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

**TO ENHANCE CROWD MODELLING**

***Abstract:***

*Nowadays, crowd modelling becomes more important in the effort of disaster prevention due to the increase in the number of public events and rapid urbanization. Various approaches have been proposed to make crowd models more realistic. Investigating crowd dynamics which unfolds in both of normal and emergency situations becomes the key for this effort since real-world emergency data is sparse. Social group dynamics has been approached in both of happened disasters and evacuation scenarios. However, the effect of social group dynamics constructed by different group members, who are different in ages, has not been investigated fully in both of evacuation simulations and real-world group data. It is caused by the fact that current crowd model studies make assumption that populations are homogeneous and the lack of a novel data collection technique which can distinguish different pedestrians in crowd. Thus, this study will explore the effect of social group dynamics in evacuation scenarios through simulations and then propose a novel data collection framework for this social group dynamics to finally validate the effects of social group dynamics through crowd simulation models with actual group data.*

1. **Introduction**
   1. Chronological human crowd disasters and efforts in disaster prevention
   2. The contribution of this study towards human crowd modelling studies
2. **Background**
   1. Crowd motion flows and self-organization phenomena in human crowd
   2. Group cohesion in nature
   3. Human crowd modelling at different scopes and agent-based models
   4. Crowd model enhancement
3. **Motivation and Research Questions**

Rapid urbanization and population growth always are 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 accidents often happen during these events (Evers, 2011), the prediction of congestion, planning of evacuation strategies, and the assessment of building layouts become important aims for risk management in urban design and crowd safety. The key to achieve these aims is the understanding of crowd dynamics leading to the formation of crowd self-organization at different events and situations especially in emergency situations (Moussaid, Helbing, Johansson, Theraulaz, 2009). It aims to enhance crowd modelling in creating realistic crowd simulation models and providing useful information for real-time crowd management (Helbing, 2015). Observable studied crowd’s self-organization include lane formation, herding, bottleneck, turbulence, stop-and-go waves. Therefore, many models of pedestrian behaviour have been proposed to describe how pedestrians move and interact to produce the patterns emerging at the scale of crowd. Highly recommended model are social-force models, Nomad model, cellular automata model, and behavioural heuristic rule model (Hoogendoorn, 2013).

To make these models are sufficient to simulate crowd behaviour in reality, two main efforts have been done. First effort is the studies focusing on calibration processes to find realistic parameters of current crowd models. Second effort is the studies trying to understand and simulate uncontrolled behaviours (leader-follower, competitive) that could be unfolded in emergency situations (Shiwakoti, 2010).

State of the art in the first effort is to find actual parameter values of crowd models. Well-known models such as social-force model (Helbing, 2000), Nomad model (Hoogendoorn, 2003) were calibrated through video recordings of pedestrian’s trajectories in Germany and Netherland to find realistic data of model’s parameters such as average velocity, desired velocity, interaction strength of pedestrians (Johansson & Helbing 2007), (Daamen & Hoorgendoorn, 2012). Social-force model was then used to explain the LoveParade disaster happened in Germany, 2010 (Helbing, 2012). The report of survivors from another fire disaster occurred in the nightclub Lame Horse in Perm, Russia in the year 2010 was used to calibrate a panicking model’s parameters including velocity, crowd density on forward directions (Bratsun, 2013). Another recent study (Zeng, 2014) also performed acquiring actual parameters of social force model when simulating pedestrians at crosswalks. The study was performed and calibrated in Japan since more than 30% of fatal traffic accidents there were pedestrians. Another study, (Aguirre, 2011), used agent-based model to simulate the crush disaster happened at the Station Nightclub, USA (2003) through the technical report conducted by National Institute of Standards and Technology (Grosshandler, 2005).

In the second effort, various social factors describing leader-follower behaviour have been investigated and then integrated into agent-based models to replay clearly-reported disasters and simulate various evacuation scenarios. By using the timeline-event report of the disaster Station Nightclub, (Aguirre, 2011) categorized leaders based on age, gender, environment familiarity and then defined ‘what-if’ rules for group members when following leaders to replay the disaster. The study was validated by comparing escape numbers of different prototypes (moving with group influence, moving individually) with actual survivor number. (Pelechino, 2006) also constructed a simulation environment and created different pedestrian roles (leader, untrained leader, group members) through agent-based model to simulate evacuation scenarios.

In a recent crowd research survey (Hoogendoorn, 2013), representing social group dynamics to produce herding phenomena hasn’t been explored in current motion models. It is caused by the fact that these models almost make assumption that populations are homogeneous and well-mixed, which is not true for real population at different pedestrian-oriented places (e.g sport stadium, high schools, working places) in recent studies (Leeson, 2014) and another Naturetechnical report (Gosce, 2014). It is also explained that the earliest models including Reynold’s model (Reynolds,1987) and Social Force model (Helbing & Molnar,1995) averaged out potential influences to produce smooth flow of pedestrian movement (Collin, 2014).

In evacuation situations, pedestrians almost do not move individually to escape. They are influenced by other pedestrian’s information (age, gender, environment familiarity) as justified through disasters occurred (Aguirre, 2011); they might become obstacles to other people in the worst case because they are waiting their expected leader. Although agent-based rules have been investigated variously to describe agents follow other people, they can’t represent how the group force is integrated in group member’s desired motion and the effect between different groups (Wijermans, 2013) (Sun, 2014). The latest study from Helbing and colleagues (Moussaid, 2010) suggested that an additional group influence force should be included in current social-force model which describes pedestrian’s acceleration over the time. However, they still made the fundamental assumption that populations are homogeneous and yet considered evacuation scenarios.

Therefore, a study which explores the social influence should be contributed in this area. It should represent sufficiently the effect of group cohesion of different pedestrians towards overall evacuation results, how this influence makes pedestrians move faster, slower, or become obstacles in evacuation situations, and whether these effects are realistic. This work is inspired by biological and human studies of Couzin and colleagues. (Couzin, 2013) realized that individual fish have to balance personal information, potentially conflicting social information, and maintain group cohesion to minimize isolation risk. In human crowd, (Dyer & Helbing & Couzin, 2009) also realized that pedestrians always seek a potential leader in sudden situations.

Among various group behaviour such as leader-follower, queuing, and competitive (Shiwakoti, 2010), this study only focuses on leader-follower behaviour since this behaviour unfolds popularly in both of normal situations and disaster occurred (Almeida, 2011), (Aguirre, 2011). Three main research questions are proposed as follows to explore the effect of social human group dynamics:

**Question 1: What is the effect of leader-follower behaviour in evacuation situations?**

Firstly, it is questionable to differentiate group members inside crowd since current models only consider crowds are homogeneous. It will pave the way for further investigation of social influence between group members in different types. Thus, sub question Q1.1 is proposed to separate group members.

**Q.1.1**: **What information makes pedestrians inside crowd interact differently when moving individually in evacuation situations?**

Through the report of Station Nightclub disaster (Aguirre, 2011), the difference of age is one of factors that make a pedestrian might become follower or leader. Also, a recent calibration work through experiments imitating emergency situations found that children (<14 years old), adults, and elders (>60 years old) interact very differently in congested or evacuation conditions than in normal condition (Hoorgendoorn, 2012). A snapshot of the study is presented in Figure 1.

Therefore, this yields a fundamental consideration about whether or not a single crowd motion model with single parameter set is sufficient to cover the different parameter distributions of these pedestrian types. Moreover, understanding crowd dynamics in situations of turning, merging, and diverging scenarios is necessary for evacuation plans in traffic network containing different micro-flows (Shiwakoti, 2011). Thus, to answer Question 1.1, this study proposes two case studies to investigate the effect of different pedestrians, who are different in ages, when they are escaping individually.

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| **Figure 1**. Differen pedestrians in ages distinguished by color cap are escaping invidivually through bottleneck in slop-whoop signal condition (Hoorgendoorn, 2012) |

Case study 1: Understanding the difference in escape rates and blockage occurrence between a population having different pedestrians in ages and a population making pedestrians homogeneous.

Case study 2: Understanding the effect of two above prototypes in merging, turning, and diverging scenarios when pedestrians move individually.

To perform these case studies, a simulation tool is developed based on the social-force model as in equation (1). Developing this tool will allow us to easily customize initial parameters of each pedestrian and environment, and monitor expected information from crowd. Investigating what causes the difference in escape rate and blockage occurrences is then performed respectively on one and two dimensional simulations with simplified versions of social force model. It aims to understand the impact of possible reasons (e.g. parameter distribution, placements, velocities of pedestrians during simulation duration before phenomena occur).

(1)

Status: Simulation to be continued

Expected outcome: The difference result in escape rate and blockages between two prototypes is continuously investigating to understand more about the difference through simplified models in 1 and 2 dimensional simulations. In merging, turning, and diverging scenarios, possible impacts such as the turbulence in crossings, how quickly they diver in multiple corridors will be investigated.

**Q.1.2: What is the effect of group cohesion in evacuation scenarios when group members are different in ages?**

After distinguishing pedestrians based on ages, this question aims to understand the impact when adding social group influence. From here, a social force model separated for three above pedestrian types will be used for this question. Social group influence force will be added into this model as Helbing’s suggestion (Moussaid, 2010) in equation (2). A population contains different groups inside (adult group, children group, elder group, and a group of three pedestrian types) will be investigated to understand group cohesion and the interaction between groups in three case studies. Their results will be compared with the result of pedestrians escaping individually.

(2)

Case study 1: Understanding the effect of group cohesion when performing simulations of different groups escaping through one-exit gate, merging, diverging, and turning situations.

Case study 2: Understanding the effect in above situations when group size is changed and group members are placed sparsely.

Case study 3: Understanding the effect in networks of merging, diverging, and turning layouts.

Status: Simulations to be performed. Three prototypes as bellow will be compared each other.

* Crowd of pedestrians moving individually (by using equation (1))
* Crowd of pedestrians following a leader in a group
* Crowd of pedestrians maintain a certain distance to the group’s centre of mass.

Expected outcome: Proposed case studies aim to understand whether the group cohesion can become obstacles to other group’s movement (non-moving or moving upstream), and how group is sunk and stretched because of other group’s pedestrians in these situations. It is also expected to see the impact when changing group size such as how a pedestrian moves when intersecting with a group moving in a turning situation and the interaction between pedestrians in group and out-group pedestrians. Different network layouts are constructed from evacuation situations conducted in Finland (Rinne & Tillander & Gronberg, 2010). They include eighteen evacuation situations in different building types ranging from hospital to stadium were conducted in Finland in 2007 to 2010. These situations are detailed with floor layout information.

**Questions 2: How to acquire actual data of group members in above situations**?

Recently, real-world data for crowd research becomes more important because of the demand in calibrating models and constructing new agent-based rules (Helbing, 2011). The currently largest accessible dataset in this area is from real-world data constructed by 1200 participants over five-day experiment in Germany (Lammel & Seyfried & Bernhard, 2014). However, conventional data acquisition techniques, which rely on camera-based approach, make pedestrians interchangeable. Thus, it raises a need for acquiring data which can distinguish pedestrians inside group. Human-sensing based approaches are recommended in recent studies. (Kjargaard, 2012) used accelerometer and compass sensors on mobile device and Wifi to detect flock of pedestrians. (Seer, 2014) used Kinect sensors to calibrate social force model. (Claudio, 2014) used Bluetooth to scan nearby device to propose proximity graphs for lane formation and bottleneck detections. Thus, this study proposed two sub-questions to acquire data of different group members and group influence as in Table 1:

**Table 1**- Data acquisition of group member and group information to infer group cohesion

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| **Scope level** | **Acquired Data** |
| Group (meso level) | Percentage of pedestrian types in group  Total population size  Average speed at a certain time |
| Individual (micro level) | Pedestrian type  Environment familiarity  Pedestrian trajectory  Distance to other group members at a certain time  Distance to group’s centre of mass  Heading direction at a certain time  Average speed over the time  Speed at a certain time  Desired speed |

Table 1 represents required data to understand the effect of group cohesion towards different pedestrian inside group and other groups.

**Q.2.1: What is the technique to collect movement data of group members in turning, diverging and merging scenarios?**

This study will develop a downloadable mobile application to allow pedestrians in the same group register information (name, age, environment familiarity, and group ID- assigned to distinguish with pedestrians in other groups) and track their positions when moving in the same group. When the application is enabled by pedestrians, it will collect periodically nearby MAC addresses and Bluetooth signal strength of surround devices and transfer to server. To infer pedestrian’s locations, predefined devices (mobile devices or iBeacon devices with known MAC Address, a unique identifier) are placed at known positions in Cartesian coordinator. Inferring locations is performed commonly through triangulation and trilateration techniques. It was successfully applied in previous study (Wang, 2013). Mobile-based data collection framework offers a lightweight method comparing to lab-controlled experiments using camera-based approach because of time, cost, and pedestrian identification. This method takes advantages of existing floor layout design (corridor, turning, merging, and diverging situations) rather than constructing experimental obstacles, and it also easily captures natural movement of different pedestrian types even in public events. A full data collection framework is represented in below figure.

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| **Figure 2**. Proposed group member data collection framework |

Status: An Android mobile application is almost finished. It allows pedestrians register information and scans surrounding devices (iBeacons and mobile devices) for each 1-second interval and then transfers to server. The server side development is in progress. It also allows tracking real-time indoor position of pedestrians on server side.

Expected outcome: A data collection framework is developed to collect vast data of large crowd in public events. A Hadoop distributed file system is used to store raw data, inquiring group information and pedestrian’s trajectory over the time is developed as scripts to access these files.

**Q.2.2: How to deploy the data collection framework in social aspect?**

Take advantages of this lightweight data collection framework, this study will perform case studies:

Case study 1: Two groups with different sizes start together at NICTA area and go in the same direction to the kitchen at Floor 6, Building H, Monash Caulfield.

Case study 2: Two groups go in the same direction from NICTA area and turn right to exit gate at elevator at Floor 6, Building H, Monash Caulfield.

Case study 3: A population is mixed from above two groups. The population starts at the exit gate and then diverge into two escaping directions (NICTA area, kitchen area).

Case study 4: Members of two groups are placed at NICTA and kitchen areas respectively, they go to emerge and escape at main exit gate of the floor.

Above four case studies aim to understand group cohesion of adult pedestrian types.

Case study 5: It is also expected to perform experiment at workshops hold at SensiLab, Monash University. A workshop’s common agenda means that a population of participants who have different topic attention often gather at the welcome area at the beginning time of the workshop and then split into different rooms of majors. This case study will provide a compound data of pedestrians who might not familiar with design layout of SensiLab, and who are moving simultaneously at turning, merging, diverging layouts, and who are different in ages.

Case study 6: The application will be installed on prepared devices. This case study aims to collect data of pedestrians in other public places rather than in Monash area. A shopping area is expected. Random group of pedestrians visiting the area is invited to use the application and moving naturally to capture their movement. It aims to collect data from different pedestrian types (in ages and environment familiarity).

**Question 3: What qualitative effects of group cohesion occur in both of simulation environment and actual observed data?**

The effect of group cohesion is investigated in group members itself and with other groups in turning, merging, and diverging scenarios especially in high-density places. Thus, this question is divided into these scales.

**Q.3.1: What is the impact of group cohesion on group members?**

Through collected data in Question 2, this study presents a methodology as in figure 3 to investigate the effect of group cohesion towards group member and leader of a group.

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| **Figure 2**. Proposed methodology to understand group cohesion effect |

Group members in case studies 1, 2,3,4,5 in Question 2 are uniform in pedestrian type (adults) and design layout familiarity, thus these case studies aims to understand the effect of group cohesion on group members position and speed since they are maintaining a certain distance with group’s centre of mass.

In case study 6 in Question 2, a group leader is selected as a group

What is with leader, uniformed individual with group of young, elder, or adult, mixed?

one of them is leadership, heading direction over the time, a position of leader in core position and one starting on the periphery of the group is most effective way of guilding the group quickly and accurately to a target, test through coner, … merging, divering., with different pedestrian types

**Q.3.1: What is the impact of group cohesion on other group’s movement?**

what is the impact when a group of different pedestrians moving and interact with an individual moving alone,

**Question 4: How to calibrate the social force model integrated group dynamics in which group members are different in ages?**

This study will investigate optimization techniques and previous calibration studies to extract optimal parameters which minimize the distance error between actual position and predicted position from the model after an interval T seconds (equation 2).

(2)

This work defines three approaches to calibrate the model’s parameters:

* Using dataset from pedestrians in the same group but group’s centre of mass
* Using dataset from pedestrians in the same pedestrian types and then constitute for group
* Using dataset from pedestrians in the same pedestrian types and then constitute for group, but specific person, not group’s centre of mass

To verify the model’s parameters, this study proposes the verification methodology:

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| **Figure 2**. Verification methodology based on two approaches for each group |

*//new validation by pedestrian in group by familiarity, identify person to follow. //it could be a non-linear function depends on pedestrian types*

* Is the model’s parameters fit for all scenarios including turning, merging, diverging situations of the same group?
* Is the model after calibrated of each group fit with other group’s information in each scenario?

Verification process based on pedestrian-type approach is to understand how different pedestrian types in the same group moves through turning, merging, and diverging layouts.

**4. Project Trajectory**

**4.1 Project components**

The proposed research questions in this study can be separated into core and peripheral elements, and the associated probability of non-completion.

**Table 2**- Importance and probability of failure of proposed research questions

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| --- | --- | --- |
| **Research Questions** | **Importance level** | **Probability of Failure** |
| 1)What is the effect of leader-follower group behaviour in evacuation situations? | Core Element | Nil |
| 2)How to acquire actual data for different pedestrian types and group influence in above situations? | Core Element | Nil |
| 3) What principles of group cohesion generate qualitative effects in both of simulation models and actual observed data? | Core Element | Nil |
| 4) How to calibrate the social force model integrated group dynamics in which group members are different in ages? | Low | Medium |

**4.2 Workflow**

The figure illustrates how questions incorporate and return outcome. Question 1, 2 are investigated in order to understand comprehensively heterogeneous aspects of population before acquiring data from actual pedestrians.

The outcome of project:

it offers key information from crowd phenomena in live events which can give event organizers decisive minutes to try and restore the order of crowd before deteriorative situations can occur.

- Practical use: Investigation of social group dynamics on different pedestrian types and leadership so that easily apply for pedestrian-oriented places for disaster prevention when trying to re-order crowd before hazardous can happen

-A better data collection (pedestrian type, trajectory, environment information) for further studies and data collection framework (validation, and model calibration for each pedestrian types)

**4.3 Project Timeline**

**4.4 Project progress**

-Crowd simulation screen and quantitative results of Question 1

-Snapshot of data collection mobile application

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 31 July, 2015. I also completed 116 research training hours as in Table 3.

**Table 3**- List of professional development undertaken

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| **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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