1. **Group force model**

Acceleration of pedestrian p when moving in group is illustrated as follows:

|  |  |
| --- | --- |
| = | (1) |

The group force model represents that a pedestrian *p* at time *t* is trying to move with a certain desired speed in a desired direction pointing from pedestrian *p*’s current position to his target position. Therefore, pedestrian *p* tends to correspondingly adapt his actual velocity with a certain acceleration time . The acceleration time represents pedestrian *p* changes its current velocity and return to its desired velocity. Pedestrian *p*’s acceleration at time *t* is also influenced by repulsive forces coming from surrounding pedestrians and obstacles. They are and respectively. Pedestrian *p* is also affected by group attraction which makes pedestrian *p* move close to his group members.

is desired speed of pedestrian *p* and varies over time, given by:

|  |  |
| --- | --- |
|  | (2) |
|  | (3) |

where and are the initial desired speed and the maximum desired speed of pedestrian *p*, respectively. In social force model is constrained by constant value ***c >* 1**.

In equation (9), is considered as panic parameter model of pedestrian *p*. It illustrates how strongly pedestrian *p* aligns his preferred velocity with the motion of crowd surrounding him, given by equation (11) as suggested by **(Helbing, 2005) and (Andreasen, 2010)**:

|  |  |
| --- | --- |
|  | (4) |

where is computed by average actual speed in the desired direction. Equation (4) is transformed into equation (12) for the condition at time *t*=0.

|  |  |
| --- | --- |
|  | (5) |

When is going down in equation (11) as pedestrian *p* is in high density place (e.g bottle neck scenario), implies → 1 which implies → as in equation (5).

When is going up, it implies → 0, which implies → . Since > by ***c >* 1**, it means that when average velocity is going up, the desired force going down, and vice versa. When is higher than desired force has negative direction to decelerate pedestrian *p*’s actual speed.

Interaction repulsive force created by neighbour pedestrian *q* is given by equation (6)

|  |  |
| --- | --- |
|  | (6) |

where factors and are model parameters, represent the strength of interaction force and how sensitive the repulsive force are based on the distance between pedestrians *p* and *q*, respectively.

and parameters represent radii of pedestrians *p* and *q*, and ( ≤ . Literally, the higher value means pedestrian *p* feel more uncomfortable and want to move further away from pedestrian *q* caused by the increase of repulsive force. The exponent function is used to describe that the repulsive force decrease exponentially if is high. The repulsive force achieves at the highest value when pedestrians *p* and *q* collide ( = ). Factor is the unit vector pointing from pedestrian *q* to pedestrian *p* to illustrate the force direction making pedestrian p avoid pedestrian *q*.

Group attraction force created by group members is given by equation (7)

|  |  |
| --- | --- |
|  | (7) |

Factors and are model parameters, represent the strength of group attraction force and attraction range of pedestrian *p* towards his group members. The higher value makes attraction force increase since and represent radii of pedestrians *p* and *q*, and ≤ . Factor is the unit vector pointing from pedestrian *p* to pedestrian *q* to illustrate the force direction making pedestrian p move close to pedestrian *q*.

In general, the model allows members move close together when they are in far away by the attraction force and move far away each other by the repulsive force .

The obstacle force between pedestrian *p* and wall γ in equation (1) is represented in equation (8)

|  |  |
| --- | --- |
|  | (8) |

here *U* is a model parameter to represent the strength of obstacle force, and is the unit vector pointing from wall γ to pedestrian *p* to make the agent avoid the wall. Because of exponent component in equation (8), the obstacle force always satisfies the condition.

Summary parameters of group force model

|  |  |  |
| --- | --- | --- |
| **Parameter** | **Component** | **Description** |
|  | Desired Acceleration | Initial desired velocity |
|  | Desired Acceleration | Acceleration time to reach desired speed |
|  | Repulsive Force with other pedestrians | Interaction strength |
|  | Repulsive Force with other pedestrians | Interaction range based on distance between *p*, *q* |
|  | Group attraction force | The strength of the social attraction between group members |
|  | Group attraction force | The attraction range of group members |

1. **Experimental Design**

Simulation result of the model using repulsive and attractive forces

|  |  |
| --- | --- |
| **Parameter** | **Range** |
| (m/s2) | [2.5-3.0] |
| (m) | [0.3-0.5] |
| (m/s2) | [0.5-1.0] by simulating 2ped, not overlap |
| (m) | [0.6-0.8] |

Refine parameter ranges so that pedestrians do not overlap and the ranges satisfy

This work is just to know which parameter controls group cohesion degree before simulating different groups.

The above model is simulated on Monash Cluster to measure group cohesion degree and group average speed with below parameter ranges. Each parameter is sampled uniformly in its range for 2000 times. Parameter combinations (16000 times) are set up for the experiment. Each parameter combination is simulated at ten times in which each time has different placements. Parameter combinations share the same context including placement and radii of group members.

|  |  |
| --- | --- |
| **Parameter** | **Range** |
| (m/s) | [1.2 -1.6] |
|  | [0.3-0.7] |
| (m/s2) | [2.5-3.0] |
| (m) | [0.3-0.5] |
| (m/s2) | [0.5-1.0] |
| (m) | [0.6-0.8] |

Plot parameter distribution

Plot model’s output distribution

Plot correlation testing

Plot Sobol indices

Plot verification

1. **Experimental design for the effect of group behaviour on crowd dynamics**

Suppose, we have two groups