Incorporating Human and Social Behavior in Computational Egress Analysis

1. MOTIVATING PROBLEMS

Recent studies of past disastrous accidents have shown that human behavior plays a crucial role affecting evacuation time and patterns. For example, in the 9/11 World Trade Center studies, people demonstrated helping behaviors, even towards strangers, while evacuating [1]. Decision to evacuate depends on many human factors, such as presence of authorities and individual's experience and familiarity with the environment. Such factors have significant influences, for example, resulting in delayed reaction to initial evacuation. Crowd density and group relationships can greatly affect evacuation patterns [2,3,4,5,6]. There is a clear need to better comprehend the different human and social behaviors for emergency evacuation analysis, simulation, design and planning. Based on analyses of recent fire and emergency events, social scientists have developed theories that attempt to capture human behavior based on individual characteristics, group relationships and crowd behaviors. Our research proposes to incorporate some of these theories in a computational framework that will potentially lead to more accurate virtual simulation of emergency evacuation and to better support "what-if" design scenarios for emergency planning and management.

Although provisions governing egress design are prescribed in codes and standards [7,8], it has long been recognized that code provisions alone are not sufficient for design of safe egress. Particularly for spaces with complex geometry, local geometry and local environmental constraints can affect crowd movement [9]; these effects are rarely considered in the codes and standards. Many egress simulation tools are now available. However, as concluded in a recent study to UK Cabinet office [10], current tools focus mostly on animating crowd movements, with oversimplified social behavior assumptions in the virtual crowd. There is a need for simulation tools to "improve the realism and accuracy of crowd behaviors and movement, in addition to improving visual aesthetics" [10].

This interdisciplinary research, with investigators from engineering, computer science and sociology, proposes to study current theories regarding human and social behaviors in emergencies and to incorporate social theories in an agent-based computational simulation framework. So far, for the year-1 seed project, we have (1) conducted a number of field observations (in partnership with our industry partner), (2) established a computational framework based on human and crowd behaviors as discussed in the literature, and (3) simulated several scenarios that take into consideration social relationships and interactions between evacuees and operational staff. In the proposed year-2 seed project, we plan (1) to formalize the computational framework and to implement different social behaviors into the simulation platform, (2) to validate the model with real-life data, and (3) to actively engage industrial collaborators and on-campus public safety and facility management personnel to establish metrics for validations.

From the theoretical perspective, integrating social science theories into engineering simulation models represents a fundamental and novel research endeavor. The computational model aims to support performance-based egress design analysis of facilities under specific circumstances and for specific events. The research will provide designers and facility managers useful recommendations to improve safe egress systems by addressing the unique characteristics of the facilities and the occupants. In addition, the tool can potentially be used to evaluate safety and evacuation procedures and formulate better crowd management policies for the operation of large facilities.

2. THEORETICAL AND PRACTICAL POINT OF DEPARTURE

2.1. Social Theories – Understand how people react in emergency situations

The proposed research builds upon a wealth of social theories that have been developed by social scientists on the subject. Earlier theories [12,13] focused on the change of the internal state of the people and assumed non-adaptive behaviors during emergencies. Group mind-theory by Le Bon [12] suggested that people in heightened mood would be "transformed" to be a part of the crowd and lose individuality.

The bounded rationality theory by Mintz [13] argued that people act rationally to achieve a better outcome under limited cognitive capacity. Sherif and his colleagues [14], who are social psychologists, were among the first who suggest that interactions between people can lead to emerging social norm, driving crowd behaviors that are socially-ordered. This alternative explanation divulged a new realm of crowd theories resting at the social and the group level. Several recent social theories, such as the emergent norm theory by Turner and Killian [14], the affiliative theory by Mawson [15], as well as the place script theory by Donald and Canter [16], further elaborated the importance of past experience and social settings on people's reaction in emergencies. The summary of the mechanisms derived from the social theories is presented in Table 1.

Table 1 Mechanisms derived from social theories

THEORY	MECHANISMS
Group mind [12]	–Transformation process takes place which individuals become a part of the crowd with anonymity and share group emotion and objective. They become identical to the others in the crowd. –Transformed person would feel, think and act in a manner different from in the state of isolation
Bounded Rationality [13]	–People act adaptively with limited capacity as a result of their perception of the situation, the expectation and reaction of others, rather than the emotional excitement from the crowd. –Individual rationality, expectation and reward system can explain cooperative or competitive behavior.
Emergent Norm [14]	–Milling as a social interaction process facilitates the collective definition of the situation. –Keynoting is predisposition convergence shared by a major portion and advocated by a keynoter. –Pre-existing social structure and roles govern human behaviors during emergency situations.
Affiliation [15]	–People's motivation to move to a particular direction in emergencies is based on place and people affiliation and familiarity.
Place Script [16]	–Social role and place rules (together they form the place scripts) govern the reaction of people.

2.2. Computer simulation – Attempts to simulate crowds with behaviors

Many computational tools are now commercially available for egress simulation and design of exits. Zheng, Zhong and Liu [17] reviewed different egress simulation models by classifying them into cellular automata, lattice gas, social force, fluid dynamics, agent-based, game theory and experiments with animals. In the past several years, "agent-based model" has been widely adopted in the crowd simulation field. We reviewed and summarized in Table 2 several approaches that implement human behaviors in agent-based simulation models.

Table 2 Decision making implementation in computer models

Model	Methodology	Summary
OCEAN Personality Model [20]	Mapping and evaluation function	The OCEAN personality framework is mapped to agents' behaviors through a set of utilities functions. The model is capable in simulating a range of individual behaviors such as panic, impatience and escape.
ViCrowd Model [21]	Rule-based	Crowd is modeled by 1) scripted behaviors 2) defining behavioral rules using events and reactions, and iii) by providing an external control to guide crowd behaviors in real time. A rule-based system is built to control the agents' behaviors.
FSM for emergency situation [22]	Social force and potential field	It is an extended version of Helbing's social force model to incorporate normal life behaviors and risk behaviors with social force constructs. The decision behavior (i.e. behavior triggered by an event) is modeled with a simple Finite State Machine to handle the agents' states change.
Way-finding model in EXODUS [23]	Graph search with cost function	Agents' navigation decision is defined by the result of graph search that returns a path with the lowest cost. The criteria in the cost function include travel distance, travel time and the number of turns.
MASSEgress [24]	Decision tree	Based on the agent's urgency level, it invokes the corresponding decision tree and check situational conditions to decide the egress behavior.

2.3. The gap between social behaviors and simulation model

"The fundamental understanding of the sociological and psychological components of pedestrian and evacuation behaviors is left wanting [in commercial computational simulation]" [18]. The sentiment has been echoed by authorities in fire engineering and social science [3,11]. This makes all the more significant the fact that MASSEgress, the model we propose to further develop, has been recognized as a pioneering and sophisticated approach to bridge this gap [11]. Specifically, a recent study commissioned by the UK Cabinet Office [10] has highlighted our effort in addressing the need to incorporate human behavior in egress simulation. Moreover, there have been other recent efforts to incorporate social behaviors into simulations in both industry R&D studies and academic research. For example, the crowd simulation team in Disney R&D aims to improve park designs and understand guests' movement pattern through incorporating some commonly observed behaviors of park guests [19]. Aguirre et al [11] describe the use of an agent-based simulation model, which attempts to incorporate the pro social theory in simulating emergency evacuation. Some of the features of the program include implementation of leader role agent and "group-stickiness" parameters, which provide means to simulate population at a group level and observe emergent pattern as a result of social relationships. Such group effects on evacuation patterns have not been explored in current tools. In summary, there is an increasing interest in both the industry and the academic research community to incorporate human and social behaviors into simulation tools to achieve more reliable simulations results for facility designs.

3. PROPOSED RESEARCH

We propose to study social theories and develop an egress simulation framework incorporating human and social behaviors. We conjecture that the process of human decision-making in emergency situation is affected by three basic factors: individual decision, group's pre-existing and emergent norm, and crowd characteristics. In the past 6 months, we have conducted field observations, and developed a preliminary computational framework that allows us to incorporate some of the social behaviors observed in the field. In the year-2 research, we propose to implement different social behaviors to further instantiate the computational framework. Furthermore, the social behavior models will be evaluated with field data. We also plan to develop a set of metrics to validate the simulation model.

3.1. Implementing different social behaviors in computer simulations

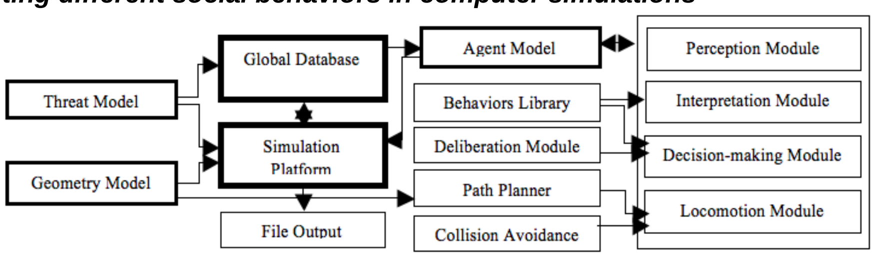


Figure 1 Computational Simulation Framework

Figure 1 schematically depicts the system architecture of the multi-agent simulation framework which consists of three major components, namely *Global Database*, *Simulation Platform*, and the *Agent Model*. A Global Database is designed to maintain all the information about the environment and the agents. A Simulation Platform is developed to perform the simulations and to visualize the results. The Agent Model consists of four basic modules to update the agent's decision:

1. A **Perception Module** collects the information of surrounding environment as perceived by an agent. The information includes visible threats, group members' locations and group status, neighbors' location and crowd status, and visible floor objects (e.g. doors and exit signs).
2. An **Interpretation Module** takes the perceived information as physical cues and social cues and translates them into the agent's beliefs of the situation, such as the perceived dangerous level of the threat and urge to leave the building.
3. The **Decision-making Module** determines the goals of the agent at the current time step and evaluates each behavior in the **Behaviors Library** by assessing how close the goals satisfy the given behavior. The **Deliberation Module** then assigns the plans in executing the most desirable behaviors.
4. The **Locomotion Module** executes the final decision and calculates agent's movement using **Path Planner** and **Collision Avoidance** procedures**.**

The design of the simulation framework is highly modularized such that future extensions, such as staircase modeling, smoke and fire simulation model as well as new behavioral assumptions of the population, can be implemented easily by modifying the corresponding module(s).

3.2. Data Gathering

The data collected so far has been mainly in the format of videos footage. While the theme of our study is emergency evacuation, it is extremely difficult to take videos during emergencies because the occurrence of emergency events is unpredictable and often dangerous. Although there is CCTV footage which possibly capture the events, access to emergency evacuation data is usually restricted and is not available for public use. Occasionally, for large-scale emergency events, such as the stampede which occurred in the 2010 Love Parade, videos taken by witnesses can be found online. Even though these videos capture only local crowd patterns, they lend many insights about human responses in real emergencies. Our plan is to continue to collect and archive emergency videos for analyses. If necessary, qualitative records such as surveys, interview scripts and guidelines would be collected as well.

In collaboration with our industrial partner, Disney Imagineering, and University Public Safety Department, we have started to systematically and strategically collect crowd movement data, especially during mass gatherings at public areas. We have conducted field experiments during the park opening in one of the highest traffic intersections at Disneyland, CA, and at an evacuation drill in one of the Disney parks. We will continue to work collaboratively with Disney R&D to collect data from outdoor park areas and in certain indoor facilities. In collaboration with the on-campus public safety office and event management office, we plan to gather new data for sports arenas. The areas planned for data collection in the immediate future (during this coming summer) are enlisted in Table 3.

Table 3 Suggested areas of video taking

Venue	Shooting Area	Time	Expected Observation
Disneyland outdoor area	Main Street Entrance to Discovery Land	After parade /All day	• Group navigation in high crowd density • Stop-and-go behavior
Disneyland theater	Aladdin (Figure 3a) Disneyland Junior (Figure 3b) Stunt Show	After show	• Initial delay to start exiting • Orderly exiting behavior • Group navigation
Stanford Stadium	Tunnel receiving graduates from field (Figure 2b) Tunnel exit A-F at mezzanine level	Commencement Exiting /Post-game exiting	• Effect of emotions on exiting behaviors • Initial delay to start exiting • Group navigation • Exit route preference

(a) (b)

Figure 2 (a) Location of the Main Tunnel in Stadium and (b) Video Shooting Location

(a) (b)

Figure 3 (a) Aladdin Show Theater and (b) Disneyland Junior Theater

Our data collection activities, besides videotaping of crowd movement, will gather information needed for simulations. The information includes (1) the building geometry; (2) occupants demographics; (3) the locations of signaling devices and designations (i.e. attraction points); (4) the communication; (5) staff arrangement; and (6) the total number of occupants in the facility and the total exiting time.

3.3. Model Calibration and Validation

We plan to calibrate and validate our framework with real-life egress data and online archives of past emergency events [4,24,25]. In order to utilize the data from different sources and of different formats, we need to establish a set of validation metrics (1) to extract the input parameters as simulation assumptions, and (2) to compare the simulation results with real-life observation through some measureable criteria. In developing the validation metrics, we plan to integrate views from both industry and research groups. Our research team, Disney R&D, and the crowd simulation group at Technical University Munich have held regular meetings to identify crowd simulation issues and to define a set of useful validation metrics. Table 4 shows an excerpted summary of the validation metrics.

Table 4 Examples of Input and output parameters

Level of Description	Input^	Output
Individual	Average waiting time	Navigation speed
Group	Separation distance	Navigation speed and Navigation form
Crowd	Influx rate/ initial location	Density
	Mood	Navigation pattern
	Population assumption*	Overall traveling speed
	Density	Congested area
Exiting	Delay time	Route adopted
	Total evacuation time	Exits usage

^It is noted that the list of input parameters are not the only model input assumptions. Other inputs, such as unimpeded walking speed and body sizes are set as the default input to the model.
*Population assumption defines the occupants using top-down approach and specifies the demographics, social network and any specific role of the population.

Figure 4 shows the proposed validation process. The input values for a specific scenario would be extracted from the simulation results. The output of the simulation will be compared to the observed scenes from videos with the metrics proposed in Table 4. In order to assume appropriate behavioral assumptions, we refer to social scientists' studies of human behaviors. In addition, we would actively seek the feedback from Stanford University's event management and Public Safety Department to incorporate their expert knowledge when validating the simulation framework.

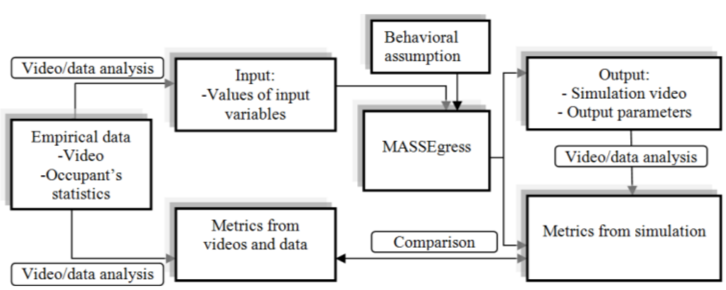


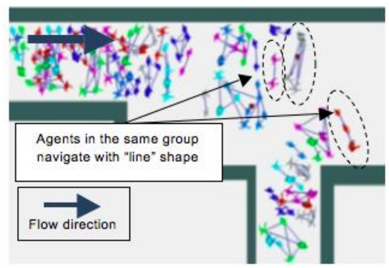
Figure 4 Proposed validation process

3.4. Summary of Research Accomplishments and Further Investigations

For the first year seed project, we have carried out a comprehensive study on the state-of-the-art social theories related to egress and have designed a computational framework to implement different theories for egress analysis. The following briefly summarizes our progress and accomplishments to date.

- *Literature review on the social theories to develop the computational framework*. We studied the variables adopted by the social scientists when explaining human behaviors in emergency situations. These variables are classified into individual, group and crowd level and are implemented in the computational framework. The multi-level analysis of social theories drives the design of social agents in the simulation, which represents the evacuees.
- *Establishing collaborations with industry partners and university event management teams.* Regular meetings are held with Disney's researchers to discuss issues in data collection and model validation. In addition, we have met with personnel in Stanford University's Public Safety Department and Athletics Department to understand the operation and crowd control procedures. We have obtained positive feedback and consent from the Police Chief of Public Safety Department and the Deputy Director of Athletics Department on the use of video recorders for crowd data collection.
- *Collecting and analyzing crowd movement data*. We are collaborating with our industry partner, Disney Imagineering, to collect first-hand video data on crowd navigation. We have conducted field observations and analyzed the film to identify group behavior and flow patterns. In addition, we have obtained useful CCTV footage of Stanford Stadium from Public Safety Department. Based on our preliminary analysis of the videos, we identified some interesting social behaviors, generalized the observed behaviors and incorporated in the computational framework. Figures 5(a) and 5(b) show examples of the navigation patterns of groups encountering multiple flow directions.

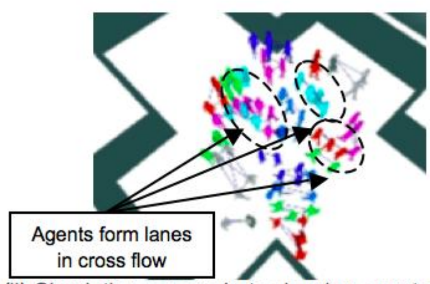
(i) A frame of video showing guests in groups exiting from the gate (unidirectional flow indicated by the blue arrow). The groups organize themselves in form of horizontal "line" shape as they navigate the corridor to the gate.



(ii) Simulation screenshots showing agents in social groups navigate to the left. The grey lines connecting agents indicate the social ties between them. Agents in the same group navigate with "line" shape (indicated by circles).

(a) Groups navigate in form of horizontal "line" shape in unidirectional flow

(i) A frame of video showing guests in groups navigating a congested intersection (multi-directional flow indicated by the green and red arrows). Groups form "lanes" when there is multi-directional flow.



(ii) Simulation screenshots showing agents in social group navigate in all directions. Agents form lanes when there is multi-directional flow (indicated by circles).

(b) Groups form lanes when they encounter multi-directional crowd flow

Figure 5 Examples of crowd flow patterns

In addition to continuing the works described in the first year proposal, the second year project will include future research on the following critical issues:

- *Implementing different social behaviors in computer simulations.* To address the challenge in translating social mechanisms into algorithms that can be implemented in the simulation framework, we would conduct further study about how human react to external cues (such as alarm and fire) [1,6] and develop mapping functions which translate the cues to different levels of emotional urgency and time delay. We also propose further study in decision analysis techniques to incorporate expert knowledge in the modeling assumptions.
- *Developing unified validation metrics jointly with industry partners and research groups.* We have established a strong collaborative effort with Disney Imagineering and crowd simulation group in Technical University Munich, to discuss different aspects of crowd simulations, particularly on data collection and validation. So far, we have jointly identified several interesting sets of videos and have formulated a set of validation metrics based on the observations on crowd flows and group behaviors. In order to further develop the validation metrics and to perform validation tests, we plan to work with different teams within Disney R&D, such as the computer vision team in Zurich, to explore different techniques to analyze the flow patterns and extract the quantitative parameters, such as crowd density and speed.
- *Engaging University's event management team and Public Safety Department in the design evaluation process.* To derive insights from the simulations to aid egress design, we will explore different statistical and data visualization techniques to organize and to display the results, such as the one shown in Figure 6. By organizing and presenting the results in a systematic, visual manner, we plan to work closely with Stanford University Public Safety Department and the event managers from Athletic Department to identify and address key concerns in egress design and evacuation planning.

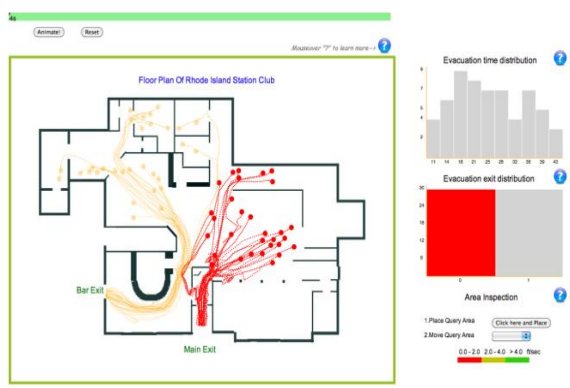


Figure 6 An interactive visualization tool designed to show simulation result

We realize that, in order to simulate a wide range of scenarios with a large crowd, we need to continuously improve the scalability and modularity of the computational model. New and effective algorithms will be developed to enhance the simulation of crowd movement. Last but not least, as we further our exploration of social theories of crowds and egress, new and emerging social network theories will be explored and incorporated in the simulation framework.

3.5. Research Impact

Human and social behavioral factors have been largely ignored in current egress simulation tools. By adopting an innovative approach considering crucial social factors in an agent-based simulation framework, our research results can potentially be beneficial to evacuation planning and egress design. From the safety design perspective, the outcome of the proposed research can be used to evaluate both existing and new egress designs. From the crowd management and facilities operations perspective, the research results can provide insights for event organizers and facility managers in developing a wider range of possible solutions to crowd problems and designing specific evacuation plans under different scenarios. Additionally, the tool will potentially serve as a valuable platform for researchers in fire engineering and social science to carry out virtual experiments and hypothesis testing on human behaviors in emergency situations, which are not easy, if not impossible and inappropriate, to obtain in real life setting. Last, but not least, this research will bring a better understanding of social science research to enhance virtual design simulation.

4. RELATIONSHIP TO CIFE GOALS

This research supports the “conformance” and “globalization” areas of this year’s Call for Proposal. First, proper egress system and emergency planning are important functional considerations of building designs to ensure the human safety. This egress simulation framework, upon completion, provides stakeholders a reliable tool to assess the design conformability with the explicitly stated project development objectives from safety engineering perspective. Moreover, the functionality goal states that the six-sigma reliability check should be used to monitor the process steps that significantly affect human or facility life safety. The proposed framework can generate realistic results of rare events, which can be used as the input of the statistical checking tool to ensure the process quality for “highly reliable and ultimately highly resilient facilities”. Second, this project will subsequently lead to significant contributions to crowd safety research, which is an increasingly important issue in facility design due to recent natural and man-made events occurred globally, and increasing safety and security regulatory measures.

In sum, this highly interdisciplinary research will have significant impact in virtual design practice and can lead to immediate industrial applications to support operations and facility management with characteristics that satisfied CIFE’s missions.

5. INDUSTRY INVOLVEMENT

Externally, we have established an on-going collaboration with Disney R&D and the crowd simulation group in Technical University Munich, particularly in the interest of establishing validation metrics on crowd flow and group behaviors. Ms. Stephanie Huerre, the researcher of guests’ movement at Walt Disney Imagineering, has agreed to collaborate and to exchange data with us. Police Chief Laura Wilson from Stanford University’s Public Safety Department, and Mr. Ray Purpur, the Deputy Director of Athletics Department, have granted us permission to collect data, as well as provide assistance to our research at Stanford Stadium for a number of up-coming events. Working closely with crowd management experts will enable us to identify key issues in emergency planning and address a range of useful “what-if” scenarios with our simulation framework. We will work with any organizations that have an interest in being involved in our continuing research effort towards understanding social behaviors in a crowded environment and egress simulation.

6. RESEARCH PLAN, SCHEDULE AND RISKS

To-date, we have (1) evaluated different social theories regarding crowd and emergencies, (2) conducted field observations and collected crowd movement data, and (3) implemented selected social theories in a computational simulation framework. We have started to establish metrics to validate the model with real-life data. For the proposed second year research period, the research plan is as follows:

- By the end of Fall Quarter 2012 – we plan to work on the scalability issue to handle large crowd with high density. The simulation framework will require further enhancements in the geometry models to accommodate complex layouts for some particular facilities, such as stadiums and theaters.
- By the end of Winter Quarter 2013 – we plan to consolidate the validation metrics for testing the simulation tool by replicating real-life scenarios under non-emergency situation and emergency situation.
- By the end of Spring Quarter 2013 – we plan to run simulations with different occupants’ behavioral rules and to test emergency operational plans. We will focus our simulations on one or two particular types of facilities so that detailed analysis of our theories and simulation results can be assessed.

- By the end of Summer Quarter 2013 – we plan to complete a detailed report on the findings of this study. We anticipate that we will produce a range of experimental results, generate benchmark simulations and replicate both emergency and non-emergency real-life scenarios. A set of "what-if" analysis will be carried out to address concerns in egress design and planning.

Throughout the research period, we will continue to conduct field observations, collect data on crowd movement at different events, and to synthesize and archive the results.

This interdisciplinary research is a high-risk, high-payoff project involving researchers from Civil Engineering, Computer Science and Sociology. By partnering with industry and academic researchers, as well as on-campus event management and security team, we hope to gain better understanding of crowd gathering and people movements, especially during emergencies. We anticipate the following risks:

- *Complex human behavior in emergencies.* Due to the high complexity of human behavior, especially in emergencies, an agent-based simulation paradigm with a modular decision-making process is employed to mimic the crowd interaction. This approach provides high modularity and flexibility so that new modules can be incrementally added to account for new theories and observations without re-structuring the program.
- *Source of validation data.* We are highly aware of the challenge in obtaining useful real-life validation data; therefore, we have established collaboration with the industry partner and the interested research group in sharing data and exchanging knowledge. We also realize that the videos obtained would mainly capture crowd movement under normal and non-emergency situation. To assume realistic behaviors in emergencies, we will refer to online archives of past fire events to obtain useful egress data and conduct interview with crowd control and public safety personnel to obtain insight on emergency management. We will also expand our collaboration with relevant research groups (such as the disaster management center at University of Delaware) who study historical disasters from the human and social behavior perspectives.
- *Large computational demand and presentation of simulation results.* To overcome the computational demand in simulating large crowds and ensure the system scalability, we will continue to seek and develop efficient algorithms, particularly from AI and Robotics research, to efficiently and realistically simulate the crowd movement. Furthermore, we plan to develop visualization tools that can enhance the presentation of simulation results. Ability to display simulation results in a concise and systematic manner will play a very important role in demonstrating our research to facility management and safety organizations, as well as soliciting feedback of our research from practitioners.

7. NEXT STEPS

This research will provide insights into egress designs and emergency responses due to natural and man-made disasters. We will continue to pursue government funding opportunities such as NSF, NIST, FEMA, Office of Homeland Security and others. To test our result with industry, we will constantly seek feedback from our industry partner through continuous collaboration. Successful demonstration of this research may lead to practical products needed by the industry.

BIBLIOGRAPHY:

[1] Averill, J. D., Mileti, D. S., Peacock, R. D., Kuligowski, E. D., Groner, N., Proulx, G., Reneke, P. A., and Nelson, H. E. (2005). *Occupant Behavior, Egress, and Emergency Communications*, Technical Report NCSTAR, 1-7, NIST.

[2] Mawson, A. R. (2005). “Understanding Mass Panic and Other Collective Responses to Threat and Disaster,” *Psychiatry*, 68, 95-113.

[3] Aguirre, B. E., Torres, M. R., Gill, K. B., and Hotchkiss, H. L. (2011) “Normative collective behavior in the station building fire,” *Social Science Quarterly*, 92(1), 100–118.

[4] Grosshandler, W., Bryner, N., Madrzykowski, D., and Kuntz, K. (2005). *Report of the Technical Investigation of the Station Nightclub Fire*, Technical Report, NCSTAR 2: Vol. I, 2005, NIST.

[5] Drury, J., Cocking, C., and Reicher, S. (2009) “Everyone for themselves? A comparative study of crowd solidarity among emergency survivors,” *British Journal of Social Psychology*, 48, 487–506.

[6] Proulx, G., and Reid, I. M. A. (2006). “Occupant Behavior and Evacuation during the Chicago Cook County Administration Building Fire,” *Journal of Fire Protection Engineering, 16(*4), 283-309.

[7] ICBO, “Means of Egress,” *2009 International Building Code*, Chapter 10, 2009.

[8] CFPA Europe, “Fire safety engineering concerning evacuation from buildings,” *2009 CFPA-E Guidlines*, 19: 2009.

[9] Helbing, D., Farkas, I., and Vicsek, T. (2000). “Simulating dynamical features of escape panic,” *Nature*, 407:487-490.

[10] Challenger, W., Clegg W. C., and Robinson A.M. (2009). *Understanding Crowd Behaviours: Guidance and Lessons Identified*, Technical Report prepared for UK Cabinet Office, Emergency Planning College, University of Leeds, 2009.

[11] Aguirre, B. E., El-Tawil, S., Best, E., Gill, K. B. and Fedorov, V. (2011) “Contributions of social science to agent based models of building evacuation,” *Contemporary Social Science*, 6(3), 415–432.

[12] Le Bon, G., *The Crowd*, Viking, New York, 1960. (Original publication, 1895)

[13] Mintz, A. (1951). “Non-Adaptive Group Behavior,” *Journal of Abnormal and Social Psychology*, 46, 150-159.

[14] McPhail, C., *The Myth of the Madding Crowd*, Aldine de Gruyter, New York, 1991.

[15] Mawson, A. R. (2005). “Understanding Mass Panic and Other Collective Responses to Threat and Disaster,” *Psychiatry*, 68, 95-113.

[16] Donald I., and Canter D. (1990). "Behavioural Aspects of the King's Cross Disaster," *Fires and Human Behaviour*, 15- 30.

[17] Zheng, X., Zhong, T., and Liu, M. (2009). “Modeling crowd evacuation of a building based on seven methodological approaches,” *Building and Environment*, 44(3), 437-445.

[18] Galea, E., (Ed.), Pedestrian and Evacuation Dynamics, *Proceedings of 2nd International Conference on Pedestrian and Evacuation Dynamics*, London, UK, CMC Press, 2003.

[19] Huerre, S. (2010). “Agent-based crowd simulation tool for theme park environments,” *Proceedings of 23rd International Conference on Computer Animation and Social Agents*, 2010, Saint-Malo, France.

[20] Durupinar, F., Pelechano, N., Allbeck, J., Gudukbay, U., and Badler, N. I. (2011). "How the Ocean Personality Model Affects the Perception of Crowds," *IEEE Computer Graphics and Applications*, 31(3), 22-31.

[21] Musse, S. R., and Thalmann, D. (2001). "Hierarchical model for real time simulation of virtual human crowds," *IEEE Transactions on Visualization and Computer Graphics*, 7, 152-164.

[22] Braun, A., Bodmann, B. E. J., and Musse, S. R. (2005). "Simulating virtual crowds in emergency situations," *Proceedings of the ACM symposium on Virtual reality software and technology*, 244. ACM Press.

[23] Veeraswamy, A., Lawrence, P., and Galea, E. (2009). "Implementation of cognitive mapping, spatial representation and wayfinding behaviours of people within evacuation modelling tools," *2009 Human Behavior in Fire Symposium*. Available at: http://gala.gre.ac.uk/1297/.

[24] Pan, X. (2006). *Computational Modeling of Human and Social Behavior for Emergency Egress Analysis*, Ph.D. Thesis, Dept. of Civil and Environmental Engineering, Stanford University.

[25] Witness and Grand Jury statement released on the web for the public and were available at http://www.riag.ri.gov.public/pr.php (accessed June 1, 2011).

[26] Interview scripts collected for the project "Effects of Social Identity in Responses to Emergency Mass Evacuations" were available at http://www.esds.ac.uk/findingData/snDescription.asp?sn=5987 (accessed June 1, 2011).