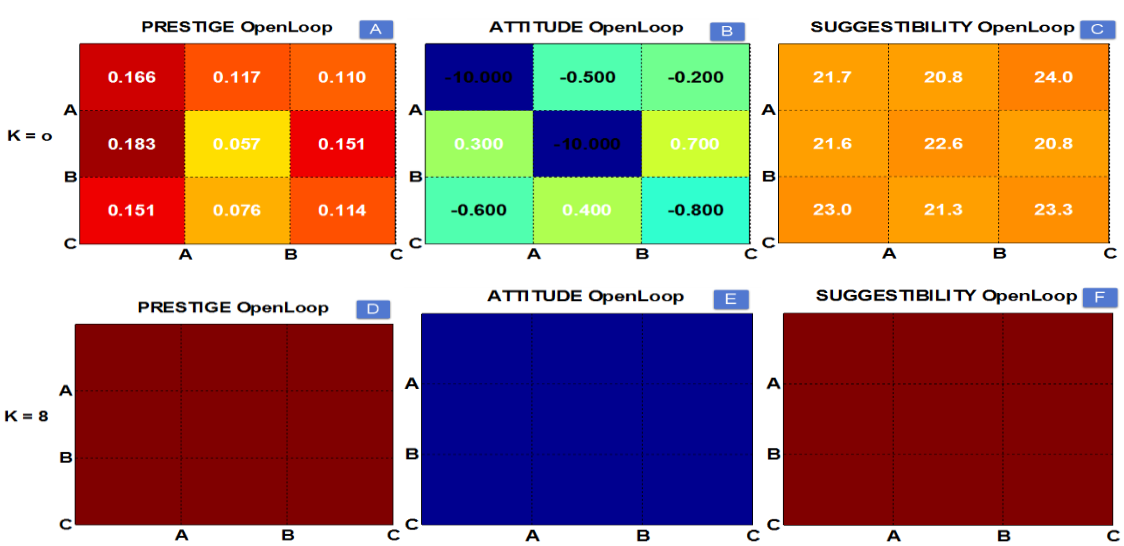
The attitudes and control signals are shown in Figs. 5 and 6. For example, in Fig. 5(A), the initial absolute values of attitude between (0,1) are (0.5,0.2,0.3,0.7,0.6,0.4,0.8). Therefore,

$$K_a = \frac{0.5 + 0.2 + 0.3 + 0.7 + 0.6 + 0.4 + 0.8}{7} + 0.02 = 0.52$$

The initial attitude (at $k = 0$) of the first individual, which is located at the A$^{th}$ row and A$^{th}$ column, is -10. Therefore, for the first individual in the crowd, the control signal i.e. the value of the attitude of the control agent is

$u_1(0) = -K_a a_1(0) = -0.52(-10) = 5.20$

until the first student's attitude approaches zero as shown in Figure 5(E).



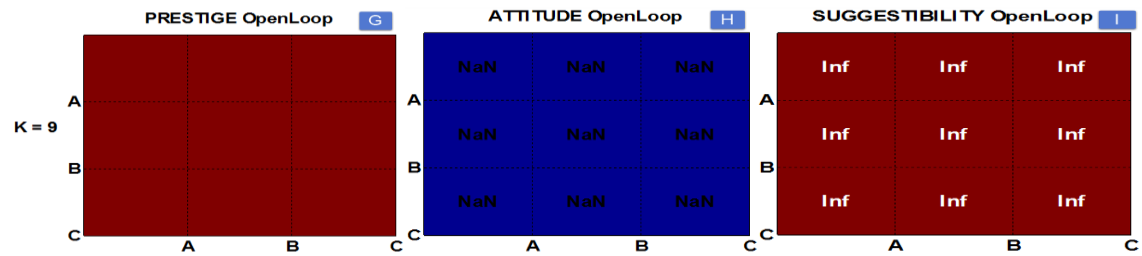



**Figure 3** The existing non-linear plant model – no control agent included

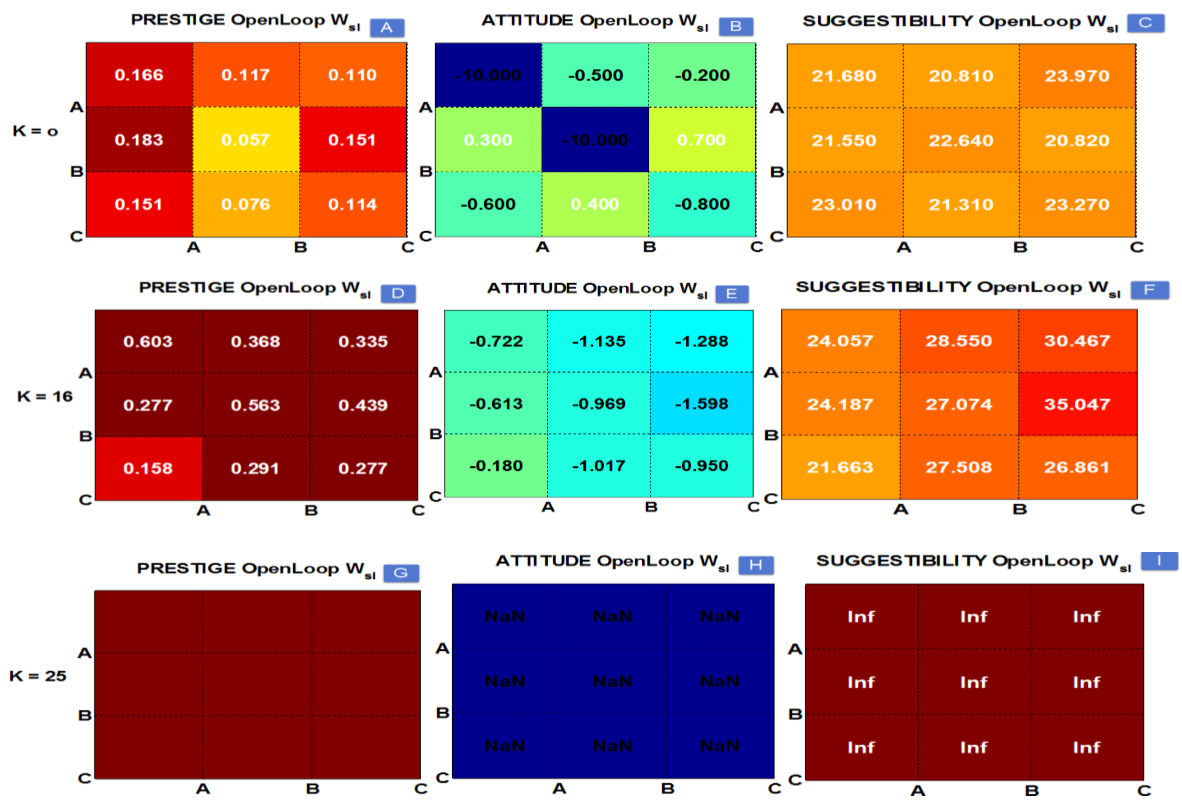



**Figure 4** The proposed nonlinear crowd's psychological model in which the weight of social interaction ($W_{SI}$) was considered – no control agent included

It can be observed from Fig. 5 that for the existing model, after $k = 16$, the attitude values of the individuals in the crowd become zero, indicating a calm or stabilized crowd. On the other hand, Fig. 6 shows that this situation happens after $k = 6$. This shows that, with the proposed model that includes the effect of social interaction factors, shorter time is taken for the crowd to stabilize. This is the consequence of the weighting factors ($w_{ij}$) that are included in the model to represent social interactions between individuals in the crowd, where it can take into account the effect of distance between 2 individuals in the crowd, which in turn affects the speed of propagation of the attitude of each of the individual across the whole crowd resulting in realistically shorter stabilizing time when the distance between individuals are shorter and vice versa.

For the second control approach, Figs. 7 and 8 show that the stabilizing times for both cases improved. The attitudes of the individuals for the existing model approached zero after $k = 25$ whereas the attitudes of the individuals for the proposed model approached zero after $k = 13$.

Although the performance of the previous controller is better, from the stabilizing time viewpoint, this control approach has eliminated the need to have one control agent for each individual in the crowd, where in this case, the control agent targets the individual with the highest absolute value of attitude at each time step, as shown in Figs 7(B),(D).

From Eqs. 14 and 15, the initial value of the control signal is 3.20, based on the cancellation of the largest attitude value in the crowd, which in this case belongs to the individual in row A and column A (with attitude value of 10) as shown in Figs. 7(B) and 8(B). This process was repeated at every time instant. The summary of the stabilizing time obtained for both crowd psychological models and the two nonlinear control approaches are given in Table 1.

**Table 1** Two models with same initial conditions

| Nonlinear control approach | Stabilizing time for the new model | Stabilizing time for the existing model |
| --- | --- | --- |
| $n$ control agents for $n$ individuals in a crowd | $k = 6$ | $k = 16$ |
| 1 control agent for $n$ individuals in a crowd | $k = 15$ | $k = 25$ |

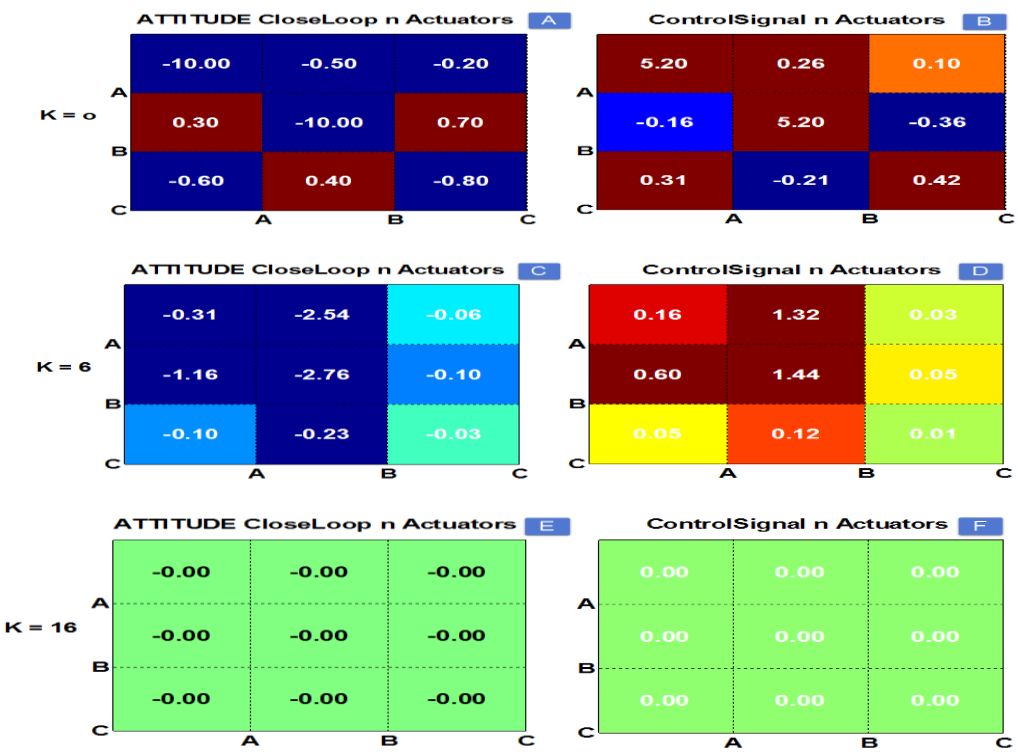



**Figure 5** Closed loop response for the existing model using the first control scheme. This controller scheme requires 9 control agents. The crowd becomes calm after $k = 16$

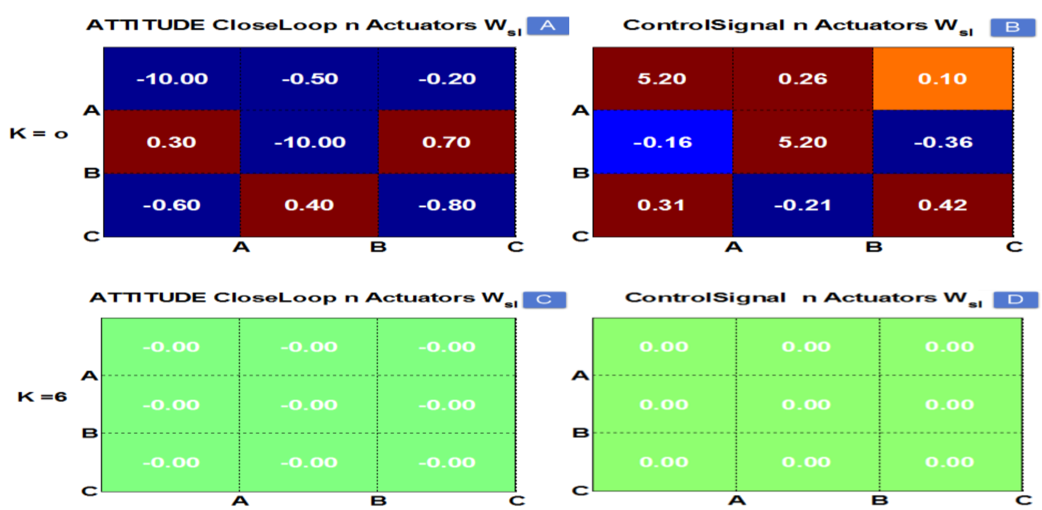



**Figure 6** Closed loop response for the proposed model using the first control scheme. This controller scheme requires 9 control agents. The crowd becomes calm after $k = 6$

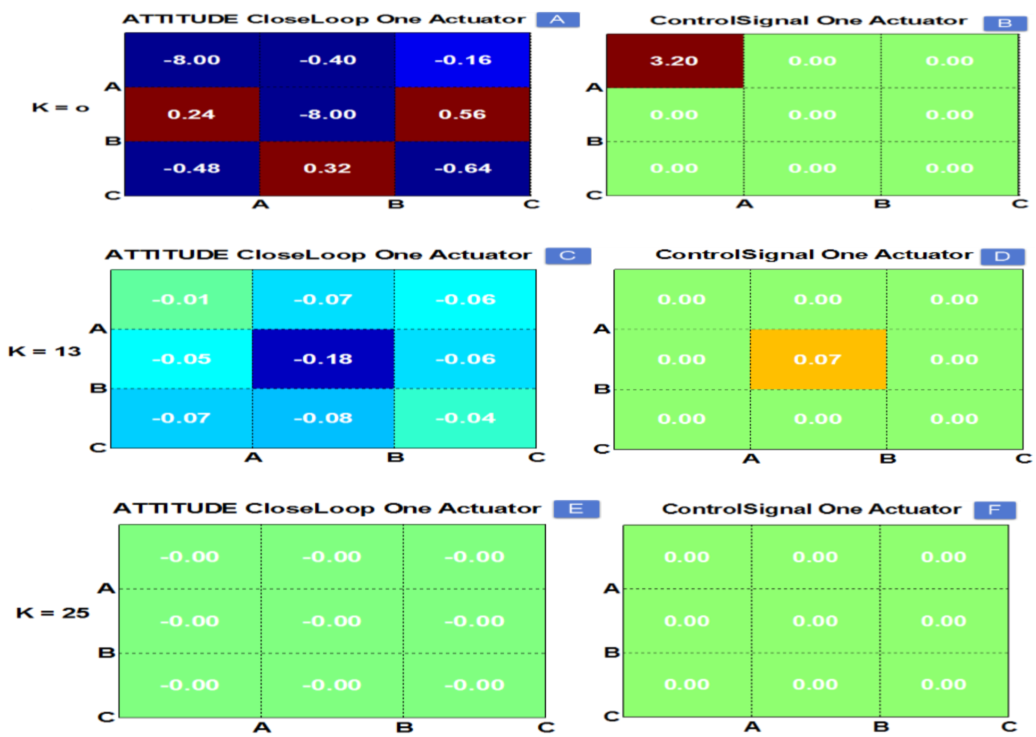



**Figure 7** Closed loop response for the existing model using the second control scheme. This controller scheme requires only 1 control agent. The crowd becomes calm after $k = 25$

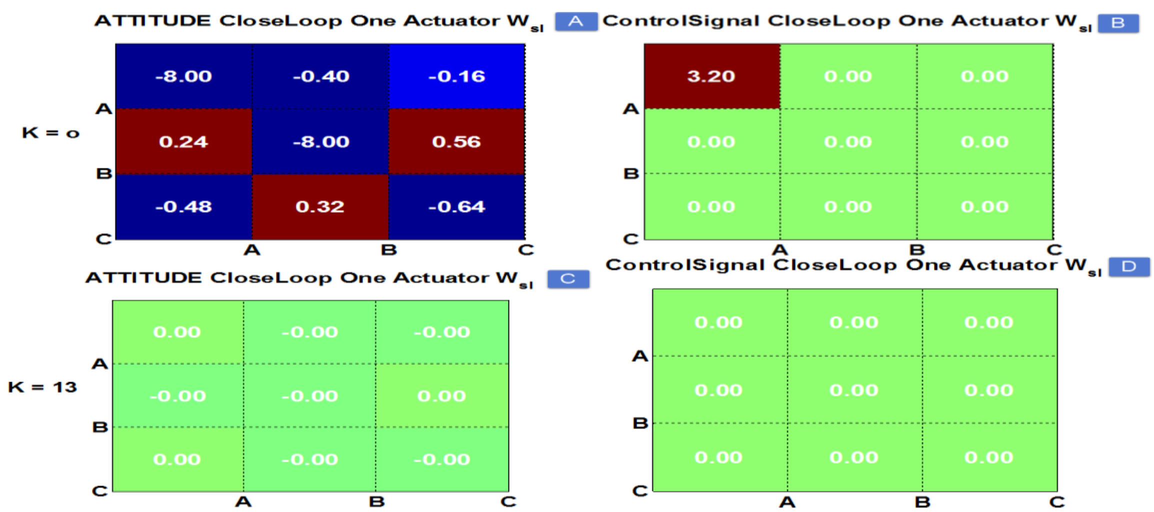



**Figure 8** Closed loop response for the proposed model using the second control scheme. This controller scheme requires only 1 control agent. The crowd becomes calm after $k = 13$

This similar approach can be applied to crowd dimensions of greater than 3x3, used in this work. However, as the crowd becomes bigger, the stabilizing time could be longer, depending upon the initial values of psychological dynamic factors of the agents in the crowd.

## 4.0 CONCLUSION

This paper presents a modified version of the crowd psychological model where weighting factors related to social interactions between individuals in the crowd are added to the existing model. In this work, the type of social interaction factor considered is also dependent on the distance between the individuals in the crowd as distance has a considerable effect on the propagation of the crowd's psychological parameters, namely, its prestige, attitude and suggestibility. It has been shown that the inclusion of the social interaction weight has allowed social interactions between individuals to be included and results in a more accurate representation of the crowd's psychological factor propagations. Since the psychological dynamics of crowd is naturally unstable, this paper has also discussed the application of two nonlinear control approaches to stabilise the crowd to make it calm. The control could be implemented via actions of authoritative figures such as security officers, policemen or teachers where they prevent the behaviors of the agents from spreading across the entire crowd. Results show that for a crowd of *n* number of agents, the single-agent controller gives similar performance with the *n*-agent controller but with much less control effort. The simulation results also show that it takes less amount of time to stabilise a crowd when the crowd model includes social interaction weights. In this study, Future works would involve the study on various control theories to improve the controller. The method for the control agents to sense the psychological state of each person and communicate with other control agents to stabilize the crowd can also be investigated.

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