Simulating Campus Evacuation: Case of York University

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ABSTRACT
University campuses possess a unique dynamic different than any businesses or grade schools and require a unique perspective when it comes to emergency evacuations. While Universities in North America came across all types of hazards (natural, conflict, and technology) requiring a campus evacuations, the ever-present of these incidences cause one to wonder whether the created plan would ensure sufficient time for the campus community to safely evacuate. As a case study, the York University's Keele campus was selected for its unique surrounding environment (MacMillan Yard, railways lines, fuel storage depot, and Black Creek) and AnyLogic as the program of choice for the agent-based simulation. The model reproduced the number of students (agents) registered during the winter semester of 2014. The weekly cycle runs continuously until informed of an evacuation. The agents then proceeded through four evacuation stages. Overall, the model assisted in visualizing the spatial distribution of agents, understanding peaks in agent populations, the total population in buildings and on campus, and the buildings utilized.

Author Keywords
Evacuation Simulations; Agent-based Simulation; Mass evacuation; Anylogic; York University

ACM Classification Keywords

1. INTRODUCTION

The basic understanding of an evacuation is channeling individuals away from harm [1]. However, a chaotic environment may result in the loss of life and or safety, health and welfare of people [2]. A solution to assist in this task is computer simulations, models recreating the environment in question and learning through an evacuation simulation.

Evacuation simulation became popular in the 1990s [4], while the separate study of evacuations and computer simulation have been studied since 1917 [3] and the 1960s [4] respectively. Various types of models have evolved and range from modeling evacuation on mass rapid transit station [5] to placement of road barriers to configure university campus emergency evacuation [6]. School evacuations present a certain level attention when it comes to the public as it often involves a large group of young individuals. University campuses in particular laid out a different environment than any workplace or grade schools with inconsistent hours throughout the week and a dynamic population. The inconsistent hours and population caused one to question the impact it can have on a campus evacuation. This paper utilized York University's Keele Campus as a case study to assist in the evacuation process.

This paper is organized as follows. Section 2 briefly reviews evacuations and evacuation simulations. Section 3 illustrates the benefits of utilizing agent-based simulation. Section 4 describes the design of the campus evacuation simulation. Section 5 provides a background understanding of York University's Keele Campus. Section 6 provides the model results and analysis, and Section 7 provides a conclusion and future research for the case study.

2. EVACUATIONS AND EVACUATION SIMULATIONS

The act of evacuating universities in North America is not an uncommon phenomenon and is attributed to all types of hazards. Fire, bomb threats, earthquakes, hurricanes, chemical leaks are some of the main causes for partial or full evacuation of university campuses. For example Tulane University in Louisiana, United States of America (USA) was evacuated in 2005 due Hurricane Katrina [7]; In 2013, the University of Massachusetts Dartmouth, Massachusetts, USA, was evacuated as the entire campus became a crime scene and potential location for domestic terrorism linked to the Boston Marathon Bombing [8]; and many universities (e.g. York University, Ontario, Canada [9] and Windsor University, Ontario, Canada [10]) experienced bomb threats and required the evacuation of several buildings. In each of these cases, the institution took responsibility in evacuating the campus population. Full campus evacuation in large universities can be considered as a complex mass evacuation which is more complicated than a single building evacuation. Most university in North America and have developed campus evacuation plan as part of their emergency management programs. To be effective, these plans must be tested and practiced through real or simulation exercises.

The number of individuals involved in an evacuation, can cause one to wonder how to prepare for such event? A

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rehearsal or drill might seem like a practical solution. Although, the concern in evacuating a large area is associated to the time requirement, finances necessary to emulate an emergency situation, and the appropriate population size to evacuate. Alternatively, the area of study can be replicated through an evacuation model and the agent's interactions in the simulation model can be studied. From this understanding, it could help develop optimal strategies, clarifying any misunderstandings, and assist with implementation [11]. The versatility, complexity, and plethora simulation models (such as evacuation from buildings [12-14], evacuation from ships [15], and evacuation for individuals with disabilities [16]) illustrate its feasibility in replicating intricate evacuation cases. Overall, simulations can assist in better understanding the events attributed to evacuations.

3. AGENT-BASED SIMULATIONS OF EVACUATION

There are varied approaches when it comes to simulation models focused on pedestrian centered environments. While various crowd simulation have been associated with cellular automata models, lattice gas models, social force models, and fluid-dynamics models [17, 18], this paper utilized an agents-based model as a methodology of choice.

Agent-based simulations allow for developing more microscopic, realistic, and modular evacuation simulations. Individual evacuees and their characteristics can be included in the models and applied to a building only, multiple buildings or the entire community. The main factor which attracted to this method was autonomous decision- making entities. As each agent accounted for the actions of other agents and the information gathered from its environment [19], it depicted a human in a social atmosphere. Thus provided an insight when it comes to evacuations and identified aspects such as queuing and herding behaviours [20]. Agent based evacuation simulations can use discrete, continuous (2D, and 3D), and GIS spaces. This study uses a GIS space that is also available in AnyLogic simulation software. This enables us to combine existing GIS data into the simulation process.

4. CAMPUS EVACUATION SIMULATION

Anylogic 7.12 was utilized in this study. AnyLogic is a multi-model simulation tool that allows agent-based modelling to be combined with discrete and system dynamic modelling.

We used GIS space for our campus evacuation simulation. The scaled map gathered from OpenStreetMap assisted in the recreation of the physical attributes (buildings, fields, parking lot) on campus as well as road networks between and within buildings.

The key agents in the model are: Buildings, Students, and Evacuation Zones.

The Building agents represented the physical location of the student agents on campus. To take into consideration the height of the building, the number of floors per building was integrated in the model with data gathered from the Planning & Architectural Design branch of the campus Services and Business Operation.

The Student agents represent the student population on campus. To understand the population dynamics, the course enrollment statistics for the winter semester of 2014 were utilized. The data was first sorted to only include the students requiring a physical presence, followed by isolating each building. This arrangement provided a building time schedule indicating when classes were being offered throughout the week.

The Evacuation Zone indicated the final destination of the evacuees. Four regions were selected to identify the possible travelling directions (north, east, south, and west).

The last component of the model was the evacuation procedure. Prior to this addition, the model would only be recreating the students attending classes. By creating a state diagram it provided step-by-step instruction for the Student agents when they evacuated. These agents traveled through four stages (Alarm, Building Evacuation, Evacuating, and Evacuated) and are illustrated through a color changes (from black, to yellow, to red, to green).

4.2 Conceptual Model

Campus evacuation for in class students can be divided into three stages: evacuation warning, building evacuation, open space evacuation (Fig. 1). Warning is usually sent through mass notification systems inside and outside buildings (alarms), large TV screens around the campus, and mobile applications. The time it takes for individuals to receive and act on evacuation warning is a function of their locations, activity, personal characteristics, etc. In this study we use a triangular function with the minimum value of 2.83, maximum value of 8.58, and the mean value of 5.7. The average start time value of 5 minutes was utilized in the model based on the study by Proulx and Fahy [21]. They examined the average evacuation start time for mid-height apartment buildings (6 to 7 stories). Our model allows for these parameters to be set by the users as well.

Building evacuation is the process of evacuating the buildings in which individuals reside. In a campus environment this could range from a one story to high rise buildings. To determine the time it took to descends a multi-level buildings the equation (1) provided by Galbreath [22] was used.

$$T = \frac{N + n}{r \; x \; u} \qquad (1)$$

Where

T = the time required, in minutes, to evacuate a building by stairs

N = the total number of individuals

n = the number of people per floor

r = 45, a constant value selected as the number of people surpassed 0.27m^2 (3ft^2) per person

u = 18.2, the average number of door calculated based on a random sample of five buildings of the case study.

As for the agents' walking speed a range was provided based on Federici et al. walking speed of 1.38m/s [23] and Rinne et al. inclines of 0.55m/s [24]. Again this has been set as a parameter that can be set and changed by the users before or during the simulation. Agents follow the existing road (both streets and walkways) networks to reach to the designated evacuation site that are parking lots in different sides of the campus. While we have not considered the impacts of density on individuals' walking speed, this can be incorporated in the simulation through a network density function that reduces the walking speed as more individuals use certain portion of the roads and path ways.

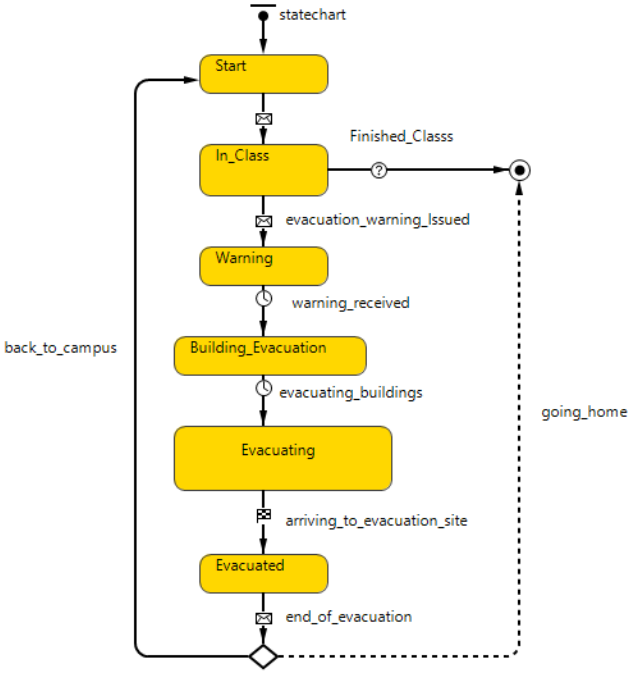


Figure 1. Students evacuation model

5. YORK UNIVERSITY

York University is the third largest university in Canada and second largest in Ontario. Of its two pedestrian oriented campuses in Toronto, Keele is the larger campus and holds 95% of the university's 53,000 student population [25]. Located in northern Toronto at the intersection of Keele Street and Steeles Avenue West, the surrounding attributes presents a unique atmosphere. To the north of the property, in the city of Vaughan, is MacMillan Yard, the largest rail yard in Canada [26]. Additionally, the rail lines protruding to and from the rail yard are less than 500m north of campus and 750m east of campus. To the South East corner is the fuel storage depot, containing cylindrical tanks of ethanol, diesel, gasoline, and jet A-1 fuel. To the west of campus is Black Creek, a tributary of the Humber River Valley [27]. While each of the features presented a potential hazard to the university, they are only a few of the 33 potential hazard identified for the City of Toronto.

The campus has experienced its fair share of evacuation, revolving around factors such as fires (real and false alarms) and bomb threats [28]. Throughout these incidents, the university utilized the York University Emergency Plan, a plan created by the University's Emergency Preparedness Program, providing the steps and parties involved for a successful evacuation [29].

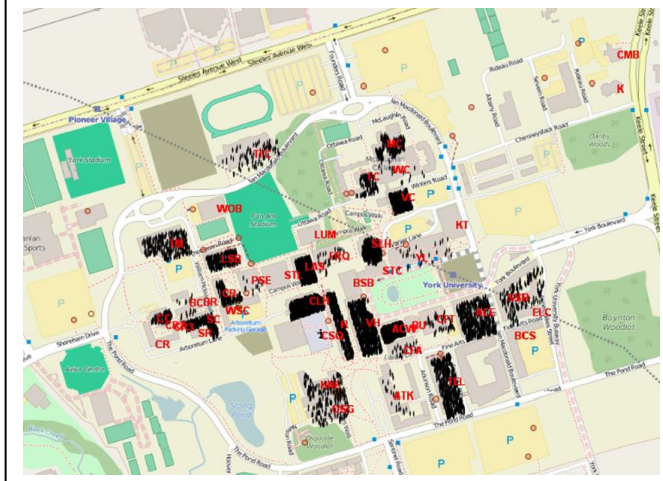
6. MODEL RESULTS AND ANALYSIS

As the simulation ran, the students enrolled in courses were constantly entering and leaving classes. However, when the evacuation alarm rang the agents entered the four stages of evacuation, demonstrated through their color change (Figure 2). Through over 40 simulations, the time required for a population of 3000-13000 to safely evacuate ranged from 44 minutes to 67 minutes. Despite the population difference of over 10000, the location of students on campus had an overall affect in the time required to travel to an evacuation zone.

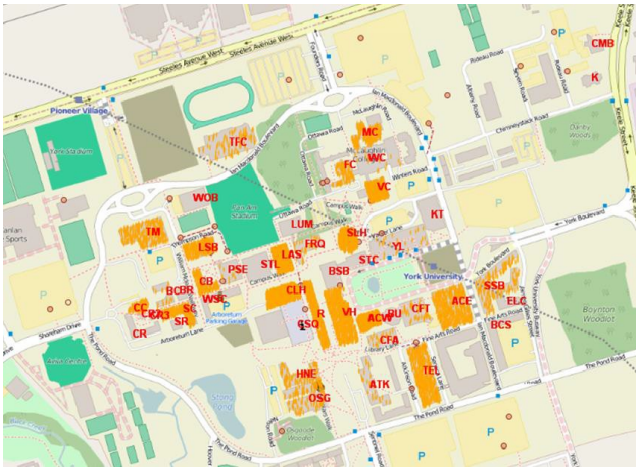
To assist with the information gathered from the map, a graph was simultaneously generated to illustrate the dynamic population changes throughout the week (Figure 3). Additionally, a time series plot was also created for buildings holding classes on campus (visible by clicking the respective building on the map). The visual representation on the graph, not only allowed to see the changes in population through time, but allowed to see the student population peaks throughout the day, the total population in building and campus, as well as any buildings being utilized for classes. By possessing a better approximation of students on campus, it can greatly assist in evacuation and emergency situation, particularly when it is necessary to know the number of individuals involved in a situation.

7. CONCLUSION AND FUTURE RESEARCH

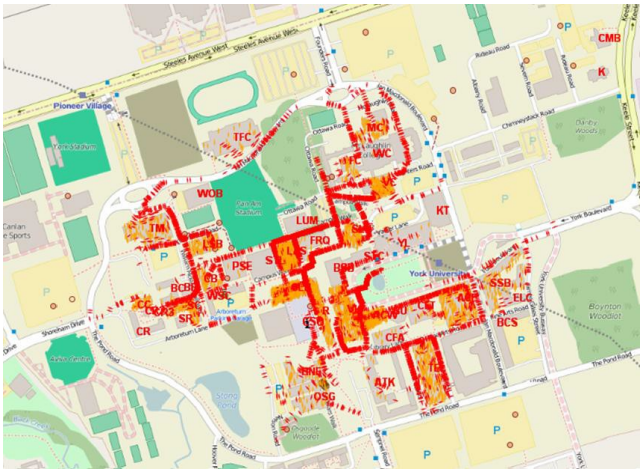
Through this simulation model, a clearer perspective is gathered should an evacuation take place on the Keele campus at York University. The simulation provides a dynamic spatial mapping of the student population on campus, while the time series plot provided statistical data identifying population peaks throughout the day, current population in buildings and on campus, and which buildings were being utilized for classes. Although overall informative, more data is required in order to be representative of the whole campus. By integrating the remaining students, employees, and visitors and including stress and panic behaviors [30] it would provide a more comprehensive perspective of the individuals on campus. The future expansion of this simulation will include staff, campus residences, and campus restaurants, shops, libraries, and sport facilities.



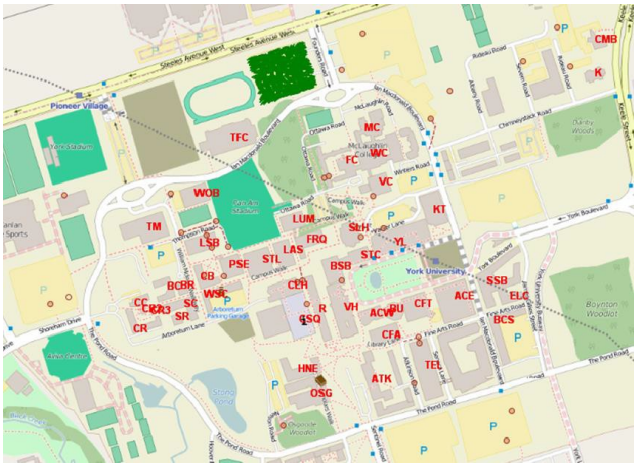
a) The alarm is rang informing agents (black) to evacuate



b) Agents (orange) recognize they need to evacuate



c) Agents (red) travel to the predetermined evacuation zone



d) Agents (green) arrived at their evacuation zone

Figure 2. The steps involved in an evacuation procedure

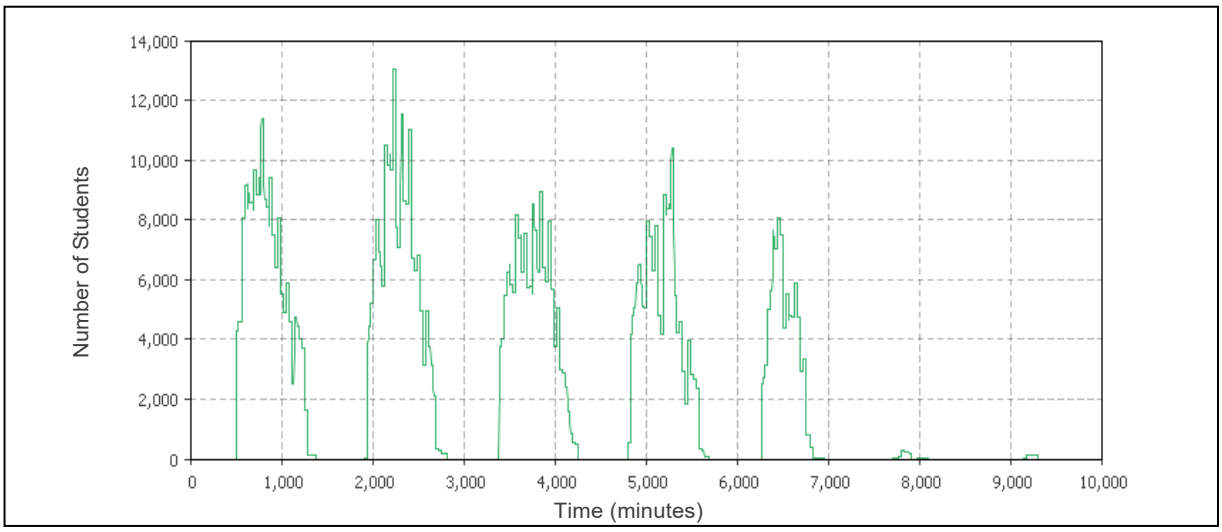


Figure 3. Number of students enrolled in the Winter 2014 Semester at the York University Keele Campus (Time 0 = Monday 00:00)

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REFERENCES

1. Penuel, K. B. & Statler, M. (2011). *Encyclopedia of disaster relief*. Thousand Oaks: Sage Publications
2. Emergency management Ontario (EMO). (2014). Emergency Management Doctrine for Ontario. *Emergency management Ontario.* Retrieved from https://www.emergencymanagementontario.ca/english/insideemo/legislationandregulation/emergency_management_doctrine.html
3. Ng, C. M.Y. & Chow, W. K. (2005). A brief review of the time line concept in evacuation. *International journal on architectural science*, 7 (1), 1-13.
4. Liu, S., Murray-Tuite, P., & Schweitzer, L. (2014). Incorporating Household Gathering and Mode Decisions in Large-Scale No-Notice Evacuation Modeling. *Computer-Aided Civil and Infrastructure Engineering* , 29: 107–122. doi: 10.1111/mice.12008
5. Wu, G., Chien, S., & Huang, Y. (2010). Modeling the occupant evacuation of the mass rapid transit station using the control volume model. *Building and Environment, 45*(10), 2280-2288. doi:10.1016/ j.buildenv.2010.04.015
6. Cai, H., Rahman, A., Su, X., & Zhang, H. (2014). A GIS-microscopic simulation approach for optimizing road barrier placement and configuration in university campus emergency evacuation. *International Journal of Disaster Resilience in the Built Environment, 5* (4), 362-379. doi:10.1108/IJDRBE-06-2012-0014
7. Harding, A. (2006). Paul Whelton: Rebuilding Tulane after hurricane Katrina. *The Lancet, 367*(9511), 643-643. doi:10.1016/S0140-6736(06)68248-2
8. Jenkins, S. & Goodman, M. (2015). 'He's one of ours': A case study of a campus response to crisis. *Journal of Contingencies and Crisis Management, 23*(4), 201-209. doi:10.1111/1468-5973.12086
9. Cooper, A. (2008). Three charged in York University bomb stunt. *Toronto Star*. Retrieved from http://www.thestar.com/news/gta/2008/11/08/three_charged_in_york_university_bomb_stunt.html
10. The Canadian Press. (2015). University of Windsor subject of bomb threat; nothing found. *Bellmedia.* Retrieved from http://toronto.ctvnews.ca/university-of-windsor-subject-of-bomb-threat-nothing-found-1.2656217
11. Ren, C., Yang, C., & Jin, S. (2009). Agent-Based Modeling and Simulation on Emergency Evacuation. *Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering Complex Sciences,* 1451-1461. doi:10.1007/978-3-642-02469-6_ 25
12. Pelechano, N. & Malkawi, A. (2008). Evacuation Simulation models: Challenges in modeling high rise building evacuation with cellular automata approaches. *Automation in construction* 17(4), 377–385
13. Liu, Z., Jacques, C.C., Szyniszewski, S., Guest, J.K., Schafer, B.W., Igusa, T., Mitrani-Reiser, J. (2016). Agent-Based Simulation of Building Evacuation after an Earthquake: Coupling Human Behavior with Structural Response. *Natural Hazards Review* 17 (1), 04015019-1-14
14. Ding, Y., Weng, F. (2016). A comparative study of evacuation strategies for high-rise building via combination of stair and elevator based on computer simulation. *International Journal of Emergency Management*, 12 (1), 41-54.
15. Glen, I.F., Galea, E.R., & Kiefer Kevin, C. (2001). Ship evacuation simulation: Challenges and solutions, Discussion. *Society of Naval Architects and Marine Engineers* 109, 121–139
16. Christensen, K. & Sasaki, Y. (2008). Agent-Based Emergency Evacuation Simulation with Individuals with Disabilities in the Population. *Journal of Artificial Societies and Social Simulation* 11(3), 9–21
17. Zheng, X., Zhong, T., & Liu, M. (2009). Modeling crowd evacuation of a building based on seven methodological approaches. *Building and Environment, 44*(3), 437-445. doi:10.1016/j.buildenv.2008.04.002
18. Bruzzone, A., Massei, M., Longo, F., Poggi, S., (2014) Agresta, M., Bartolucci, C.,Nicoletti, L.Human behavior simulation for complex scenarios based on intelligent agents. *Simulation Series*, 46 (2), 71-80
19. Deadman, P. J. (1999). Modelling individual behaviour and group performance in an intelligent agent-based simulation of the tragedy of the commons. *Journal of Environmental Management* 56(3): 159-72.
20. Pan X. S., Han C. S., Dauber K., & Law K. H. (2007). A multi-agent based framework for the simulation of human and social behaviors during emergency evacuations. *AI and Society* 2007;22:113–32
21. Proulx, G. & Fahy, R. F. (1997). The time delay to start evacuation: Review of fire case studies. *International association for fire safety science.* Retrieved from http://www.iafss.org/publications/fss/5/783/view%3E
22. Galbreath, M. (1969). Time of Evacuation by stairs in high buildings. Ottawa: National research council of Canada division of building research.

23. Federici, M.L., Gorrini, A.,Manenti, L., & Vizzari, G. (2012). An innovative scenario for pedestrian data collection: the observation of an admission test at the University of Milano-Bicocca. *Pedestrian and evacuation dynamics* 2012, 143-150.
24. Rinne, T.,Tilander, K. & Grönberg, P. (2010). Data collection and analysis of evacuation situations. *VTT Technical Research Centre of Finland*. Retrieved from http://www.pelastusopisto.fi/download/35629_T2562.pdf
25. York University. (2015). Building the Future. *York University*. Retrieved from http://about.yorku.ca/building-the-future/
26. CNW Group Ltd. (2014). Expansion of the CN Macmilan Bridge Underway in the City of Vaughan. *CNW Group Ltd.* Retrieved from http://www.newswire.ca/en/story/1343857/expansion-of-the-cn-macmillan-bridge-underway-in-the-city-of-vaughan
27. Google maps. (2015). *York University*. Retrieved from https://goo.gl/maps/mJBMNe6QNfz
28. York University . (n.d.). York university security incident statistics 5 years fiscal comparison. *Security Services York University.* Retrieved from http://security.info.yorku.ca/files/2013/02/2011-2012_5_Year_Category_Comparison.pdf
29. Office of emergency preparedness. (2011). York university Emergency Plan. *York University.* Retrieved January 23, 2015, from http://www.yorku.ca/epp/documents/YorkUniversityEmergencyPlan.pdf
30. Wang, J., Zhang, L., Shi, Q., Yang, P., Hu, X., (2015). Modeling and simulating for congestion pedestrian evacuation with panic, *Physica A: Statistical Mechanics and its Applications*, 428, 396-409