Simulating the Evacuation of Students Attending Classes at the York University's Keele Campus

A Major Paper submitted to the Faculty of Environmental Studies in partial fulfillment of the requirements for the degree of Master in Environmental Studies, York University Ontario, Canada

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Abstract

Since 1901, Canada has recorded over a thousand disasters (CDD, 2015). Ontario, a province possessing the highest number of incidents and evacuations, has adapted and learned from these experiences. The *Emergency Movement and Civil Protection Act* (1990) for example, legally obliged government organizations to maintain an emergency management program. Despite the measures set out by the government there were still a dominant paradigm of disaster, leading many to believe nothing could be done, when one occurs, or that they would not be affected one. Morris (2009) proved otherwise when it came to school shootings (a technological disaster). Morris illustrated awareness and preparedness in school led to resilient students who were less affected by the disasters. An important observation, as school disasters in particular have the ability to cause jarring impacts to a community.

This Major Paper presents a simulation model that evacuates students attending classes at the York University Keele Campus. The agent-based model was constructed with data acquired from York University's Office of Institutional Planning & Analysis, York University's Planning & Architectural Design branch of the Campus Services and Business Operation, and scientific journals. The model reproduces the number of registered students during the winter semester of 2014, from Monday to Sunday. This cycle stops, when a signal is given, informing of an evacuation. From this instance, students, proceeded through a series of steps before arriving to one of four predetermined evacuation zones. These steps included: 1) pre-movement 2) descend the corresponding multi-floored building and 3) travel at an assigned speed to the evacuation zone.

Forty evacuation scenarios, ten for each evacuation zones, were generated at varying times of day, throughout the week. The gathered times were further analyzed with three variables: the student population, the number of buildings holding classes, and the percentage of buildings within the vicinity of an evacuation zone. The student population demonstrated a logarithmic relationship with time, where evacuation time became more consistent as the population sized increased. When it came to the analysis of the number of buildings holding classes, the greater number of buildings, meant the buildings were more spread out and resulted in similar evacuation time for all four evacuation zones. The last case examined the percentage of buildings within the vicinity of an evacuation zone, half of the evacuation zones possessed a linear relationship, where the greater percentages meant a shorter arrival time.

Foreword

This Major Paper was written to fulfill the final component of the Plan of Study, a personalized curriculum for the Masters in Environmental Studies (MES) degree. My paper focused on the evacuation simulation of student attending classes at the York University Keele Campus. The topic combining both my areas of concentration, sustainable planning and emergency management, and the completion of my learning objectives outlined in my curriculum.

My first area of focus was sustainable planning**,** the ability to create equitable, efficient, and eco-friendly methods to maintain or improve the current environment. In this topic, my objectives entail: possess an understanding of past planning applications and an awareness when it comes to future practices; acquire the skills and knowledge in the creation of a transportation system; and have the ability to reproduce a concept in a familiar environment. This paper successfully accomplished these objectives. It analyzed past scenarios in section 4.0 Disasters in Canada, exploring the occurrence of disasters within the last century. As for the two remaining objectives they were achieved through creation of the simulation model with the computer software Anylogic 7.12. A task requiring to understand the attributes of the Keele campus, such as the surrounding land use and transportation network, and applying the evacuation concepts to the campus.

The second area of focus was emergency management, interpreted as the ability to reduce the impact and cope with disasters by being recognizant of the impacts hazards can have on a community. My objective in this topic was to obtain a planner's perspective of how to plan or prepare for and emergency situation. The creation of the simulations assisted in this goal, as it speculates evacuation times.

Acknowledgement

I would like to express my sincere gratitude to my supervisor, Dr. Ali Asgary, for his guidance in the world of evacuation modeling and for providing me the opportunity to work on this topic for my Major Paper. To the York University's Office of Institutional Planning & Analysis and the Planning & Architectural Design branch of the Campus Services and Business Operation for their assistance in data provisioning. To my professors and colleagues, for their patience, advice, and encouragement during my time at the Faculty of Environmental Studies. Lastly, my family and friends for providing me continuous help and support.

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1.0 Introduction

Disasters have often captured the attention of many across the world. However, these occurrences are no longer considered a rarity but have become a common affair. The 1960s was the pivotal point where the number of disasters started to increase. Prior to this time, the number of occurrences worldwide was less than 50, but by the 2000s, the number of recorded disasters was nine times the norm of the 1960s (CED, 2009). These unfortunate incidents, led societies to become increasingly stressed and communities placed a greater effort in mitigation, preparation, response, and recovery from disasters (Assaf, 2011). School disasters in particular have had jarring impacts on the community, due to the involvement of large groups of children, youth, or young adults. The safety of individuals in the learning environment falls on the institutions to keep the individuals safe during a hazard or disaster. This may entail an evacuation, removing the individual from the imminent threat; if not, it may result in a loss of life and or safety, health and welfare of people (EMO, 2013). While acting out an evacuation is the best way to teach individuals what to do during such an event, as well as to understand how they would react; it might not be feasible or possible when one takes into account the expenses and the time requirements for the activity. An alternative technique is computer modeling, recreating what could happen digitally and learning from its outcome.

1.1 Research Overview & Objective

The objective of this Major Paper was to develop a simulation model that evacuates students attending classes at the York University Keele Campus. This model then provided the ability to analyze the various factors which influenced the evacuation time.

The specified location and individual involved in this simulation, were selected through careful consideration. The Keele Campus was chosen as the study area as it was recognized as the second largest university in a province possessing the highest rate of disasters and evacuations. It was chosen over the largest university due to its location, in a low socioeconomic region, surrounded by features (McMillan Yard, a fuel storage depot, an unstable resident area, and Black Creek) increasing its risk of hazardous events. To represent the individuals affected by the hazard in campus settings, two questions were asked: which individuals represent the largest population on campus? and why were they going to campus? These questions resulted in the selection of students attending classes to demonstrate the interaction during an evacuation.

To create the model, it entailed data collection, modification, and assembly. The data utilised in the model provided the foundation for the model's operation. The university provided the class schedules (Office of Institutional Planning & Analysis [OIPA]) and campus building characteristics (Planning & Architectural Design branch of the Campus Services and Business Operation), while the remainder, such as pre-movement time and travelling speed, were collected from scientific journals. The acquired data, was then modified to reflect the attributes desired in the model. The assembling process entailed using a computer software, Anylogic 7.12, to create: Geography Information System (GIS) map with *OpenStreetMap*; a hazard, informing individuals to leave; agents, reacting to hazard, and attributes collecting data as evacuation procedures were ran.

This model was accomplished through the following items which represented the research objectives:

- Accurately replicated the campus layout and pedestrian routes, which included transportation infrastructures as well as internal and external paths.
- Reproduced the Keele Campus' class schedules for the winter semester of 2014 (the most recent data at the time).

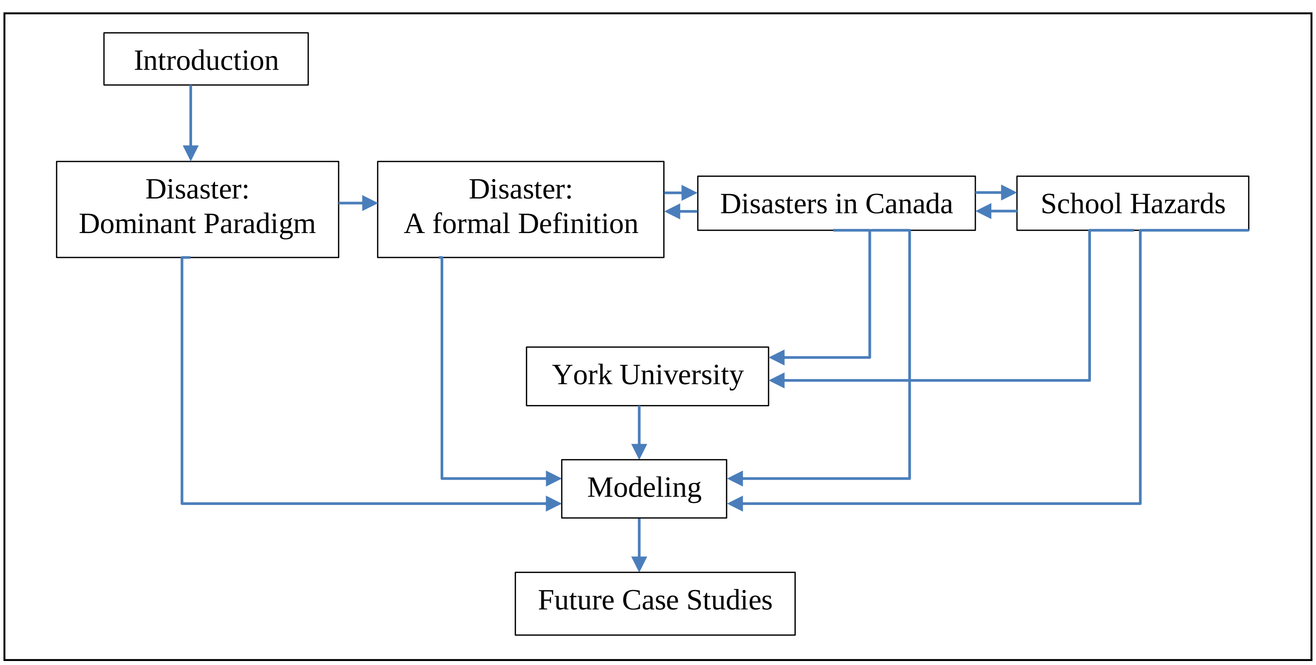
- Identified the student populations at any point-in-time on campus or within buildings holding classes.
- Integrated variables which contributed to evacuation strategies such as pre-movement time, time requirements to descent multi-floored buildings, and travelling speeds.
- Displayed the evacuation results while agents travelled to evacuation zones across campus.

While the aforementioned objectives comprised of separate modeling, analysis, and functional tasks, they were closely interrelated. Each of these tasks were key in replicating the Keele Campus environment and evacuation scenarios. This Major paper combined these elements to demonstrate evacuation scenarios reflective of the students attending classes.

1.2 Major Paper Roadmap

Based on the research objective and evacuation plan, the following has been organized in eight chapters. Figure 1.1 illustrates the following interactions.

Figure 1.1 – Major Paper organization chart



The Introduction of the Major Paper provided a brief understanding of the timeline of disasters and the impact of school disasters. It also outlined research objectives and a description of the proposed framework.

Chapter 2 examined the dominant paradigm associated with disasters. It identified vulnerable individuals during a disaster and how they are often linked with the concept of social inequality.

Chapter 3 provided a formal definition of disasters from the *Emergency Framework for Canada*.

Chapter 4 identified the presence of disasters in Canada, where Table 4.2 categorized Canadian disasters by event types requiring an evacuation from 1901 to 2014. Additionally, it examined the development and properties of the *Ontario's Emergency Management and Civil Protection Act*.

Chapter 5 looked into topics of the school hazards, examining cases of school shootings and the importance of preparedness.

Chapter 6 took a closer look at the York University Keele Campus, including the surrounding environment, the campus itself, the past hazards on campus, the current evacuation plan, and the use of the campus as an evacuation zone.

Chapter 7 examined the practicality of modeling at various scales and the applicability of evacuation models. The chapter goes into further details describing the elements used in the construction of the model, as well as the final product, the theoretical and simulation analysis, and results.

Chapter 8 proposed future developments in the model, strengthening the attributes pertaining to the agents, the buildings, and the landscape.

2.0 Disaster: Dominant Paradigm

There are several social perceptions when it comes to disasters, one such perception is responsibility. As many undesirable losses have been associated with disasters, they have been recognized as acts of God or simply a wild force, giving the impression that little can be done when disasters strikes (Thomas & Philips, 2013). This reaction is often seen with events, possessing a high number of injuries and deaths, e.g. natural disasters, where blame and responsibility is only associated to nature and omitting any association with humans (Tobin & Montz, 1997).

Despite these perspectives, nature is not at fault during a disastrous event, the responsibility falls onto humans. While it is easier to blame an uncontrollable force, it is necessary to take a step back and understand the various interacting elements. These elements can be generalized in three groups: the physical world, the built environment, and the human system (Mileti, 1999). The physical word is attributed to anything made by nature, while the built environment entails what people have constructed. The human system, on the other hand, is anything ascribed to our social construct, consisting of our political, social, and economic system. In comparison to the physical and the built world, the human system is highly dependent on various factors unique to the individual, the community, and the country. An example is how much attention a community places on emergency activities prior and after a disaster. This influences how individuals react, reinforcing the concept that someone's behaviour is "limited by perception and prior knowledge" (Tobin & Montz, 1997). However, intellect may not be the only variables influencing an individual's decision, the other factors include: income disparity, class, race, ethnicity, gender, age, disability, health, literacy, family, and households (Thomas & Philips, 2013). Although, having a particular social criterion does not make someone immediately vulnerable to a hazard, their susceptibility is dependent on the context of the situation.

When disaster strikes, everyone is exposed and only some are vulnerable (Thomas & Philips, 2013). As vulnerability cannot be identified without context, it is difficult to ensure everyone will be able to withstand or evade the threat. It is only after the impact of an unfortunate event, the public notices similarities among the people affected by the hazard. These similarities are often attributed to the previously listed social criteria, which is primarily due to our social construct. An example of such grouping took place during the summer of 2005. Hurricane Katrina, one of the costliest and deadliest hurricanes striking in the United States of America hit the poorest areas in the country. This made it quite difficult or impossible for individuals to evacuate, even when evacuation warnings were made (Penuel & Statler, 2011). This disaster, as well as many others "[brought] to the surface the poverty which characterizes the lives of so many inhabitants" (Hardoy and Satterthwaite, 1989). A reality, defined by social construct, greatly influences where people can live and renders some more prone than others (Bankoff, 2006). From this understanding, disasters associate social vulnerabilities with social inequalities.

Despite the belief that nothing can be done to protect against a disaster, steps can be taken to help reduce the impact. These steps can also be defined as resiliency, the "ability of a system to absolve, deflect, or resist potential disaster impact and the ability to bounce back after being impacted" (Peacock, 2010). An attribute further strengthened by understanding, managing, and reducing risks. This is not only achieved through an authoritative perspective; instead, open communication is necessary between all levels of authority and the public (NAS, 2012). Reinforcing a community's ability to deflect harm does not only assist an individual, it can also strengthen a community and or a country.

Strengthening a community's resiliency falls under the domain of emergency management, which traditionally, was the government's sole responsibility; however, this is not the case today. Instead, the task of preparedness has evolved to include various parties, ranging from households and businesses participants to inter-government departments and the private sector. Multiple factors have influenced this change, including: the increasing number of disasters, greater public awareness, and the growing population's housing needs (Lindell et al., 2007). Despite the involvement of more actors in emergency management, a large portion of responsibility still falls under the government. In Ontario, emergency management falls under the branch of Emergency Management Ontario (EMO) of the Ministry of Community Safety and Correctional Services. Their mission states: "EMO will lead the coordination, development and implementation of prevention, mitigation, preparedness, response and recovery strategies to maximise the safety, security and resiliency of Ontario through effective partnerships with diverse communities" (EMO, 2012). As humans continue to develop and adapt the planet to our preferences; it renders the population vulnerable to disasters. A profession, such as emergency management, to help communities to cohabitate with nature and become resilient is required.

3.0 Disaster: A Formal Definition

Canada's emergency management framework (2014) identifies a disaster as a social phenomenon, an interaction between a hazard and a community. In this interaction, the presence of a hazard destabilizes the community and can overwhelm a community's ability to cope with the situation. This affliction can influence the community's physical environment as well as their social, health, and metal status. However, not all hazards are recognized as a disaster and must also be characterized within one of five supplementary categories:

- killed ten or more people;
- 100 or more people affected, injured, infected, evacuated, or homeless;
- appeal for national or international assistance;
- historical significance; and
- significant damage or interruption of normal process (e.g., affected community cannot recover on their own) (CDD, 2013).

Disasters in the database are further classified within three categories: natural, conflict, and technology. Natural disasters are events associated with the natural environment such as geological (e.g., earthquake, tsunami), meteorological (e.g., drought, flood), and biological (e.g., epidemic, pandemic). Conflict disasters are incidents revolves around aggravated human discord (e.g., terrorist, hijacking). Finally, technology disasters are associated with technological failures such as transportation accidents (e.g., derailment release, fire) or infrastructure failure (e.g., energy, transportation). While disasters are classified in many categories, they are perceived as a social construct defined and dependent on human involvement (WHO, 2002).

4.0 Disasters in Canada

Disasters are not uncommon in Canada. The Canadian Disaster Database has identified 1027 disasters from 1901 to 2014. Of all the provinces and territories, the province of Ontario possessed the highest rate of disasters at 18% followed by Québec (13%) and British Columbia (13%) (Table 4.0). The higher percentage place a concern for Ontarians, as Ontario possesses 38% of Canada's population (Statistic Canada, 2014). While a greater number of individuals can be placed in harm's way in the event of hazards; the provinces and territories have evolved through there interactions with hazards.

Table 4.0 – The occurrence of disaster in Canadian provinces from 1901 to 2014

	Alberta	British Columbia	Manitoba	New Brunswick	Newfoundland	Northwest Territories	Nova Scotia
Disaster count per province	156	166	119	89	85	27	82
Percentage of disaster per province	12%	13%	9%	7%	7%	2%	6%

	Nunavut	Ontario	Prince Edward Island	Québec	Saskatchewan	Yukon	Total
Disaster count per province	9	228	39	173	110	16	1299*
Percentage of disaster per province	1%	18%	3%	13%	8%	1%	100%

* Some disasters were not bounded by provincial jurisdiction leading to a higher value in the total number of disasters in relation to the number of disaster

The disaster which greatly influenced the province of Ontario's perception of floods was Hurricane Hazel. The hurricane started its path in Grenada on October 5th of 1954; it slowly grew as it travelled from South America to Canada, leaving piles of chaos behind and almost eradicating various cities. It arrived in Southern Ontario by October 15, 1954 and possessed winds travelling 110km/h and 285 millimetres of rain in 48 hours. The combination of wind and water led to the stripping of streets, bridges, homes, and trailers being washed off. Despite the evacuation of 7472 individuals (CDD, 2013), this devastating event resulted in 81 casualties and 4,000 family were left homeless across southern Ontario (TRC, n.d.). This upsetting event led to the unification and promotion of the conservation authority in the municipal and provincial government. Flood Control plans were created by the Metropolitan Toronto and Region Conservation Authority in 1959, the concept of flood protection quickly resonated with the remaining Conservation Authority throughout the province (TRC, n.d.A). Flood plains have now become a large factor when it comes to development in Ontario.

Dating back to the 1800s, trains have been utilised to move individuals as well as goods across Canada. This practice is still common today with roughly half of goods are transported by the Canadian railway, the fifth largest rail network in the world (RAC, 2011). While train incidences are not common; derailment releases have however, been associated with an evacuation rate of 78% of the time (CDD, 2015). One unfortunate derailment releases took place 36 years ago in Mississauga, a city west of Toronto. At the time, a train carrying mix cargo was travelling to a rail yard near Toronto. Due to the lack of lubrication, a wheel barrel overheated and caused the cars to detach. The escaped cars crashed and led to several cars, carrying propane tanks, to explode which formed a chlorine cloud over the city (Mississauga, 2015). This hazardous event led to the evacuation of approximately a quarter million individuals (Sylves & Waugh, 1996) and was recognized as one of the largest peacetime evacuation in North America (Mississauga, 2015).

4.1 Evacuations in Canada

The act of evacuation has been linked to hazards and disasters. The concept is not restrained to any of the three type of disasters (natural, conflict, or technology); instead, it is applicable to each case. The basic understanding of an evacuation is to channel people away from harm, a technique identified to be effective and widespread when protecting the public against a disaster (Penuel & Statler, 2011).

In Canada, the predominant form of disaster requiring an evacuation, based on the Canadian Disaster Database's records from 1901 to 2014, falls under the category of natural disasters (247 occurrences), followed by technology (89), and conflict (27) disasters (Table 4.1). Amongst the three event subgroups of natural disasters (biological, meteorological, and geological), the prevalent form of evacuation is meteorological. It represents 98% of the natural disaster's evacuations; although, evacuations only occur 32% of the time during a meteorological disaster (Table 4.1). The high percentage is associated to the flood event type, the highest percentage of incidences of the event subgroup, possessing a higher number of evacuations (Table 4.2). Table 4.1 and Table 4.2 illustrate disasters are not always coupled with evacuations. However, there are past incidences where a disaster meant a 100 % likelihood of an evacuation, these events entail infestation (biological), disturbance/demonstration (civil incident) and water (infrastructure failure); although these have only occurred once or twice within the last century. On the other hand, hazards which have occurred more often, greater than 50 incidents, had mixed results in terms of evacuations. Floods had the highest incident rate (298) with a 42% evacuation rate, severe thunderstorms (113 incidents) had a 9% evacuation rate, wildfires (91) with an 91% evacuation rate and winter storms with the least amount of incident (67) had a 12% evacuation rate. While hazards identified between the two categories, possessing a higher than average evacuation (78% and 88%) and occurred less than 20 times, are associated with transportation accidents, derailment releases and fires. The values show evacuations are not always attributed to one type of disaster and instead, it is dependent on the situation. Overall, natural and conflict disasters are seen to have a higher chance of requiring an evacuation compared to technology disasters.

While the concept of evacuation can appear simple, it does possess a certain level of complexity. Evacuation can be classified in four categories:

- emergency protection for short-term, pre-impact response;
- preventative under long-term, pre-impact conditions;
- rescue during short term and immediately after impact; and
- reconstruction during long-term, post-impact phase (Penuel & Statler, 2011).

The most common type of evacuation entails pre-impact conditions. This scenario is only taken if there is sufficient time to communicate between the scientists monitoring the situation, the administrators determining appropriate actions, and the public reacting to the administration's decision (UNISDR, 2013). While this appears straightforward, how information is transferred from one party to the next, particularly to the public, can significantly hamper a successful evacuation. Generally, when the public does not notice anything abnormal in their everyday activities, they do not see any reason to leave. This may also be the case if the person announcing the evacuation, is not a strong public figure (EMO, 2013). While the evacuation may be mandatory by mayoral ordinance (or rarely optional) it cannot be enforced by police arrest. Many other factors comes into play when it comes to the overall success of an evacuation such as clarity of the notification, the amount of confidence the public has in its leaders, the length of the warning time, and the evacuees (Penuel & Statler, 2011). In the end, the success of the evacuation is strongly dependent on the area affected.

Table 4.1 – Disasters categorized by event subgroup requiring an evacuation from 1901 to 2014

	Event Subgroup	Incidence	Evacuation Required	Percentage of Evacuation per Disaster	Percentage of Evacuation per Subgroup in each Category
Natural	Biological	16	2	13%	1%
	Meteorological	747	241	32%	98%
	geological	47	4	9%	2%
	Total	810	247	30%	
Conflict	Arson	77	21	27%	78%
	Civil Incident	5	1	20%	4%
	Hijacking	47	5	11%	19%
	Terrorist	11	0	0%	0%
	Total	140	27	19%	
Technology	Fire	71	21	30%	24%
	Hazardous Chemicals	77	21	27%	24%
	Transportation Accident	68	41	60%	46%
	Infrastructure Failure	14	1	7%	1%
	Explosion	47	5	11%	6%
	Space Event	1	0	0%	0%
	Total	278	89	32%	

Table 4.2 – Canadian disasters categorized by event type requiring an evacuation from 1901 to 2014

Event Group	Event Subgroup	Event Type	Incidence	Evacuation Required	Percentage of Evacuation per Disaster
Natural	Biological				
		Epidemic	14	0	0%
		Infestation	2	2	100%
		Pandemic	0	0	0%
	Meteorological				
		Avalanche	14	3	21%
		Cold Event	9	0	0%
		Drought	46	0	0%
		Flood	298	124	42%
		Geomagnetic Storm	1	0	0%
		Heat Event	6	0	0%
		Hurricane / Typhoon / Tropical Storm	35	3	9%
		Storm - Unspecified / Other	16	0	0%
		Storm Surge	9	0	0%
		Storms and Severe Thunderstorms	113	10	9%
		Tornado	42	10	24%
		Wildfire	91	83	91%
		Winter Storm	67	8	12%
	Geological				
		Earthquake	5	0	0%
		Landslide	39	4	10%
		Tsunami	3	0	0%
		Volcano	0	0	0%
Conflict	Arson				
		Non-Residential	44	11	25%
		Residential	27	10	37%
		Vehicle	6	0	0%
	Civil Incident				
		Disturbance / Demonstrations	1	1	100%
		Rioting	4	0	0%
	Hijacking				
		Air	19	0	0%
		Marine	7	1	14%
		Rail	15	4	27%

		Vehicle	6	0	0%
	Terrorist				
		Biological	0	0	0%
		Bomb Attacks	7	0	0%
		Chemical	0	0	0%
		False Alarm	0	0	0%
		Hoax	0	0	0%
		Kidnapping / Murder	2	0	0%
		Nuclear	0	0	0%
		Radiological	0	0	0%
		Shootings	2	0	0%
Technology	Fire				
		Non-Residential	44	11	25%
		Residential	27	10	37%
	Hazardous Chemicals				
		Non-Residential	44	11	25%
		Residential	27	10	37%
		Vehicle	6	0	0%
	Transportation Accident				
		Derailment Release	18	14	78%
		Fire	17	15	88%
		Leak / Spill Release	18	7	39%
		Marine Release	8	1	13%
		Vehicle Release	7	4	57%
	Infrastructure Failure				
		Communications	1	0	0%
		Energy	1	0	0%
		Manufacturing / Industry	7	0	0%
		Transportation	4	0	0%
		Water	1	1	100%
	Explosion				
		Air	19	0	0%
		Marine	7	1	14%
		Rail	15	4	27%
		Vehicle	6	0	0%
	Space Event				
		Space Debris	1	0	0%

4.2 Policy in Ontario

Emergencies in Ontario fall under one of two categories, international or public emergencies. In the event of international emergency, such as a war, the federal government takes the leadership role and the provincial government, the supporting role. However, these roles are reversed when it comes to emergencies regarding, public welfare or public order (EMO, 2014). These incidents rely on the emergency programs created by government bodies, including the municipality, agency, board, commission, or any other government branches. Each of these institutions is legally obliged to create, develop, and maintain an emergency management program based on the Emergency Management and Civil Protection Act (1990). This tactic allows organizations to be aware of all the possible threats, as well as to be knowledgeable of how react should that threat occur.

This level of preparedness was not always present in Ontario; prior to this time, the Emergency Plan Act only gave municipality the permission, and not the obligation, to create an emergency plan (EMO, 2012a). While municipalities had the option to create a plan, the concept often fell through or the plan was out of date. Various reasons contributed to this status; some were attributed to the dominant paradigm of disaster, where individuals believed nothing can be done when disaster strikes. While others believed hazards did not have a high chance of occurring and would not affect them. These mentalities were also perceived by policy workers resulting in minimal attention and investments when it comes to prevention, mitigation, preparedness, or relief (Auf der Heide, 1989). However, much more attention was given if a hazard had directly impacted a community or if a community had identified with another community affected by a similar hazard. As these individuals were in state of shock and were mentally aware of the situation, they would understand the threat of the hazards and place a greater emphasis in emergency management. This phenomenon is described as a policy window, allowing for change in the current system (Solecki & Michaels, 1994). This was also the case when it came to the evolution of the Emergency management and civil protection act, which was constantly updated due to incidents revolving around SARS, 9/11, and Hurricane Katrina (EMO, 2014).

The constant updates in emergency management and in the civil protection act, involved various changes in policies as well as techniques. A common technique utilized against hazards is “hardening targets”, particularly when it comes to technological solution (e.g., strengthening or enlarging a dam) or communication equipment (Auf der Heide, 1989). An example of communication upgrade occurred in the United States of America after the event of September 11th, 2001. Individuals at the time were only informed by television broadcasts and radio channels, the warning system heavily relied on the population to be using theses entertainment devices. While the country cannot expect everyone to either be listening to the radio or watching the television, the Federal Emergency Management Agency (FEMA) developed an integrated public alert and warning system, a system which would allow to send messages through various forms of media including but not limited to cell phones, cable television, satellite radio, pagers, and the internet (Morris, 2009). While the system’s upgrade was important, it also placed less funding in fields such as evacuation planning; an area which could have made a large impact during a disaster such as Hurricane Katrina, by assisting the people with disabilities or individuals without access to transportation (Thomas & Philips, 2013). The constant updates of policies and emergencies programs provide a greater sense of security to the community.

The emergency management and civil protection act does not require emergency plans for non-government institutions; while not mandatory, it is strongly beneficial for organizations possessing population numbers, equivalent or greater than, a small town. This is the case for 35 of the 96 Universities and Colleges across Canada possessing a population greater than 10,000 students (Universities Canada, 2015). While the main objective of these learning institutions is to educate, a hazard can cause immediate and long term damages to the university and college, which would affect enrolment, decrease funding, reduce institutional confidence, and increase insurance cost (OEP, 2011).

5.0 School Hazards

School safety is a topic which pertains to all members of the community. At a glance, schools can be perceived as a place for formal education geared towards children. However, children are not the only ones who utilize the space, instead it is associated to all members of the community. This may include the use of the building for evening courses, degrees, or personal development. While these learning institutions can incorporate anyone from the community, school disasters often capture the attention of many due to the involvement of a large group of children, youth, or young adults. The most common type of hazards is fires, but it does not exclude the possibility of shootings, intruder alerts, and bomb threats (Penuel & Statler, 2011). Depending on the severity of the situation, these unfortunate events can define the community.

School shootings, in comparison to any other hazards, have often distinguished communities. This is often the case as the public perceives school shootings as disturbing events aimed at the defenseless. While many do not want to imagine such events, it is a threat and a concern. Unfortunately, the United States of America (USA) has experienced many of these undesirable events. One event which caused much debate recently in the USA was the Sandy Hook Elementary school shooting in 2012. This tragedy, led to the death of 27 individuals of which 20 were children in a Connecticut elementary school. This shooting is recognized as the "second-deadliest school shooting" in the United States by a single gunman. It was exceeded by the Virginia Tech massacre in 2007, a tragedy which resulted in the death of 32 individuals (Associated Press, 2012). These devastating shootings have led to much debate pertaining to gun laws and school safety in the USA. In Canada, the most shocking school massacre took place in Montreal, Québec at École Polytechnique in 1989 which resulted in 14 injured and the death of 14 women (Linderman, 2014). No matter the city or country, school shootings have resulted in a greater awareness for public safety. As once a safe environment for individuals to further their knowledge, they are now associated to dangerous and unsafe locals.

While the impact of school shootings and any other hazard events are devastating, learning and being aware of such event can help students during the aftermath. Morris (2009) identified the differences between schools that place emphasis on safety prior to an incident and those who placed a lesser importance on the matter. Schools that have safety in mind, possessed students who were less affected by the hazards compared to non-prepared schools. Students who were prepared were able to continue in their studies as opposed of being distracted by the tragedy. School safety is an important factor during the event of hazards and teaching the future generation proper techniques for prevention, mitigation, preparedness, and relief (Penuel & Statler, 2011). In addition to the impact it can have in a day-time environment, preparedness can also assist during non-day-time hours, assisting those who utilizes the building during non-traditional hours. Having a high level of preparedness through the entire day will enable the institution to become an exemplar of resiliency in the city (Penuel & Statler, 2011).

6.0 York University

York University was founded in 1959 and is now recognized as the third largest university in Canada (and second largest in Ontario). It is composed of approximately 53,000 students and 7,000 faculty and staff dispersed between two Toronto campuses. Glendon Campus, the smaller of the two is located in the heart of Toronto at Lawrence and Bayview. North West of Glendon Campus is Keele Campus (Steele and Keele), a large campus holding 95% of the student population (YU, 2015a). While each campus differs per location, they fall within the boundaries of Toronto and are susceptible to 33 hazards identified by the city (Table 6.0) (City of Toronto, 2014). While some hazards may seem highly unlikely in a post-secondary environment, it does represent a certain level of risk to the community.

Table 6.0 – Hazards identified for the city of Toronto

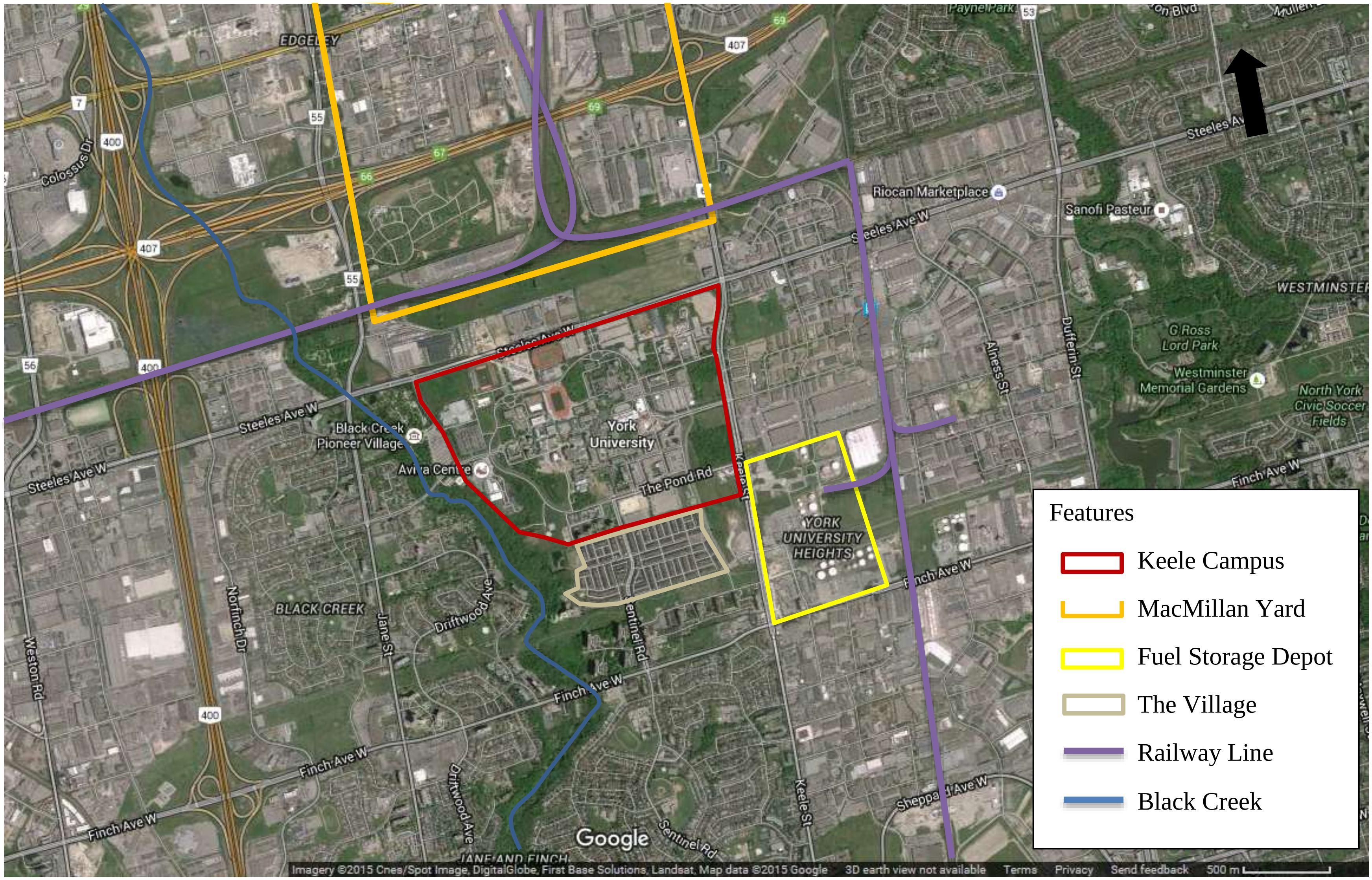
Natural Hazards	Conflict Hazards	Technology Hazards
Agricultural and Food Emergency	Civil Disorder	Electrical Energy Failures
Air Quality Emergencies	Cyber Attack	Explosion and Fires
Building / Structural Collapse	Special Events	Financial Sector Failures
Dam Failures	Terrorism and Sabotage	Hazardous Materials (including Radiological) – fixed site
Earthquakes	War and International Emergencies	Hazardous Materials – Transportation Incident
Erosion an d Landslides		Nuclear Facility Emergencies
Extreme Cold		Petroleum/Fuel Emergencies (including pipelines)
Extreme Heat and Humidity		Telecommunication Accidents: Aircraft
Floods		Telecommunication Accidents: Expressway
Freezing Rain Storms		Telecommunication Accidents: Railway
Geomagnetic Storm		Water Supply Emergencies
Human Health Emergencies and Epidemics		
Hurricanes		
Lightning Storms		
Snowstorms/Blizzards		
Tornadoes		

6.1 Keele Campus' Surroundings

The Keele Campus is located at the border of Toronto and Vaughan (Steeles Avenue West) between Black Creek Parkland and Keele Street to the east, within the York West Ward of the York University Heights neighbourhood in Toronto. It is surrounded by industrial areas towards the north and east, and residential features at the west and south. The campus' prominent surrounding features are identified Figure 6.0, illustrating McMillan Yard, the fuel storage depot, York University Village, and Black Creek.

The York West Ward is composed of 48,205 inhabitants and possesses a high ethnic population of East Indian, Italian, and Chinese (Toronto, 2008). The majority (43.5%) of the people are identified as the working class falling within the age range of 25 to 54 years old (Toronto, 2008). The ward's level of education appears to be lower than the city's average, more specifically, the census data identifies there is a 10% higher than average number of individuals who do not possess a certificate, diploma or degree and 15% lower than average who lack a university certificate, diploma or degree (Toronto, 2008). Potentially by association, the ward possesses a high rate of private household under the low-income cut-off (Toronto, 2008A). This indicates households will be using a larger portion of their income towards food, shelter, and clothing. These low values place the university in a low-socioeconomic region.

Figure 6.0 – Keele Campus and its surrounding features (Google maps, 2015)



North of campus, in the city of Vaughan, is MacMillan Yard. The rail yard has been operated by the Canadian National Railway (CNR) since the late 1950s and is recognized as the largest rail yard in Canada, measuring 6.5km in length and 1.6km in width. The yard operates 24 hours a day, seven days a week, and handles over one million railcars per years (CNW, 2014). The rail line utilized by the railcars to and from the yard is less than 500m north of Campus and about 750m east of campus. CNR train derailments have received a bit of attention within the last few years particular with the Lac-Mégantic incident in 2013, where a runaway oil train exploded in the center of town, killing 47 individuals. Following this incident, derailments continued to increase and in 2014, it was recorded to be 73% higher than the last 5 years with 39 derailments. The reason behind the increase in derailment was associated to either track problems or the lack of maintenance. However, the higher number of derailments in 2014 seems more troubling due to the higher rate of crude oil transportation and the potential of deadly accidents (Reuters, 2015).

At the south east corner of campus is the Shell/Petro Canada fuel storage depot. It contains 24 cylindrical tanks (Google Maps, 2015) and possesses various external labels indicating Ethanol, Diesel, Gasoline, and Jet A-1. While not much occurs on the premises, apart from pumping the content in and out of the tank, disastrous events have been associated with fuel depots. Two worldwide events in particular have shown the impact a fuel storage depot can have on a community. One of the two events is recognized as the largest fire in Europe since World War II and took place in 2005, at the Brucefield fuel depot, in England (HFRS, 2006). The fire took hold of 22 fuel tanks and resulted in a large smoke plume travelling to neighbouring countries. Luckily, there were no deaths and only a few injured (Morgan et al., 2008). However, the second case was not as fortunate, it took place at the Vasylkiv fuel depot, Ukraine in 2015.

An explosion of 16 tanks, 30 km from Kiev (ABC News, 2015), resulted in a three day fire and the death of five individuals and 15 injured (Interfax-America, 2015). While explosion of fuel storage depots are not common occurrences, they do have devastating consequences.

Directly south of the Keele campus is the York University Village. The Village is an area of 130 acres (YU, 2012) which consists of 800 privately owned homes and was constructed over the span of six years, from 2003 to 2008 (Robson, 2011). York University is associated to the Village by name, it states “it has no ownership and no legal jurisdiction within this residential community of privately owned homes” (YU, 2012). Despite this fact, many students from the university reside in these buildings due to the low housing cost. Originally, these housing complexes consisted of three to four bedrooms; currently, they are able to hold a dozen or so of tenants (Robson, 2011). While being a cheap place for students to rent, safety has been an ongoing concern. Assaults, and even a murder, have been reported in this neighbourhood. While such events can happen anywhere, the high turnover rate of people entering these buildings, student and non-student, have made it difficult for people to know their own neighbours (Marrow, 2012).

West of campus and encased in the Black Creek Parkland is Black Creek, a tributary of the Humber River. This creek starts in Vaughan and menders down to the Humber River in Lambton Park. It is located in a heavy urbanized area which caused it to become one of the major sources of bacteria and water chemical pollutant in the Humber River (BCCP, 2013). In addition to its degraded state, the Toronto Conservation Authority identifies Black Creek Parkland as a flood plain area (TRCA, 2010). While the flood plain does not encapsulate the campus, it has however has impacted the day-to-day operations. During the summer of 2005, torrential rain raised Black Creek and resulted in the conversion of Finch Avenue into a 20m crevasse (Stuart, 2005). While it disrupted the most common avenue to travel west-to-east in the city and a route to the Keele Campus, it also resulted in extensive flooding of the campus, surpassing the Stong pond's storm water management capabilities (Sandberg, 2015). Despite Black Creek encasement, its pass history demonstrates a level of risk to the university.

6.2 Keele Campus

The Keele campus is a self-contained pedestrian oriented community. It consists of "five libraries, 92 buildings, athletic facilities, residences, [and] a shopping mall" (YU, 2015). However, this is not the final count as the campus is constantly growing with new projects and additions. While portraying Keele Campus as a small village, it is not an isolated community and instead, it is comprised of various parties and iconic features of the past.

The Keele Campus has constantly been adding buildings to accommodate the growing student body, the new student center is no an exception. The new addition aims to create a multi-purpose facility to satisfy the growing need of the Keele Campus (Yfiles, 2013). To further assist with campus needs, a subway entrance is being constructed by Harry W. Arthurs Common. The new subway entrance will be one of the six new stops for the subway extension, which will be travelling from Toronto Transit Commission's terminal station, Downsview Station, and travelling to the Vaughan Metropolitan Centre (YRRTC, 2015). The direct connection on campus will assist the two largest distributions of York students (based on residence) in Toronto (18,772) and Vaughan (5,199) (YU, 2014).

The new development on the Keele Campus will also be assisting various parties on campus. These parties are identified through buildings that either do not belong to the university or is shared with the university. The shared facility consists of the Archives of Ontario, the Burton Auditorium, and several sport and recreation facilities, while the non-York University building are recognized as the Stephen E. Quinlan Building (also known as Seneca at York building), the Harry Sherman Crowe Housing co-op, and the computer methods building. Despite the concept of the Keele Campus being an isolated village at the edge of Toronto, these buildings assists in creating a vibrant atmosphere for its community.

As the campus is constantly growing and expanding, it does not ignore its historical significance. Four buildings on the York University property have been recognized as relicts of the past farming landscape which ceased to exist in the 1960s (Unterman McPhail, 2008). These buildings have also been identified by the City of Toronto's Inventory of Heritage properties, they include: Snider (Hart) House (Toronto, 2015a), Abraham Hoover House, Jacob Stong House and Jacob Stong Barn (Toronto, 2015b). The university also possesses relatively newer buildings which have been recognized as being historically significant, these buildings consists of Winter's College, Staecie Science Library, Scott Library, Ross Building, Atkinson College, Tait McKenzie Physical Education, Petrie Sciences, Founder's College, Osgoode Hall Law School, McLaughlin College, Farquarson Life Sciences Building, Vanier College, Lecture Hall One (Toronto, 2015); they have enriched the Keele Campus leaning atmosphere by preserving and bringing awareness to the past.

6.3 Past Hazards

As school disasters are able to shake the roots of a community, it is fortunate there has not been a hazard which has defined York University. However, the Keele Campus has had many experiences with hazards and evacuations. In the last decade or so, incidents have predominantly revolved around fires, bomb threats, and shootings.

The occurrence of building fires are attributed with the most common type of hazards. While it is required by law to have fire drills (OFM, 2004), it can be quite an annoyance if they are false alarms. From 2007 to 2015, York University experienced 189 to 261 false alarms every year, identifying it as the most common type of incident at York University (YU, n.d, n.d.a). While the number of incidences tend to increase towards the end of the year, the high occurrences of false alarms during exams, seemed like a rarity when compared to other Greater Toronto Area Universities, such as University of Toronto and Ryerson University (Brown, 2009). In addition to the students' constant frustration with exam re-scheduling, each false alarms is also attributed to a cost. In 2009, 261 false alarms were recorded and the university paid more than $93,000 in charges (Yfiles, 2011). Despite these high occurrences, actual fires have also taken place on campus. From 2007 to 2015, 7 to 24 fires have been recorded every year (YU, n.d, n.d.a). While minimal compared to the number of false alarms, some have had large impacts on the Keele Campus community. On December 13th of 2010 for example, a fire broke out in the Central Utilities Building, damaging the heat source on campus. While no casualties, exams were again cancelled and 4000 resident students were evacuated (Vukets, 2010). The ratio of real to false fire alarm at the Keele Campus is a serious concern; causing many to question whether the ringing fire alarm is just a false alarm.

Bomb threats, like fire alarms, are recognized as one of the top reasons behind exam re-scheduling. While occurring only 2 to 13 times in the last 7 years, and 22 times in the academic year of 2007-2008, they pose a large concern for everyone's safety on campus. Bomb threats have been reported throughout campus affecting regions such as Ross Building, Vari Hall, Curtis Lecture Hall, and Harry W. Arthurs Common (Cooper, 2008; Pecoskie, 2009; Pagliaro, 2010). In a 2008 incident, a paper bag was left on the bus with the message "I am a bomb". The presence of the paper bag, resulted in the evacuation of several thousand people, including those in the food court and several vendors. While it was a hoax made by three York University students, the package led to the presence of "uniformed police officer, bomb squad, fire services, ambulance services, and York University and TTC security" (Cooper, 2008). Whether it is a threat or an actual event, it is a serious offense, where each incidents requires the presence of all emergency personnel and the partial or entire evacuation of the campus.

One of the most traumatizing events at the Keele Campus was attributed to gun violence. Gun violence can fall within various categories defined by security services; this includes armed robbery, assaults, or pointing or shooting a firearm. Since the academic year of 2010 to 2011, there has been less than three incidents every year, a drop of 50% compared to the previous three academic years (YU, n.d, n.d.a). Despite the diminishing occurrences, a shooting incident occurred on March 6th of 2014 at 22:45 left eight students traumatized and unable to return to their classes. While the two injured students were not targeted by the shooter, they felt let down by the university (Stark, 2014). Shootings, in comparison to fires and bomb threats, possess a one-to-one interaction between the shooter and victim, an event, if experienced, leaves many traumatized.

Since 2007, the numbers of fire alarms, bomb threat, and shootings have decreased; however, each incident remains a risk towards the Keele Campus community.

6.4 York University's Evacuation plan

The three hazards of fires, bombs, and shootings, have each demonstrated the importance of an evacuation. An act, when provided sufficient time, can assist and save the lives of a community. To assist in this task, the York University Emergency Plan (YUEP) describes the steps and parties involved for a successful evacuation. This plan was created through the York University's Emergency Preparedness Program (EPP), a program applicable to all teaching facilities at York University, whether at the Keele or Glendon Campus. While the YUEP identifies the functional role when it comes to emergency planning, management and response, the responsibility does not fall solely on these individuals, instead it states "every member of the York community shares responsibility for emergency preparedness". Through this plan, as well as any other EPP, their goal is to return to the primary mandate of the university, teaching and conducting research (OEP, 2011).

6.5 Keele Campus as a Shelter Zone

When it comes to an emergency situation at the Keele Campus, students, staffs, and faculties are generally assumed to be the only individuals affected. This is not always the case as the Keele Campus has been utilised as an emergency shelter in the past. This scenario took place during the summer of 2008, when ten thousand residents and business owners, within a 1.6 kilometre radius of the propane facility explosion, were asked to evacuate. Red Cross and the Salvation Army established an emergency shelter location at the York University's Tait Mackenzie Building (Canada Newswire, 2008). Despite the number of displaced individuals, the number of evacuees in the building did not exceed 120 visitors at one time. Albeit, the university was prepared to accommodate more individuals, the evacuees preferred to stay with family and friends and hence the emergency shelter never reached maximum capacity (Coutts, 2008). While the university is perceived as an enclosed community geared towards teaching and researching, the campus is multi-functional.

7.0 Modeling

As section 4.2 identified the necessity of emergencies plans for government agencies in Ontario, it is as important to know if emergency plans are realistic and feasible for the target population. In case of large crowded facilities for example, an unrealistic perception can result in greater severity and an increase in casualties (Abdelghany et al., 2014). While experiments, in general, have been utilised to assist in testing concepts and plans, a large scale experiment requiring a large crowd can be impractical. Additionally, the act of rehearsing an evacuation can take up several hours, a requirement many individuals might not be willing to give up, and requires funding to reinforce evacuation measures and procedures outlined in the emergency plan (Penuel and Statler, 2011). The alternative, computer modeling, has often been preferred as the technique of choice. Models have long been utilised within the field of social sciences and have sometimes been preferred over experiments (Gilbert, 2008). The versatility of computer modeling can provide a perspective of various scales and identify elements which can assist with travel routes and the overall success of an evacuation.

It is also necessary to know which type of model is best suited for the case scenario. There are three options: macro-simulation, meso-simulation, and micro-simulation. A macro-simulation generally examines the area of concern through a larger lens and assumes a value for variables such as density and velocity. Various models have utilised a macroscopic lens such as a Macroscopic Dynamic Traffic Assignment (Yu, 1996) and Pedestrian FlowMmodel (Jiang et al., 2002). At the opposite extreme of the scale are micro-simulations; they examine the movement and interaction of agents, such as individuals. The strength of this type of model is its ability to recreate real world occurrences, like a bottle neck effect. A few models utilising this perspective are identified as Lattice Gas Model (Ngai et al., 2004) and agent based models

(Gilbert, 2008). In between the two are the meso-simulations, models for which the scale is considered as a fusion of both the macro and micro scale simulations, enabling to view agents such as vehicles as independent integers, while applying it to a larger scale. Models utilising this scale are recognized as DynaMIT and Multimodal Mesoscopic Dynamic Traffic Assignment Model (Gangi, 2011). While each also attempts have their strength and weaknesses, each models attempts to recreate social realities.

7.1 Evacuation Simulation Models

The act of evacuation has been studied throughout history with the first record dating back to 1917. This field has long evolved from its initial days, particularly due to the extensive studies within the past decades (Ng & Chow, 2006). While various studies have illustrated the complexity and diversity of evacuation simulation models, overall they possess the same attributes. The evacuation procedure can be broken down into four elements: evacuation time, Required Safe Egress Time (RSET), Available Safe Egress Time (ASET), and Total Evacuation Time (TET).

The evacuation time value is identified as the first time reference associated to evacuation simulations. It identifies the time it takes from the instant an alarm is rang to the arrival of the safe location inside, or outside, of a building. Various studies have assisted in promoting the accuracy of this measurement, in the case of multi-story buildings for example, Galbreath (1969) identified it is dependent on four factors: the number of individuals per floors, the stairwell capacity, the density, and the number of exits, an important calculation in our modern world with the increasing number of multi-story buildings and high rises. In addition to the physical attributes, studies have also analyzed psychological factors, integrating the concept of behaviour when it comes to an evacuation. This can entail pre-movement time, the time in between the sounding of the alarm and the act of evacuation (Proulx and Fahy, 1997), or it can pertain to an evacuee's walking speed, a variable inversely proportional with crowd density (Federici et al., 2012). Understanding the physiological and psychological factors further assist in understanding what is taking place during an evacuation and the necessary data required to simulate an evacuation.

In order to assess the safety of occupants in a building, it utilizes the Required Safe Egress Time (RSET) and the Available Safe Egress Time (ASET). The RSET is identified as the amount time required to safely evacuate. It consists of three phases: recognition time, response time, and travel time. In the context of a fire evacuation, the recognition time is identified as the time an individual receives a cue informing of a fire to the point they understand there is a fire. The response time is identified as the point of acknowledgment of the fire to the initial act of evacuation. The final stage, travel time, is defined as the time from the initial act of evacuation to the point individuals have left the building (Proulx, 1995). The total duration then provides a target goal when rehearsing fire drills. This value is compared to the ASET, the time period in which the hazard has reached a critical state (Caravaty & Haviland, 1967). If the ASET is larger than the RSET it indicates the building is of a safe design and individuals are able to safely evacuate in the event of a hazard.

Obtaining the Total Evacuation Time (TET) is an important value in understanding evacuation procedures, but a difficult task to accomplish. It is identified as the travel time required for the last evacuee to arrive at the final exit (Galea & Galparsoro, 1994). This value provides the means to assess the evacuation time required for all the individuals to leave the hazardous area. However, due to complex nature of collecting this value in real life, evacuation software is often utilised as references in determining this value.

Safety has had an underlying factor when it comes to evacuation simulations. In turn, they have been associated with various factors such as hazards, large population, and building complexes. For example, universities campuses have been simulated in various scenarios consisted of pandemic influenzas (Araz, 2001), fire evacuation in libraries (Ma et al., 2012), student apartment evacuations (Jiang et al., 2011), and barrier placement in a campus evacuations (Cai et al., 2014). The concerns for university buildings and campuses are due to its dense population, highly urbanized setting, and multimodal environment, providing the impression of a town. Additional, its temporal population distribution, influenced by class time, provides a critical and unique feature when it comes to evacuations (Cai et al., 2014).

7.2 Evacuation Model Development

In this research paper, the Keele Campus simulation model utilised an agents-based model, a type of microscopic model, to represent the everyday activity on campus. This scale was selected as the students (agents) were able to interact with physical features on campus, while still being recognized as a distinct part of the computer program. The agents benefited from being a separate element as it reacted to the changing environment, the evacuation. In addition, the agents reacted with one another, exchanging information such as observation and reacted based on their observations (Gilbert, 2008). As the agents-based model simulated realistic qualities in everyday life, it provided a more representative interpretation when it comes to obtaining the evacuation time for a campus evacuation.

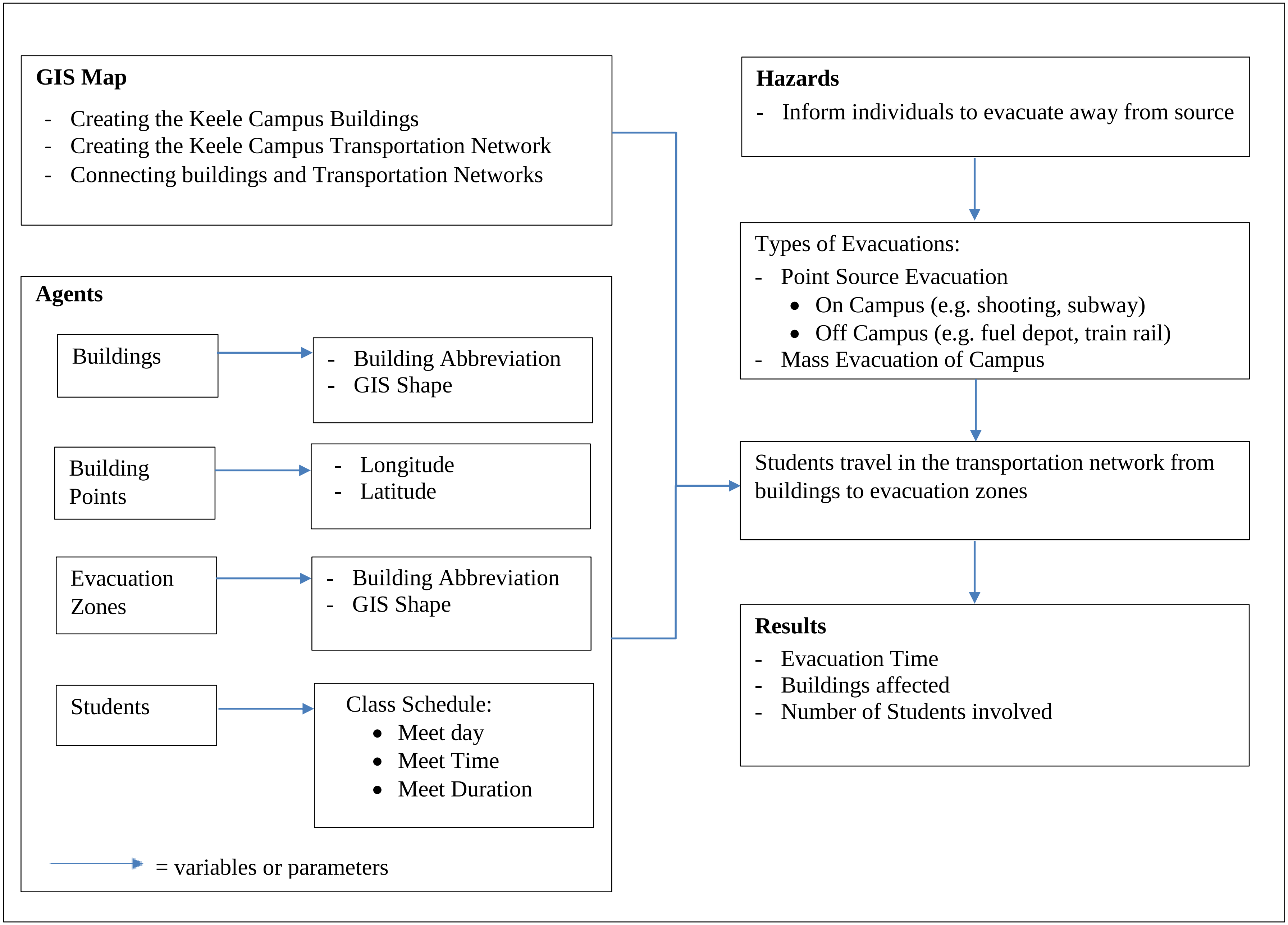
7.2A Software

The model was constructed utilizing Anylogic 7.12, a simulation tool supportive of diverse simulation methodologies and an open structure system, allowing the ability to integrate multiple platforms. Additionally, it’s embedded library further shows its practicality, as its pedestrian modeling library is recognized as one of the software's strongest attributes. This library, in particular, allows pedestrians (agents) to follow actions identified by theoretical studies. Thus, this software provides a complete coverage when it comes to effectively combining the various types of information to simulate a model geared towards a pedestrian dominated area.

7.2B Conceptual Map

A conceptual map was first created to outline the various components in the model. Illustrated in Figure 7.0 are the four main components of the model: Geography Information System (GIS) map, agents, evacuation, and results. The GIS map provided the template and an environment for the three agents: buildings, students, and hazards. These agents represented the actors interacting within the model either on a regular day, or during an evacuation. The last component of the model includes the results obtained from the evacuation.

Figure 7.0 – Building the Evacuation Model



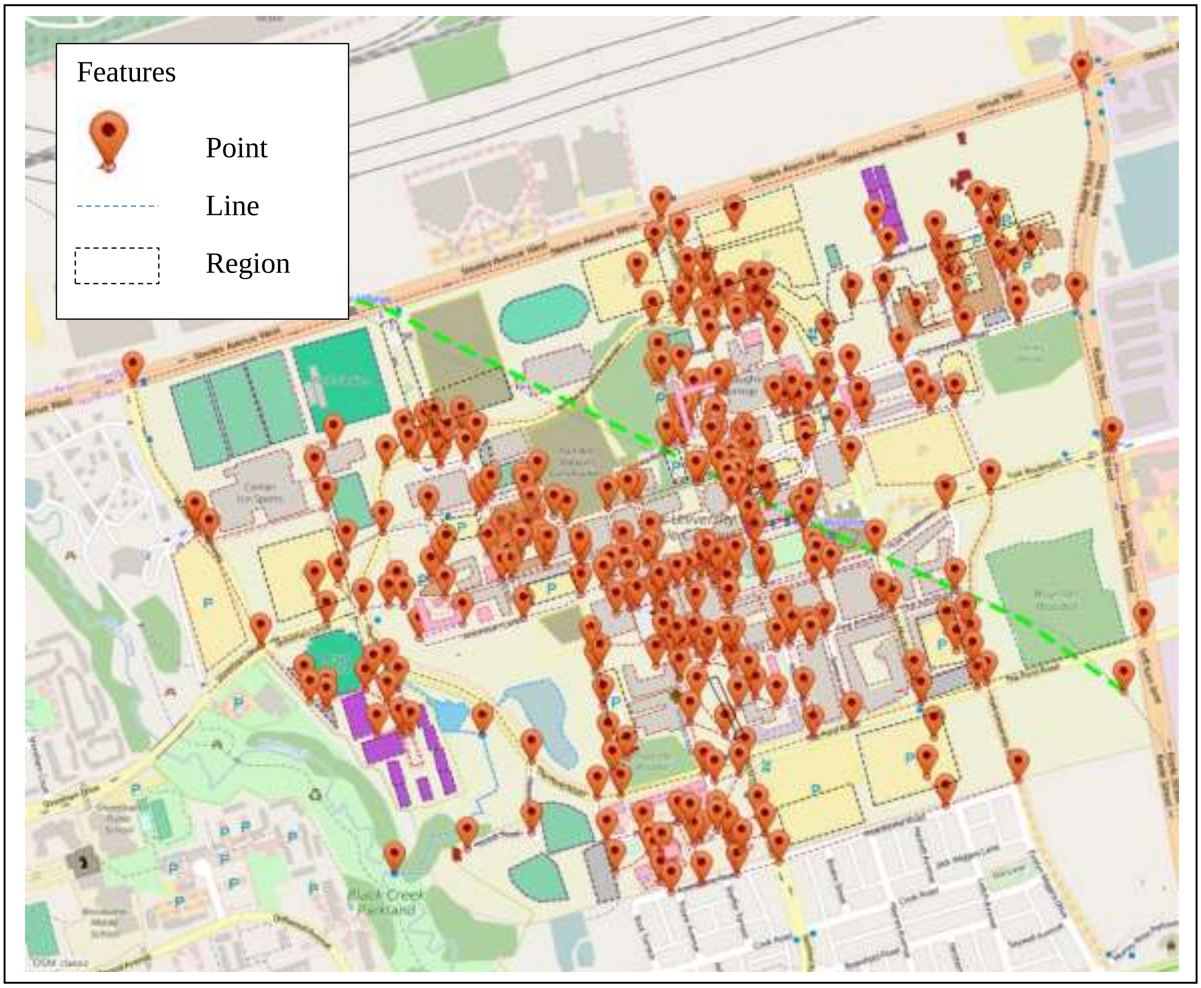
7.2C GIS Map

The first element in the model creation was to obtain a map of the Keele Campus. A GIS map was preferred as it reflects information that can be spatially stored in addition to the conventional functions of a paper map. The template utilized in the model was obtained from OpenStreetMap. In addition to the layout itself, it was necessary to extract the buildings and roads in order to be further utilised in the model.

The building facilities on the Keele Campus were extracted from OpenStreetMap and recreated in Anylogic. This entailed utilising the *GIS Region* function to create all academic, administrative, and commercial buildings; residences and apartments; parking lots (visitors and reserved) and parking garages; visual performance arts facilities; sport and recreation facilities; and historical houses. These regions were named (e.g. R_Bldg92_ACE) and were provided a title (e.g. Accolade East), based on the description obtained from the York University Keele Campus map from January 2005. In total, over 155 regions were created and labeled accordingly.

Once the buildings and regions were created, the next step was to create the pedestrian network. This was achieved by coupling the road network and the pedestrian pathways displayed by OpenStreetMap. The *GIS Route* and *GIS Point* were utilised to represent lines and points on the constructed map. In this task, a point was utilised at every line intersections and at the end of every path. As for the lines, they represent each segment of a pathway in a network. The compilation of all the regions and networks resulted in Figure 7.1.

Figure 7.1 – Keele Campus GIS Map utilized in Anylogic



7.2D Agents

The agents are defined as the building blocks that can possess a behaviour or action in the model. This model possesses four agents: *Student*, *Buildings*, *BuildingsPoints, and EvacuateZone*.

The first agent created in the model were *Buildings*. It possessed descriptive qualities (variables) which assisted in the overall outcome of the model. The first variables, *shape_region* is attributed to the name (*e.g. R_Bldg92_ACE*) given to all the building regions that were created through the *GIS Region* option. The second variable was *name*, while the name given to the *GIS Region* might be comprehensible to modellers; it is not a practical label for the everyday user. In this case, each region was associated with a building abbreviation (e.g, ACE) which was also obtained from the York University Keele Campus map from January 2005. The last variable was *FloorNum*, provided the number of floors per buildings. This data was obtained from the Planning & Architectural Design branch of the Campus Services and Business Operation; each of these variables were identified and defined in the function *intBuilding*.

The second created agent were *students*. The students represent an important feature in the model as they represent the majority of the campus population. Course timetables represent the best variable to identify this population as students are primarily present to attend educational courses. In the case for the Keele Campus Evacuation Model, the Office of Institutional Planning & Analysis (OIPA) of York University provided the data for the winter schedule of 2014. This data was sorted and organized to only include the courses that required a physical presence at the Keele Campus. A new table was created to calculate the total number of students registered to a particular timeslot during the day, based on the location of each course. This was achieved by creating a template identifying all the possible combination of start and end times during the week, gathered from the OIPA data. By then indicating a particular building on campus, a formula would extract data from the OIPA file and count all the students having class within a possible timeslot defined in the template. This process was then repeated for all 31 buildings (Accolade East [ACE], Accolade West [ACW]; Atkinson [ATK] Bennett Centre [BC], Behavioural Science [BSB], Chemistry [CB], Calumet College [CC], Joan & Martin Centre for Fine Arts [CFA], Centre for Film & Theatre [CFT], Curtis Lecture Hall [CLH], Central Square [CSQ], Founders College [FC], Farquharson Life Science [FRQ], Health, Nursing &

environmental Studies [HNE], Ignat Kanneff Building, Osgoode Hall Law School [OSG], Lassonde Building [LAS], Life Science Building [LSB], Lumbers [LUM], McLaughlin College [MC], Petrie Science and Engineering [PSE], Ross Building [R], Stong College [SC], Stedman Lecture Halls [SLH], Seymour Schulich Building [SSB], Technology Enhanced Learning [TEL], Track & Field Centre [TFC], Tait Mackenzie Centre [TM], Vanier College [VC], Vari Hall [VH], Winters College [WC], and York Lanes [YL]) possessing a course during the winter of 2014. This new Excel file identifies all the students in prescribed timeslots that have registered to at least one courses during the winter of 2014.

The created Excel file provided the model the necessary resources to display the number of students present in each timeslots. This step was achieved by creating a function (e.g. *ClassJoinAce*) to read the created Excel file. This function is similar to the existing *Schedule* function in Anylogic, except the script extracts the data directly from the Excel file. Through this method, each building possesses its own schedule (e.g. *CallSchACE*). Next, an *event* (e.g.EventAddStudentATK) was created to read the second function (e.g. *AddStudentAce*) which would obtain the number of students (e.g. *ValueACE*) identified in the schedule and display the appropriate number of students in specified region (e.g. R_Bldg92_ACE). To identify the time to the next value and the one following, two variables were created *TimeofNextValueACE* and *TimeoutToNextValueACE*, which were ran through a second event (e.g. *EventATK*). To monitor the model and see if it reads the Excel file correctly a *Data Set* (e.g. *StudenDataACE)* was added to see the values output from the model, indicating how the model reads the data. Through multiple trials, the combinations utilised to read the data correctly consisted of a recurrence time in seconds, and the necessity of an additional minute to each timeslots possessing the same start day and time. All of the V*ariables*, *Functions*, E*vents*, and *Data Set* are then grouped in a

Collection (e.g. *collectionACE*), where each building collection stored the grouped values for its buildings. To then see the overall change in student population per building, the gathered information from the *collection* is displayed in a *Time Plot*.

The third agent created in the model was *EvacuateZone*, this agent indicated the final destinations in the event of an evacuation. Four regions were identified in the *intEvacute* function and defined with two variables, *name* and *shape_region*. These regions were selected to illustrate four cardinal directions: North (Founders Road West Lot), East (York Boulevard Lot), South (Sentinel Roadt Lot), and West (Shoreham Drive Lot).

The last agent created in the model was *BuildingPoints*, it assisted in the visual association of buildings with their building abbreviation provided in the *Buildings* agent. This task was created with three variables, *name*, *lat* (latitude), and *lon* (longitude). The *name* refers to the building abbreviation as for the latitude and longitude variables provide the coordinates of the buildings, which was collected from Google Maps. These variables were then identified and defined in the *bldgPoints* function. Through this agent, the *name* variable was labeled on each building. To further assist the user in understanding the change in population per building a *show* function was created linking the building with the previously created time plots. An interaction only present if the model is ran and a building name is selected.

7.2E Evacuation

The last addition to the model reflects the procedure pertaining to an evacuation. Prior to this addition, the model would be recreating the numbers of students on campus that were registered for the winter semester of 2014. To enable the act, a step-by-step procedure (*Statechart*) is required to inform the *students* how to react in the event of an evacuation.

The *students*' statechart is illustrated in Figure 7.2, representing two possibilities; a regular day or an evacuation. Two columns can be identified in the figure; the left column provides the procedure for a regular day, while the right column indicates the presence of an evacuation. On a regular day, students begin their first step in *State*. If a student is scheduled for class, a student icon (Figure 7.3[a]) is generated. Once their class is over, the students leave. As students are continuously entering or exiting buildings, the model illustrates the changing student population attending classes over the course of a regular week, from Monday to Sunday. However, this cycle is interrupted when an alarm is rung for an evacuation, or in the case of the model, when the button "Evacuate" is selected. When the alarm is rung, students have a delay period to process the alarm. Once the students understand the need to evacuate, they enter a transitional period between the *Alarm* state and *BldgEvac* state. To illustrate this stage, the hue representing the student changes to the colour orange (Figure 7.3 [b]). During the state of the "BldgEvac" the model calculates the time required for the students to evacuate based on the number of floors identified per building. Once the calculated time has been assigned to student accordingly, they enter the state *Evacuating*, where the student changes to a red hue (Figure 7.3 [c]) and travels from the current unsafe location, to the predetermined evacuation zone. Once the students have arrived to the final destination they enter the *Evacuated* state (Figure 7.3 [d]) and are identified by a green hue.

Figure 7.2 – Student *StateChart*

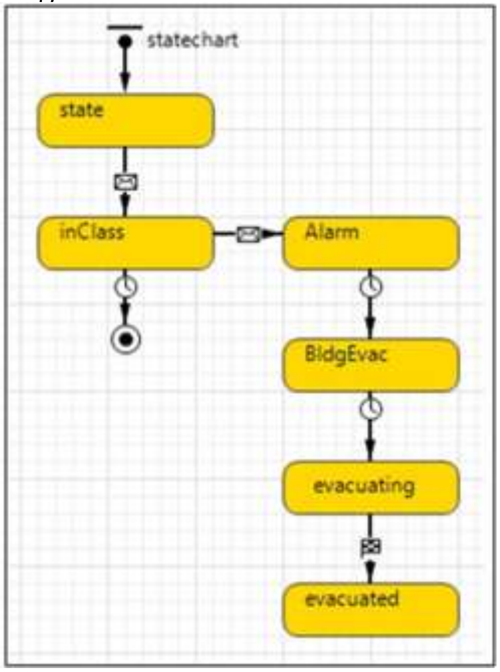
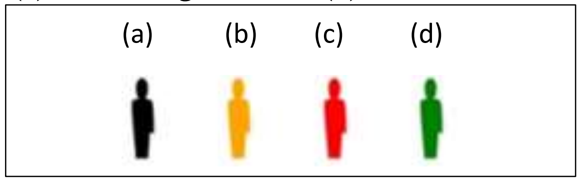
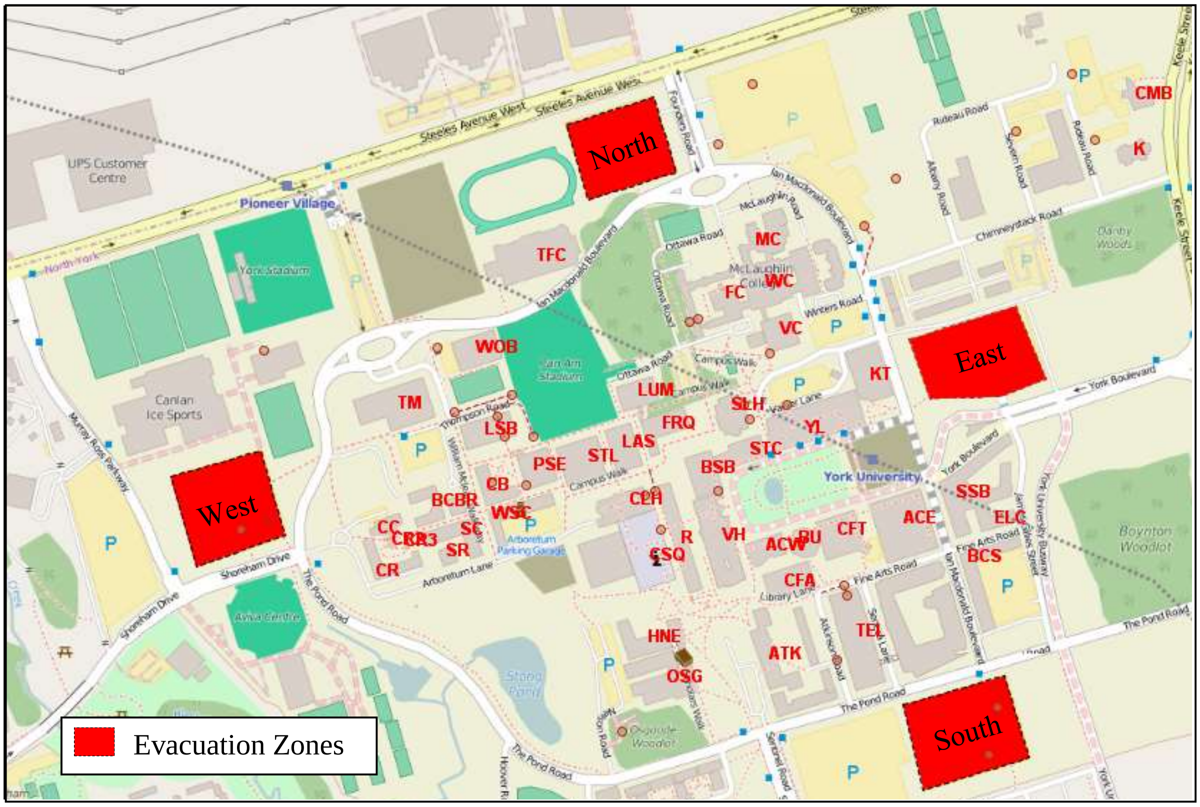


Figure 7.3 (a) to (d) – The varying states experienced by a student throughout an evacuation (a) normal state (b) alarm state (c) evacuating state and (d) evacuated state



Before the declaration of an evacuation, the model provides the user the ability to determine the safe zone for the upcoming evacuation. The model provides four possible options: "North", "East", "South", and "West" (Figure 7.4). These options indicate the location of the evacuation zone, locations which were previously identified by the *intEvacute* function. By selecting any of the cardinal directions, it represents a hazard on or off campus, where the location of the hazard in at the opposite direction of the Evacuation Zone.   In all of these options, the final destination is illustrative of a check point, rather than a final destination of a real evacuation.

Figure 7.4 – The location of the four evacuation zones



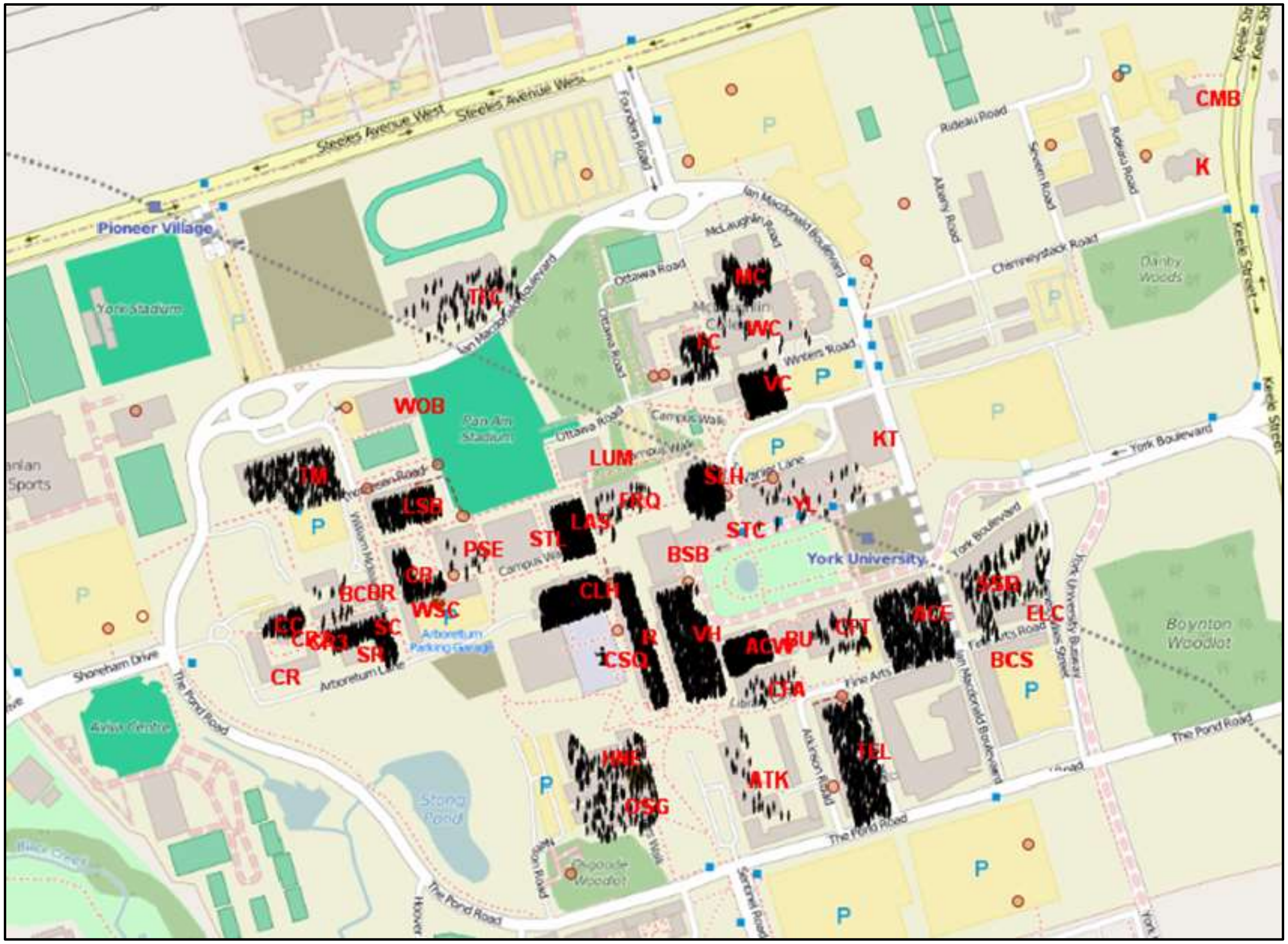
7.2F Results

To assist in the evacuation procedure a timer was integrated in the model to indicate the time requirement to evacuate the Keele Campus. This calculation is derived from the initial time where the alarm was made (when the 'evacuate" button was selected) and the time when the last individuals enters the predetermined evacuation zone. This task was accomplished with the aid of two variables (*warningIssued*, and *evacuationEnding*) and one function (*getEvacuationTime*). The function was created to calculate the time of the evacuation, by subtracting the *evacuationEnding* (the end time of the evacuation) by the *warningIssued* (time the warning was activated). The timer starts counting when a warning is issued and stops once the evacuation has been completed.

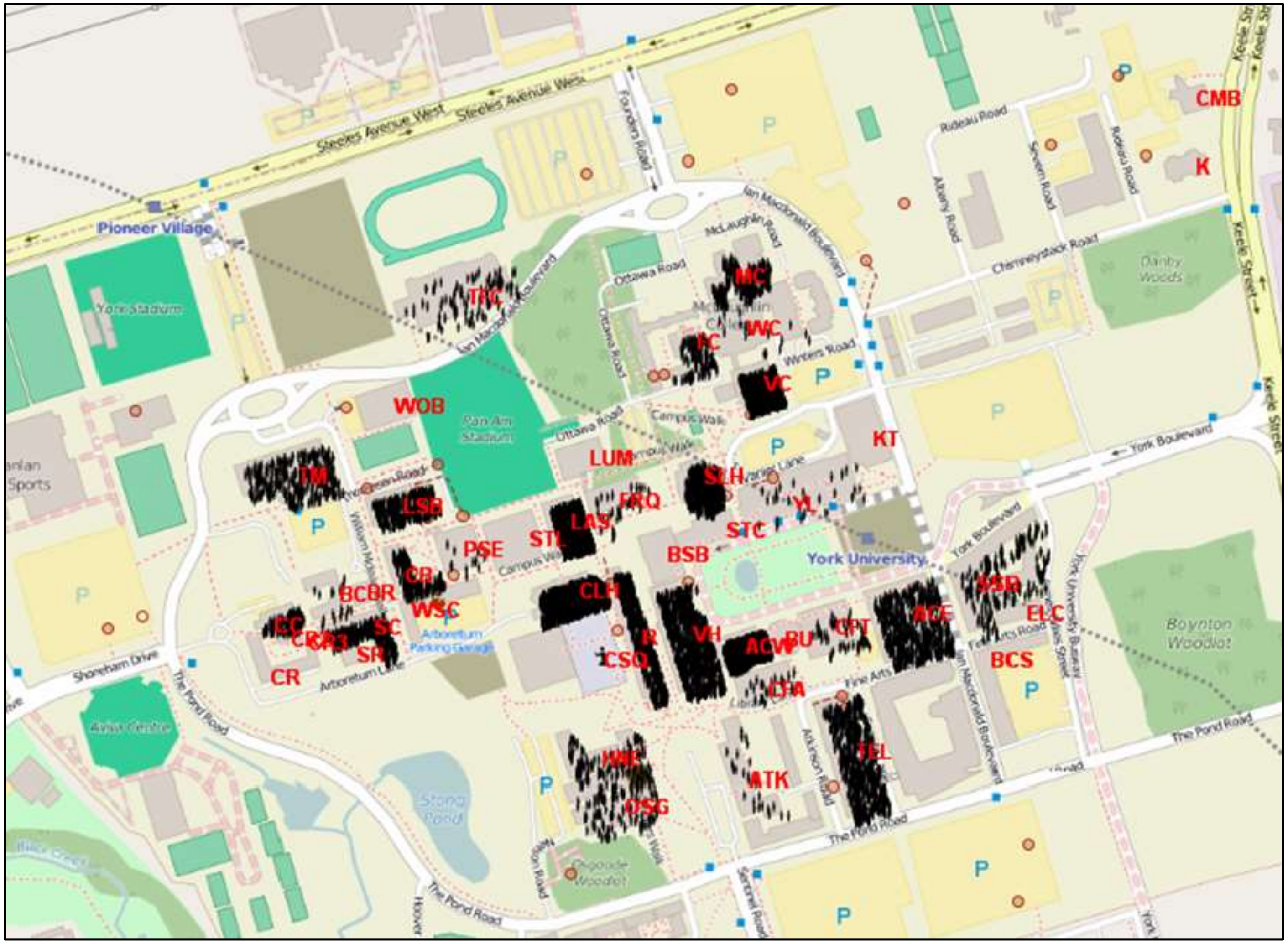
7.2G Procedure of a Campus Evacuation

The procedure of a campus evacuation is described as a linear chain of events, where individuals leave the current premise to move to a safe location. The model first portrays an average day on campus with students attending class. Once an alarm is issued, informing of an evacuation, a delay period illustrates the varying time individuals (agents) take to process the warning messages of evacuation. Once the agents have processed and understood the situation, they evacuate the buildings. These agents then travel to the predetermined evacuation zone (e.g., north). The final stage occurs when everyone has arrived at an evacuation zone. Figure 7.5 (a) to (e) illustrates the process of a campus evacuation through the Keele Campus Evacuation Model developed in this paper.

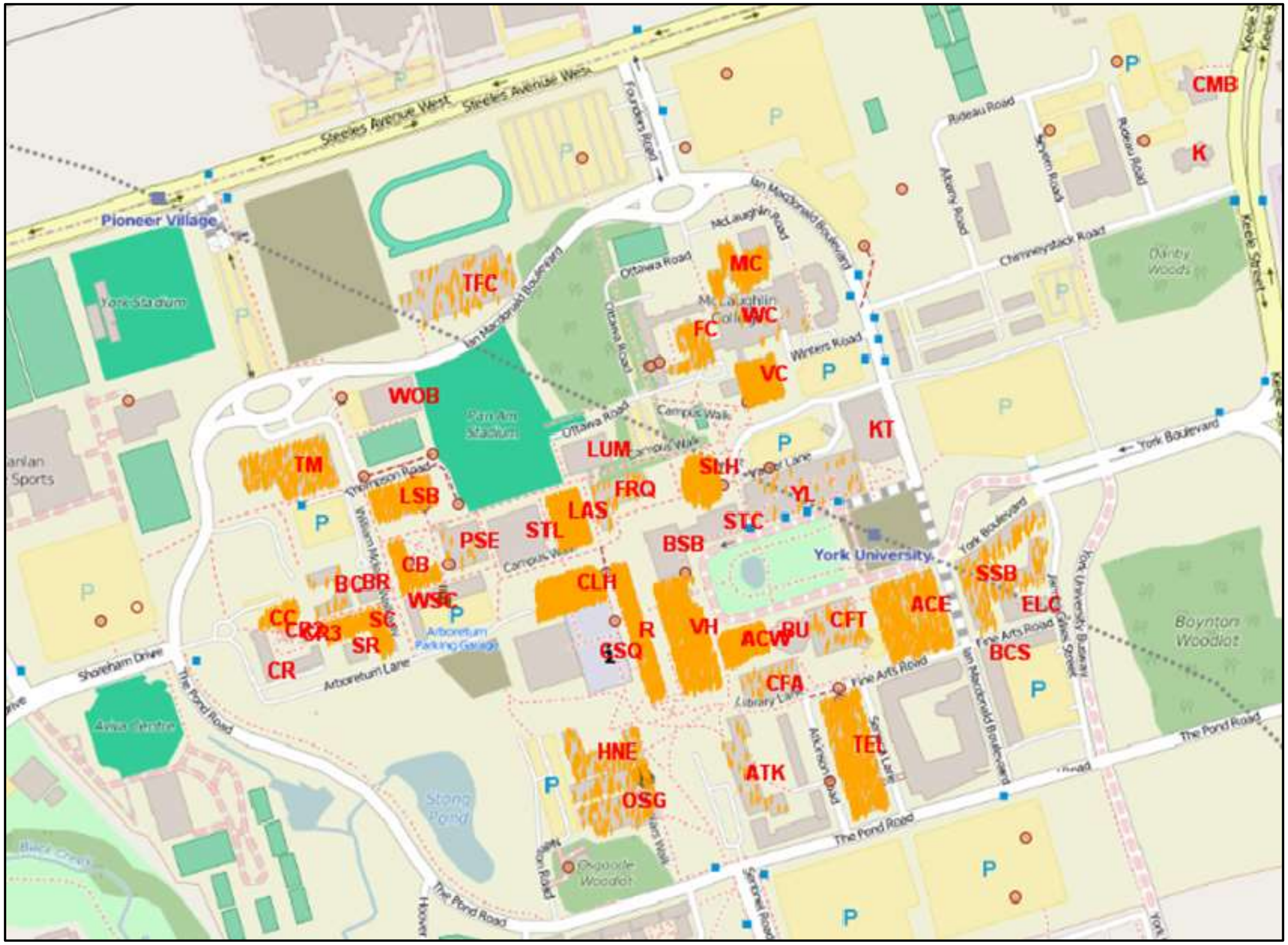
Figure 7.5 (a) to (e) – The process of campus evacuation in the Keele Campus Evacuation Model
(a) A regular day on Campus



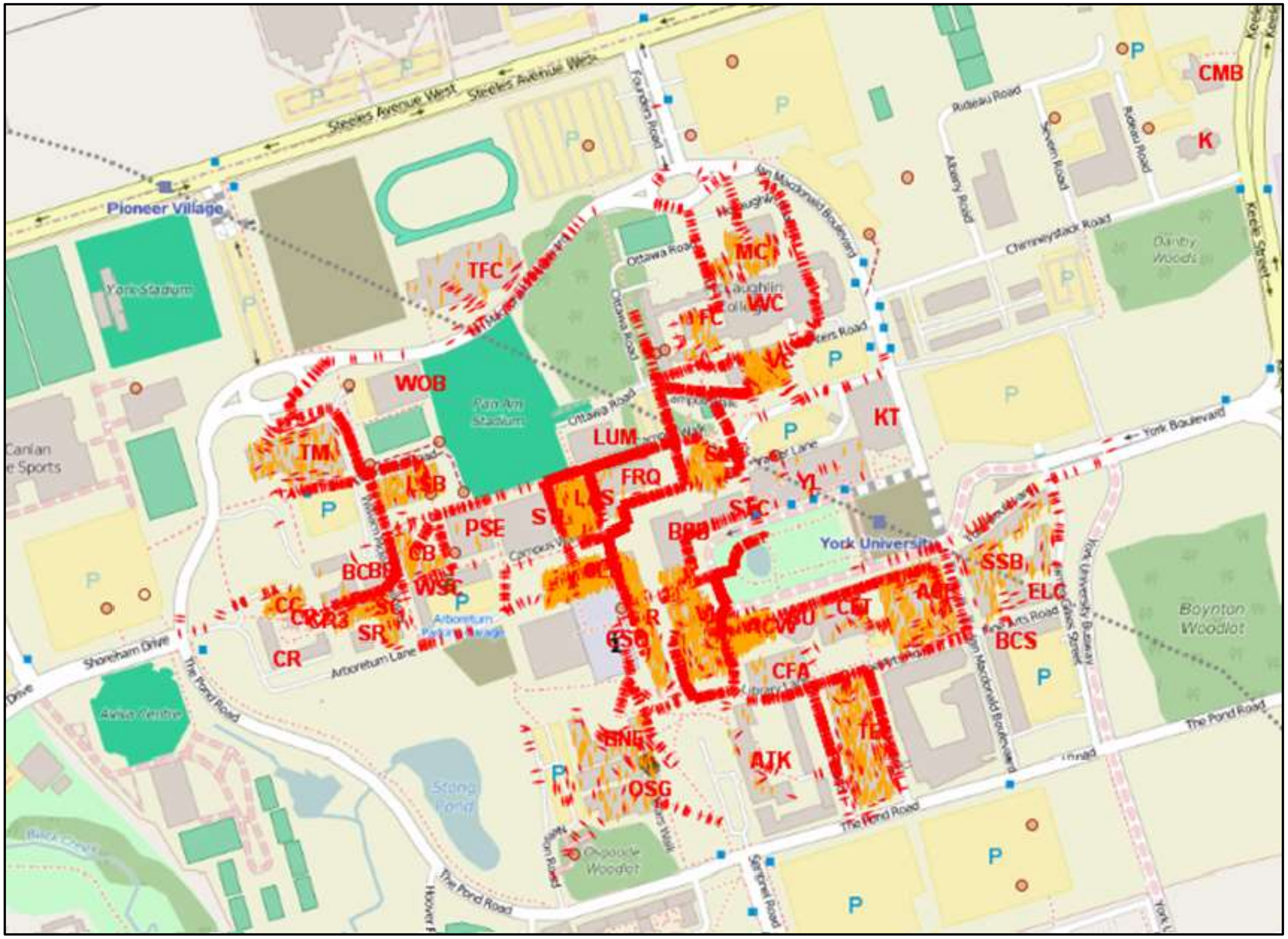
(b) Alarm is rung informing of a campus evacuation



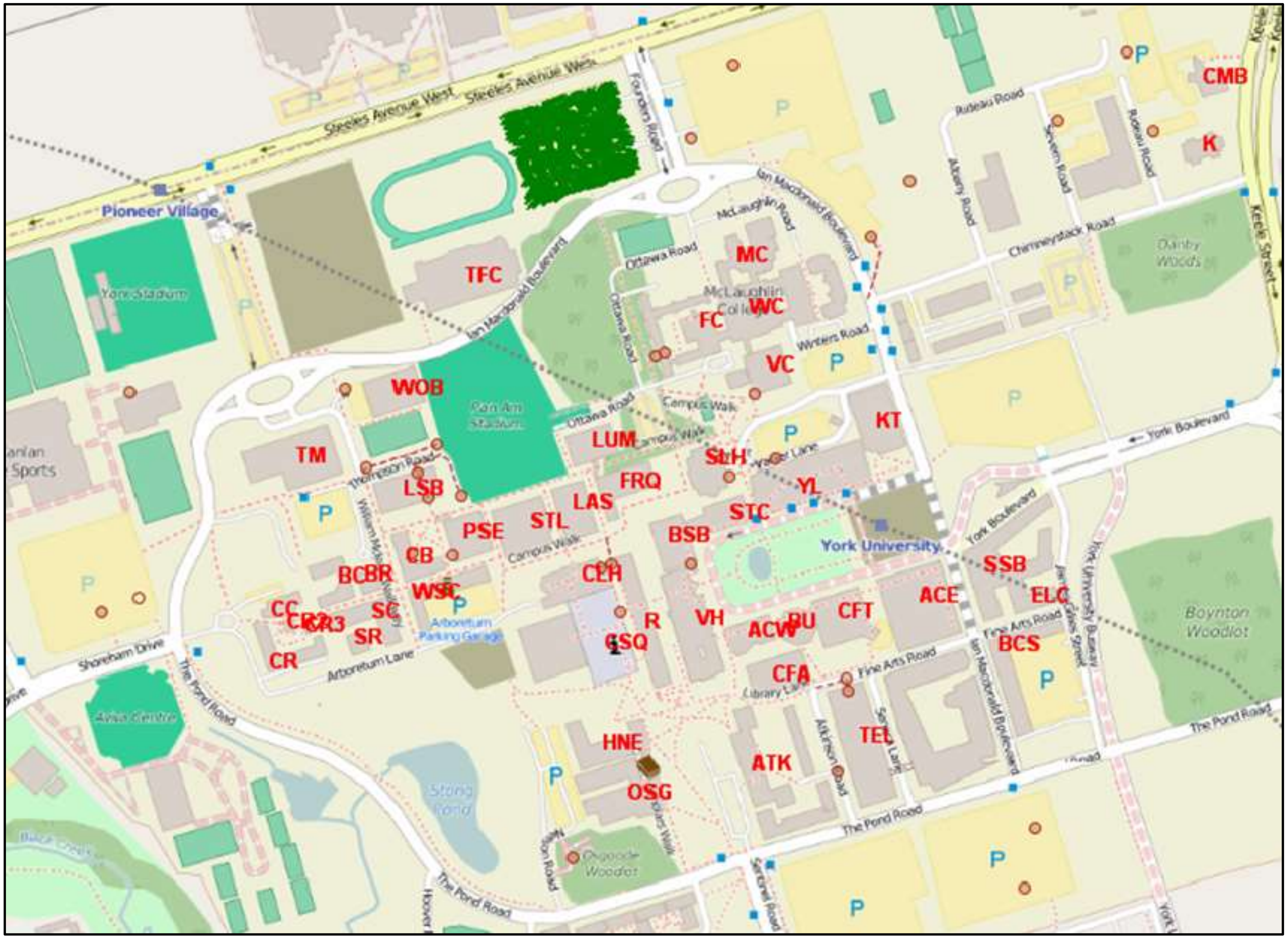
(c) Agents recognize they need to evacuate



(d) Agents leave the buildings and travel towards the predetermined evacuation zone



(e) Agents arrive to the evacuation zone



7.2H Theoretical Analysis

While the model is reflective of the population numbers on campus, not all values utilised in the model are reflective of the Keele Campus. Various factors, such as the average start time during an evacuation, the time required to descend a multi leveled building, and the walking speed during an evacuation, were not gathered from observation, but from scientific journals.

The average start time of an evacuation is identified as the time period between the evacuation alarm and when individuals start leaving the building. The delay period or pre-movement time has often been studied in association with fire alarms. Proulx and Fahy (1997) in particular studied the evacuation of mid-height apartment buildings (6 to 7 storeys) and identified the time delays ranged from 2 minutes and 49 seconds to 8 minutes and 35 seconds. The over 5 min difference in reaction time was due to the inaudibility of the alarm, where individuals, who were not able to hear the warning signal, were notified by different cues, such as fire truck or smoke.

A large factor influencing the start time of an evacuation is audibility, which is highly reflective on the architectural criteria of buildings. As this information was not successfully collected from the university, the variable which can assist in this task is the number of floors per building. Based on 114 buildings created in the model and the values obtained from the Planning & Architectural Design branch of the Campus Services and Business Operation, the average number of floors is between 5 and 6, a value which is reflective of the mid-height apartment studied by Proulx and Fahy. Hence, the varying evacuation start times identified by Proulx and Fahy, as well as the average time, were integrated in the model as the maximum, minimum, and mean value in the triangular function.

In addition to the reaction time of individuals in multi-level buildings, it was necessary to understand the speed it takes to descend each floor and leave the building. The article, *Time of evacuation by stairs in high buildings* by Galbreath (1969) provides and equation (1) which assisted with the necessary calculation.

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

Where

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

N = the number of people above the first floor utilizing the stairs to evacuate (assuming the people on the first floor have different exit locations)

n = the number of people who can stand on the stairs at 3 sq ft/ person or the number of people per floor, whichever is the smallest value

r = the rate of discharge of the stairs in people per unit exit width per minute

u = the number of exit units with a 22 inch width

This equation was utilized with slight modifications. In terms of the value N, the total number of individuals was provided in the equation as it is assumed the individuals on the first floor would also be using the same exits. In terms of the value n, the total population was evenly distributed amongst all the floors, as the collected information was organized per building rather than per building floor. When it comes to the variable r, the constant value r = 45 was utilized, as it is assumed the number of people per floor surpassed the 3 sq ft per person. The last variable u was calculated based on five building floor plans provided by Planning & Architectural Design branch of the Campus Services and Business Operation. The average number of doors accounted in these buildings was 18.2. This equation was integrated in the *calculateBuildingevacuationTime* function in the *BldgEvac* state of the student state chart.

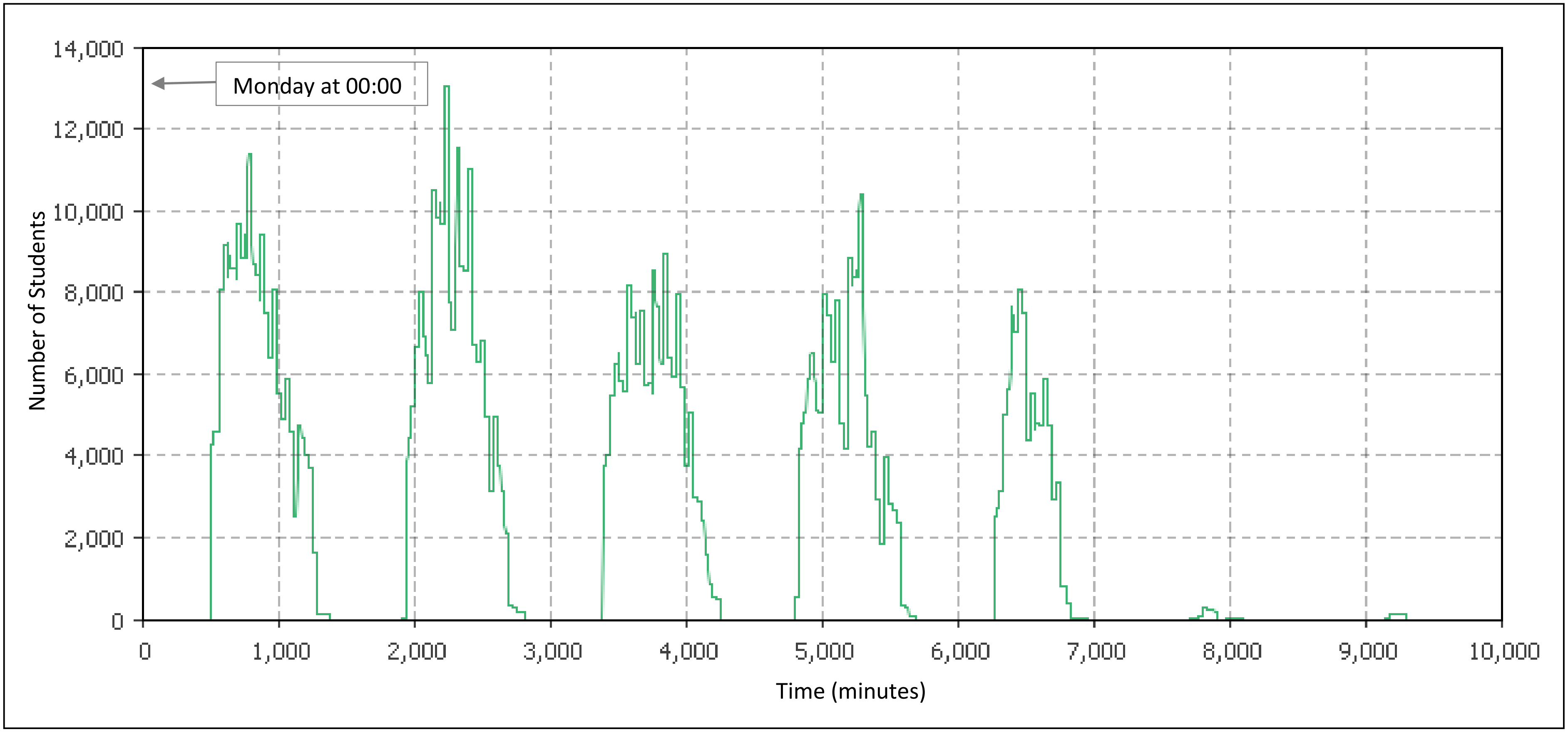
The last component which influenced the overall outcome of the model was the students' speed as they travel towards the safe zone. On average, free walking speed has a mean value of 1.38m/s (Federici et al., 2012) and when interacting with an incline, either up or down, a speed of 0.55m/s was recorded (Rinne et al., 2010). In addition to inclines or staircases, speed decreased when there was also an increase in flow density. A flow density is defined as the density of individuals travelling a certain path. When the density of people increases, walking speed usually decreases (Rinne et al., 2010). Unfortunately, this relationship was not successfully reproduced in the model as the agents travel in single file. Due to this limitation, students were randomly and evenly distributed based on a range of walking speeds (0.55m/s to 1.38m/s). This range was selected to reflect various walking speeds an individual may encounter while traveling to the safe zone.

7.2I Simulation Analysis

Utilizing the Keele Campus Evacuation Model developed in this paper, simulation experiments were conducted to explore how the evacuation time is influenced by various factors. The simulations analysis entails a regular week on campus and evacuations dependent on the time of day and location of evacuation zones.

The first simulation illustrated a regular day on campus. The simulation ran for the duration of a week with no disturbances (Figure 7.6). Seven peaks were identified on the graph; the most predominant peaks represent the five weekdays and the two smaller peaks, the weekend. The graph represents the population of registered student at any point during the week.

Figure 7.6 – Total number of students registered in courses requiring a physical presence during the winter semester 2014 at the York University Keele Campus over the length of a week



When a closer look is taken on each day of the week, they each possess varying features which could affect the overall outcome of an evacuation. These factors entail class hours and the number of buildings involved (Table 7.0). The day and time of lessons can identify the number of individuals partaking in an evacuation. Throughout the week, the earliest start time for a class is around 08:00 or 08:30 and the latest classes ends around 22:00 from Monday to Friday and at 18:00 and 09:00 on Saturday and Sunday, respectively. When weekdays are compared, the change in student population is similar throughout the day. For example, the majority of classes occur around mid-day with the highest number of students in classes identified in the afternoon at around 13:00. While each weekday possess a similar schedule in terms of when classes are offered, they do have different values in term of the number of students in class at one time or the total number of students registered in courses in a day. While students can register in more than one course per day, the values are relative to one another and expressive of the total number of students on campus per day. The time and day of an evacuation assisted in predicting population size and determined approximately the number of students leaving each building.

The location of students in buildings prior to an evacuation assists in determining escape routes. In the 31 buildings with classes during the week, Mondays and Thursdays are the only days utilising all the buildings. On the other weekdays, ATK (on Tuesday), TFC (on Wednesday and Friday) and WC (on Friday) do not hold any classes. As for the weekend, a few buildings are utilised ACE, ACW, MC, R, SSB, TEL, and VC on Saturday as well as R and SSB on Sunday. The three buildings which were not utilised on the weekday are identified within the perimeter of the campus. While the students from these buildings contribute to the total number of people evacuating, it has minimal impact on the centre of campus possessing the highest concentration of buildings.

Table 7.0 – Descriptive qualities of every day of the week

Day of the Week	Earliest Time Class Begins	Latest Time Class Ends	Largest Student Population in Class at One Time	Total Number of Student Registered in Courses	Total Number of Buildings Holding Classes
Monday	08:30	22:00	11375	51215	31
Tuesday	08:00	22:00	13032	55202	30
Wednesday	08:30	22:30	8941	46865	30
Thursday	08:00	22:00	10413	46865	31
Friday	08:30	21:30	8083	22094	29
Saturday	08:30	18:00	267	583	7
Sunday	08:30	09:00	142	142	2

To observe how population size affects an evacuation, multiple scenarios, based on time and day, were selected and compared with four possible evacuation selections. The criteria utilised as well as the results, entailing the buildings involved in the process, the number of students evacuated, and the time it took for each evacuation were provided in Table 7.1. When each of the indicated scenario were ran, the model was stopped at specific times to record the number of students and building involved at this point in time. For example, in the seventh scenario, Thursday at 14:45, the timer was stopped at 6720. The overall map (figure 7.7) illustrated the location of students attending class and adjacent was the graph indicating the total number of students on campus (Figure 7.8). To obtain a better understanding of the student population per buildings, a building was selected, and a graph identified the number registered students, Figure 7.9 illustrates a sample of these graphs. The majority of these graphs mimic the overall campus population. However some buildings, have unique patterns such as ATK, BSB, and CFA where the number of students attending courses varied.

Table 7.1 – Simulations utilizing the Keele Campus Evacuation

Criteria		Scenarios									
	Day	Monday	Monday	Tuesday	Tuesday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
	Time	10:35	15:46	11:00	13:15	15:20	19:40	14:45	16:00	10:00	9:20
	Time (min)	635	946	2100	2235	2360	4060	5205	6720	7800	9200
Buildings Involved in the Evacuation (X = Yes)	ACE	X	X	X	X	X	X	X	X		
	ACW	X	X	X	X	X	X	X	X		
	ATK	X	X			X					
	BC	X	X	X	X	X	X	X	X		
	BSB		X	X	X	X		X			
	CB	X	X	X	X	X	X	X	X		
	CC		X	X	X	X	X	X			
	CFA	X	X	X	X	X		X	X		
	CFT	X	X	X	X	X		X			
	CLH	X	X	X	X	X	X	X	X		
	CSQ		X	X	X	X		X	X		
	FC	X	X	X	X	X	X	X	X		
	FRQ	X	X			X		X			
	HNE	X	X	X	X	X	X	X			
	OSG	X	X	X	X	X	X	X	X		
	LAS	X	X	X	X	X	X	X	X		
	LSB		X	X	X	X	X	X	X		
	LUM		X	X	X	X	X	X	X		
	MC	X	X	X	X	X	X	X	X	X	
	PSE	X	X	X		X	X	X	X		
	R	X	X	X	X	X	X	X	X	X	X
	SC	X	X	X	X	X	X	X	X		
	SLH	X	X	X	X	X	X	X	X		
	SSB	X	X	X	X	X	X	X		X	X
	TEL	X	X	X	X	X	X	X	X		
	TFC	X	X	X	X	X		X			
	TM	X	X	X	X	X		X			
	VC	X	X	X	X	X	X	X	X		
	VH	X	X	X	X	X	X	X	X		
	WC		X	X	X			X			
	YL		X	X							
Total Number of Buildings Evacuated		25	31	29	27	29	21	29	20	3	2
Total Number of Students Evacuated		8900	6394	6477	13032	8652	3003	8819	3300	267	118
Arrival to Evacuation Zone (min)	North	53:24	54:15	57:10	54:50	54:43	49:30	53:55	51:52	34:04	47:26
	East	44:40	49:38	49:44	48:11	51:18	48:48	51:44	49:10	35:13	26:05
	South	59:21	58:04	64:55	66:51	65:01	55:16	62:35	57:21	48:39	30:54
	West	63:57	57:49	60:05	64:40	58:41	61:31	62:29	53:40	47:04	61:52

Figure 7.7 – Students attending class on Friday at 16:00

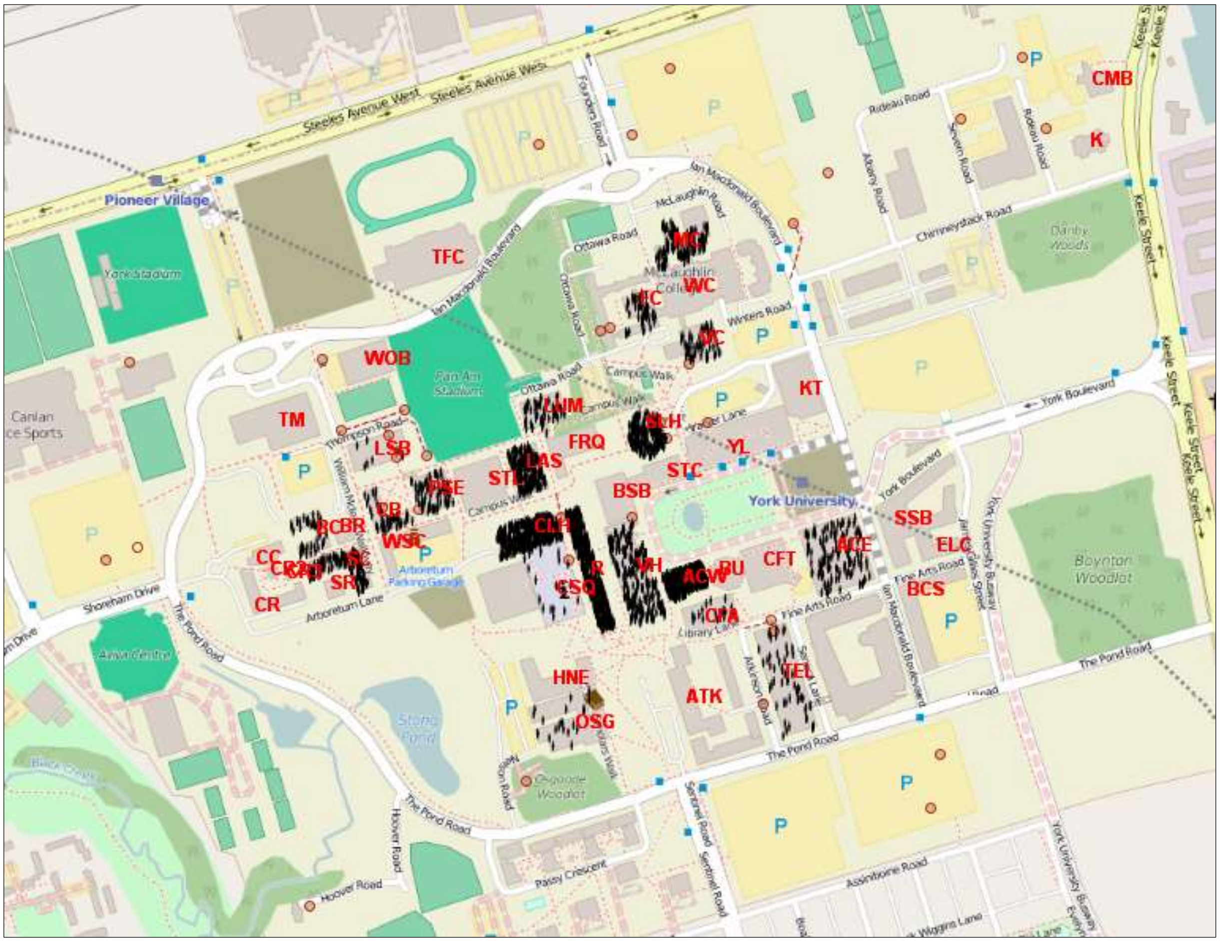


Figure 7.8 – Timeline of students attending class from Monday, 00:00 to Friday, 16:00

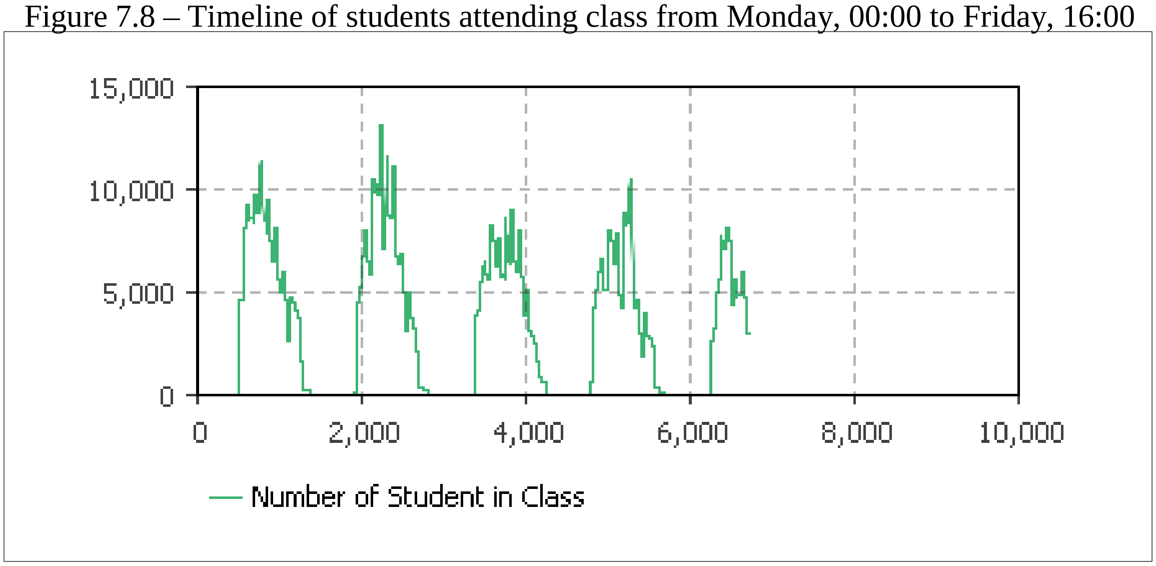
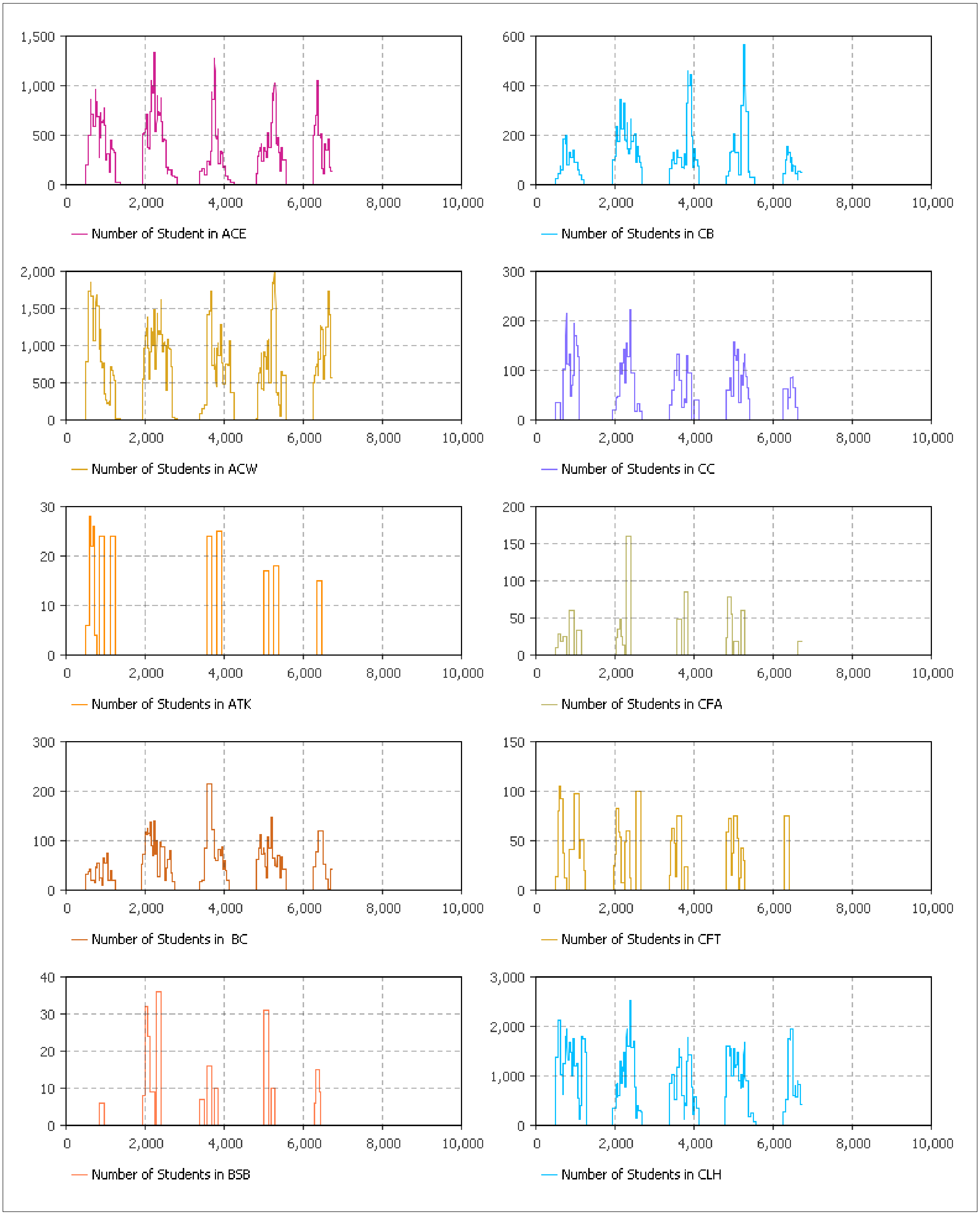
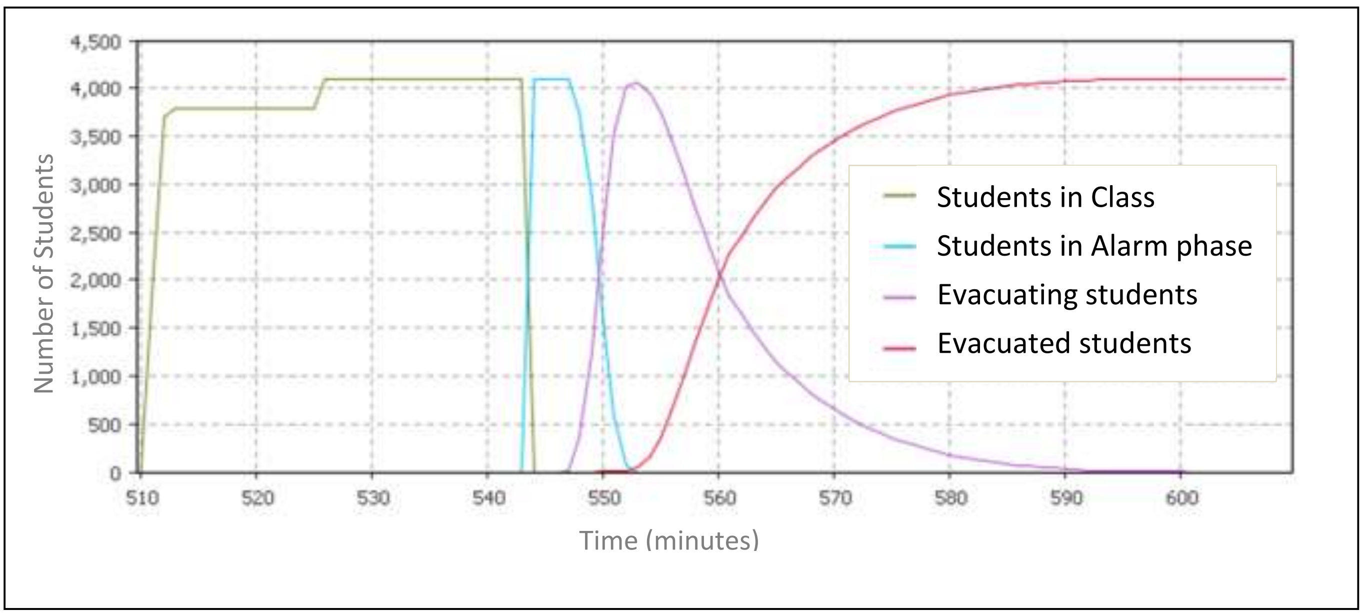


Figure 7.9 – Timeline of students attending class from Monday, 00:00 to Friday, 16:00 per specific building



While the model ran, it also generated a graph (Figure 7.10), informing the states of the student population. The graph's four states entail: when they are in *Class*, in the *Alarm* phase, *Evacuating*, and *Evacuated*. Three variables (Students in alarm phase, Evacuating students, and evacuated students) possess a dependent relationship with the previous phase. Because of this relationship, a smooth transition was seen as the student population are all going through the evacuation phases. In addition, as time progresses each transitional phase also increase in time. In the case of the first transition, for example, it took less than 2 minutes for all the students to hear the alarm. The following transition, when students understand they required to evacuate it took less than 10 minutes. As for the last transition, when students travel towards the evacuation zone, it required the most amount of time, approximately 50 minutes.

Figure 7.10 – Progression of student through evacuation phases

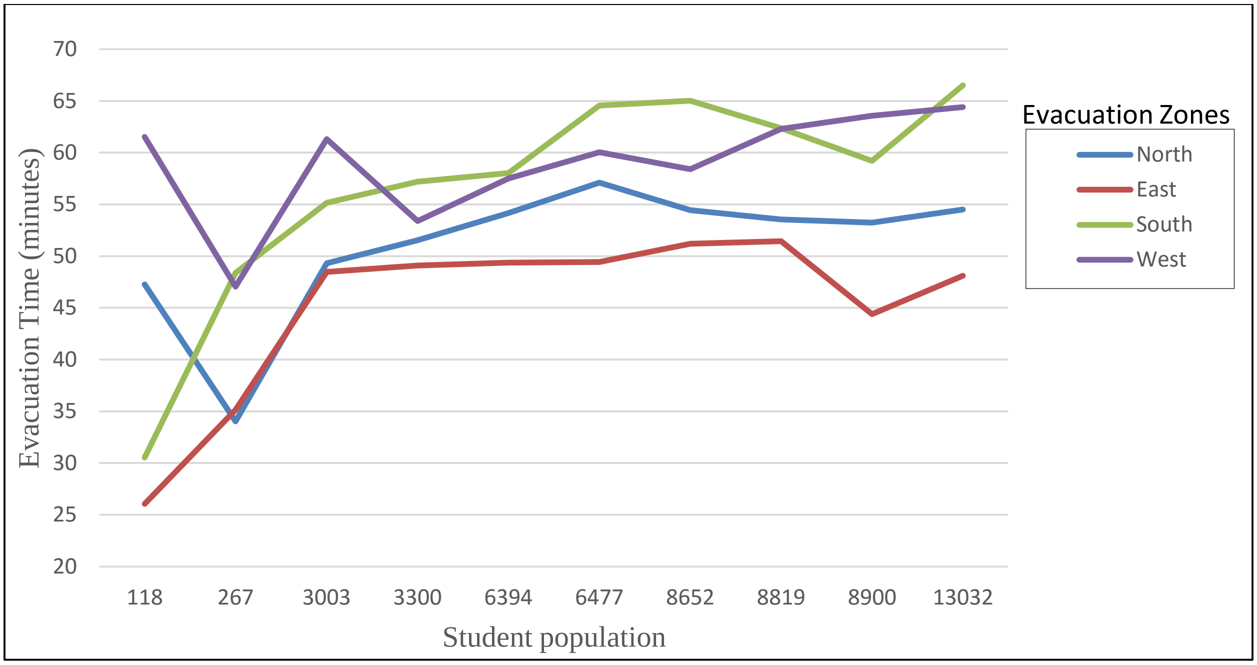


7.3 Results and Discussion

While the values gathered from Table 7.1 assisted in the collection of evacuation times for single journeys from class to evacuation, combining the observations provides a different outlook. Within the table, three variables were identified as contributing factors for the evacuation time: population size, buildings involved, and location of buildings.

Population size is speculated to be a large influence when it comes to evacuation. It is generally assumed, as more people are present, more time is required. To confirm whether this speculation holds, the number of individuals present was directly compared with the time required to evacuate. Figure 7.11 displays this relationship by also grouping the values for each evacuation zone and displaying it over time. The overall results did not indicate a clear-cut relationship. This expected relationship was only apparent with the South evacuation zone. The East evacuation zone also demonstrated a trend similar to the expected time required, however the evacuation time dipped when it reached a population of 8900 and increased again as it reached a population of 13032. As for the North and West evacuation zone, they both possess non-expected results, having a relatively high evacuation time when it comes to a low population count. Notably, the West line took over 60 minutes for a population of 113 individuals to arrive at the destination, a value higher than 7 other observations. Overall however, once it passed the 3000 population size, the time requirement from that point onward had a 5 to 10 minute error bar from the time value of 3003 population count.

Figure 7.11 – The time required to reach evacuation zones based on student population

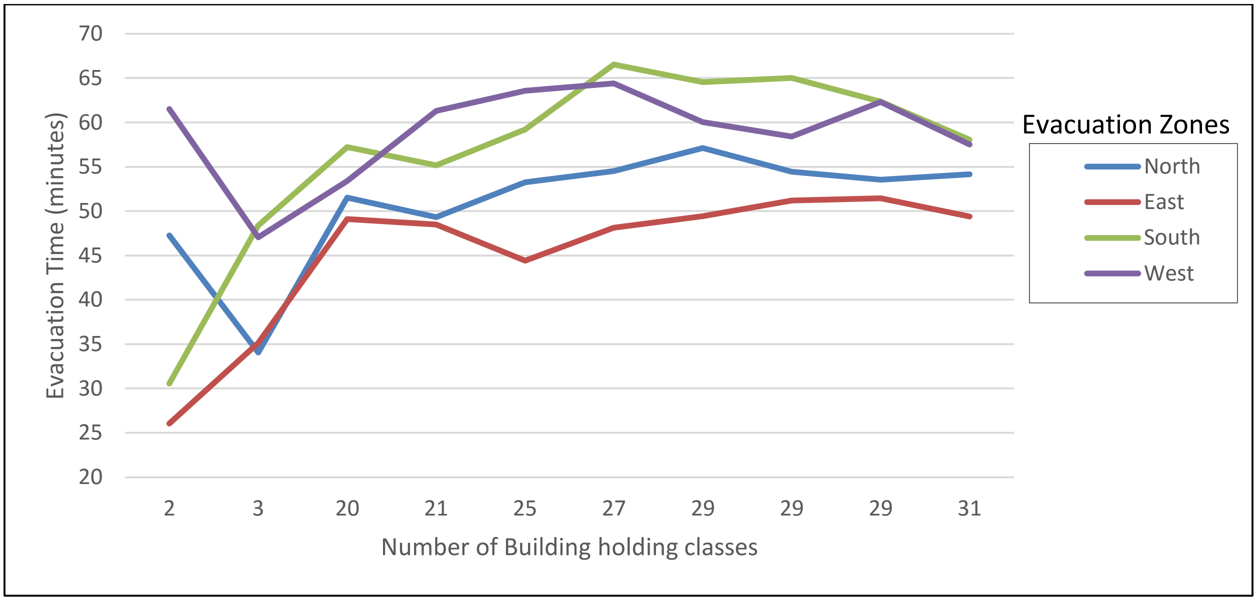


When examining the two smallest population sizes and comparing the evacuation time with other student populations a striking difference was noticed in the number of buildings holding classes. To analyze this relationship, the number of buildings holding classes were compared with the evacuation time. Figure 7.12 also illustrates mixed results. When observing a low number of buildings holding classes, the North and West evacuation zones again demonstrated a high evacuation time, while the South and North evacuation zone remain low. When taking a closer look at the buildings involved, the two buildings holding classes on Sunday were also identified as two of the three buildings utilized on Saturday. Additionally, there was only a difference of 100 individuals from Saturday to Sunday, the similarity in the two days caused one to wonder whether there was simply a glitch in the simulation.

Taking another glance at Figure 7.12, there was also a tapering-off effect. In the scenarios possessing 25 to 27 buildings, there was a 20 minute difference between the longest

(West) and shortest (East) arrival times. The difference in values progressively diminished as more buildings were included in the evacuation simulation. By the time the examined scenario reached 31 buildings, there was less than a 10 minutes difference between the South and East evacuation times. This trend gave the impression that evacuation reached a plateau, as more buildings were present, and hence better able to distribute the student population.

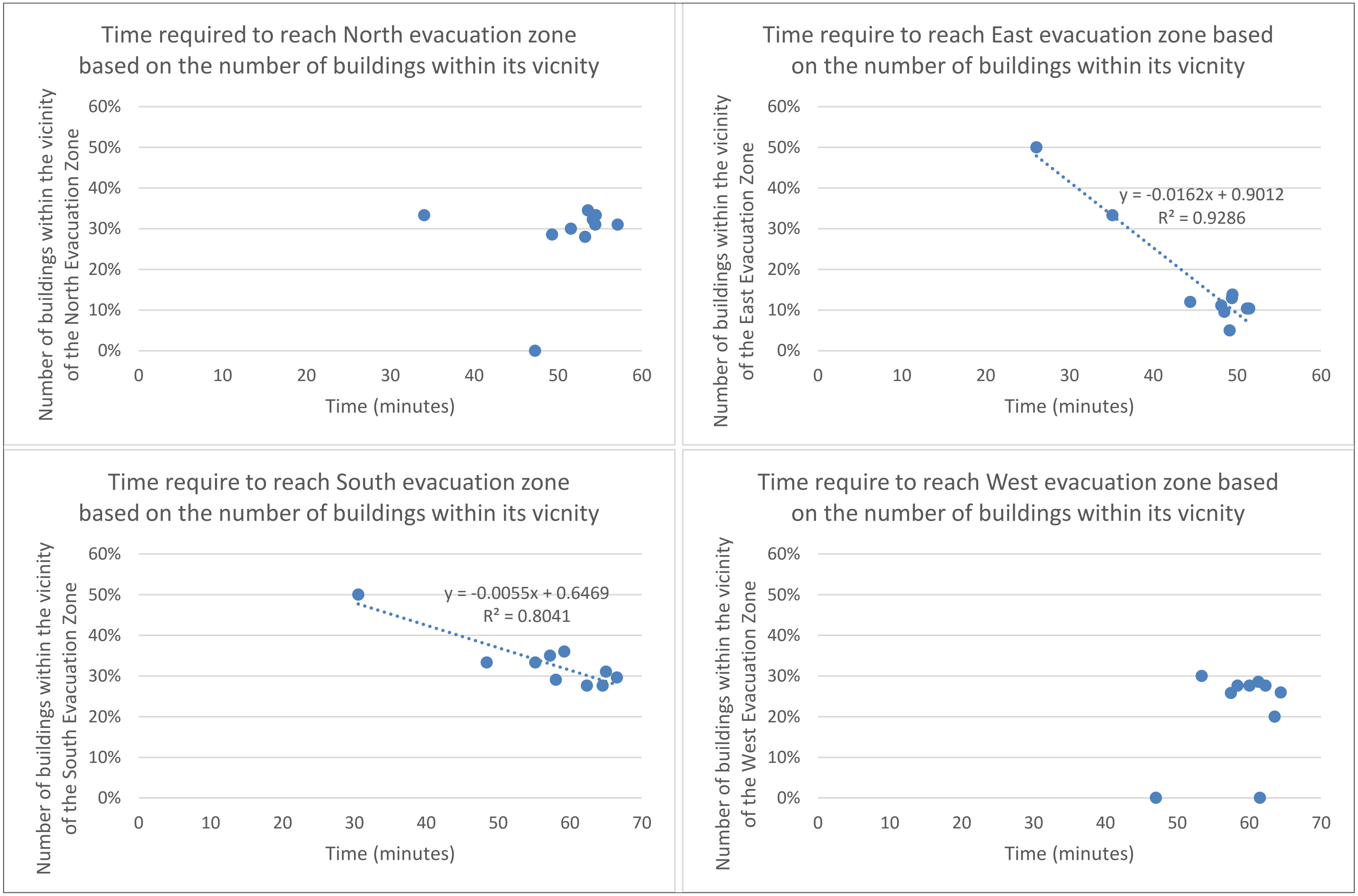
Figure 7.12 – The time required to reach evacuation zones based on the number of buildings holding class



The location of these building appeared to have an underlying factor in the overall outcome of the evacuation. To examine this relationship, the campus was divided into four sections and based on these sections, the presence of these buildings would be labelled North (BSB, FC, FRQ, LAS, LUM, MC, SLH, TFC, VC, and WC), East (ACE, CFT, SSB, and YL), South (ACW, ATK, CFA, HNE, OSG, R, SC, TEL, and VH), and West (BC, CB, CC, CLH, CSQ, LSB, PSE, and TM). The values gathered from Table 7.1 were then calculated accordingly and normalized. Figure 7.13 further demonstrated the relationship between evacuation time and the corresponding evacuation zones. The graphs demonstrated an interesting relationship, where they each possessed a unique pattern. Overall, the North and West buildings have clusters of points when the percentage of buildings within the vicinity of an evacuation zone reaches 30% and two isolated points. The clusters indicated it takes 50 to 60 minutes to reach the North and West evacuation zones. While the clusters did provide an understanding of when the variable reached 30%, they lack variations to obtain a more wholesome analysis. When observing the values from the East and South evacuation zones, they both possessed a linear relationship. Indicating a greater number of buildings within the vicinity of an evacuation zone required less time for students to evacuate. The high R square values 0.9286 (East) and 0.8041 (South) illustrated strong associations between the two variables. However, due to the variation in the four plots, an overall consensus cannot be made pertaining to evacuation time and the number of buildings within the vicinity of the evacuation zone.

Overall, the population size, the buildings involved, and the location of buildings appeared to have an influence in determining the evacuation time. While stray points have been identified in the experiments, if omitted, the general relationship between population and time demonstrated a logarithmic relationship, where the evacuation time became more constant as the population size increased. In terms of the number of buildings involved, the greater number of buildings holding classes demonstrated a more even distribution of students and less of a variation in evacuation time. Lastly, when it comes to the vicinity of buildings to evacuation zones, it appears to have a direct association with half of the evacuation zones. While these speculations have been made, more simulations experiments are required to strengthen these observations.

Figure 7.13 – The time required to reach evacuation zones in relation to number of buildings within its vicinity



8.0 Future Study

The Keele Campus Evacuation Model provided an overview of evacuations for students attending classes during the winter semester of 2014. While providing practical information in terms of class distribution, these re-enactments were not a 100 percent reflective of the winter semester of 2014. To enable a more realistic daily interpretation, it would be necessary to integrate more information about the agents, the buildings, and the landscape.

The agents in the model have played an important role in visualizing the impact of an evacuation, but by integrating the remaining students, employees, and visitors, it will provide a more comprehensive perspective of the individuals on campus. As students represent the dominant population on campus, fully understanding their activities is key in developing an accurate analysis. This entails knowing when they are not in class, but still on campus. This can be achieved by examining the number of individuals in areas not utilised for teaching purposes, e.g., student centres, recreational centres, libraries, and studies areas. In addition, it would be practical to understand how student dynamics change based on various periods in a semester, such as during mid-terms, finals, and exams. York University employees and independent workers at the university support the students in obtaining an education. They represent the second largest group on campus. The last agent which should be added to the final count are the visitors. While they represent a small population when compared to the students and employees, the visitors identify the university as a multifunctional place, utilised for conferences, open houses, and emergency shelters. The analysis of these three agents demonstrates that additional information is required to fully represent all the individuals on campus. Although, based on my personal attempts, the desired data is not readily available. In turn, the retrieval of the data can only be obtained through surveying and by manually counting individuals.

The gathered building information assisted in the calculation of the evacuation time for students on campus. This process can be enhanced by taking into account all buildings on the Keele Campus, whether or not owned by the university. As the current model only considered students in class, the time requirement can be much larger with the presence of individuals from non-owned university buildings. Additionally, to provide a more accurate calculation, it is necessary to evaluate each building's staircases and their maximum capacity. The varying values could change the dynamics and overall time requirement for an individual to reach a safe zone.

The last element which can assist in the overall outcome of the model is the topographic landscape. For examples, slopes, can greatly influence an individual's travelling speed. By having these elements already prescribed to the landscape, the agents would be able to react accordingly. Furthermore, creating paths allowing individuals to freely move within an area would enable these individuals to vary speeds based on the crowd density.

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