**EXPLORING THE HETEROGENEITY** **INSIDE POPULATION TO ENHANCE CROWD MODEL IN EMERGENCY SITUATIONS**

***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 in emergency situations. Investigating crowd dynamics which unfolds in both of normal and emergency situations is the key to make current models more realistic since real-world emergency data is sparse. Social group dynamics has been approached in both of happened disasters and evacuation scenarios. However, integrating social group influence into crowd motion models has not been explored fully since these models make assumption that populations are homogeneous. Thus, this study will explore the impact of social group dynamics between pedestrians who are different in ages in the same group in evacuation scenarios. A data collection framework is then proposed to finally contribute a crowd model integrating this dynamics.*

1. **Introduction**
   1. Chronological human crowd disasters and efforts in disaster prevention
   2. The contribution of this study towards human crowd research community
2. **Background**
   1. Crowd motion flows and self-organization phenomena in human crowd
   2. Crowd modelling at different scopes and agent-based models
   3. 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). 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, and cellular automata model, behavioural heuristic rule model (Hoogendoorn, 2013).

To make these models are sufficient to simulate crowd behaviour in emergency situations, 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) 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 the 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 *Nature* technical 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 emergency 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 pedestrian’s desired motion (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. 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 influence between different pedestrians inside group and how this influence makes pedestrians move faster or slower in emergency situations. 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.

//make sure no one work in this area from 2010-2015

//merge Q1 into q2,//specific , how many social influencer relationshiop , we only study leader follower, Most influence in, //what type of social influence most

//qualitative effect between situation simulation and real actual, if I have leader, what happen

//stop talking panic

//extend to new case study

//what data are use will extract from data experiment must clear data.

//Also inspired by children follow their parent although their parent moving behind, Helbing use centre of mass

Thus, to address the social group dynamics in crowd motion models, this PhD study proposes main questions:

**Question 1**: **What fundamental information makes pedestrians interact differently in emergency situations when only moving individually?**

Firstly, it is questionable to differentiate pedestrians inside crowd since current crowd models only consider crowds are homogeneous. It will pave the way for further investigation of social influence of these types and between pedestrians in different types. Through the report of Station Nightclub disaster (Aguirre, 2011), the difference of age is one of factors that make pedestrians 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). 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.

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

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). Therefore, to answer Question 1, this study proposes two sub-questions:

**-Does a population having different pedestrian types in ages generate different escape rate and blockages than a homogeneous population does in one-exit gate?**

To answer this sub question, a simulation tool is developed based on the social-force model. 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).

Status: Simulation completed

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.

**- Do these two prototypes (heterogeneous and homogeneous population) generate different escape rates, blockages and turbulence phenomena in merging, turning, and diverging scenarios?**

Possible impacts such as the turbulence in crossings, how quickly they diver in multiple corridors will be investigated.

Status: Simulation to be performed

Expected outcome: The impact of pedestrian types in evacuation scenarios will be quantitatively investigated.

**Question 2: What is the impact of social group influence in evacuation situations**?

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), equation (1). 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.

(1)

Case study 1: What is the impact when performing simulations of different groups escaping through one-exit gate, merging, diverging, and turning situations?

Case study 2: What is the impact in above situations when group size is changed and pedestrians in the same group are placed sparsely?

Case study 3: What is the impact when simulating pedestrian groups in a network of merging, diverging, and turning layouts?

Status: Simulations to be performed

Expected outcome: Proposed case studies aim to understand whether the group cohesion can become obstacles to other group’s movement, 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 pedestrian in group with out-group pedestrian. 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 3: How to acquire actual data for different pedestrian types and group influence 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 pedestrian types and group influence:

**-What is the technique to collect movement data of groups?**

This study will develop a downloadable mobile application to allow pedestrians in the same group register information (name, age, 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 idenntifier) 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.

|  |
| --- |
|  |
| **Figure 2**. Proposed 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.

**-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 will 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.

The experimental times of each case study is at least three for further investigation.

**Question 4: How to calibrate and validate social group influence in current force model**?

This question is the key to integrate the social group dynamics into current social force model. Each group information (pedestrian type percentage, total population size, average speed) and information of each pedestrian inside that group (pedestrian type, trajectory, distance to other group members, distance to group’s centre of mass, heading direction, average speed, desired speed) are extracted for calibration and validation process of the model in equation 1.

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 two 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:

|  |
| --- |
|  |
| **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.

**Question 5**: **What is the shared information between group members to infer leadership?**

This question aims to put a deeper understanding on the shared properties between group members about:

* How does a pedestrian select a temporary pedestrian inside group to follow in a meantime?
* What group’s parameter changes if a new member joins?

**4. Thesis Structure**

**5. Project Trajectory**

**5.1 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 1**- Importance and probability of failure of proposed research questions

|  |  |  |
| --- | --- | --- |
| **Research Questions** | **Importance level** | **Probability of Failure** |
| 1)What fundamental information makes pedestrians interact differently in emergency situations when only moving individually? | Core Element | Nil |
| 2)What is the impact of social group influence in evacuation situations? | Core Element | Nil |
| 3)How to acquire actual data for different pedestrian types and group influence in above situations? | Core Element | Nil |
| 4) How to calibrate and validate model? | High | Nil |
| 5)What is the shared information between group members to infer leadership? | Low | Low |

**5.2 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:

-A better data collection (pedestrian type, trajectory, environment information) for further studies and data collection framework

-A parameter set of different pedestrian type so that we can apply easily in pedestrian-oriented places

- Investigation of social influence on different pedestrian types, leadership

**5.3 Project Timeline**

**5.4 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 1.

**Table 2**- 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 |

1. **References**

Aguirre, B. E., El-Tawil, S., Best, E., Gill, K., Fedorov, V., (2011) Contributions of social science agent-based models of building evacuation. *Contemporary Social Science: Journal of the Academy of Social Science*, Pages 415-432.

Bratsun, D., Dubova, I., Krylova, M., Lyushnin, A., (2013) Computational Modelling of Collective Behavior of Panicked Crowd Escaping Multi-floor Branched Building. *Proceedings of the European Conference on Complex Systems*, Pages 659-663.

Daamen, W., & Hoogendoorn, S. P.,2012. Calibration of pedestrian simulation model for emergency doors for different pedestrian types. *Transportation Research Record*, 2316, 69 - 75.

Dyer, J. R. G., Johansson A., Helbing, D., Couzin, I, D., Krause, J., (2009) Leadership, consensus decision making and collective behaviour in humans. *The proceeding of The royal society part B*, pp. 781-789.

Evers, J. (2011) Modelling Crowd Dynamics: a Multiscale, Measure-theoretical Approach. *Master Thesis*. Eindhoven University of Technology, The Netherlands.

Gosce, L., Barton, D. A. W., Johansson, A., (2014) Analytical Modelling of the Spread of Disease in Confined and Crowded Spaces, *Nature Scientific Reports*, Vol. 4(4856).

Grosshandler, W., Bryner, N., Madrzykowski, Kuntz, K., (2005). Report of the Technical Investigation of the Station Nightclub fire. Technical report, *National Institute of Standards and Technology, USA*, 2005. Available at <http://fire.nist.gov/bfrlpubs/fire05/PDF/f05032.pdf>

Hoogendoorn, S.P., Duive, .D.C., Daamen, W., (December 2013). State-of-the-art crowd motion simulation models. *Transportation research part C*, Volume 37, Pages 193-209.

Hoogendoorn, S.P., Bovy, P. H.L (2003) Simulation of pedestrian flows by optimal control and differential games. *Optimal Control Applications and Methods*, Volume 24, Pages 153-172.

Helbing, D., Molnar, P., (1995) Social force model for pedestrian dynamics. *Physical Review E,* 51.

Helbing, D., Farkas, I., Vicsek, T., (2000). Simulating dynamical features of escape panic. *Nature*, Pages 4487-4490

Helbing, D., Balietti, S., (2011). How to Do Agent-Based Simulations in the Future: From Modeling Social Mechanisms to Emergent Phenomena and Interactive Systems Design.

Helbing, D., Mukerji, P., (2012). Crowd disaster as systemic Failures: Analysis of the Love Parade Disaster. *EPJ Data Science*, Volume 1(7).

Johansson, A., Helbing, D., Pradyumn, K.S., 2007. Specification of the social force pedestrian model by evolutionary adjustment to video tracking data. *Advances in Complex Systems*, 10, 271-288.

Kjargaard, M. B., Wirz, M., Roggen, D., Troser, G., (2012) Detecting Pedestrian Flocks bby Fusion of Multi-Modal Sensors in Mobile Phones. *Proceedings of UbiComp Conference*.

Lammel, G., Seyfried, A., Bernhard, S., (2014) Large-scale and microscopic: a fast simulation approach for urban areas, 93th Transportation Research Board, Washing DC.

Moussaid, M., Helbing, D., Garnier, S., Johansson, A., Combe, M., Theraulaz, G., (2009) Experimental study of the behavioural mechanism underlying self-organization in human crowds. *The proceeding of The royal society part B*.

Moussaid, M., Perozo, N., Garnier, S., Helbing, D., Theraulaz, G., (2010) The Walking Behaviour of Pedestrian Social Groups and Its Impacts on Crowd Dynamics. Plos One, Vol 5(4)

Moussaid, M., Theraulaz, G., (2012). Traffic Instabilities in Self-Organized Pedestrian Crowds. *PLos Computational Biology*.

Pelechano, 2006. Crowd Simulation Incorporating Agent Psychological Models, Roles and Communication. *In proceeding of 1st Workshop of Crowd Simulation*.

Reynolds, C., W., (1987), Flocks, herds and schools: A distributed behavioural model, New York, *NY: ACM*, 25-34.

Seer, S., Rudloff, C., Matyus, T., BBrandle, N., (2014). Validating social force based models with comprehensive real world motion data. *In proceedings of Pedestrian and Evacuation Dynamics, PED 2014*, pp 724-732.

Shiwakoti, N., Sarvi, M., Enhancing the panic escape of crowd through architectural design. *Transportation research part C*, Volume 37. Pages 260-267.

Rinne, T., Tillander, K., Gronberg, P. (2010) Data collection and analysis of evacuation situations Espoo 2010. VTT Tiedotteita Research Note 2562.

Wang, Y., Yang, X., Zhao, Y., Liu, Y., Cuthbert, L., (2013). Bluetooth Positioning using RSSI and Triangulation Methods. *In Proceedings of IEEE 10th Consumer Communications and Networking Conference (CCNC).*

Weidmann, U., Uwe, K., Schreckenberg, M. (eds). (2012) Pedestrian and Evacuation Dynamics 2012, *Springer*.

Wijermans*,* (2013). CROSS: Modelling Crowd Behaviour with Social-Cognitive Agents. *Journal of Artificial Societies and Social Simulation*.

Zeng, W., Nakamura, H., Chen, P., 2014. A Modified Social Force Model for Pedestrian Behavior Simulation at Signalized Crosswalks. In *the 9th International Conference on Traffic & Transportation Studies*, 521 – 530.