**EXPLORING THE HETEROGENEITY** **INSIDE POPULATION**

**TO ENHANCE CROWD MODELLING OF GROUP DYNAMICS**

1. **Introduction**

Rapid urbanization and population growth are always inevitable challenges for every country in the effort of planning infrastructure, estimating traffic needs and capacities, and increasing the safety of pedestrians since over 70% of the world population is predicted to live in cities by 2050 (Weidmann, 2012). With the increase in the number of public events and the number of accidents during these events (Evers, 2011), the demand of realistic crowd simulation models becomes important for risk management in urban design and crowd safety. To make an effort for creating realistic simulation models, various studies aim to understand and simulate behaviours which can unfold in both normal and emergency situations such as group of pedestrians moving or competing each together.

Group cohesion behaviour is observed by its cohesion degree and formation. Cohesion degree denotes the average distance to group’s centre of mass from each group members. Observable human group formations are V-like, line-abreast, U-like, or river-like (Helbing, 2005). Group members might are in different positions of each formation. Group cohesion behaviour is important in both of normal and evacuation scenarios. In normal situation, group cohesion behaviour can affect out-group pedestrian’s speed and movement direction. In crowd disasters, pedestrians belong to same group may move irrationally to maintain its cohesion and consequently being obstacles for other pedestrians.

Various models have been proposed to simulate group cohesion behaviour such as social-force based model, cellular automata model, and agent-based models. However, these models have not yet explored the impact of agent’s parameters on group cohesion behaviour, while an actual group contains different group members, whose physical parameters (speed, interaction strength) are different to others. Group of different members can be easily seen in both of normal and emergency situations. (Aguirre, 2011) found that a pedestrian may select another pedestrian based on demographic traits to move together in a group through the crush disaster happened at the Nightclub, USA, 2003.

Therefore, this PhD study aims to investigate the impact of group cohesion behaviour on flow rates according to group member’s parameters. This impact is then investigated through proposed case studies of simulation scenarios.

Section 2 of this report represents the start of the art of studies modelling group cohesion behaviour and their advantages and limitations. Section 3 analyses the drawback of current models and present the need of this research study through proposed research questions. Section 4 presents research methodology to achieve these questions. Section 5 presents the project’s contribution. Section 6 reports current working progress for these questions followed by Sections 7 as requirement from IT faculty for compulsory research training hours.

1. **Literature Review**

This section reviews current models that incorporate group behaviour. Modelling approaches are various from investigating social forces that affect each pedestrian’s acceleration, modelling the changes of each cell on a grid layout, to defining behaviour rules to describe agents follow other.

**2.1. Social force model for group behaviour**

Moussaid, Helbing and colleagues (Moussaid, 2010) created the social group model based on the social-force model (Helbing & Molnar, 1995, 2000). The social group model (equation 1-2) 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. The repulsive force’s directions and group force direction are represented in Figure 1. The group influence force aims to describe that an individual in group continuously adjusts its position to reduce its head direction and maintain group’s centre of mass, but also avoid other group members. The group force is represented in equation 3.



**Fig 1**. Repulsive forces and on pedestrian *p* created by pedestrian *q* and wall γ.

|  |  |
| --- | --- |
|  | (1) |
| = | (2) |
|  |  |

where is desired speed of pedestrian *p* and varies over time, is an uncertainty factor.

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

The social group force describes that pedestrian p at time *t* turns his gazing direction to see their partners. Thus, vision force is included to help pedestrian p adjust its position to reduce the head rotation. At the same time, pedestrian p keeps a certain distance to the group’s centre of mass by the force . A repulsive force is added to support pedestrian *p* avoid other group members.

To summary, the social force model comprises parameters that need to be set at initial simulation time as in Table 1:

**Table 1** – Social-group force model’s parameters

|  |  |  |
| --- | --- | --- |
| **Parameter** | **Component** | **Description** |
|  | Desired Acceleration | Initial desired velocity |
|  | Desired Acceleration | Acceleration time to reach desired speed |
|  | Desired Acceleration | Constant to find maximum velocity |
|  | Repulsive Force with other pedestrians | Angular component |
| *A* | Repulsive Force with other pedestrians | Interaction strength |
| *B* | Repulsive Force with other pedestrians | Interaction range based on distance between *p*, *q* |
| U | Obstacle Force | Obstacle interaction strength |
|  | Simulation | Radii of pedestrian *p* in simulation environment |
|  | Group vision force | The strength of the social interactions between group members |
|  | Group attraction force | The strength of the attraction effects |
|  | Group repulsion force | The repulsion strength between group members |

Social-force based model has possessed a long-life modification period by its author and colleagues for more than a decade in order for simulating the additional factors affecting individual’s acceleration or being easier towards calibration process. However, it almost uses the same parameter distribution to simulate pedestrians inside crowd as in Table 2.

**Table 2** – Social-group force model’s parameter value

|  |  |  |
| --- | --- | --- |
| **Parameter** | **Value** | **Reference** |
| (m/s) | avg. = 1.34, st. dev. = 0.26 | (Helbing, 1995) |
| avg. = 1.3, st. dev. = 0.3 | (Helbing, 2005) |
| (s) | 0.5 | (Helbing, 1995) |
| 1.0 | (Helbing, 2000), (Helbing, 2005) |
|  | 1.3 | (Helbing, 1995), (Helbing, 2005) |
| *A* (m/s2) | 3.0 | (Helbing, 2005) |
| *B* (m) | 0.2 | (Helbing, 2005) |
|  | 0.75 | (Helbing, 2005) |

Through observation, Moussaid found that pedestrians in same group likely move in a line-abreast formation to allow them communicate with each other easily. When crowd density increases, group of pedestrians automatically change its formation into V-shaped or river-like pattern. According to the study, when the model parameter = 0, it shows that group members only try to stick together with no communication rule. When = 4, a V-shaped structure is created.

The authors applied the same value of each parameter in Table 2 and parameters of group force including to all pedestrians inside group to see these patterns. In fact, human group formation is various from V-line, U-like, line-abreast, to river-abreast as in actual observation (Helbing, 2005). However, this model did not mention at which values of parameters other group formations could be created. It also raises a question whether these parameters have to be the same for all group members to establish these structures.

* 1. **Cellular automata model for group behaviour**

Cellular automata-based group behaviour model is the approach relying on of Von Neumann’s idea that divides space into uniform grid or hexagonal cells. At each time *t*, variables at each cell are updated according to a set of local rules or its neighbour cells (Zheng, 2009). Common local rules are moving direction, or avoidance rules. Every cell in the space can be in different states including free, an obstacle, or occupied by a pedestrian. General cellular automate model is formed as formulas 4-6.

|  |  |
| --- | --- |
| where | (4) |
|  | (5) |
|  | (6) |

Every cell has variables of path field, obstacle field, and density field. Path field is to identify distance from current cell to destination cell. Obstacle field indicates for every cell the distance from an obstacle or a wall. Density field is to indicate for each cell the crowd density in the surroundings at the current time step *t.* When running a CA-based pedestrian model, there is several update strategies including parallel update, sequential update, or shuffled sequential update.

To simulate group behaviour, Vizzari (Vizzari, 2013) constructed pedestrians on these defined cells. A pedestrian is represented as a utility-based agent having following attributes:

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

where:

* Id: identification number of pedestrian *i*
* GroupId: identification number of group that pedestrian *i* belongs to
* State: represents pedestrian’s current cell that and direction followed in last movement
* Actions: is the set of possible actions to choose an appropriate cell from equation (5) and equation (6).
* Destination: reflects current path field of the cell where pedestrian *i* is in

A utility function was proposed by the author as in equation 8. The function estimates the probability of cell c to allow pedestrian *i* move in to maintain group cohesion at each time step *t*.

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

where:

* , , , , , , are model’s parameters for their corresponding functions
* is the goal attraction derived from current cell’s path field and destination cell’s path field
* represents obstacle repulsion from obstacle field of current cell *c* over the maximum distance to obstacles from any cell in grid layout
* represents separation value to allow pedestrian *i* avoid other pedestrians. It is measured by density field of current cell *c* over the predefined maximum density.
* represents whether this cell is the same direction with previous movement of pedestrian
* represents a small probability to allow two pedestrians stay on the same cell.
* represents cohesion value of cell *c* if pedestrian *i* move in towards other group member’s position
* is used in the case of large group which can be separated into sub groups. It represents the cohesion value of current pedestrian toward the largest group.
* is the distance from cell *c* to pedestrian *i*’s current cell position. *d* is only equal to 1 or

Group cohesion degree is then defined as in equation (9) to represent the average distance from each group member to group’s centre of mass. The study used this degree to support pedestrian *i* trade off current goal attraction with group cohesion based on predefined rules.

|  |  |
| --- | --- |
|  | (9) |

The study then measured the correlation between group size and speed in various design layouts. However, this CA-based model only allows pedestrians move in neighbour cells rather than in further cells at each time step. Moreover, it applied the same value of each parameter, , , , , , for whole group members to measure the group speed. Thus, it neglected the heterogeneity in speed, interaction strength, and model parameters of actual group members. The effect of these parameters on group formation was not investigated.

**2.3. Agent-based model for group behaviour**

In agent-based model, (Pelechino, 2006) constructed a simulation environment and created different pedestrian roles (leader, untrained leader, group members) through agent-based model to simulate evacuation scenarios. (Aguirre, 2011) construct a simulation environment of and compared the difference in escape numbers of several prototypes constructed on agent-based model. The prototypes include individual behaviour, intermediate group (revert to individual behaviour while in duress), full group behaviour (follow group leader). The escape numbers are compared with actual survivor number. On social aspect, the author mentioned that a group leader can be selected by other through demographic traits such as age, gender and familiarity with environment. A group member follows leader if they are in the leader’s line of sight.

Another recent study (Cheng, 2014) constructed an agent-based model to simulate passengers at airport-check in area. The result shows that group behaviour has a significant impact on the performance and utilisation of airport’s services. The study also presents a case study of the model to evaluate evacuation strategies of the airport. By comparing the evacuation times of individual passengers and group of passengers, the study found that group dynamics influence significantly on evacuation behaviour of passengers and total evacuation time.

However, these models did not investigate group cohesion degree and how group behaviour affects flow rate when varying parameters of group members. They only focus at creating variously rules for pedestrians follow other to measure escape rate.

1. **Problem Statement**

**3.1. Problem definition**

Group cohesion behaviour is the behaviour of objects moving towards the average positions of their neighbour over the time (Reynolds, 1987). The definition of this behaviour was motivated by the visual appearance of coherently flying objects, among flocking bird and imaginary spaceships (Vicsek, 2012). The behaviour has been investigated widely on collective motion of different flocking organisms including homing pigeon flocks (Kattas, 2012) (Nagy & Vicsek, 2010), fish school (Couzin, 2013), bacterium (Cisneros, 2007).

In human behaviour research, it has been observed in UK at different places (train station, shopping centre, university campus, Clumber Street) and showed that pedestrians in crowd are in group of two or more members. The percentage of people in groups at these places is 37%, 50%, 28%, 50% (Singh, 2009). Pedestrians in same group might be family members, colleagues, or pedestrians have the same interest. Human group cohesion is often observed by its degree (the average distance from group members to group’s centre of mass) and formation (U-like, V-like, line- abreast, river-like) (Helbing, 2005).

Human group cohesion behaviour modelling is important since it helps to simulate correctly how pedestrians in group automatically changes its group formation to adapt to different situations and represents the effect of group on out-group pedestrians for escape rate measurement. . The importance of group cohesion modelling is reported in a recent study (Aguirre, 2011). The study constructed agent-based model to simulate the crush disaster happened in Nightclub, USA, 2003. It measured the difference of escape numbers between simulation prototypes (pedestrians move individually, pedestrian move with group). The prototype having group behaviour was more fit with deceased avatars and survivor numbers. The study explained that these avatars were less likely to abandon their groups and instead spent more time trying to find their group members.

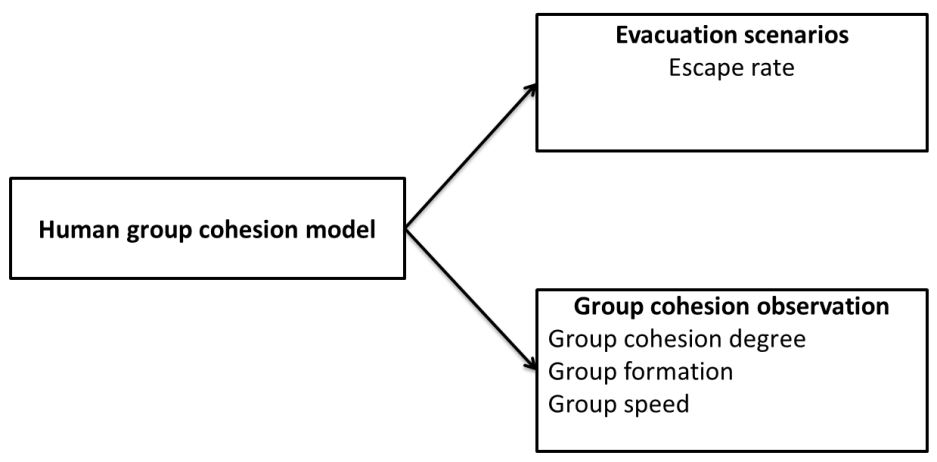


Figure 1. State of the art in human group behaviour modelling

Figure 1 shows current state of the art in human group cohesion models. Through literature review in section 2, the models mainly categorized into three approaches including agent-base models, force-based model, and cellular automata model. The models aim to understand two targets as in Figure 1.

In agent-based approach, various behaviour rules describing how pedestrians follow together have been created and the difference of survivor numbers between simulation prototypes using these rules are compared. However, one of the clearest limitations of agent-based models mentioned in the future work of the study (Weijmen, 2013) is the lack of a standard mechanism to measure the effects of agent’s parameters in the pedestrian’s force calculation. Moreover, agent-based approach only focuses on defining rules rather than investigating the impact when varying agent’s parameters on escape rate.

Current group force model and cellular automata model make assumption that populations are homogeneous. According to parameters of social force model (parameters in Tables 1 and 2, and parameter of group force ) and automata model (parameters in equation 8), these authors set the same parameter values for all pedestrians. These two models almost investigate group speed, group formation, and group cohesion degree when varying group population size. Considering group members are homogeneous is not true for an actual group which contains different members whose physical attributes such as speed, interaction strength are different (Daamen & Hoogendoorn, 2012). Thus, this limitation makes modellers and simulation software’s end users simulate inaccurately different group members. It raises a question about whether these group-force parameters are different for every group members to help them maintain group cohesion.

To summary, the effect of group member’s parameters has not been investigated on group cohesion degree and flow rate through interacting with other group members and out-group pedestrians respectively. A recent survey on the research field (Hoogendoorn, 2013) shows that force-based model is sufficient at simulating other observable human crowd self-organization comparing to other models. Therefore, this study proposes follow questions to analyse the effect of group member’s parameters on overall flow rate.

**3.2. Research Question**

1. How does group member’s parameters affect flow rate when group members maintain cohesion behaviour?

1.1. How does group cohesion degree change when varying group member’s parameters?

1.2. How do group member’s parameters affect flow rate when group members interact with out-group pedestrians?

**3.3 Research project’s contribution**

Group cohesion is important since it affect out-group pedestrians for escape rate measurement. Current models make pedestrians homogeneous and same parameters to explore the effect of group cohesion on group speed and flow rate. However, they didn’t investigate on the difference from group members parameter distribution .Thus, the contribution of the proposed study is to support:

* Modellers understand possible impacts of group cohesion behaviour on flow rates according to different parameter settings of group members.
* Event organizers restore the order of crowd before deteriorative situations can occur when groups are trying to escape a door in love events.

1. **Research methodology**

This section presents the research methodology to resolve the proposed question. The main question is to explore the impact of group member’s parameters on flow rate when group members maintain cohesion behaviour. Its first sub question aims to understand the impact of a group member’s parameters to group cohesion degree. Its second question explores this impact on overall flow rates through interacting with out-group pedestrians in case studies of directional flows and evacuation scenarios.

* 1. How does group cohesion degree change when varying group member’s parameters?

Since social-force model and group-force model keep the same parameter values for group members, first work in this question is to investigate whether setting the same parameter distribution is sufficient to simulate various group members, who have different parameters values in reality. According to a recent calibration study (Daamen & Hoorgedoorn, 2012), it found that pedestrians different in age groups (children: <14 years old, adults, elders > 60 years old) are different in parameter distribution (desired acceleration, acceleration time, interaction strength, and interaction range) as in equations 10-13. Thus, a hypothesis testing is applied in the original force model to measure two prototypes. First prototype uses the same distribution and second prototypes uses different distribution for each pedestrian type.

|  |  |
| --- | --- |
|  | (10) |
|  | (11) |
|  | (12) |
|  | (13) |

After measuring two approaches, group force model is simulated to measure the impact of each group member’s parameter settings.

* What group cohesion degree can be created by varying parameters of each group member?

This question investigates two group types. First group contains *N* pedestrians having the same distribution (likely same pedestrian type). Second group is same size but has different percentages of pedestrian types who are using different parameter distribution as mentioned in the study (Daamen & Hoorgedoorn, 2012). For each group type, a scanning parameter space is performed to understand at which parameter value of group force , following criteria is emerged:

* a new pattern of group cohesion behaviour in group cohesion degree, group formation is established
* group cohesion behaviour change smoothly or discontinuous

This works is performed by measuring the interactions of each pair of parameters on proposed criteria. It aims to determine areas having same criteria on two-dimensional space when varying parameter values in horizontal and vertical directions.

Investigate ANOVA framework for discrete and continuous parameters

Investigate Vicsek’s study

* What parameter sets of other group members help to maintain group cohesion degree?

The combination of three parameters on N pedestrian’s parameters is scanned on proposed criteria to give a general understanding when the model produces the same group cohesion degree. Two group types are also compared each other on the same combination of group force’s parameters. Hypothesis testing will applied on each criterion to make sure the difference when varying parameters.

To understand the sustainability of group cohesion at the parameters giving the same group cohesion, this work will further investigate:

* the changes of group behaviour when removing *k* agents in group
* the position of group members
  1. How do group member’s parameters affect flow rate when group members interact with out-group pedestrians?

This question aims to understand the impact of group cohesion when group members interact with other pedestrians moving individually in simulation environments. Scenarios are unidirectional & bio-directional flows, and evacuation through a door. These scenarios aim to explore the effect of how group can be obstacle for out-group pedestrians or move upstream to maintain its cohesion.

A simulation environment of a population is setup. The population includes group *A* (who are always influenced by the group’s centre of mass) and crowd *B*. Crowd *B* is the set of pedestrians use the same parameter distribution (same pedestrian type) and only have individual behaviour. This sub question considers two case studies:

* Case study 1: Group *A* interacts with crowd *B* in the same and opposite directional flow. The simulation is repeated *n* times
  + Hypothesis: Flow rate of the population is the same over *n* times when using the same parameter setting found in sub question 1.2
  + Analysis: This case study expects to see whether hypothesis is accurate. Moreover, positions of group members at each simulation time will be assigned manually to see the impact of group member’s position.

* Case study 2: The population escape a door
  + Hypothesis: Escape rate will be the same over *n* simulation times when using the same parameter setting found in sub question 1.2
  + Analysis: Expect to see the impact of group member’s position.

1. **Research progress**

Simulation

Hypothesis testing of two prototypes about escape rates, blockage frequencies

Research time line

1. **Coursework and professional development**

As required from our faculty, I completed the course FIT 5143 in the first semester 2015. I am attending the course FIT6021 from 21 July, 2015. I also completed 116 research training hours as in Table 3.

**Table 5**- List of professional development undertaken

|  |  |
| --- | --- |
| **Activity** | **Hours counted towards coursework goal** |
| Faculty Induction | 4 |
| Research Integrity | 12 |
| FIT 5143 Course | 48 |
| FIT 6021 |  |
| FIT 4012 | 15 |
| Monash Seminar/workshop attendance | 22 |
| Participation at Monash Bootcamp Commercialisation workshop in the year 2015 | 15 |

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