Spatial and Temporal Analyses of Emergency Calls Responded by the City of Vaughan Fire and Rescue Service during the 2013 Ice Storm

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1. Introduction:

Responding to emergency incidents during large disasters and emergency events is a very important and highly critical service. Studies show that the nature and volume of service requests in large emergencies change significantly depending on the type, time, extent, and duration of disasters. Considering that disasters could impact fire services as well as the larger communities in which fire stations operate, response becomes more challenging, resource intensive, with high risk for both fire fighters and people. (Asgary, Rezvani, & Nosedal-Sanchez, 2017) This research aims to provide some insights into response patterns during the 2013 ice storm in the city of Vaughn by using the incidents database of the Vaughan Fire and Rescue Service (VFRS).

According to the Canadian Disaster Database, the 2013 ice storm occurred from December 20th 2013 to January 1st 2014. Therefore, December 20th to December 31st has been considered as the study period. This study investigates how the 2013 ice storm has affected the responses provided by the Vaughan Fire and Rescue Service (VFRS) and the results are compared to the same period for years 2009 to 2016. The temporal patterns of different attributes of the responses during the study period will be examined on hourly, daily and yearly basis. Also, the spatial pattern of locations that have been received responses during the study period would be analysing by means of kernel density. This method will classify the areas from low intensity to high intensity. Finally, spatiotemporal analysis is applied on records by using comap technique to reveal how spatial pattern of the incidents may change over time.

2. Background:

2.1 The 2013 ice storm

The ice storm is a type of winter storm when freezing rain results in damaging accumulation of at least 6.4 mm of ice on exposed surfaces, according to the U.S. National Weather Service (Hauer, Dawson, & Werner, 2006).

Ice storm may result in freezing rain which can cover any object with a layer of ice which is smooth and slippery. This situation results in hazardous commute conditions for drivers and pedestrians.

Moreover, the ice layer is heavy and will add noticeable weight to trees and tree branches which may break them. The falling trees and branches can cause road closures, damaging the electricity and telephone lines and cause other destructions as well.

The ice storm also forms an ice layer on the power and telephone lines which adds a massive weight to them. This extra heavy weight can break the power and telephone lines and even break the poles and collapse them. Therefore, ice storm can severely increase the risk of power outage and leave people without power for several hours or even several days. Damages resulted from ice storms can be extremely high. Based on historical data in Southern Ontario, the risk of an extensive power outage is very high when freezing rain exceeds 40 mm, although even 30 mm of freezing rain may have severe impacts and causing power outage (Klaassen & Cheng, 2003).

The electricity outage during ice storms have a potential to directly and indirectly affect human health due to unintentional carbon monoxide (CO) poisoning. The slight CO poisoning can cause nausea, dizziness, and headache. Severe CO poisoning is life-threatening and can cause unconsciousness, heart failure, and death (Hartling & Brison, 1998). During lengthy power outages caused by severe ice storms, people start using very different types of exposed flames, charcoal and propane barbecues, for lighting, cooking, and heating in confined locations which leads the high incidence of CO poisoning (Renn & Conners, 1997; Toronto City Manager, 2014).

Ontario and Quebec experienced a severe ice storm (The 2013 ice storm) from the evening of December 21, 2013 through December 22, 2013. The worst-hit areas were along the shores of the Lake Ontario and in some areas up to 3 cm (1.2 in) ice accumulation on the ground was reported. This ice storm produced freezing rain, ice pellets and wind resulting in wide-spread power outages. More than 600,000 power outages at the height of the storm were reported by Hydro One, the utility company that serves mostly rural areas of Ontario (Ontario Goverment News Release, 2013). Also, over 300,000 hydro customers in Toronto were without power for three days which resulted in disruptions to the city services (Armenakis & Nirupama, 2014). The Toronto Hydro company reported an estimated cost of CA$12.9 million due to the ice storm (Freeman, 2014).

During December 20^{th} to 31^{st} of 2013, all cities in the area experienced an extremely increased demand for first responders due to the extent of the ice storm damages, prolonged power outage, the lack of heating, use of inappropriate heat source etc. For instance, the Toronto Fire Services received 316 calls for CO exposures and Toronto Emergency Medical Services (EMS) received 1100 calls for general medical problems, slip and fall as well as CO poisoning (Toronto City Manager, 2014).

2.2 Spatiotemporal Analyses

Studying the objects or events that are changing in time and space are often essential in different scientific and social areas. The location and geometry properties of the object is so-called spatial data. The information of timestamp or time interval for which the object is valid is also called temporal data. The spatiotemporal analyses are referring to the mathematical methods that are developed to study this spatial and temporal data with the main interest in smoothing the data and predicting time evolution of response over a certain spatial and temporal domain. Generally, the spatiotemporal analyses involve processing large and complex set of spatial and temporal data which needs immense computational efforts. Nowadays due to dramatical advances in computer hardware and software technologies and developing novel techniques for analysing big data, the spatiotemporal analyses is widely considered in different research areas such as hydrology, ecology, geology, social sciences, medicine etc.

These spatiotemporal data sets are often very large, for example, air pollution measurements of the last ten years which were observed every day at over one hundred locations or data of all emergency calls and their responses for a large city, e.g. Toronto, over the last decade. Mathematical models, with statistical nature, should be employed to accurately analyse these big data sets. The proper mathematical model will allow accurate forecasting in future time periods and interpolation over the entire spatial region of interest (Sahu & Mardia, 2005). Any spatiotemporal data explains a spatial and a temporal phenomenon of an event that may happen at a certain time and location. It is essential to efficiently identify the spatial and temporal features of spatiotemporal events in a big spatiotemporal database since many of these events interact with each other and present patterns which may help to understand the physical phenomenon behind them.

Developing a mathematical model for spatiotemporal events is a complex process due to two main reasons. Firstly, the spatial and non-spatial properties of the events are continuously changing and these changes may be discrete. Secondly, any spatiotemporal event is under influence of co-located neighboring events in the database. For instance, the fire spread is influenced by rain and changing wind speed and direction. Understanding spatiotemporal phenomena calls for processing, analysis and mining of vast amounts of spatiotemporal data along spatial, temporal and thematic attribute dimensions at multiple levels of granularity (Venkateswara Rao & Govardhan, 2012).

The spatiotemporal data analysis and mining is an emerging research area with applications in many important domains such as:

- Meteorology: all kinds of weather data, moving storms, tornados, developments of high pressure areas, movement of precipitation areas, changes in freezing level, droughts.
- Biology: animal movements, mating behavior, species relocation and extinction.
- Crop sciences: harvesting, soil quality changes, land usage management, seasonal grasshopper infestation.
- Forestry: forest growth, forest fires, hydrology patterns, canopy development, planning tree cutting, planning tree planting.
- Medicine: patients’ cancer developments, supervising developments in embryology.
- Geophysics: earthquake histories, volcanic activities and prediction.
- Ecology: causal relationships in environmental changes, tracking down pollution incidents.

- Transportation: traffic monitoring, control, tracking vehicle movement, traffic planning, vehicle navigation, fuel efficient routes.

In addition to the mentioned areas, the spatiotemporal has been implemented in emergency response planning and management area. One of the main topic in the emergency response planning is to study the pattern of the fire incidents and fire calls and analyze the responses provided by first responders. However, this specific research area has not been considered by researchers and there are very few published works in literature.

Therefore, this research work specifically utilizes the spatiotemporal analysis methods to study the fire calls during the 2013 ice storm in a case study of City of Vaughan in Ontario, Canada.

2.3 Research Works on Fire Incidents Analysis using Spatial and Temporal Methods

There are limited studies on spatial and temporal analysis of fire incidents in published literature. Some of the possible reasons for this situation are (1) lack of detailed geocoded data collected by fire services in the past, (2) unavailability of GIS data of fire incidents to researchers and (3) lack of GIS skills within fire services. However, the GIS-based techniques can identify dwelling characteristics potentially correlated with the fire incident. This information can be used to produce maps of risk at detailed geographical scales. In this section, some of the main research works are reviewed that implanted spatial and temporal analysis in investigating fire incidents.

Pew et al. (2001) investigated spatial and temporal patterns of wildfires caused by human in the temperate forest of Vancouver Island in British Columbia province of Canada (Pew & Larsen, 2001). Their study demonstrated that GIS and spatial and temporal analysis can be used to generate a meaningful probability model of human cause wildfire in the studied area of Vancouver Island. Also, the results of this study were helpful to identify the areas with high risk of fire occurrence, types of human caused wildfire that needs the most response preparedness and also help to delimit fire management zones.

Corcoran et al. (2007) investigated the patterns of the fire incidents using spatial and temporal analysis in South Wales as a case study. The authors focused on implementing the spatial methods which were more commonly used in crime investigation. This research had two main contributions. Firstly, it studied the relationship between different types of call-out to incidents and a variety of socio-economic variables. Secondly, it investigated spatial relationship between different types of call outs using measures of spatial correlation or association. The authors applied spatial methods to micro-level fire incident data to find their relationship patterns and explore their spatial dynamics. The results of this research showed that there are certain variations in the strength of the relationship between incident types which is not similar to the broad trend derived from the 2001 Census of population in South Wales. The author recommended that their analysis approach would be beneficial for variety of Fire and Rescue Services applications such as targeted campaigns for schools in high risk areas, predicting future spatial patterns in fire incidents and analysing the potential impact of spatial interventions in any performance monitoring exercise.

Asgary et al. (2010) studied structural fire incidents in Toronto, Canada using three methods of spatial, temporal and spatiotemporal (Asgary & Ghaffari, 2010). The main research contribution of their work was to prove effectiveness of spatiotemporal methods for investigating spatiotemporal patterns of fire incidents. They showed the effectiveness of using a combination of different types of information in identifying the spatiotemporal patterns of fire incidents. Results of their work showed how the patterns of structural fire incidents in Toronto vary with the time of the day, the day of the week, and the month of the year. Also, they showed that fire trends vary according to incident type and can provide important exploratory analysis prior to more detailed investigations. The result of these types of analysis can be used by planners and decision makers to improve fire safety.

2.4 Motivation and Justification

During most disaster and emergency situations total number of 911 calls increases (Conzelmann, Sleavin, & Couvillion, 2007; Rajaram, et al., 2016) and demand for and pressure on fire services rise. The 2013 ice storm in the Greater Toronto Area (GTA) is a good example that resulted in a widespread power outage and left a very large number of customers without power (Armenakis & Nirupama, 2014), demand for first responders, including fire services increased significantly (City of Toronto, 2013). Most of this increase was attributed to the use of inappropriate heating sources and generators in enclosed spaces (Rajaram, et al., 2016). In particular, the City of Toronto reported a five-fold increase in the number of carbon- monoxide related calls to fire services during this event.

Disasters and emergencies could limit the capacity (human, equipment, communication) as well as the ability (access, environment, etc.) of fire stations to effectively perform their operations as they do in normal situations (Nirupama, Adhikari, & Sheybani, 2014). Such conditions may result in different levels and patterns of human and property losses (Yates, 2013). For example, studies have shown that large scale power outages have increased human impacts (i.e. mortality and morbidity) through fires and carbon monoxide poisoning (Cukor and Restuccia 2007; Lawrence et al. 2004) among other things. During the power outage situations people start using very different types of exposed flames for lighting, cooking, and heating which leads to more fire accidents and losses.

The fire stations' response to emergency calls during large disaster and emergency events is a very important and highly critical service. Fire response become even more critical during disaster events (Asgary, Sadeghi Naini, & Levy, 2009). For example, there may be an immediate increase in certain types of fires or rescue services. An impaired traffic network may lead to longer fire response and service times that indirectly affect the impacted population.

Lack of or impaired fire services during major emergencies should also be considered by the general public and businesses that are active in disaster and emergency zones. Even if their own house or building might not have been impacted directly, their risk will be higher because it is likely that emergency services may not be easily accessible. One study on Calgary flood showed that even when certain employees could access the work place during the Calgary flood without difficulty, the risk to employees was much greater than normal situations because "if something happened to them in the work place there likely would have been no fire, police, or ambulance services available to respond" (Nielson, 2015). This is important, partially because unlike many other community services, fire services are not something that can be provided by spontaneous volunteers (Waldman, Simona, & Matt, 2016).

Fire incidents have been examined in normal conditions from different aspects (Asgary et al., 2009a; Asgary et al., 2009b; Asgary et al. 2010; Asgary et al., 2012; Sadeghi-Naini and Asgary, 2013). However, studies on fire incidents during major disaster and emergency situations are rare globally and very limited in Canada. A pioneering study in this area was conducted by (Warheit, 1996). This study investigated the functioning of fire stations in major emergencies based on the examination of fire station operations in a number of domestic and foreign disasters. He examined fire departments in terms of their typical organizational patterns, their disaster-related tasks and activities, and their organizational adaptation to demand situations. He argues that unlike many other organizations fire department are likely to continue to cope with tasks similar to their pre-disaster responsibilities since their specialized tasks can seldom be pre-empted by other groups or agencies. (Asgary, Rezvani, & Nosedal-Sanchez, 2017)

Disasters have the capacity to undermine fire departments primary mission. Understanding the nature, volume, impacts, and response performances and resilience of fire incidents during major disasters and emergencies is very important and such a study provides valuable information to fire departments for risk mitigation, preparedness and response management during major disaster and emergencies in their respected communities. While fire departments are proficient at planning and preparing for normal operating conditions (Simpson & Hancock, 2009), better understanding and preparedness for major disaster events is more challenging, in part due to having few data associated with rare, potentially catastrophic events (McLay, Boone, & Brooks, 2012). Better knowledge of the expected situations and preparedness leads to a better fire response to people during such events. (Asgary, Rezvani, & Nosedal-Sanchez, 2017)

It is believed that the ability to accurately assess the nature and volume of fire incidents during a disaster is critical for effective use of fire departments' resources. Therefore, the results of this study provide insight into the factors that can assist the Vaughan Fire and Rescue Service leaders in planning for disaster events. Preparedness decisions that could be enhanced as a result of this research include improved methods for contingency planning for scheduling staff on short notice, determining which types of fire response units are more likely in demand in different disaster situations, what challenges fire response personnel might face on the ground, and what type of impacts they might expect.

This research enables the Vaughn Fire Rescue Service (VFRS) to learn from the 2013 ice storm effects. Fire stations are subject to disruptions caused by extreme events. This study can provide evidences of possible disruptions that have been caused to fire stations in major events such as ice storms. Therefore, the outcome will help VFRS to better prepare themselves for future events.

Some of the key research questions of this study are:

- What types of incidents were more common during the ice storm in the City of Vaughan?
- What type of emergency calls received during the 2013 ice storm compared to the same period in 2009-2012 and 2014-2016?
- What have been the temporal patterns of incidents responded by VFRS during the ice storm?
- What have been the spatial patterns of incidents during the ice storm?
- What have been the overall impacts of incidents during the ice storm?

3. Study Area and Data:

3.1 City of Vaughan

The City of Vaughan is located in the Province of Ontario, Canada. From municipal perspective, Vaughan is part of the regional municipality of York. As Figure 1 shows, Vaughan is located north of City of Toronto. On the east side, Town of Richmond Hill and City of Markham, and on the west side, city of Brampton are the neighbourhood municipalities.

Figure 1 Map of Greater Toronto Area (GTA)

City of Vaughan with the population of 319,893 is one of the top 10 fastest growing municipalities in Canada during the 2006-2011 period and the population will reach to 416,600 by 2031 according to the York Region forecast. It is positioned as the 17th largest municipality in Canada (Population, 2018). Also see Appendix I. The geographic location of Vaughan, appointed the city to become an entry to the Greater Toronto Area (GTA) with market access to 135 million US and 20 million Canadian consumers within a one-day drive (Figure 2). Provincial highway systems support direct connection to the US interstate highway system in less than a 1.5-hour drive. According to Appendix II, highways 400 and 407, the two of the main GTA highways, are passing through City of Vaughan. Highway 427, the Ontario's second busiest freeway by volume and third busiest in North America, is also crossing the west side of City of Vaughan. Ontario Ministry of Transportation have announced to extend Highway 427 north to Major Mackenzie Drive in City of Vaughan. The construction began in 2017 and is expected to be completed by 2020. (Ministry of Transportation, 2016). The Pearson International Airport, Canada's busiest and largest airport, is located within 10 Km of Vaughan. Also, Port of Toronto, one of Canada's largest major inland ports, is located 30 km south of the City.

In terms of household and the dwelling characteristic of Vaughan, Table 1, demonstrates complete and detailed information according to2016ensus. There are 94,250 private dwellings in the City of Vaughn while more than 65% of them are single-detached houses.

Figure 2 Location of City of Vaughan in North America

Also, the household size is shown in

Table 2, where 304,145 people of the city's population are living in the private households. And the average household size is 3.2 persons. In terms of age characteristic of Vaughan population, 18.8% of the population are 0-14 years old, 67% are 15-64 years old, 14.2% are 65 or older and finally, 1.7% are 85 years old or over. Appendix III.

Table 1 Household and the Dwelling Characteristic City of Vaughan (Census 2016)

Structural Type of Dwelling	*Number*	*Percentage*
Single-detached house	61,215	65%
Apartment in a building with five or more storeys	9,805	10%
Semi-detached house	7,685	8%
Row house	10,175	11%
Apartment or flat in a duplex	3,345	4%
Apartment in a building with fewer than five stories	1,990	2%
The other single-attached house	30	0%
Moveable dwelling	5	0%
Total occupied private dwellings	94,250	
Other attached dwelling	23,230	

Table 2 Household size in City of Vaughan (Census 2016)

Household Size	*Number*	*Percentage*
1 person	12,155	13%
2 persons	22,760	24%
3 persons	18,295	19%
4 persons	24,125	26%
5 or more persons	16,920	18%
Total private households	94,255	
Average household size	3.2 person	

Similar to the City of Toronto, Vaughan is a multicultural city, has a very diverse population and approximately 106,225 of the total population speak in a language other than English or French. The detailed table of the top non-official language mother tongue is presented in Appendix IV.

The Vaughan Fire and Rescue Service (VFRS) has nine active fire stations which are 7-1, 7-2, 7-3, 7-5, 7-6, 7-7, 7-8, 7-9, 7-10. Fire station 7-4, located at 10665 Islington Avenue, Kleinburg, was in service between 1969 to 2013. VFRS currently provides services to the northwest portion of the City from Fire Station 7-9 (9601 Islington Avenue) in Woodbridge. As, Kleinburg is a rapidly growing community within the City, a new fire station is required to provide more efficient and responsive fire and rescue services. Therefore, a brand-new fire station 7-4 is planned to be built within the Heritage District in Kleinburg at 835 Nashville Road. The current nine fire stations provide full service emergency response within city borders and can even help neighbouring municipalities, when necessary. Emergency responses, in general, include: fires, medical emergencies, technical rescues and hazardous material incidents. (Population, 2018)

3.2 Fire Departments Response

According to the Standard Incident and Injury Reporting Manual legislated by the Office of the Fire Marshal of Ontario, incident reporting is a method of tracking fire, explosion and other emergency responses executed by Ontario fire departments. There is a standardized format to record any information regarding the occurrence that would be forwarded to the Office of the Fire Marshal (OFM). The data would be compiled on a municipal and province-wide basis. By referencing to the Manual, "an occurrence is an incident that results in a fire department emergency response" (Standard Incident and Injury Reporting, 2009). There are three categories of occurrences for each of them reporting is mandatory. These categories are:

- ***"Fires and explosions***: involving structures, vehicles or open areas (whether or not they result in property losses, injuries or deaths) constitute the first category of occurrences to which fire departments respond. Despite involvement in other activities, these occurrences remain of utmost interest and of primary concern given their potential to result in large property losses, injuries and deaths. As a result, even if a fire department is notified of such an incident after it has already occurred, the occurrence should be reported.
- ***No Loss Outdoor Fire***: (excluding suspected arson, vandalism, children playing, fires resulting in exposure fires) This incident type has been separated from the fire category to identify small uncontrolled outdoor fires that were easily contained and resulted in no injury or loss.
- ***Other Emergency Responses***: Fire departments respond to emergencies other than fires. Responding to overpressure ruptures, pre-fire conditions, false fire calls, public hazards, rescues, medical calls, assistance to other fire departments and public service calls are the fire departments responsibilities as well. These types of responses constitute the third category of occurrences to which fire departments respond" (Standard Incident and Injury Reporting, 2009, pp. 2-3).

3.3 Data Set

Vaughan is an appropriate municipality for examining the emergency calls responded by VFRS as it is one of the fast-growing cities in Canada and metropolitan Toronto is located in its neighbourhood. For this study, VFRS provided the data set included all the incidents that have been responded by the city's fire stations. The data set included all the recorded incident responses between January 2009 to December 2016. Each record contains a list of attributes such as alarm time, alarm date, responding station, the incident's postal address, longitude and latitude of the incident, type of response, dispatch time and date, arrival time and date, clear time and date, the incident district, alarm type and finally incident's property type. For further investigation, some additional attributes have been created and added to each record such as dispatch duration which was the difference between time of arrival and time of receiving alarm, clear duration that was the difference between the time of clear and the arrival time and if the incidents happened during the day or night time, etc.

To apply spatial analysis, the records have been converted to shapefile (GIS Data) using their longitude and latitude. The shape file of all the incidents responded from January 2009 to December 2016 have been created at the Advanced Disaster, Emergency and Rapid-response Simulation research centre (ADERSIM), based at York University. Although, there was a slight difference in number of records in the shape file, but it did not have a huge impact on spatial and spatio-temporal analysis.

According to the Canadian Disaster Data Base, the 2013 ice storm was officially happened from December 20^{th}, 2013 to January 1^{st}, 2014 (Public Safety Canada, 2015). As the data set did not include January 1^{st}, 2017 records, all the analyses have been applied on the data between December 20^{th} to 31^{st} for year 2009 to 2016. In Table 3, the number of responses during each of three specific periods are displayed. The first column is the number of all responses of each year, the second column is the responses in the month of December of each year and the last column is the total responses between 20^{th} to 31^{st} December of each year.

Figure 3, Figure 4, Figure 5 are showing the comparison of the number of responses between 2009 – 2016 in those three periods in column chart format.

Table 3 Fire Station responses during 3 periods

Year	Total	December	20 to 31 December	GIS Data 20 to 31 December
2009	10612	898	380	376
2010	9816	915	351	350
2011	10166	797	322	320
2012	10282	875	361	342
2013	10444	1214	648	647
2014	10099	844	297	297
2015	10428	873	329	327
2016	10950	920	335	335
Average	10350	917	378	374

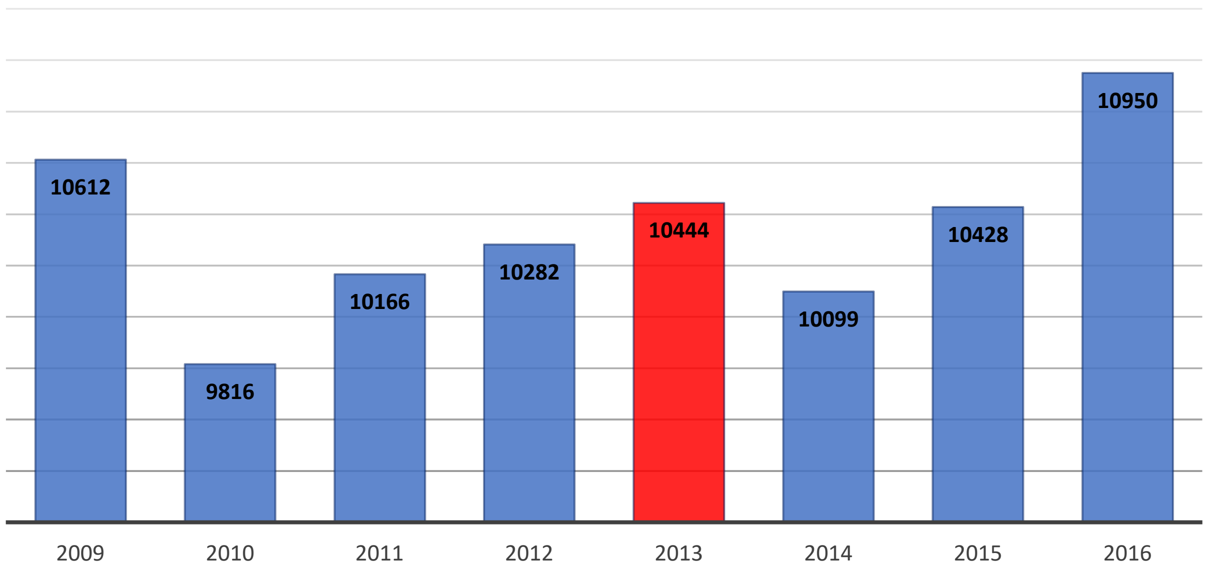


Figure 3 Total Responses for Each Year

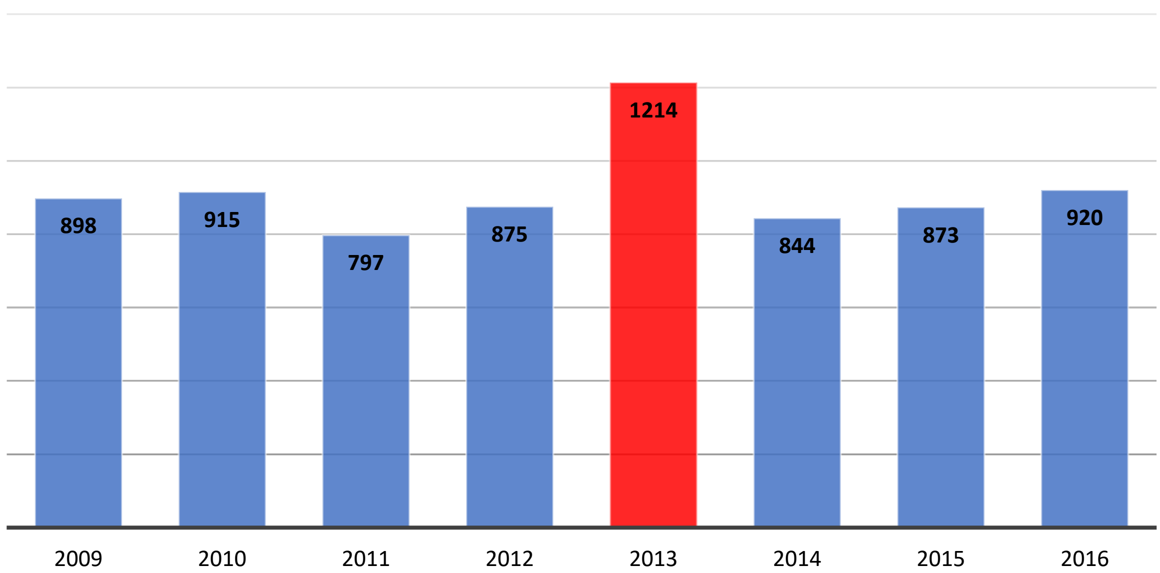


Figure 4 December Responses

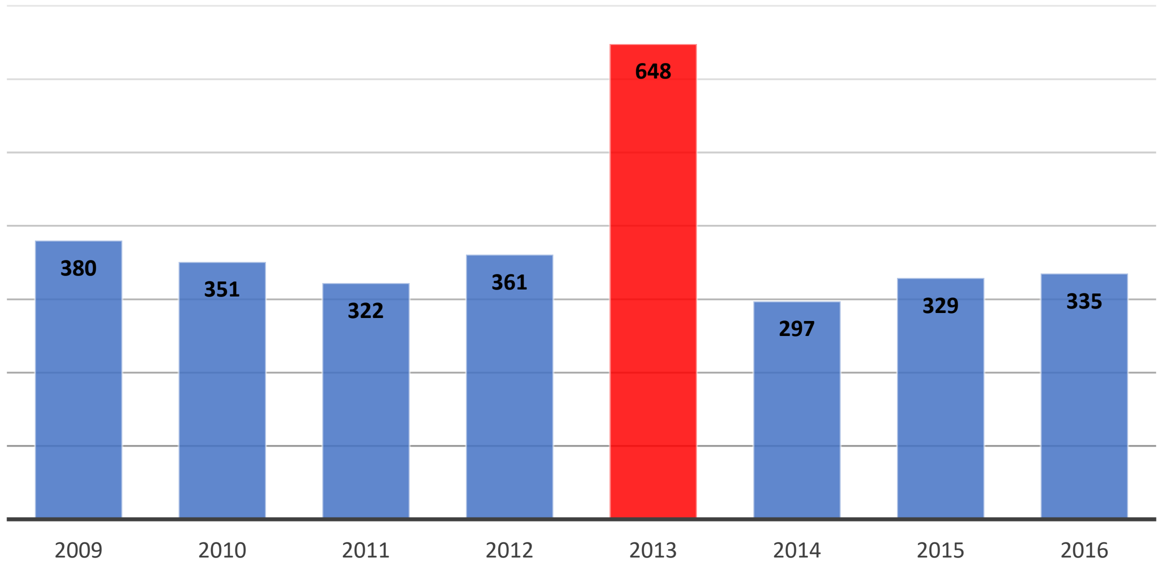


Figure 5 December 20th – 31st Responses

The attribute “type of response” was included 10 main categories shown in Table 4. For the study period, medical/resuscitator responses contain 42% of the total responses. The “false fire calls”, “Rescue”, “other responses” and “CO false calls” contain the most number of responses respectively and eventually, these 5 categories contain more than 90% of the total responses.

Table 4 Number of responses per response type category during December 20th to 31st for years 2009 to 2016

Response Type		Total	Percentage
Category 1	Property Fires/Explosions	54	2%
Category 2	Overpressure rupture/explosion (no fire)	3	0%
Category 3	Pre-conditions/ No fire	78	3%
Category 4	Burning (Controlled)	7	0%
Category 5	False fire Calls	495	16%
Category 6	CO False calls	227	8%
Category 7	Public Hazard	196	7%
Category 8	Rescue	351	12%
Category 9	Medical/resuscitator call	1248	42%
Category 10	Other response	346	12%
Total Responses		3005	

4. Methodology

For this research, three different types of analytical methods have been used: temporal, spatial and spatiotemporal.

4.1 Temporal Analysis

Temporal statistical analysis empowers researchers to examine and model the behavior of a variable in a data set over time. Temporal analysis can result in an insightful vision for the fire management issues as it creates the base lines of the fire departments activities and therefor, it can show new trends. Temporal data can be demonstrated by minute, hour, day, month and year. Different studies applied temporal analysis to investigate how the variables of data-set change chronologically. Temporal analyses are often presented in simple line charts and circular plots as they demonstrate continuity and chronological order (Santos, 2016). Studies of changes in temporal patterns generally apply one of the four general models:1. Panel analysis, 2. event-count analysis, 3. event-sequence analysis, or 4. event-history analysis.

Panel analysis is a statistical method, widely used in social science, epidemiology, and econometrics to analyze two-dimensional, mostly cross sectional and longitudinal, panel data. The data are usually collected over time and over the same subjects. The state of a sample of units at two or more points in time could be presented by applying Panel analysis. (Maddala & Lahiri, 2009). An event-count analysis records and shows the number of different types of events in an interval. Event sequences analysis presents the patterns and sequences of events that occur with a relatively high frequency. An event-history analysis records timing of all changes in a sequence. (Howden & Shi, 1996). Also, weighted time span analysis and percentage change are methods that could be used for temporal analysis, although they are complex and sophisticated. Weighted time span could be conducted by ArcGIS (ArcGis for Defence, 2018). For this research, different types of fire responses statistics have been calculated and presented using the above temporal methods.

To apply temporal analysis, graphs are effective tools to evaluate data. In different studies, visual summaries of essential characteristics of data could be revealed by graphs effectively. Therefore, complex statistical equations or tests to interpret data, can be replaced by using simple plots. One of the most common forms of temporal analysis is creating a timeline to gain a clearer overview of events and to help investigators identify patterns and gaps, potentially leading to other sources of evidence (Casey, 2010). For this research, circular plots and column charts have been applied to show how different variables have changed over time.

Yearly pattern of different variables has been examined thoroughly and the results of the patterns happened in 2013 have been compared with other years in the study period. The hourly pattern of all responses provided during the whole study period and during the ice storm have been investigated. Also, the hourly pattern of each response type has been examined. To review how different variables have been affected during the 2013 ice storm, daily pattern of different variables has been displayed as the result of temporal analysis.

4.2 Spatial Analysis

As studies show, to find out spatial pattern of data, there are three common and effective methods. These methods are quadrant count method, kernel density estimation, and nearest neighbor distance. (Cressie, 2015; Dale, 1999; Stoyan & Stoyan, 1994; Asgari, 2010). To run quadrant count method, area-based techniques should be applied. On the other hand, in kernel density estimation (KDE) and the average nearest neighbour, distance-based techniques are implemented (Haggett, Cliff, & Frey, 1977). In quadrant count method, the study area is divided into n equal size sub-regions defined as quadrats and the frequency (number of events) in each of these quadrats is calculated. (Gatrell & Bailey, 1996).

The average nearest neighbour distance (ANND) and kernel density estimation (KDE) methods apply information of the distribution of the data points to describe pattern. These methods, mostly, use the mean distance to the nearest neighboring point. To apply Kernel Density estimation (KDE) for spatial analysis, the density of events in a neighborhood around those events would be measured. In other words, KDE calculates the density of point features around each output raster cell and creates a smoothly curved surface which is shaped over each point. The surface value is highest where point is located and diminishes as the distance from the point is increased, reaching zero at the search radius distance from the point. (Gatrell & Bailey, 1996; Silverman, 1986).

In ANND method the distance between each feature centroid and its nearest neighbor’s centroid location is calculated. Then, all these nearest neighbor distances are averaged. Two situations can occur: distribution of the features recognized as clustered or dispersed. The distribution of the features being analyzed would be recognized clustered if the average distance is less than the average for a hypothetical random distribution. The features are considered to be dispersed if the average distance is greater than a hypothetical random distribution (Ebdon, 1985).

To apply spatial analysis, different layers related to the study variables have been produced using ArcMap software to examine the spatial patterns of the recorded responses. The kernel density analysis of different type of responses have been explored as well as the daily responses during the 2013 ice storm.

4.3 Spatiotemporal Analysis

For spatiotemporal analysis various mapping and geospatial statistical techniques could be applied to achieve the results (Finkenstadt, Held, & Isham, 2007) As major mapping and visualization techniques, map animation, isosurface, and comaps could be mentioned. In map animation technique which is an older method a number of snapshots would be combined into a continuous sequence using animation software and as it played, imitates the illusion of movement (Dorling, 1992; HaroldMoellering, 1976; Tobler, 1970; Curtis & Leitner, 2003). By reviewing the results of the map animations, researchers could find out how spatial variables change over time and gain more insightful information from the spatiotemporal patterns.

The isosurface is another method that analyzes and visualizes spatiotemporal data. By applying this method, the pattern of events over an entire time unit such as day or week could be seen instantly. Each recorded incidence would be considered as a point in space–time (x,y,t) scale. These triplets will be an input to a three-dimensional kernel density estimation algorithm, that attempts to assess the probability density function $f(x,y,t)$. The value of this function displays the likelihood of an incident occurring at location (*x*,*y*) at time *t*. The isosurface is applied to visualize the density function in three-dimensional space.

Comap technique is an extension of Cleveland's coplot that makes use of ''small multiples'' of diagrams to visualize changes in a pair of variables over time (Cleveland, 1993; Brunsdon, 2001). By applying this method, the relationship between the locations that received different type of responses (*x* and *y*) and their temporal variation (*z*) could be thoroughly examined.

To apply spatiotemporal analysis, the effect of one granularity of time *z* (hour) and its effects on the spatial distribution of responses (*x* and *y*) for the whole study period and during the 2013 ice storm have been examined. The advantage of comaps in this context is that they are able to illustrate the entire time period of study in a single visualization, an advantage over the more traditional map animation methods used to explore spatiotemporal dynamics. The comap could be applied by sub setting observations, in this case individual responses (on the basis of the conditioning variable *z*) and displaying the output as a scatter plot. This action has been repeated for each subset, and the individual plots have been organized in an ordered set of panels such that the relationship of *x* and *y* can be explored as *z* have been increasing. The sub setting has been implemented by considering two main rules: 1: The range of each subset must have some overlap with each adjoining subset.2: Each subset must include roughly the same number of observations. The rationale for these rules is the fact that the resulting output should not be an artifact of the classification process (Corcoran & Higgs, 2007). The advantage of comaps in this context is that they are able to illustrate the entire time period under study in a single visualization, an advantage over the more traditional map animation methods used to explore spatiotemporal dynamics.

5. Temporal Analysis Results:

In this chapter, the temporal analysis has been implemented and the results show the detailed analysis for each response type during the 2013 ice storm. Yearly pattern of different variables has been examined thoroughly and the results of the 2013 ice storm have been compared with other years in the study period. The hourly pattern of all responses provided during the whole study period and during the ice storm have been investigated. Also, the hourly pattern of each response type has been examined. To review how different variables have been affected during the 2013 ice storm, daily pattern of different variables has been displayed as the result of temporal analysis.

5.1 All Responses

The column chart of Figure 6 is used to explore the temporal dynamics of all responses during the study period on a yearly basis. Annual trend shows that the number of responses was roughly similar during 2009 – 2012 and 2014 – 2016, but it has increased significantly during the 2013 ice storm. Further investigation to find out the daily patterns of the responses are shown in Table 5.

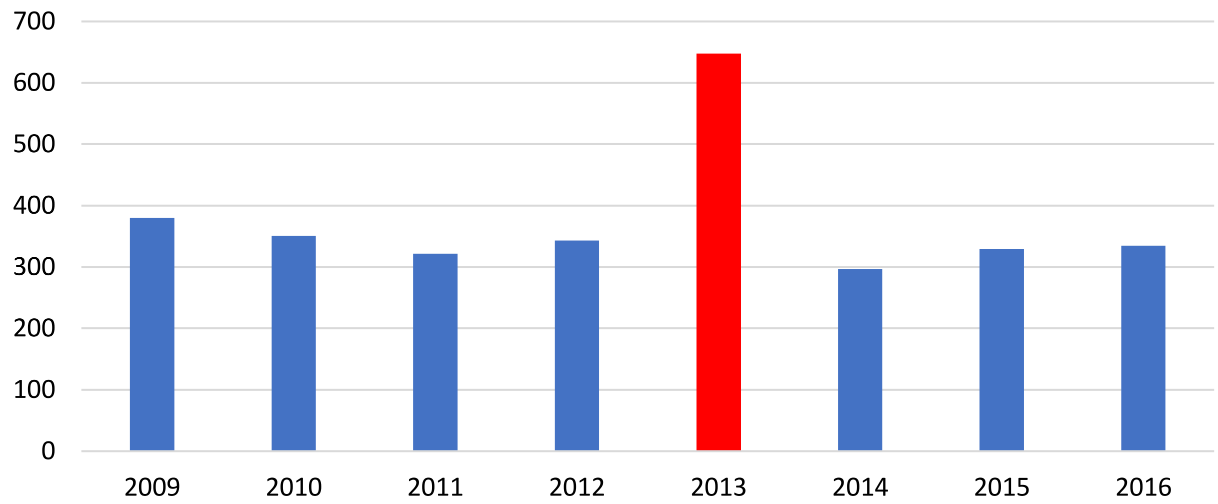


Figure 6 Temporal dynamics of all fire responses during December 20th to 31st for years 2009 to 2016

As the number of responses in 2013 has doubled, the mean value has been calculated as a measuring criterion without including the number of responses for 2013. Therefore, the effect of the ice storm can be examined precisely. Figure 7 shows that the number of responses was close to the mean value but during the 2013 ice storm, the number of daily responses has shown a huge increase especially during the December 21-25 period.

Table 5 Number of responses during December 20th to 31st for years 2009 to 2016

	2009	2010	2011	2012	2013	2014	2015	2016	Mean without 2013
20-Dec	42	38	31	28	39	21	27	38	32
21-Dec	36	35	24	47	56	23	28	35	33
22-Dec	32	24	26	27	191	33	44	28	31
23-Dec	31	33	30	25	56	31	35	29	31
24-Dec	29	25	28	28	52	32	30	24	28
25-Dec	25	29	26	26	37	18	21	25	24
26-Dec	40	25	19	20	34	29	19	21	25
27-Dec	28	22	31	22	44	13	21	33	24
28-Dec	24	37	22	27	38	13	33	22	25
29-Dec	37	25	31	33	34	27	33	33	31
30-Dec	30	29	30	31	28	27	19	24	27
31-Dec	26	29	24	29	39	30	19	23	26
SUM	380	351	322	343	648	297	329	335	337

By applying line plots (Figure 7), it is revealed that the peak happened on December 22nd as the number of responses has raised six times. For the other days in the study period, the number of responses was more than the mean value. Therefore, as an initial outcome, the 2013 ice storm intensified VFRS activities.

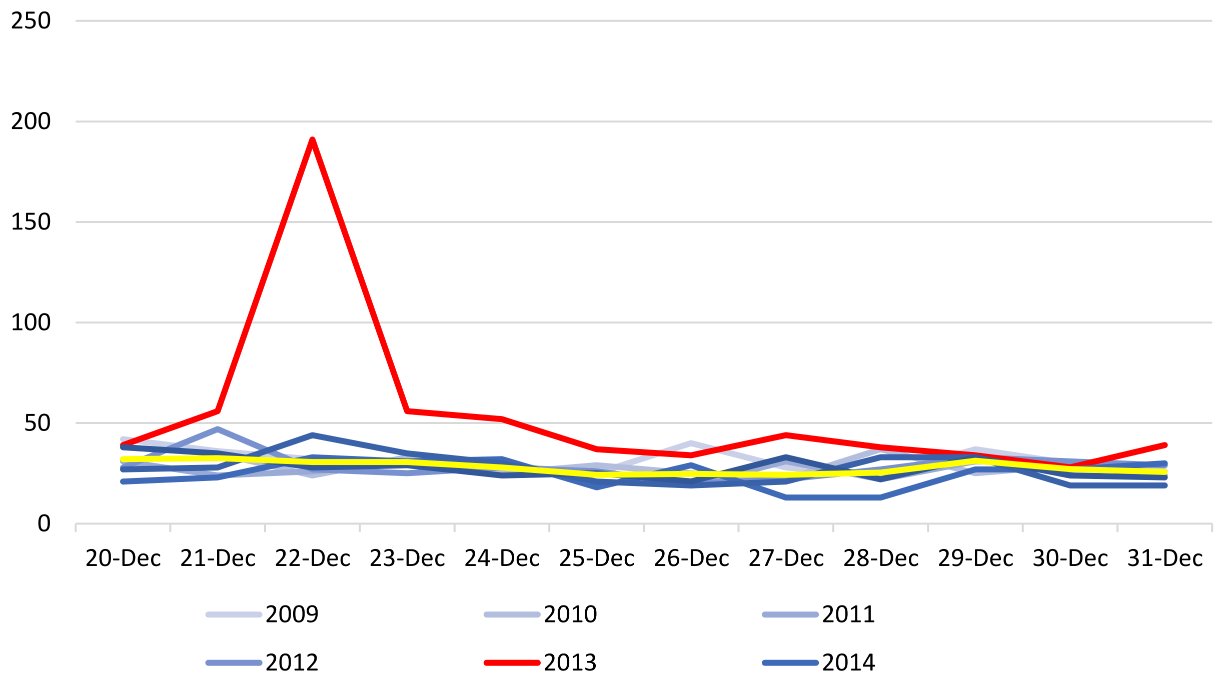
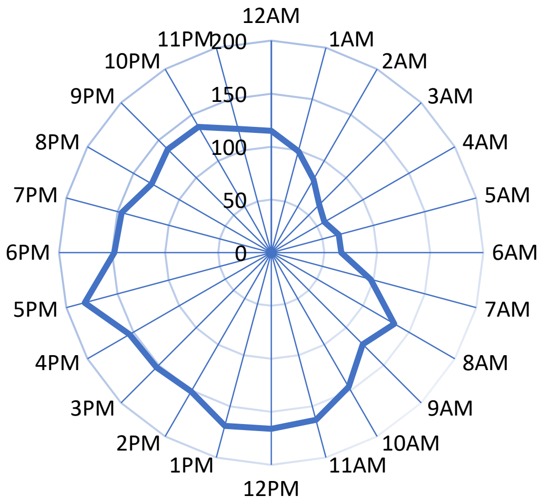
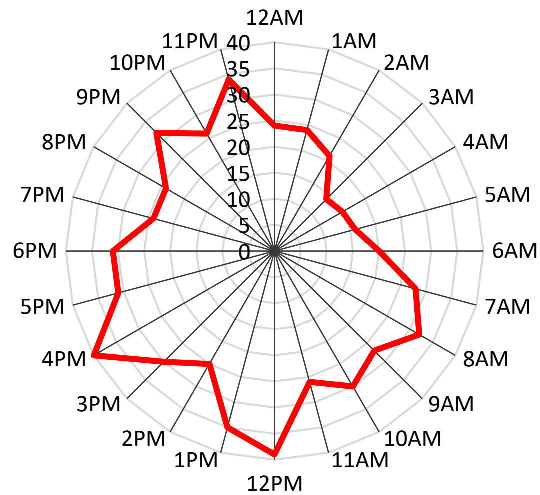


Figure 7 Total Number Daily Responses during December 20th to 31st for years 2009 to 2016

Sample circular plots are presented in Figure 8. They show the hourly patterns of all responses during the study period and during the 2013 ice storm. For the all responses plot, it is noticeable that number of responses become more frequent from 8 AM to 10 PM. They have slightly increased from 8 AM and reached to the peak at 5 PM and then moderately reduced during the midnight. The lowest number of responses happened from 1 AM to 6 AM.



a. All Responses during 2009 – 2016



b. All Responses 2013

Figure 8 Hourly patterns of all responses during December 20th to 31st for years 2009 to 2016

The hourly pattern of responses during the 2013 ice storm has changed. It slightly increased from 7 AM and reached to the peak period from 12 PM to 4 PM. The responses decreased moderately till 1 AM, but even after 8 PM the number of responses were still excessive. The least number of responses have been observed from 2 AM – 7 AM. The number of responses in 2013 has been compared to the mean value of hourly number of all responses. As Figure 9 shows, during the 2013 ice storm, the hourly responses were more frequent than the mean value. The hourly pattern shows that the 2013 ice storm significantly affected the hourly tasks of the fire stations. By examining the temporal pattern of various attributes of the records, the results would become more informative.

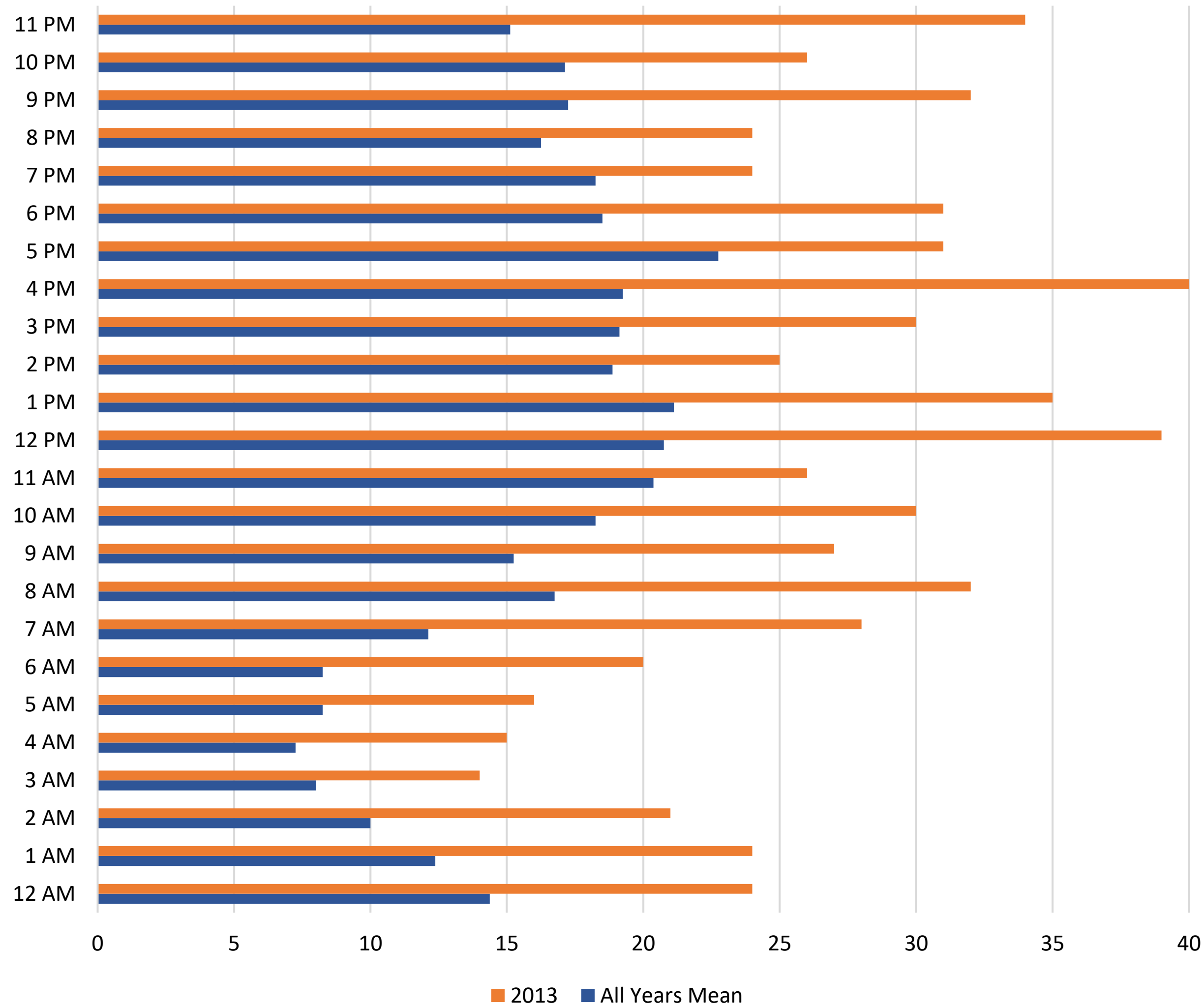


Figure 9 Hourly number of responses during December 20th to 31st for years 2009 to 2016

5.2 Alarm to Fire Department

Fire stations receive alarms through different ways. According to the standard Incident Report code list provided by the Office of Fire Marshal, there are 11 types of alarms. By reviewing the data set, type 10 and 11 did not occur during the research study period. Therefore, the result is tabulated for type 1 to 9 in Table 6.

Table 6 Number of Different Alarm fire occurrences during December 20th to 31st of 2013

Alarm to Fire Department		Number of Occurrence	Percentage
Type 1	911	523	17%
Type 2	Telephone from Civilian (other than 911)	228	8%
Type 3	From Ambulance	1267	42%
Type 4	From Police Services	332	11%
Type 5	From Monitoring Agency	390	13%
Type 6	Direct Connection	4	0%
Type 7	Verbal Report to Station (in person)	16	1%
Type 8	Two-Way Radio (fire department)	16	1%
Type 9	Other Alarm	229	8%
Type 10	No alarms Received-No response	0	
Type 11	No alarms Received-Incident Discovered by FD Personnel	0	

The most fire alarms, 42%, have been received from ambulance (type 3). Following that, 17% of alarms have been received from 911 (type 1), 13% from monitoring agency (type 5), 11% from police services (type 4) and 8% from telephone from civilian and the other sources (type 9 and 2), respectively. Alarms received as verbal, two-way radio and direct connection were rarely occurred (type 7, 8 and 6).

Figure 10 depicts the yearly pattern of all alarm types using column Plots. The yearly pattern of type 1 is fairly similar for the study period except for 2013. During the 2013 ice storm, number of alarms received by 911 have been tripled. Although, number of alarm type 2 was slightly different through 2009 – 2016, it shows a significant difference in 2013 compared with the other years. The total number of type 3 has the highest rank in the study period but during the 2013 ice storm. This type of alarm did not occur more than the other years and it followed the same pattern. The number of occurrence of alarm type 4 was fairly similar for the study period, but it was slightly higher in 2013. Similarly, the number of alarms type 5 and 1 have increased significantly and have been tripled, in 2013. Although, alarm types 6, 7 and 8 did not occur significantly but during the 2013 ice storm, all these types of alarm have been occurred. Especially, verbal report to station (alarm type 7) has happened 8 times. For the study period, type 9 has occurred fairly similar during each year and 2013 did not show a significant difference.

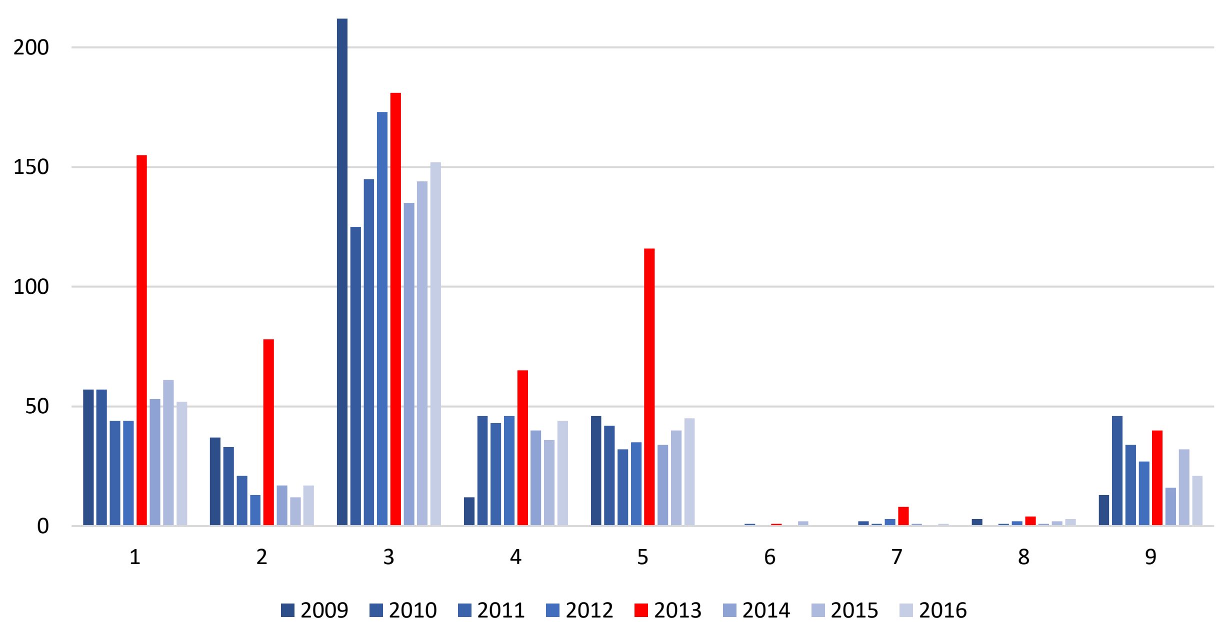


Figure 10 The yearly pattern of all alarm types during December 20th to 31st for years 2009 to 2016

Figure 11 and Figure 12 show the daily pattern of different type of alarms during the 2013 ice storm. Figure 11 displays pattern of all types of alarm. It is noticeable that different types of alarm did not show similar pattern through out the ice storm. To explore the daily pattern of each type of alarm, Figure 12 would be beneficial.

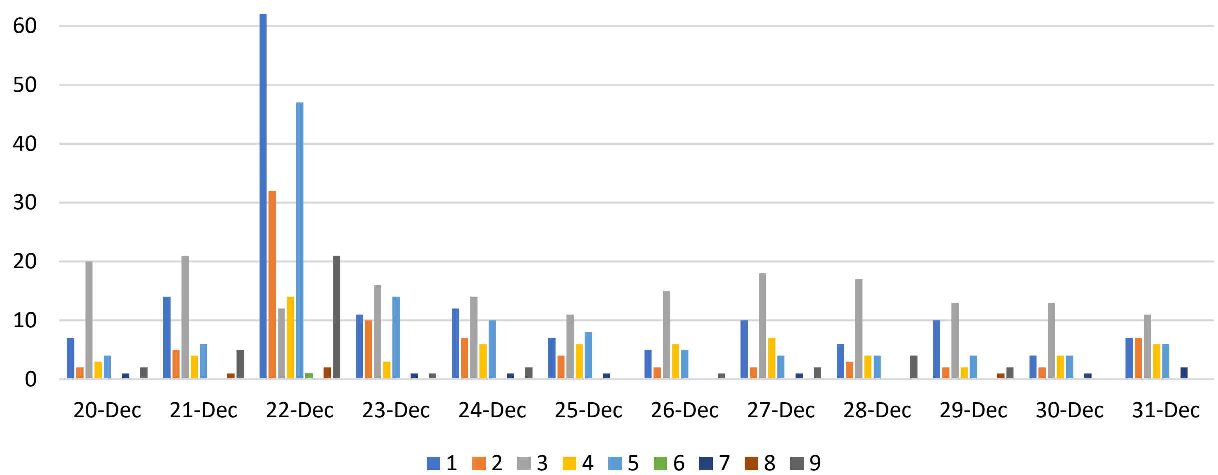
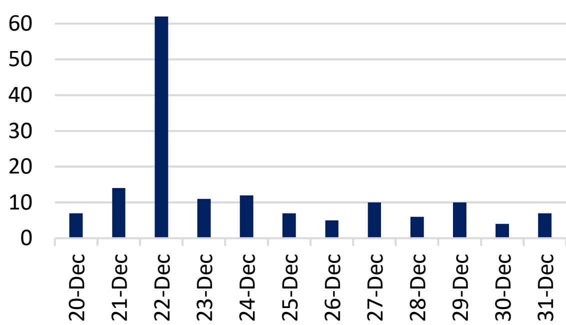
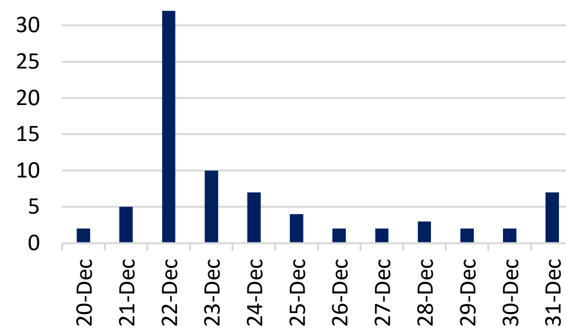


Figure 11 Daily pattern of all alarms types during each day of The 2013 ice storm

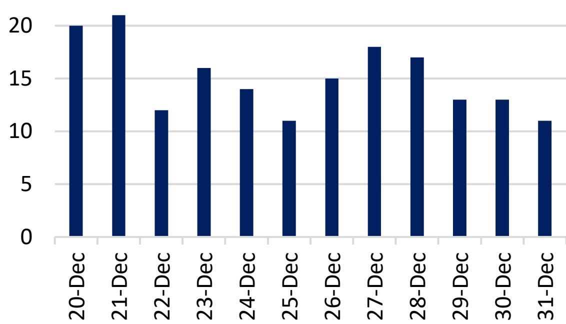
Number of alarms received by means of 911 (type 1) was fairly similar on daily basis but there was a significant difference on December 22nd and number of alarms has increased 6 times. Telephone from civilian (type 2) shows the same pattern as type 1 and the number of alarms received on December 22nd was 4 times more than the other days. Number of alarms received from ambulance (type 3) did not show the same pattern as type 1 and type 2. It is noticeable that number of type 3, similarly to yearly pattern, was almost equally spread and there was not a significant daily difference. Number of alarms received from police services (type 4) has doubled on December 22nd and stayed fairly similar for the rest of the 10-day period. Like type 1 and 2, number of alarms received from monitoring agencies (type 5) has tripled on December 22nd and it is evident that type 1, 2 and 5 follow same pattern during the study period. Verbal report to fire stations (type 7), alarms received by two-way radio (type 8) and other types of alarm (type 9) did not occur every day. Number of type 9 has increased significantly on December 22nd.



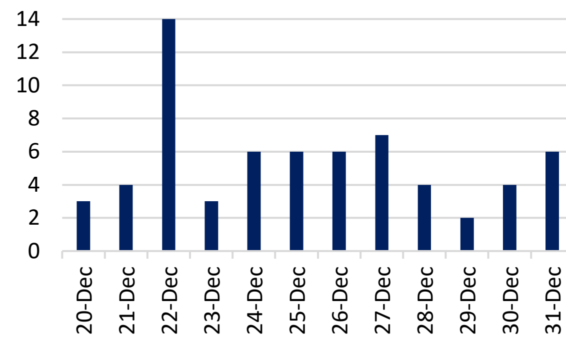
a. Alarm Type 1



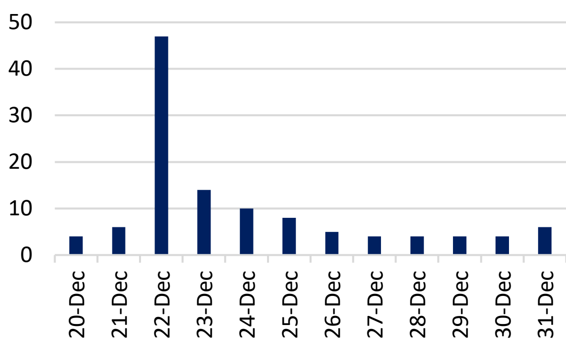
b. Alarm Type 2



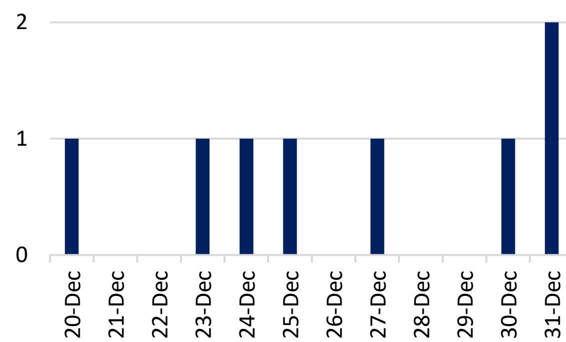
c. Alarm Type 3



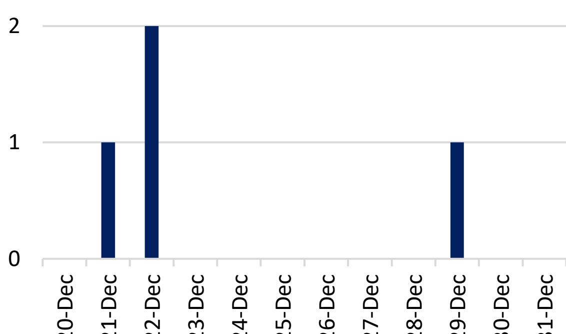
d. Alarm Type 4



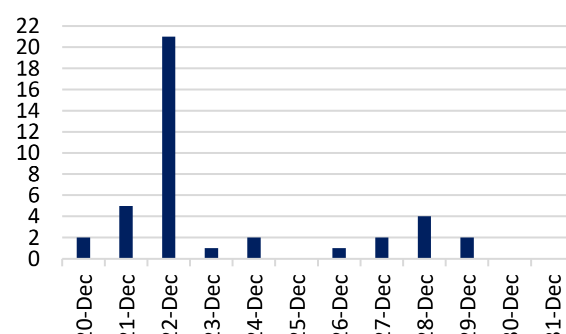
e. Alarm Type 5



f. Alarm Type 7



g. Alarm Type 8



h. Alarm Type 9

Figure 12 Daily pattern of each individual alarms type during December 20th to 31st of 2013

5.3 Responding Stations

During the study period, 8 stations were responding to calls. Station 7-4 provided responding during years 2009, 2012 and 2013. Station 7-10 became active since 2012 and has been responding during 2012 – 2016. Figure 13 is presenting the yearly pattern of stations during the study period. Although number of incidents were doubled in 2013, it did not affect the stations' activities uniformly. It is noticeable that between 2009 and 2016, stations 7-1 and 7-2 have been responding to most of the incidents and during the 2013 ice storm number of responses provided by these stations were doubled. The average number of responses made by station 7-7 and 7-3 have been similar, however number of responses by station 7-7 did not change significantly in 2013 compared with other years. On the other hand, the 2013 ice storm affected station 7-3 activities and number of responses were doubled. Station 7-5 activities did not alter significantly on a yearly basis. Number of responses carried out by stations 7-8, 7-9, 7-10 increased greatly during the 2013 ice storm. For station 7-9, it was tripled and for stations 7-8 and 7-10 it was doubled. Ice storm affected station 7-6 activities moderately.

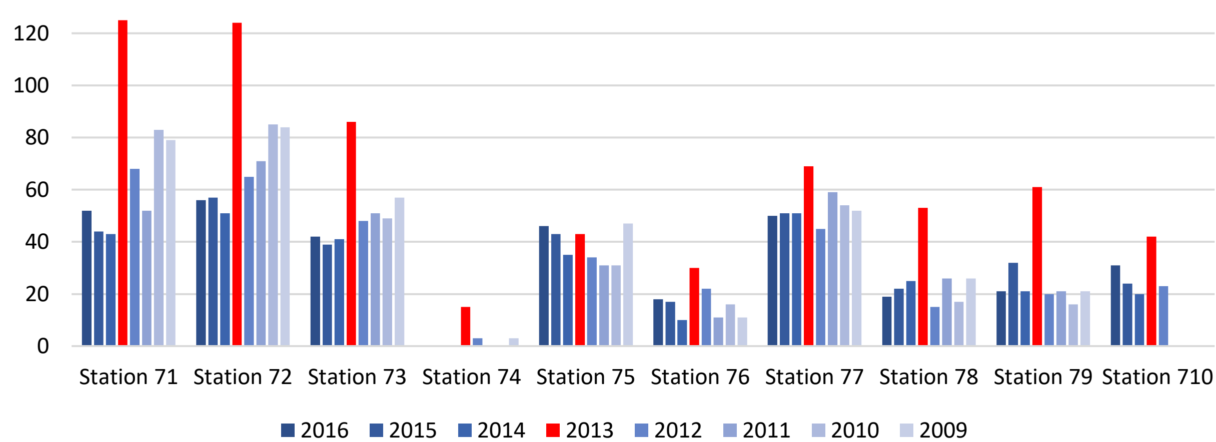


Figure 13 Yearly response pattern of all stations during December 20th to 31st for years 2009 to 2016

By analysing the records, it is revealed that some fire stations supported other stations Table 7 tabulated the total number of responses for each station, number of 2013 responses, number of responses to the other districts. In order to find the extent of responses provided to other districts, the percentage have been calculated. Figure 14 displays the yearly pattern of responses provided to the other districts. Station 7-1 did not participate in responses to other districts significantly on a yearly basis. Furthermore, although number of responses provide by this station has increased 3 times in 2013, the pattern did not change considerably. More than 14% of station 7-2 responses have been dispatched to the other districts and this number have been raised in 2013. Station 7-3, 7-5, 7-6, 7-7, 7-8, 7-9 and 7-10 have provided excessive responses to other districts in 2013.

Table 7 The total number of responses for each fire station during December 20th to 31st for 2009 to 2016

	Total Responses	Not same District	Percent (Not Same District)	2013 Responses
Station 7-1	546	20	4%	125
Station 7-2	593	84	14%	124
Station 7-3	413	41	10%	86
Station 7-4	21	10	48%	15
Station 7-5	310	38	12%	43
Station 7-6	135	22	16%	30
Station 7-7	431	35	8%	69
Station 7-8	203	34	17%	53
Station 7-9	213	30	14%	61
Station 7-10	140	7	5%	42

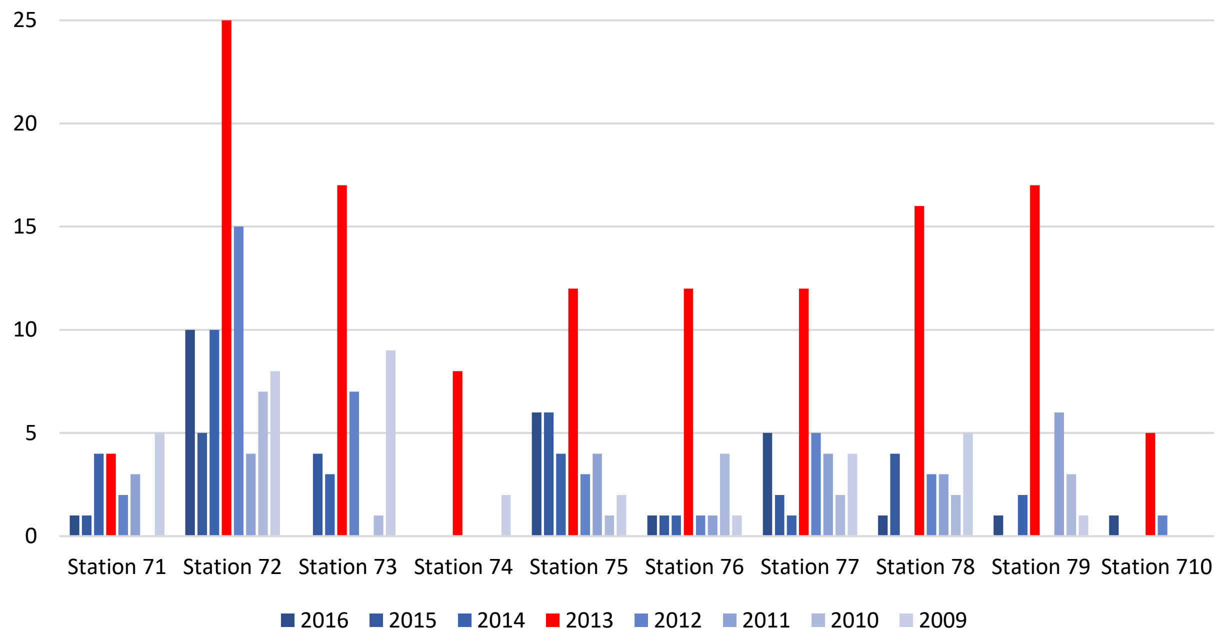


Figure 14 The yearly pattern of responses provided by fire station to the other districts during December 20th to 31st for years 2009 to 2016

To analyze the daily pattern of station activities during the 2013 ice storm, Figure 15 and Figure 16 would be helpful. Figure 15 is illustrating a complete and general comparison of daily responses provided by the City of Vaughan's fire stations to each other. Although number of dispatches reached to its highest point on December 22nd, different stations did not follow the same pattern for the whole ice storm period. As an example, on December 26th and 27th number of responses provided by station 7-1 was half of station 7-2 but on December 24th and 25th it was completely reverse.

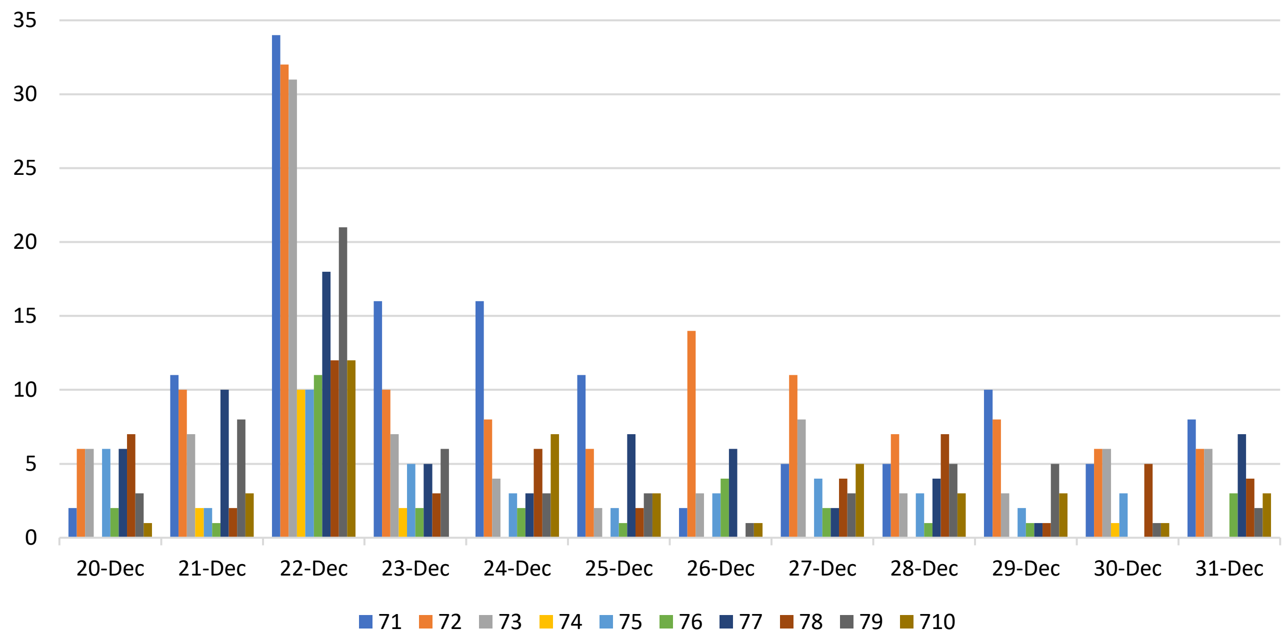
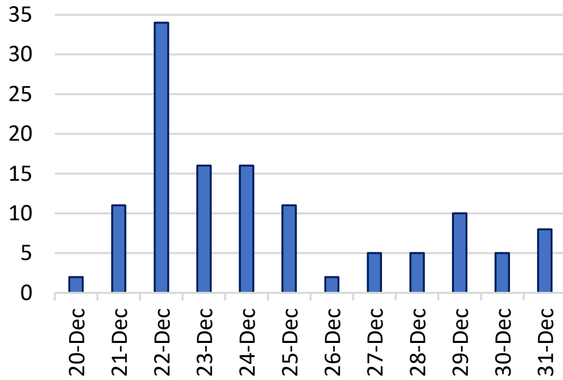
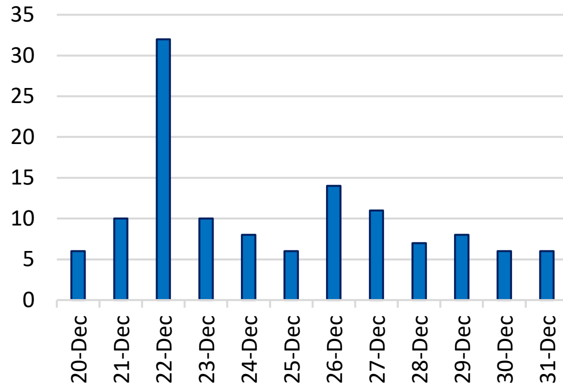


Figure 15 The yearly pattern of responses provided by fire station to the other districts during December 20th to 31st of 2013

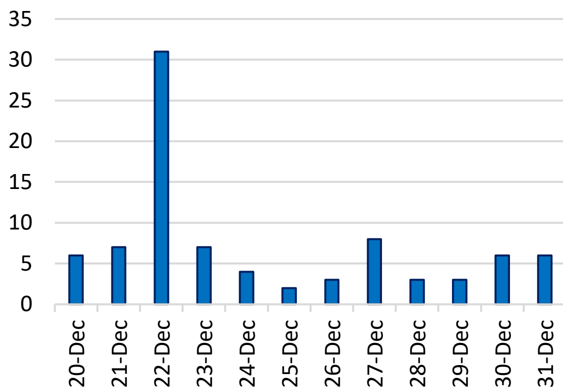
For all stations, December 22nd was the most challenging day during the ice storm period and the peak of the number of responses happened on that day. Number of responses dispatched from station 7-1 and 7-2 have been increased about 3 times but the effect was more noticeable for stations 7-3, 7-4, 7-6, 7-7 and 7-9. These stations provided response 4 to 6 times more than other days. Station 7-1 responses gradually decreased after December 22nd. The pattern for station 7-2 was different and the number of responses has increased slightly on December 26th and 27th. Although during this 10-day period the number of responses has increased considerably, some stations experienced days with no responses. For example, on December 30th, station 7-6 and 7-7 did not receive any call. Station 7-4 respond only 4 days out of 10. Station 7-10 experienced a day without any responding after December 22nd but for the rest of the 10-day period it was as busy as station 7-2.



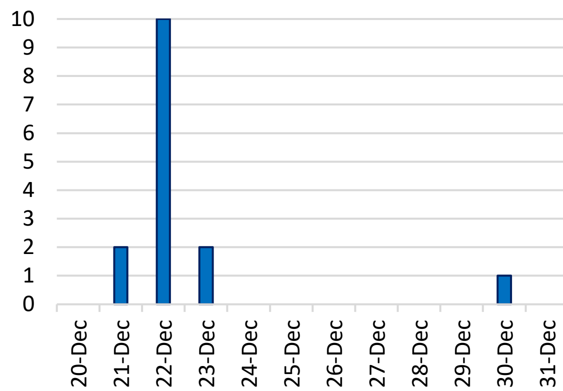
a. Station 7-1



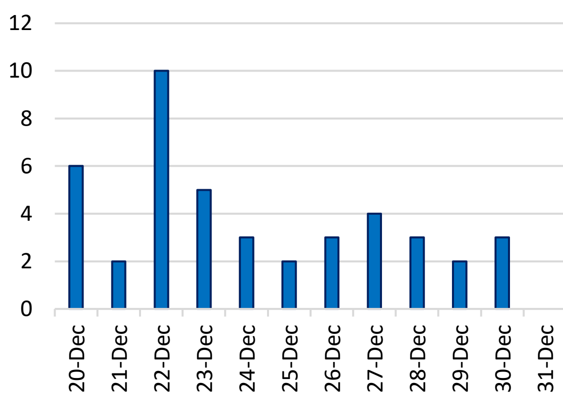
b. Station 7-2



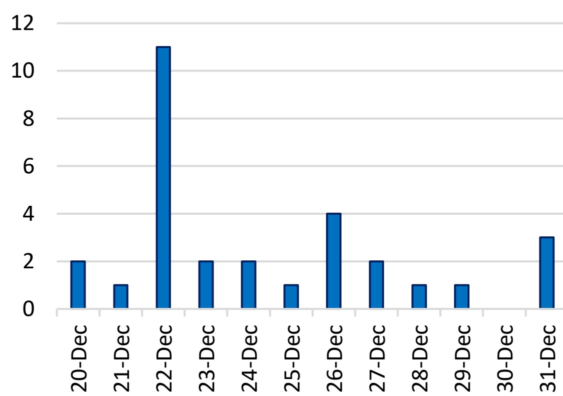
c. Station 7-3



d. Station 7-4

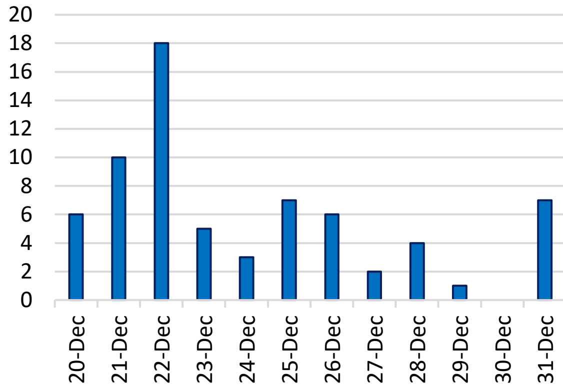


e. Station 7-5

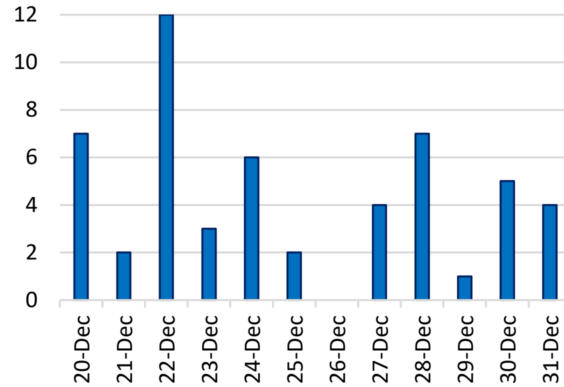


f. Station 7-6

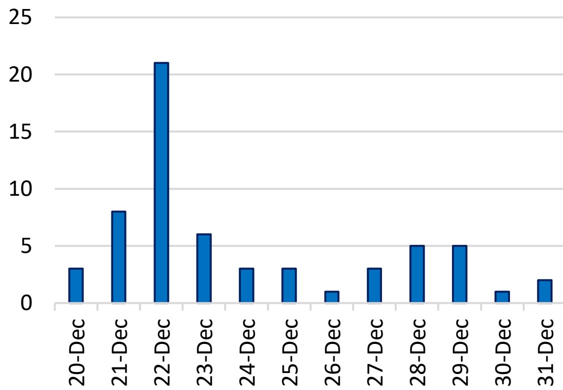
Figure 16 Responses provided by different stations during the 2013 ice storm



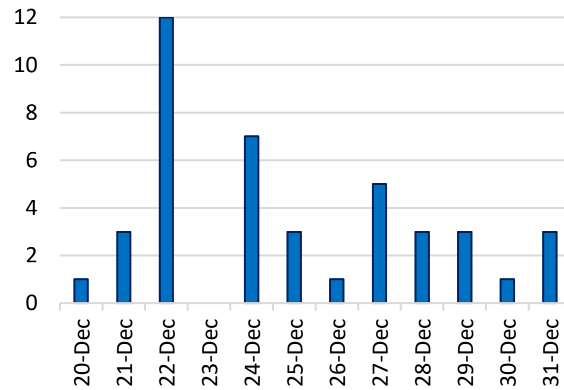
g. Station 7-7



h. Station 7-8



i. Station 7-9



j. Station 7-10

(Continued) Responses provided by different stations during the 2013 ice storm

5.4 Type of Response

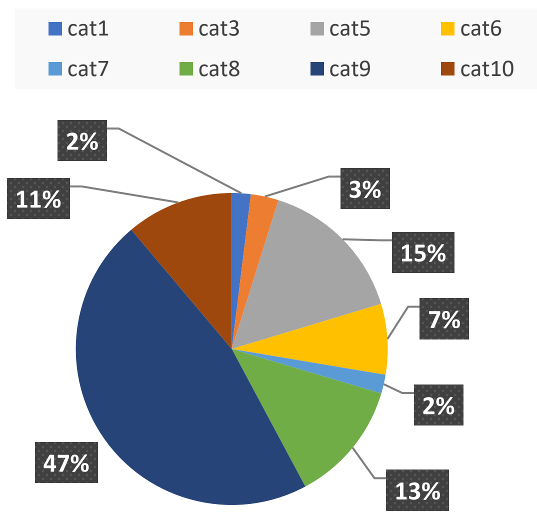
Types of responses have been classified into 10 categories. Table 8 tabulates the number of all types of responses during 2009 – 2016. Most of the responses have been related to medical calls (Category 10). False fire calls (Category 5) was the second highest cause that needed response during the study period. Rescue and other response (Categories 8 and 10) account for 12% of all responses between 2009 – 2016. Finally, CO false calls, public hazard, pre-fire condition, property fire, controlled burning and over pressure rupture had the least number of responses respectively.

As this table shows, although number of calls during the 2013 ice storm has doubled, number of medical calls (Category 9) did not change significantly. Also, controlled burning (Category 4) did not occurred in that year. Although number of Pre-Fire Conditions (Category 3) and Property Fire (Category 1) have been fairly more than average, they were not a huge issue during the 2013 ice storm.

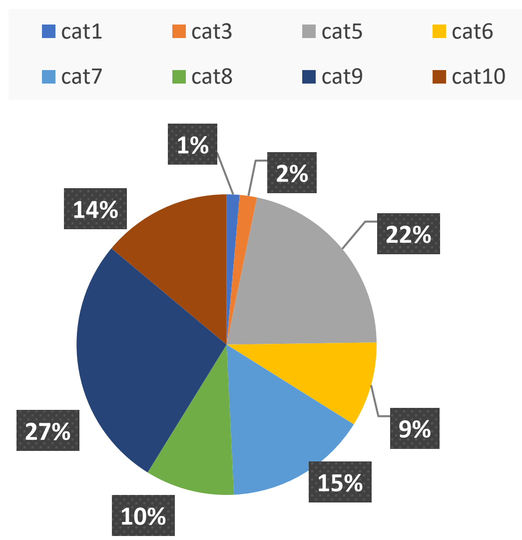
Table 8 The total number of responses per type during December 20th to 31st for 2009 to 2016

Response Type	2009	2010	2011	2012	2013	2014	2015	2016	Total	Percentage
Category 1: Property Fire	7	6	4	5	9	5	13	5	54	2%
Category 2: Over pressure rupture	1	0	0	0	2	0	0	0	3	0%
Category 3: Pre-Fire Conditions	16	8	7	8	12	13	8	6	78	3%
Category 4: Controlled burning	1	0	0	3	0	0	0	3	7	0%
Category 5: False fire calls	60	61	42	44	139	48	45	56	495	16%
Category 6: CO false calls	32	37	22	9	59	20	34	14	227	8%
Category 7: Public hazard	13	17	13	12	99	18	11	13	196	7%
Category 8: Rescue	40	29	53	45	62	29	48	45	351	12%
Category 9: Medical call	178	159	135	166	176	134	131	169	1248	42%
Category 10: Other response	32	34	46	51	90	30	39	24	346	12%
All Responses	3005									100%

Figure 17 depicts how the percentage of different type of responses has changed during the 2013 ice storm compared with the total number of responses happened in the study period. To avoid the effect of ice storm and achieve an insightful comparison, the 2013 records have been excluded for the first circular plot. During 2009 – 2016, 47% of the responses were related to medical issues (Category 9). However, as ice storm did not affect the amount of medical responses compared with the other years and although the number of total response has doubled, this type of response has included 27% of all responses. On the other hand, false fire calls and public hazard (Categories 5 and 7) have increased significantly during the ice storm. Public hazard calls (Category 7) required 2% of fire station activities in 2009 – 2016, but during the ice storm 15% of responses were related to public hazard. Number of rescue (Category 8) showed a decrease by 3% during the ice storm.



a. All types of response percentage (excluding 2013)



b. All types of response percentage in 2013

Figure 17 The percentage of responses types during December 20th to 31st for 2009 to 2016

Figure 18 indicates the yearly pattern of fire responses. Property fires, over pressure rupture, Pre-fire conditions and Burning (Category 1-4) had similar yearly patterns. It should be mentioned that 2 incidents of over pressure ruptured happened during the ice storm and one happened in 2009. As the number was not significant it did not have a huge impact on the fire stations activities in 2013.

Although the ice storm has caused the number of responses to be doubled, it did not affect different type of responses equally. Number of responses related to public hazard (Category 7) increased 5 times in 2013. CO false calls (Category 6) has occurred significantly, especially compared to 2012. Reponses related to Category 9, also, increased enormously in 2013.

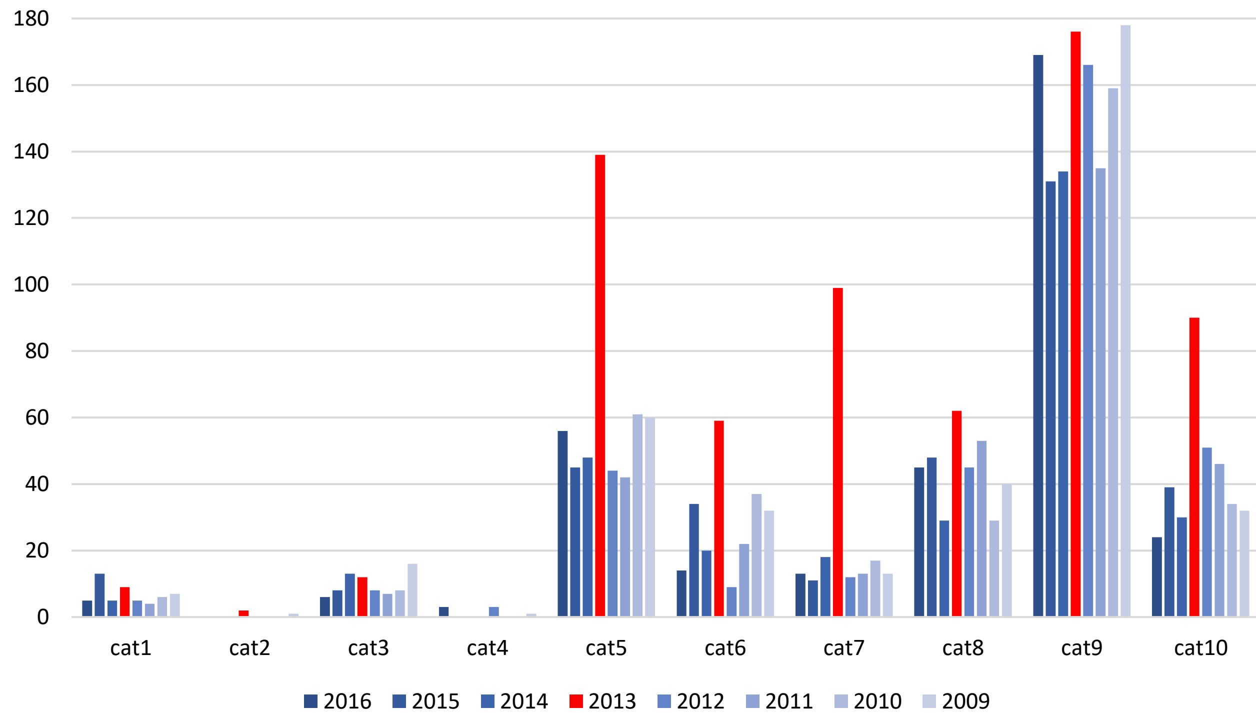
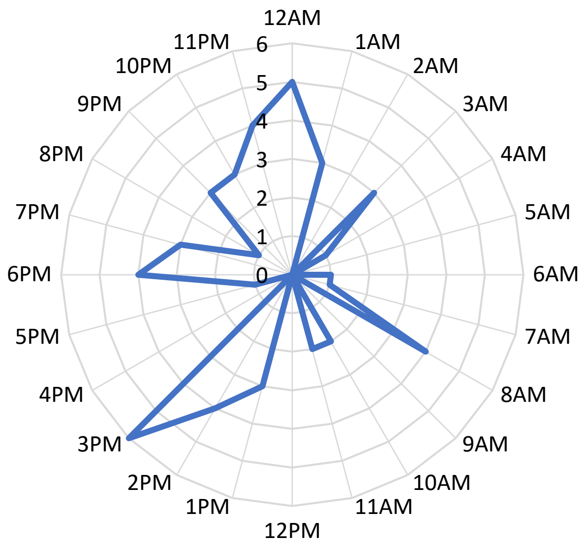


Figure 18 The yearly pattern of fire responses during December 20th to 31st for 2009 to 2016

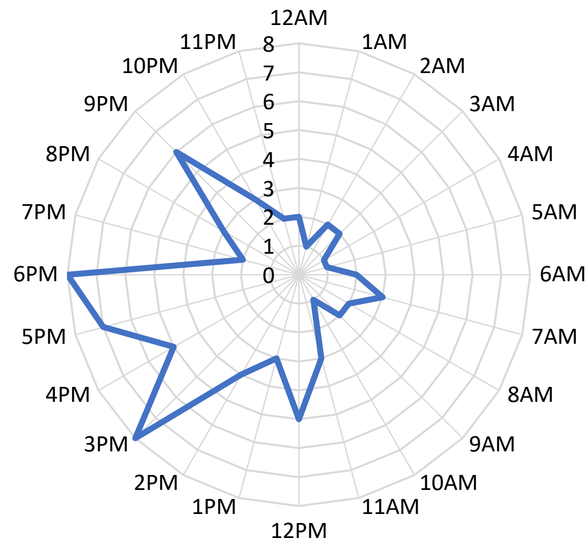
5.4.1 Hourly pattern of different type of Response

Circular plots presented in Figure 19, shows the hourly pattern of different type of responses. Over pressure rupture and Burning were not shown as they did not happen very frequently. Property fire hourly circular plot illustrates that fires rarely happened between 4 AM to 7 AM. Although in the study period the peak happened at 3 PM, from 6 PM to 1 AM, fires occurred significantly. This period is coincident with presence of people at home and that is one of the explanations why fires became more frequent in those hours. Pre-fire conditions mostly happened from noon to 9 PM. They reached the peak at 3 PM and 6 PM. Significant differences could be overserved for False fire calls and CO false calls. Most False fire calls have happened between 8 AM to 5 PM and the occurrence has decreased by midnight. The least incidents have occurred from 1 AM to 7 AM.

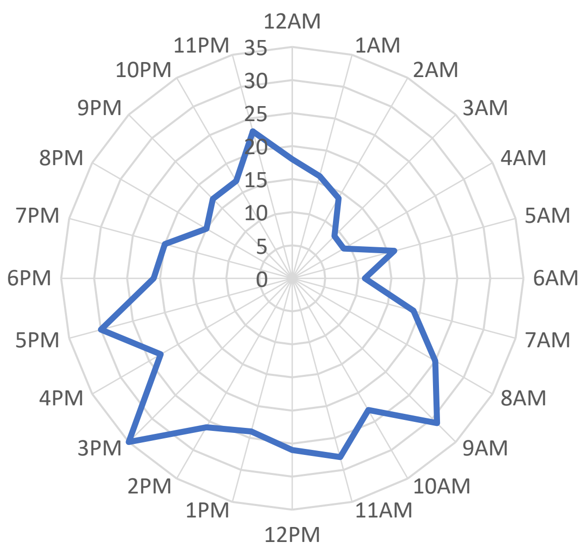
The hourly pattern for CO false calls illustrates that most CO false calls were received between 10 AM and it was continued through the day time to midnight and it slightly decreased till 2 AM, but the peak was 4PM as the number of calls has doubled. From 2 AM to 9AM the number of CO false calls showed a decline. Public hazard responses did not follow an even hourly pattern. By neglecting the fluctuations, it is noticeable that most of the responses have been provided between 10 AM to 10 PM. Fire stations have provided rescue mostly from 1 PM-5 PM. Early morning and evening, the number of rescue responses has decreased and from 9 PM to 9 AM it has dropped remarkably. Medical calls have been received mostly between 8 AM to 2 PM and the peak happened at noon. The second demanding period has been 5 PM to 10 PM. Then the number of calls has reduced slightly. Also, during night time, the number of medical calls has been considerable. Other responses have been provided from early morning to midnight although the pattern was not steady. The peak has occurred around noon and 6 PM. During night this type of response was not a huge issue for fire stations.



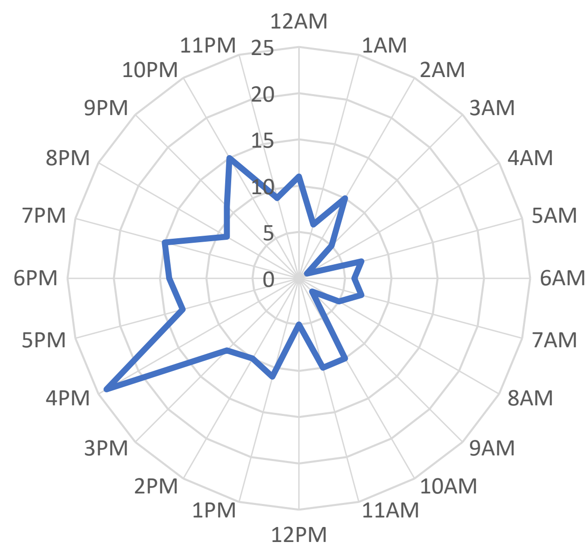
a. Property Fire/Explosion



b. Pre-Fire Conditions/No Fire

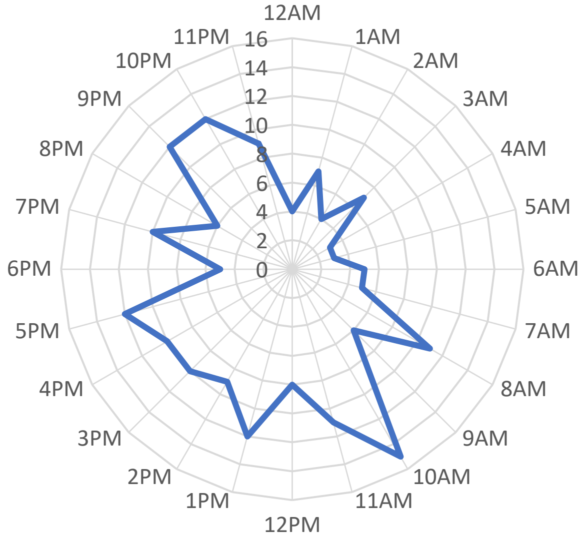


c. False Fire Calls

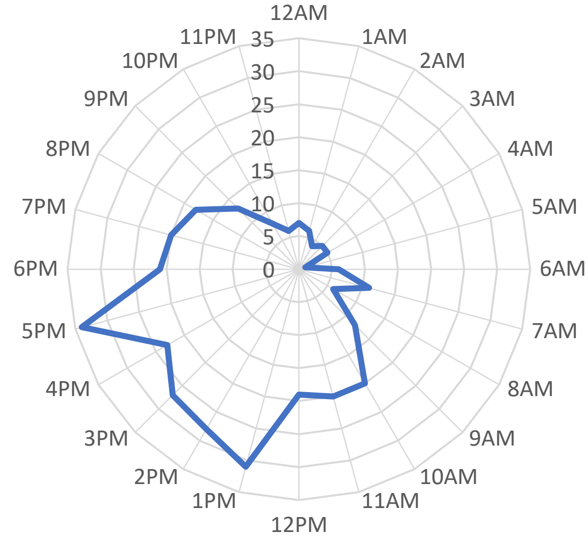


d. CO False calls

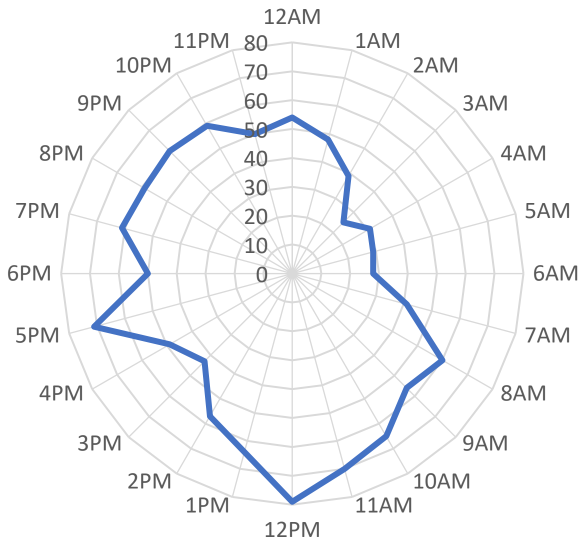
Figure 19 The hourly pattern of different type of responses



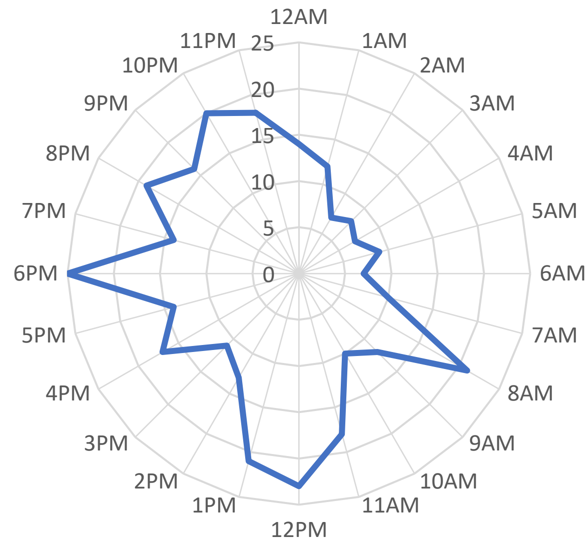
e. Public Hazard



f. Rescue



g. Medical Call



h. Other Responses

(Continued) The hourly pattern of different type of responses

5.4.2 Yearly pattern of Property Fire/Explosions

Analysing the records shows that few fire incidents have happened every year. The most fire incidents have happened in 2015 where 13 fire incidents occurred during the 10-day period. Following that, in 2013, 9 fire incidents have happened which is fairly significant compared to the other years.

Table 9: Number of different codes related to Property Fire during December 20th to 31st for 2009 to 2016

Response Category 1: Fire Calls		2009	2010	2011	2012	2013	2014	2015	2016
Code 1	Fire	7	6	3	4	8	5	11	4
Code 3	No Loss Outdoor Fire	0	0	0	0	1	0	2	1

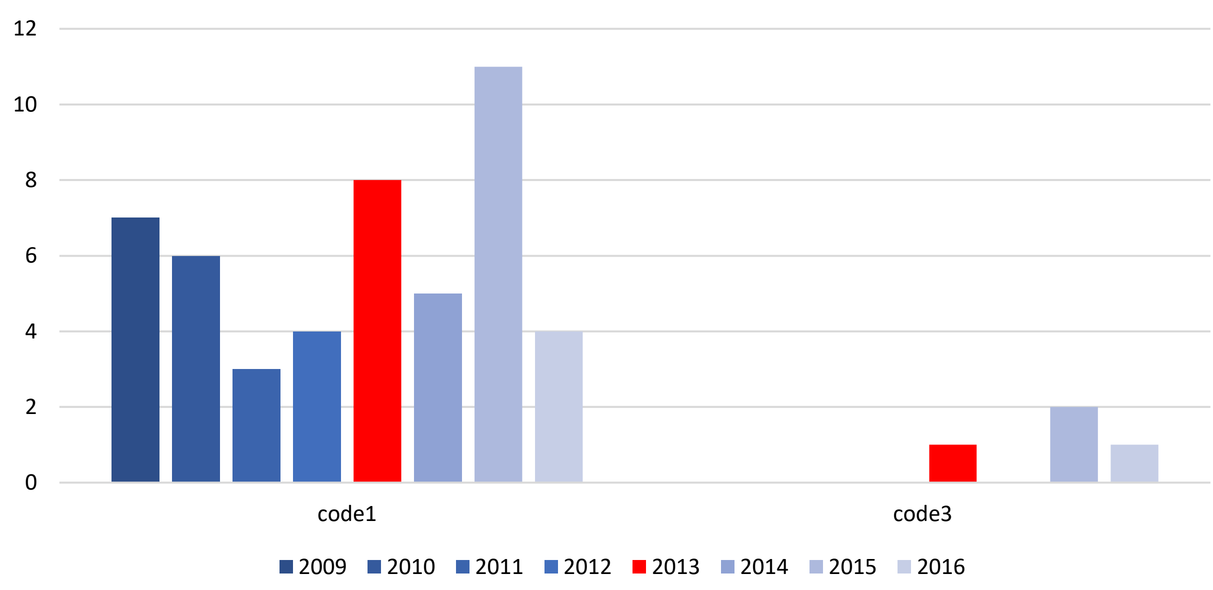


Figure 20 Yearly pattern of different codes related to Property Fire during December 20th to 31st for 2009 to 2016

5.4.3 Pre-Fire conditions

Different coded incidents in Pre-fire conditions category did not show a similar pattern during the study period. As Figure 21 displays, during the 2013 ice storm, the general pattern of each code did not change.

Table 10 Number of different coded incidents related to Pre-Fire Conditions during December 20th to 31st for 2009 to 2016

Response Category 3: Pre-Fire conditions (No Fire)		2009	2010	2011	2012	2013	2014	2015	2016
Code 21	Overheat (engines etc.)	6	5	4	0	4	2	3	3
Code 22	Pot on stove	2	0	1	1	3	4	2	0
Code 24	Other cooking	3	1	1	1	3	3	2	2
Code 25	Lightening	0	0	0	0	0	1	0	0
Code 29	Other pre-fire	5	2	1	6	2	3	1	1

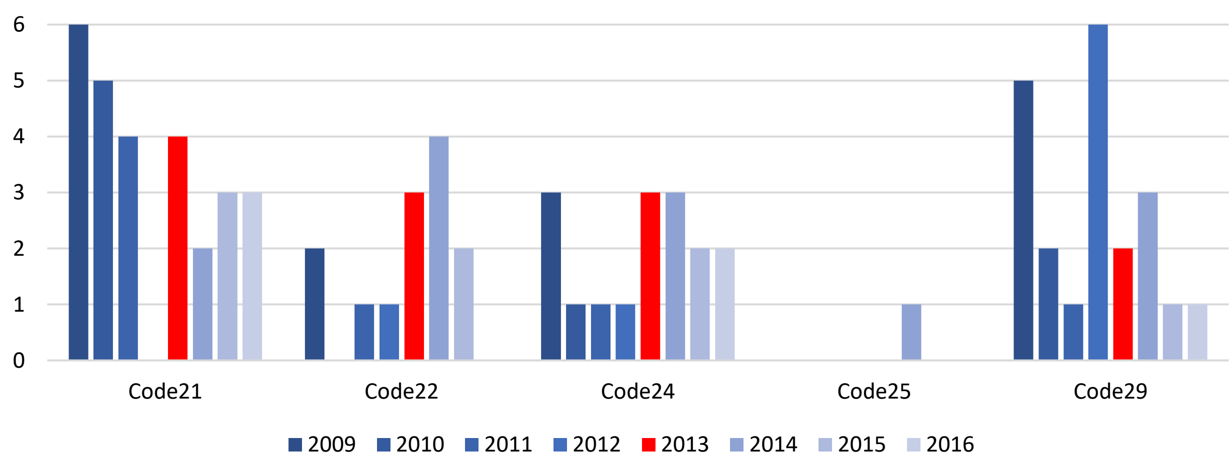


Figure 21 Yearly pattern of different coded incidents related to Pre-Fire conditions during December 20th to 31st for 2009 to 2016

5.4.4 False Fire Calls

The yearly pattern of different coded incidents (Figure 22), reveals that false fire calls related to alarm system malfunction has increased considerably and about 3 times. Human malicious intent, prank type did not change hugely. Number of other false fire calls, also, shows an increment. Accidental activation of the alarm systems has fairly amplified. Human accidental activation and human perceived activation codes did not show any difference.

Table 11 Number of incidents related to False Fire calls during December 20th to 31st for 2009 to 2016

Response Category 5: False Fire Calls		2009	2010	2011	2012	2013	2014	2015	2016
Code 31	Alarm system-Malfunction	22	22	15	14	72	17	14	27
Code 32	Alarm System-Accidental activation	11	14	8	12	18	4	7	11
Code 33	Human-Malicious Intent-Prank	2	0	0	0	4	2	1	1
Code 34	Human-Perceived emergency	8	7	8	2	9	9	5	8
Code 35	Human-Accidental	11	11	5	9	10	11	11	3
Code 39	Other False Fire Call	6	7	6	7	26	5	7	6

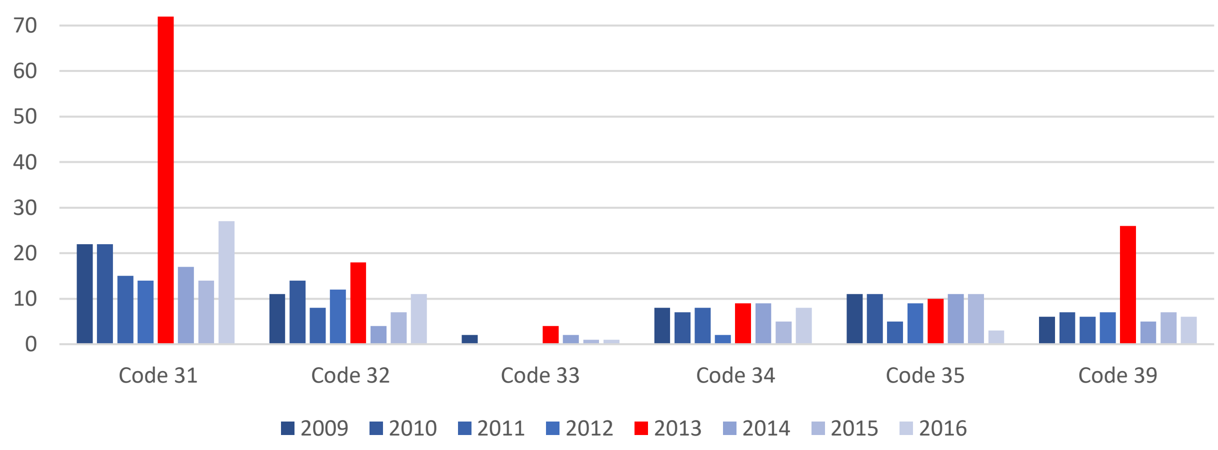


Figure 22 Yearly pattern of incidents related to False fire during December 20th to 31st for 2009 to 2016

5.4.5 CO False Calls

As Figure 23 displays, a very significant difference exists between the CO false alarm perceived as an emergency (Code 37) during the ice storm year and the other years and it is noticeable the number of this type of call has tripled during the 2013 ice storm. Also, the CO false alarms related to malfunction slightly increased compared o the other years.

Table 12 Number of different coded incidents related to Co False calls during December 20th to 31st for 2009 to 2016

Response Type Category 6: CO False Calls		2009	2010	2011	2012	2013	2014	2015	2016
Code 37	CO false alarm perceived emergency	4	10	4	2	25	5	10	6
Code 38	CO false alarm-malfunction	28	27	18	7	34	15	24	8

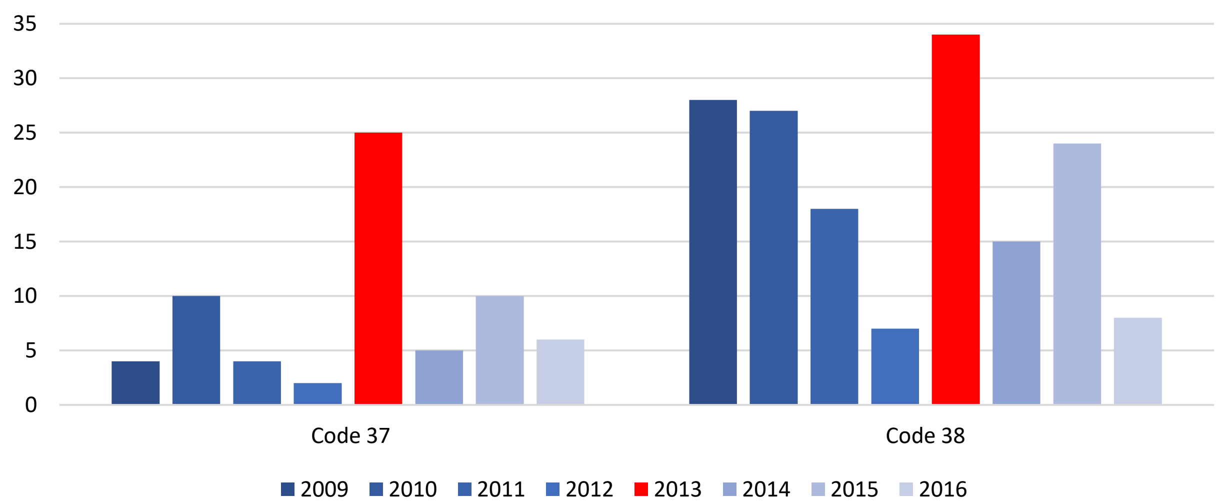


Figure 23 Yearly pattern of different coded incidents related to CO False calls during December 20th to 31st for 2009 to 2016

5.4.6 Public Hazard

Ice storm did not affect fire station responses related to public hazard, as listed in Table 13, uniformly. By reviewing Figure 24, the profound difference between number of code 50 (Power lines down) happened in 2013 and the other years is apparent. 48 power lines have been down during the ice storm which rarely occurred in other years. CO incidents doubled during the ice storm. Public hazard false calls increased slightly. The number of incidents coded 41 to 49 did not show a difference in 2013.

Table 13 Number of different coded incidents related to Public Hazard during December 20th to 31st for 2009 to 2016

Response Type Category 7: Public Hazard		2009	2010	2011	2012	2013	2014	2015	2016
Code 41, 42, 43, 44	Gas Leak (propane, Natural gas, refrigeration, miscellaneous)	5	4	3	1	3	5	3	4
Code 45, 46, 47	Spill (Gasoline, toxic chemical, miscellaneous)	1	2	3	3	2	2	0	1
Code 49	Ruptured water, steam pipe	1	3	0	0	1	1	0	1
Code 50	Power lines down	0	0	2	1	48	1	0	0
Code 53	CO Incident-CO present	2	3	4	5	9	5	4	4
Code 57	Public Hazard No action required	1	0	1	0	14	0	1	1
Code 58	Public Hazard call false alarm	0	1	0	0	5	1	1	2
Code 59	Other Public Hazards	3	3	0	2	17	3	2	0

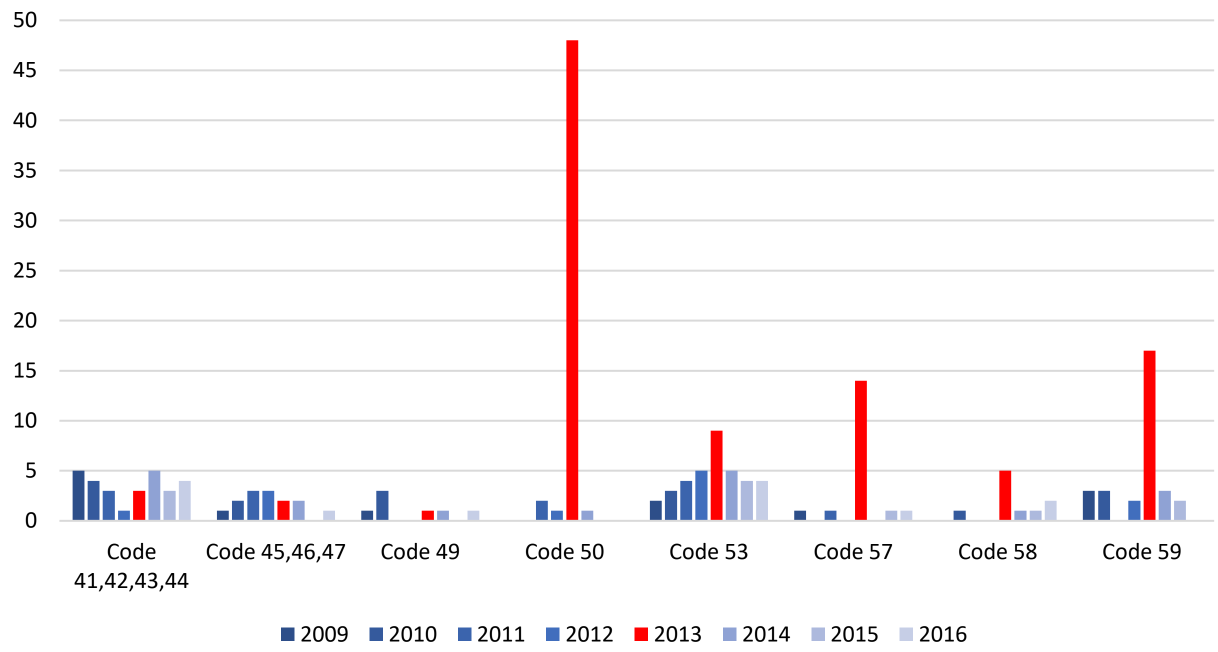


Figure 24 Yearly pattern of different coded incidents related to Public Hazard during December 20th to 31st for 2009 to 2016

5.4.7 Rescue

Incidents related to vehicle collision or extraction slightly increased during the ice storm, however as it is noticeable in Figure 25, number of rescues provided for people trapped in elevator increased hugely compared to other years. Other incidents showed same yearly pattern.

Table 14 Number of different coded incidents related to Rescue during December 20th to 31st for 2009 to 2016

Response Type Category 8: Rescue		**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Code 61, 62	Vehicle Extrication, Collision	35	25	47	42	50	25	46	41
Code 65	Home/Residential Accident	0	1	0	0	1	0	0	1
Code 66	Persons trapped in elevator	1	0	2	1	7	0	1	1
Code 69	Other Rescues	2	2	2	1	3	1	1	1
Code 698	Rescue no action required	1	1	2	0	1	2	0	0

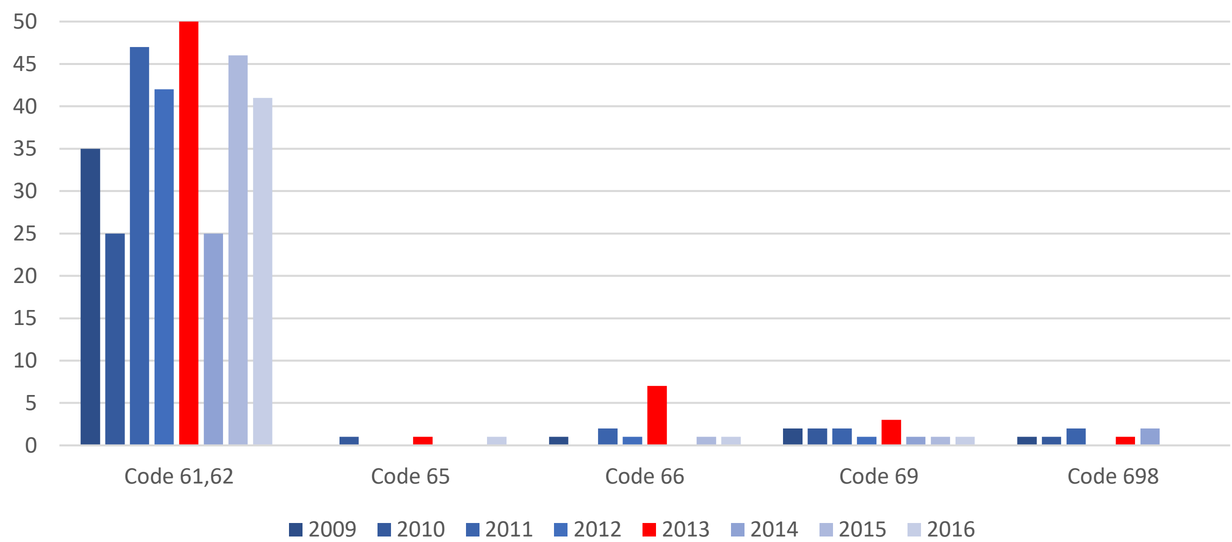


Figure 25 Yearly pattern of different coded incidents related to Rescue during December 20th to 31st for 2009 to 2016

5.4.8 Medical/Resuscitator Call

Different type of medical calls did not show similar patterns (Figure 26). The responses that provided oxygen or CPR (Codes 701-703) increased during the ice storm. Also, the number of calls related to *accidents* or *vital signs absent* (Code 85 and 88) showed an increment and doubled in 2013. It is noticeable that the ice storm did not affect the other type of medical calls significantly compared to the other years.

Table 15 Number of different coded incidents related to Medical/Resuscitator call Rescue during December 20th to 31st for 2009 to 2016

Response Type Category 9: Medical/Resuscitator		**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Code 701, 702, 703	Oxygen or CPR or Defibrillator used	40	33	15	19	39	17	17	17
Code 71	Asphyxia, Respiratory Condition	15	14	7	14	11	11	6	10
Code 73	Seizure	4	7	11	13	12	8	7	5
Code 75	Traumatic shock	1	0	0	0	0	0	1	1
Code 76	Chest pains or suspected heart attack	11	12	20	22	16	23	18	26
Code 82	Burns	0	0	0	1	0	0	0	0
Code 84	Medical not required on arrival	14	1	7	1	3	3	8	4
Code 85	Vital signs absent	2	1	4	3	8	3	4	3
Code 86	Alcohol or drug related	1	8	5	8	4	1	6	2
Code 88	Accident or illness related	4	6	4	5	10	6	4	8
Code 89	Other medical	58	54	37	47	37	32	30	44
Code 898	Medical No action required	27	23	24	33	35	30	30	48
Code 899	False alarm	1	0	1	0	1	0	0	1

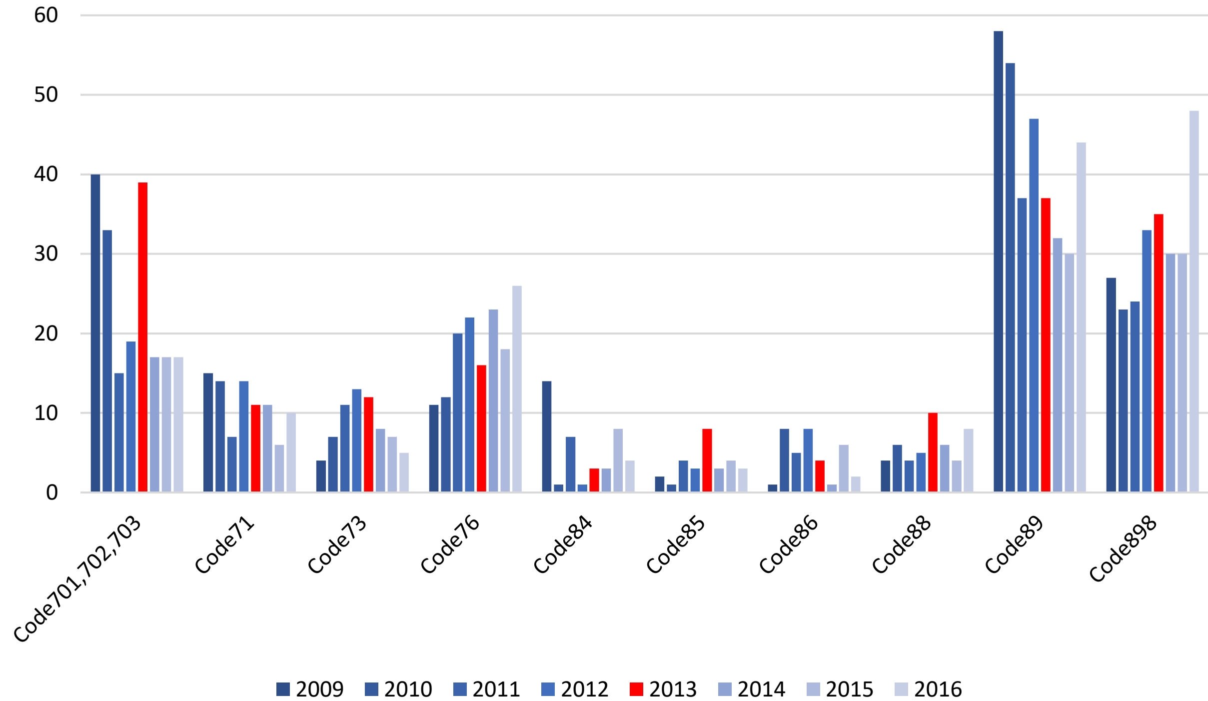


Figure 26 Yearly pattern of different coded incidents related to Medical/Resuscitator Call during December 20th to 31st for 2009 to 2016

5.4.9 Other Responses

The number of responses provided to other public services (Code 94) increased significantly about 5 times compared to the other years. Number of *other responses* (Code 99) and *incidents not found* (Code 97), also, showed an increment during the ice storm. Other coded incidents had fairly similar yearly pattern as it is shown in **Error! Reference source not found.**.

Table 16 Number of different coded incidents related to Other Responses during December 20th to 31st for 2009 to 2016

Response Type Category 10: Other Response		2009	2010	2011	2012	2013	2014	2015	2016
Code 92	Assisting Police	0	1	1	2	2	3	1	0
Code 93	Assisting other agencies	2	1	2	3	3	0	1	0
Code 94	Other public service	4	8	3	6	26	3	4	6
Code 96	Call cancelled on route	7	4	12	5	9	6	7	3
Code 97	Incident not found	2	2	3	4	9	1	2	1
Code 98	Assistant not required by other agencies	13	15	24	29	26	15	24	14
Code 99	Other response	4	1	1	2	14	0	0	0

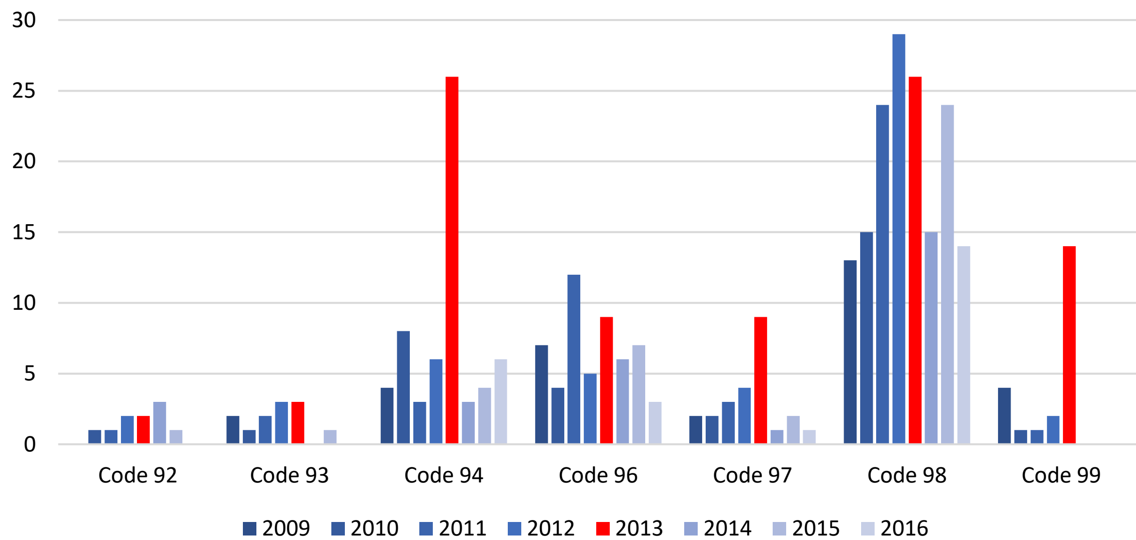


Figure 27 Yearly pattern of different coded incidents related to Other Responses during December 20th to 31st for 2009 to 2016

5.4.10 Daily pattern of all type of responses during the 2013 ice storm

Different type of responses did not show an identical daily pattern during the ice storm. Between December 21st and 23rd, 7 fires occurred. Over pressure rupture was not a significant issue during the ice storm and only two cases have been reported in 2013. Although Pre-Fire conditions (Over heat, pot on stove, lightening, fire works and other pre-fire conditions) have not appeared every day, on December 22nd, the most Pre-Fire conditions have happened. False fire calls, CO false calls, Public hazard, Rescue and other response display a similar pattern and December 22nd was the most challenging day to provide these types of responses. On the other hand, as Figure 29 displays, the number of medical calls rarely changed on a daily basis and the most calls related to medical issues occurred between 26 to 29 of December.

Table 17 Number of different type of responses during the 2013 ice storm

	20-Dec	21-Dec	22-Dec	23-Dec	24-Dec	25-Dec	26-Dec	27-Dec	28-Dec	29-Dec	30-Dec	31-Dec
Cat 1 Property Fires	0	1	3	3	0	0	0	0	0	2	0	0
Cat 2 Over Pressure Rupture	1	0	0	0	0	0	0	1	0	0	0	0
Cat 3 Pre-Fire Conditions	0	0	3	0	0	2	1	2	1	0	1	2
Cat 5 False Fire Calls	6	6	57	16	12	8	8	5	6	3	6	6
Cat 6 CO false calls	3	2	22	8	7	3	0	2	2	2	1	7
Cat 7 Public Hazard	3	13	46	4	9	3	2	4	5	4	2	4
Cat 8 Rescue	6	9	17	3	3	3	5	6	2	2	3	3
Cat 9 Medical Call	15	13	15	12	13	11	16	17	18	16	14	15
Cat 10 Other Response	5	11	28	10	8	7	2	7	4	5	1	2

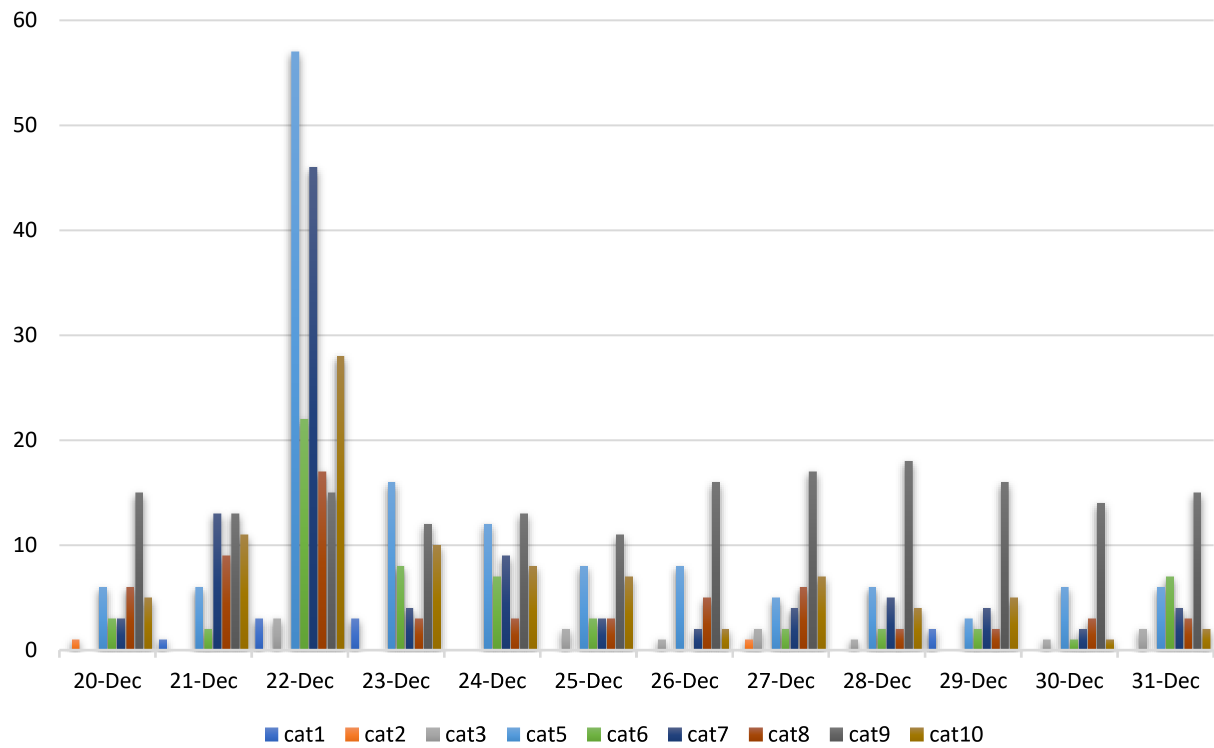
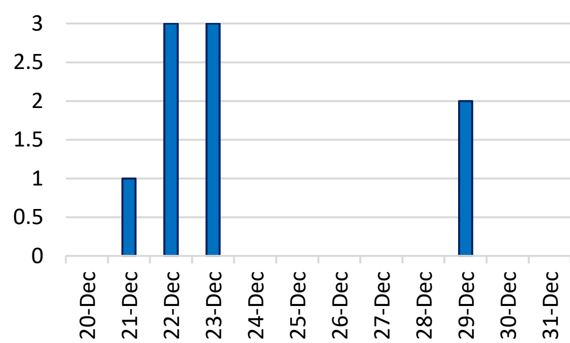
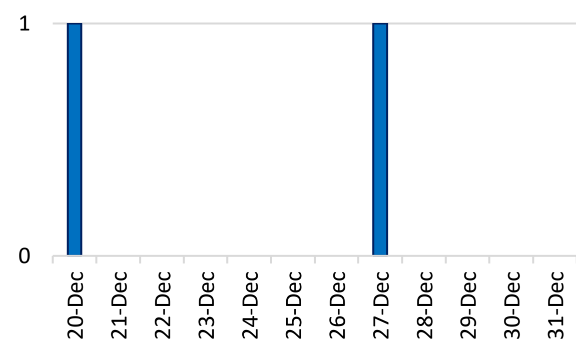


Figure 28 Daily pattern of different types of Responses During the 2013 ice storm

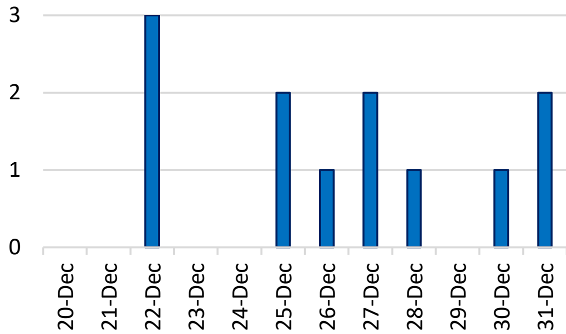


a. Property Fire, 2013

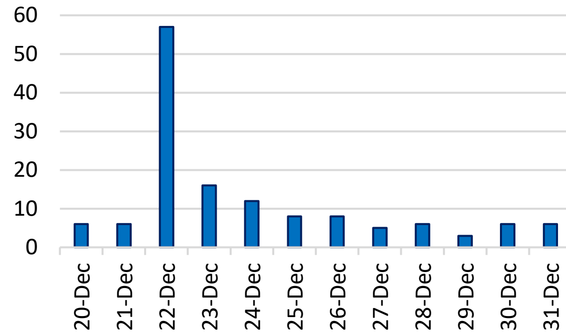


b. Over pressure rupture, 2013

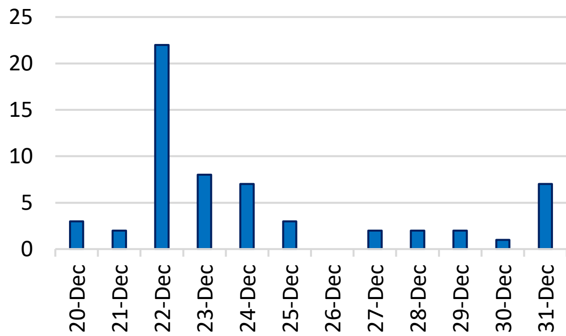
Figure 29 Daily pattern of each category of Response Type during the 2013 ice storm



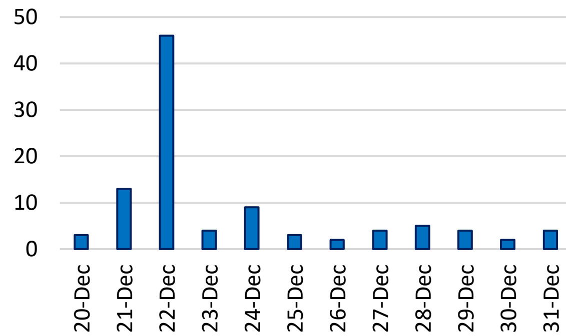
c. Pre-Fire Condition, 2013



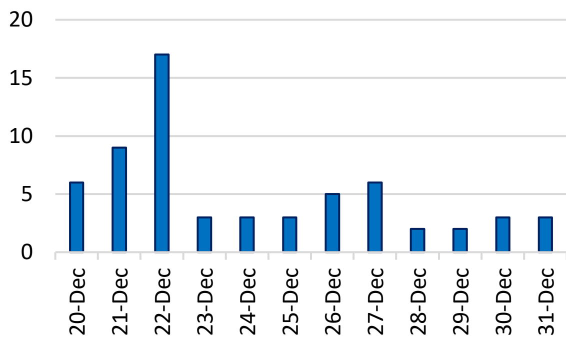
d. False Fire Calls, 2013



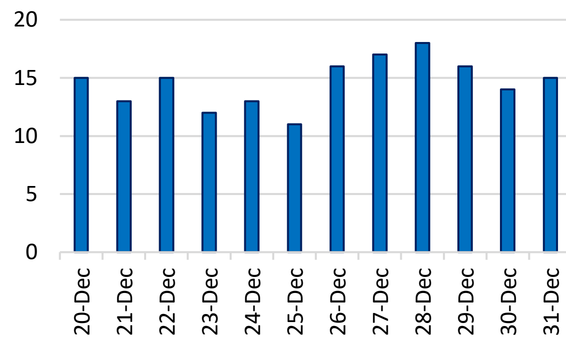
e. CO False Calls, 2013



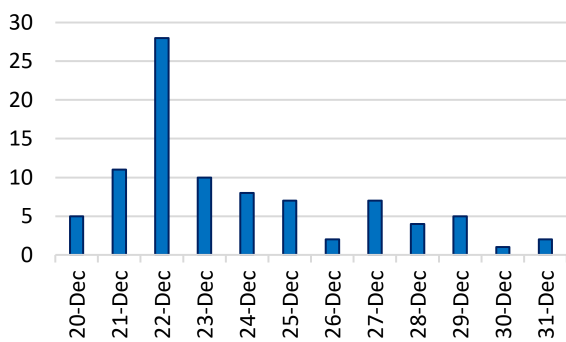
f. Public Hazard, 2013



g. Rescue, 2013



h. Medical/Resuscitator, 2013



i. Other Responses, 2013

(Continued) Daily pattern of each category of Response Type during the 2013 ice storm

5.5 Property Type

According to Standard Incident Report Codes list, the response could be provided to 6 types of classified properties. Also, there are some structures or properties which are not classified by the Ontario Building code. There are about 1000 different types of coded properties in these 7 Groups, as shown in Table 18. The detailed coded properties are shown in Appendix V.

By reviewing Figure 30 and Figure 31, it is noticeable that a significant amount of responses dealt with residential properties. Although the proportion of responses provided to different type of properties changed slightly, the number of responses shows a significant difference. The portion of responses to residential properties (group C) increased 1% in 2013. Group G included incidents happened at the side walks and Hydro Poles. The increment in responses provided to Group G properties was related mostly to incidents happened at Hydro poles as well as vehicle incidents.

In Figure 31 and Table 19, the vehicles that are included in Group G are displayed as an individual variable. Also, the mean value did not include 2013 responses. The number of incidents in Group A tripled in the ice storm. Number of incidents related to properties in Group B did not show a huge difference during the ice storm. As it was mentioned above, most of the responses during the ice storm occurred at residential properties.

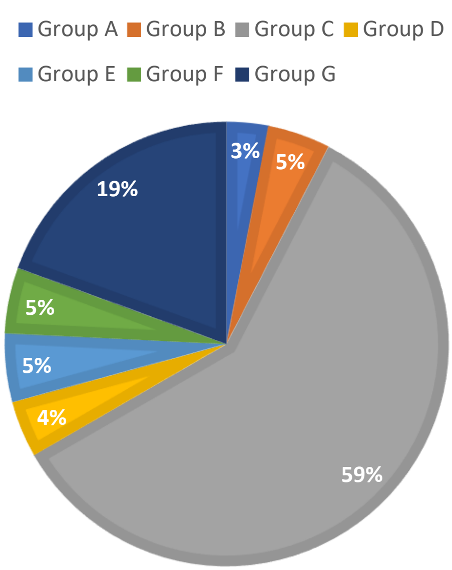
The responses related to group D, E and F slightly increased. Also, the number of incidents related to vehicles did not change significantly. This result was noticed in the response type as well. The number of responses in Rescue and related to vehicles did not change notably during the ice storm.

Table 18 Different group of properties

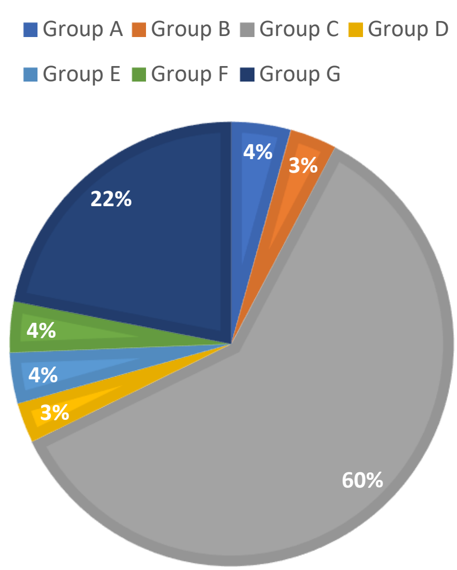
Response Type		
Group A	Assembly	1. Production viewing performing arts 2. Museum, Art Gallery, Auditorium 3. Recreation, Sport Facility 4. Education Facility 5. Transportation Facility 6. Arenas, Swimming pools 7. participating, Viewing open air facility 8. Other Assembly (Restaurants, Church, Court, etc.)
Group B	Care and Detention	1. Persons under restraint 2. persons under supervisory care 3. care facility 4. Transitional shelter 5.Group, retirement home 6. Other care and detention
Group C	Residential	1.Dettatched/Semi/Attached Residential 2. Dual Residential/Business 3. Rooming/Boarding 4.Multi Unit Dwelling 5. Seasonal dwelling/Mobile home 6. Hotel, Motel, Lodging 7. Other Residential (Residential camp, Hostel, etc.)
Group D	Business and Personal Services	1. Banks 2. Post Office 3. Police station (without detention quarters) 4. Fire Station 5. Other Business and Personal Services
Group E	Mercantile	1. Food/ beverage Sales 2. Department Store/Catalogue/mail outlet 3. Specialty stores (clothing store, pharmacy, florist, etc.) 4. Other Mercantile
Group F	Industrial	1.Vehicle Sales/Services 2. Utilities 3. Manufacturing or Processing 4. Storage different Products
Group G	Properties Not Classified	1.Mine/Well 2.Vehicles 3.Classed Under National Farm Building Code 4.etc.

Table 19 Number of responses received by different type of properties Responses during December 20th to 31st for 2009 to 2016

Property	2009	2010	2011	2012	2013	2014	2015	2016	Total	Mean excluded 2013
Group A	20	10	7	4	28	10	10	10	99	10
Group B	15	19	13	14	22	7	20	20	130	15
Group C	232	226	177	203	389	191	178	186	1782	199
Group D	14	16	13	10	19	14	9	21	116	14
Group E	23	13	16	19	24	14	21	11	141	17
Group F	16	18	18	14	24	9	15	23	137	16
Group G	60	49	78	79	142	52	76	64	600	65
Vehicles (Group G)	52	35	55	60	71	41	55	38	407	48



a. All years exclude 2013



b. Year 2013

Figure 30 Percentage of different type of properties Received Responses

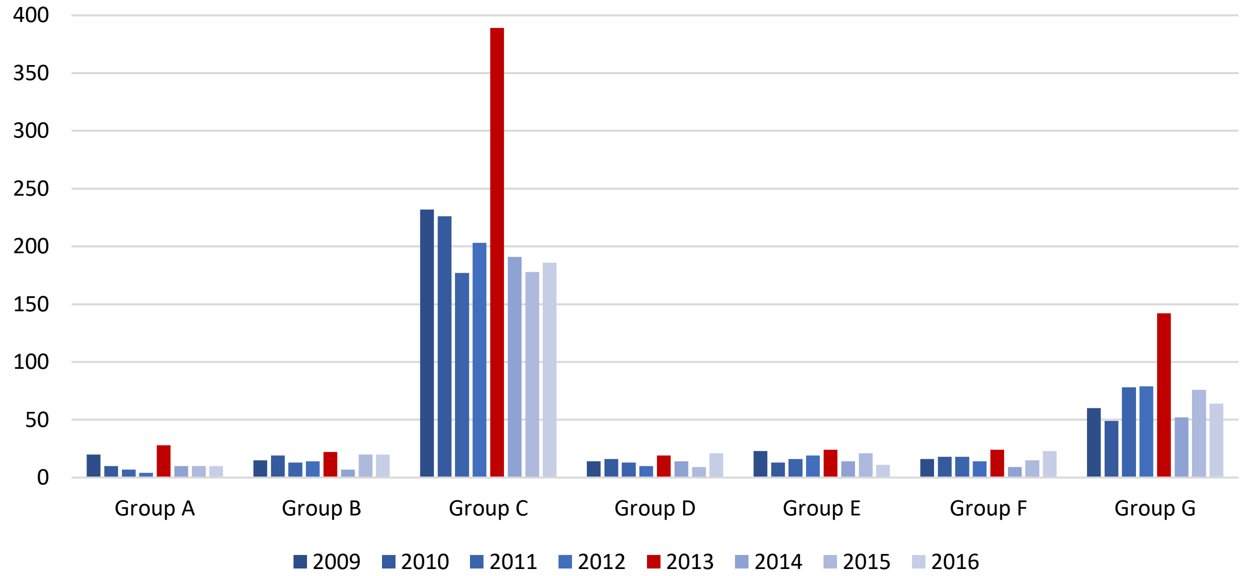


Figure 31 Yearly pattern of number of responses received by different properties

5.6 Dispatch and Clear temporal analysis

To analyse the temporal pattern (daily and yearly) of dispatch time and clear time, for each record the average dispatch time and clear time have been calculated. Dispatch is the difference between the time that the alarm was received by the station and the time that the responders arrived at the scene. Clear time is the difference between the time responders officially recorded clear and the time that the responders arrived. In Table 20 and Table 21, for all responses the average of daily dispatch and clear time have been displayed. The time is shown in minute and second format.

Table 20 Daily Average Dispatch during years 2009 to 2016

Daily Average Dispatch time								
	2009	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
20-Dec	00:05:53	00:07:26	00:06:32	00:07:06	0:07:50	00:07:42	00:06:25	00:06:41
21-Dec	00:06:57	00:06:34	00:07:15	00:06:52	0:08:38	00:06:09	00:05:41	00:06:18
22-Dec	00:05:56	00:06:52	00:07:24	00:06:08	0:09:32	00:06:08	00:06:41	00:05:54
23-Dec	00:06:27	00:06:48	00:06:48	00:06:09	0:08:11	00:06:02	00:06:08	00:06:13
24-Dec	00:07:19	00:06:14	00:06:31	00:06:47	0:07:23	00:06:23	00:06:44	00:05:55
25-Dec	00:06:46	00:06:17	00:07:13	00:05:48	0:07:30	00:05:22	00:06:05	00:05:52
26-Dec	00:07:05	00:06:29	00:07:15	00:06:32	0:06:13	00:07:18	00:06:54	00:06:57
27-Dec	00:06:07	00:06:39	00:06:23	00:06:52	0:06:44	00:06:35	00:07:02	00:06:16
28-Dec	00:05:33	00:05:23	00:06:45	00:05:55	0:06:20	00:05:43	00:06:28	00:05:46
29-Dec	00:06:51	00:07:53	00:07:06	00:06:45	0:06:49	00:05:54	00:07:06	00:07:02
30-Dec	00:06:07	00:05:51	00:05:51	00:06:40	0:06:53	00:07:19	00:06:21	00:06:07
31-Dec	00:06:18	00:07:01	00:06:08	00:06:08	0:07:05	00:06:28	00:06:54	00:06:40

The timing in Figure 32 and Figure 33 is measured in seconds. As Figure 32 displays, the average dispatch time have significantly increased between December 21st and 24th during ice storm. To provide the best protection against fire deaths and property loss, the National Fire Protection Association (NFPA) recommended that fire personnel arrive within six minutes of receiving the initial alarm. (NFPA, 2018).

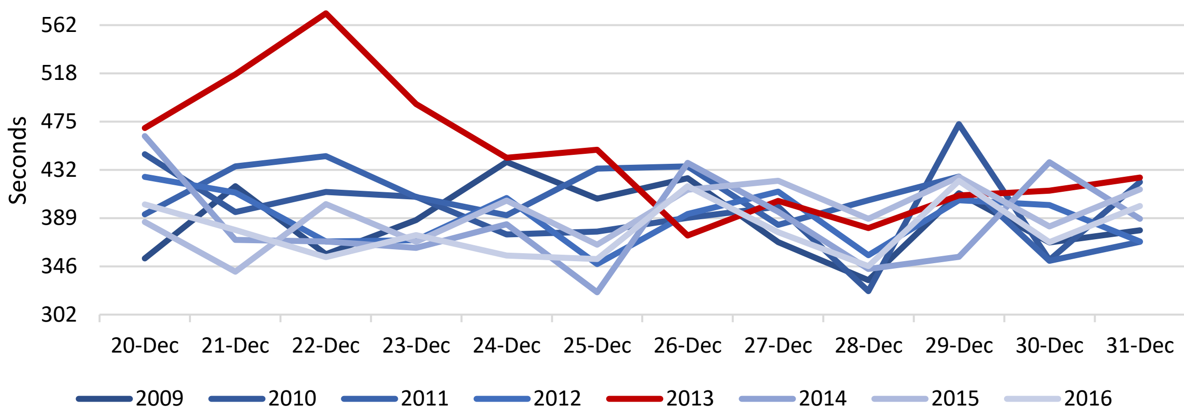


Figure 32 Daily pattern of average dispatch for years 2009 to 2016

Table 21 Daily Average clear for years 2009 to 2016

Daily Average Clear time								
	2009	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
20-Dec	00:12:24	00:13:23	00:13:52	00:14:35	00:16:52	00:24:38	00:18:19	00:16:08
21-Dec	00:11:56	00:17:27	00:14:41	00:15:39	00:29:19	00:17:08	00:19:40	00:15:52
22-Dec	00:14:36	00:14:38	00:12:17	00:13:32	00:16:29	00:17:14	00:16:01	00:11:22
23-Dec	00:15:38	00:19:32	00:13:43	00:13:12	00:18:28	00:22:10	00:18:21	00:31:08
24-Dec	00:41:55	00:17:23	00:15:21	00:20:31	00:15:03	00:14:50	00:16:51	00:18:05
25-Dec	00:17:44	00:12:01	00:13:09	00:13:46	00:22:33	00:09:43	00:15:59	00:11:56
26-Dec	00:15:36	00:16:41	00:10:18	00:17:40	00:19:26	00:13:30	00:18:48	00:14:46
27-Dec	00:16:34	00:15:51	00:16:20	00:14:27	00:14:40	00:10:32	00:17:04	00:14:28
28-Dec	00:12:27	00:16:38	00:17:35	00:12:50	00:13:27	00:12:17	00:19:06	00:19:15
29-Dec	00:13:09	00:20:41	00:15:13	00:12:43	00:24:04	00:13:37	00:13:13	00:17:11
30-Dec	00:10:46	00:17:18	00:11:47	00:10:34	00:23:14	00:15:49	00:15:16	00:18:22
31-Dec	00:18:49	00:16:22	00:11:21	00:15:55	00:15:22	00:19:59	00:12:06	00:09:42

Reviewing Figure 33 reveals that there was an increment in average clear time on December 21st, December 29th and 30th but for the other days, there was not a profound difference between the daily average clear time in 2013 and the other years.

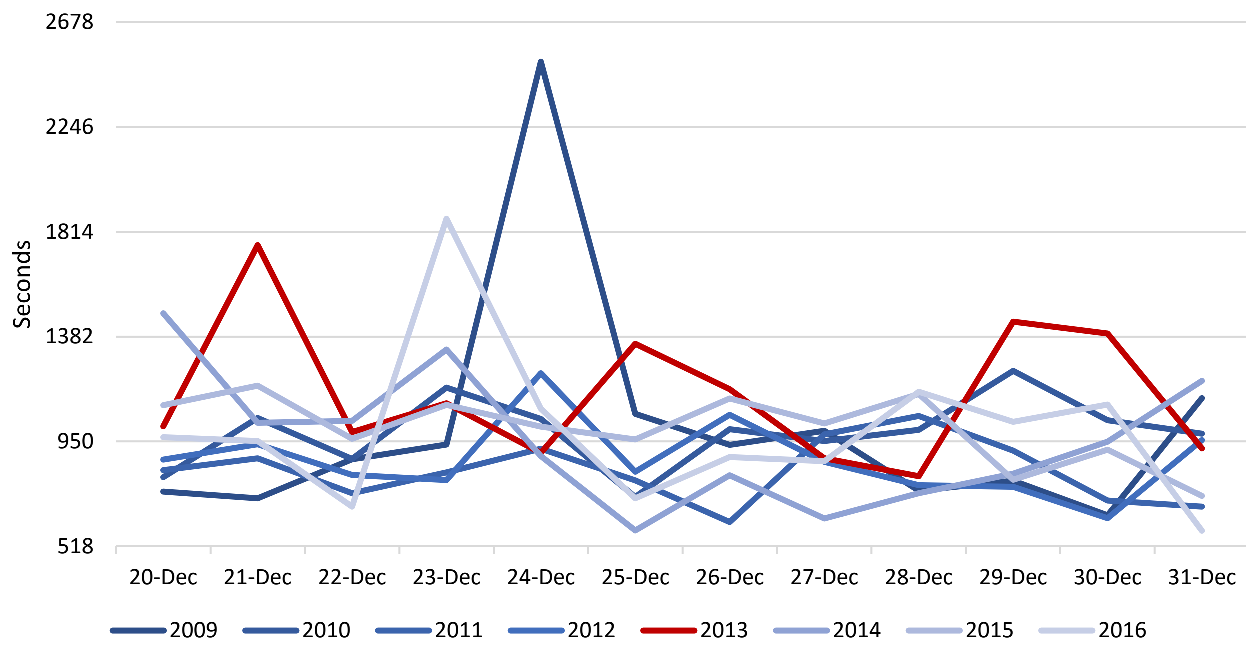


Figure 33 Daily pattern of average Clear for years 2009 to 2016

Total average daily dispatch time and clear time have been calculated and displayed in Figure 34 and Figure 35 for each year. All the total timing is measured in seconds. It is noticeable that during the 2013 ice storm, dispatch time have increased significantly and there is a moderate increment in clear time as well.

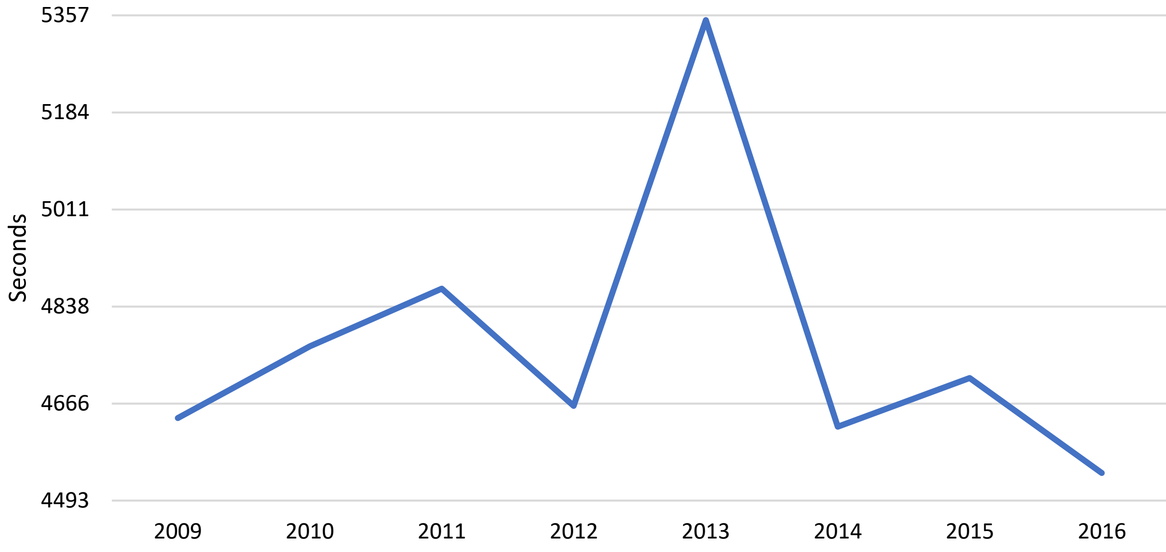


Figure 34 Yearly pattern of total average dispatch

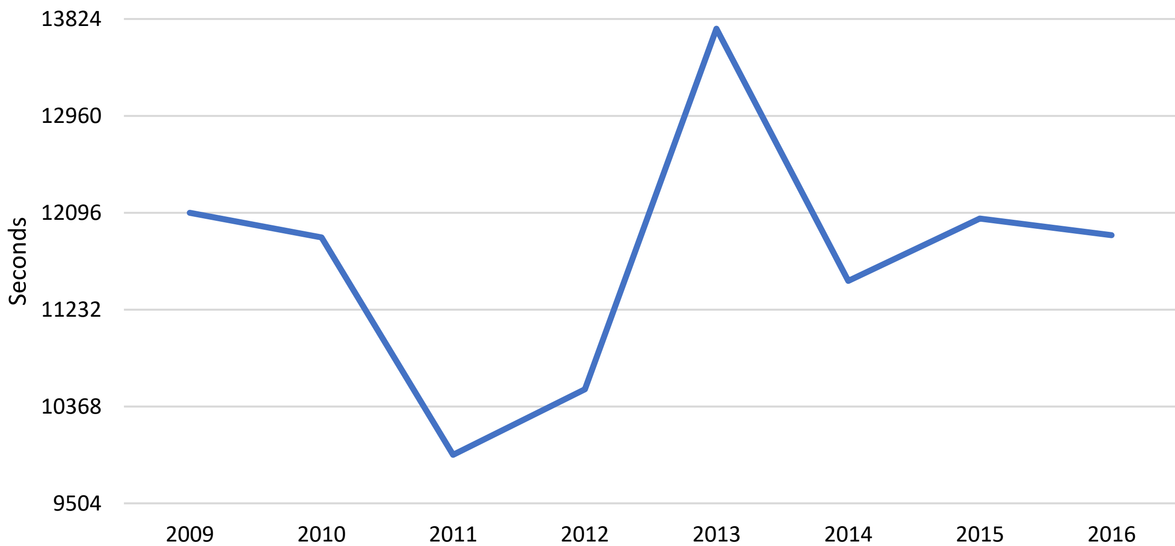


Figure 35 Yearly pattern of total average clear

5.7 Temporal Analysis Discussion

The Temporal analysis reveals that the 2013 ice storm affected the number of responses on daily basis significantly, however, it was not an even impact on all days during the ten-day period. The number of responses on December 22nd 2013 increased 6 times compared to the same day for the same days in 2009 to 2016. Also, the hourly pattern of responses showed a significant change during the ice storm compared to other years. Therefore, fire stations should be prepared in facing with similar emergencies as the calls can increase significantly and the hourly pattern of the calls also can alter as an ice storm occur.

By examining different type of alarms received during study period, alarms received by means of 911, telephone from civilian, from monitoring agencies and from police services increased notably. Although 40% of the alarms received from ambulances during the ice storm, the total number of this type of alarms did not show any difference compared to the other years. This may be explained as the number of medical calls mostly received through ambulances did not change significantly during the 2013 ice storm but other type of incidents has increased notably. Therefore, people has used different means to notify fire stations. This result may have important implications for fire stations as it shows how the type of receiving alarm can change during major emergencies. Therefore, fire stations may need to allocate alternative resources to receive the alarms promptly.

In addition, the 2013 ice storm did not affect City of Vaughan's fire stations activity uniformly. The number of responses provided by station 71, 72, 73,74, 78, 79 and 710 increased. These stations have located in the highly populated areas and as the number of incidents have increased during the 2013 ice storm it was meaningful that these stations had to provide more responses compared to the other years. Also, during the ice storm, responding to the districts other than the assigned district showed a huge increment, but this pattern was not noticed for station 71 activities. This may be explained as enormous calls have been received from station 71's assigned district and this station could not allocate resources to response to the other districts. In terms of daily responses during the ice storm, all stations have been affected significantly on December 22nd 2013.

The result shows that more than 47% of the received calls during the 2009-2016 were related to medical calls. However, although (Rajaram, et al., 2016) noted that during the 2013 ice storm, overall emergency department (ED) visits and visits related to injuries and environmental causes in City of Toronto and Ottawa was higher compared to the other years but in city of Vaughan, the number of medical calls did not increase during the ice storm period compared to the other years. Also, the number of some "other type of responses" increased remarkably. This pattern has happened as fire stations assisted other public services during ice storm. The 9-time increase in public hazard incidents was the outcome of the downed power lines. Extreme weather conditions, including high humidity, freezing temperatures, and ice storms can cause ice to form on power lines. Ice weight can put a lot of stress on power lines and damage equipment. Also, during ice storms, water can build up and freeze on tree limbs and other vegetation. The excess weight of the ice combining with wind can create hazardous conditions. Heavier branches can fall and damage power lines. Therefore, fire stations may need to be prepared for this type of responses for probable future ice storms. Also, the number of incidents related to CO (CO present) have increased. As several power outages happened during the ice storm, some of these CO incidents could be the result of burning charcoal or propane inside the houses. (Rajaram, et al., 2016) presented 98 cases of CO poisoning (3.54 cases per 100000 population) have been diagnosed in Toronto Eds during the 2013 ice storm. Therefore, VFRS may need to provide public awareness beforehand to prevent these types of emergencies during ice storms.

The number of responses related to false fire calls doubled and most of the alarms were related to alarm system equipment malfunction and other types of false fire calls. Also, the number of CO false calls increased for both codes, equipment malfunction and false perception of CO emergency. VFRS may need to investigate why these malfunctions increased during the ice storm and how they can assign more accurate sensors to prevent those malfunctions in the future emergencies. Although the ice storm did not affect number of vehicle incidents compared to the other years significantly, incidents related to people trapped in elevator increased four times. This result could be an outcome of power outage.

The hourly pattern of different type of responses showed some differences and this result may have important implication for VFRS further planning in terms of better preparedness during the peak times and allocating resources in a more insightful manner. In terms of properties which received responses, 60% of the properties were residential and 20% were related to vehicles and this pattern did not change significantly during the ice storm. People may refuse unnecessary transportations during ice storm and therefore the incidents related to vehicles did not increase significantly.

6. Spatial and spatiotemporal Results:

Figure 36 dispalys all provided responses during the 2013 ice storm period. Although the map is showing the spatial pattern to some extent, kernel density analysis is used to to find out more about the spatial patterns of incidents. By examining Figure 37, it is noticable that significant number of responses have been provided to the Southeast of the City of Vaughan. Also, there are areas near the highway 400 which are showing moderate intensity as well as Southwest of city of Vaughan.

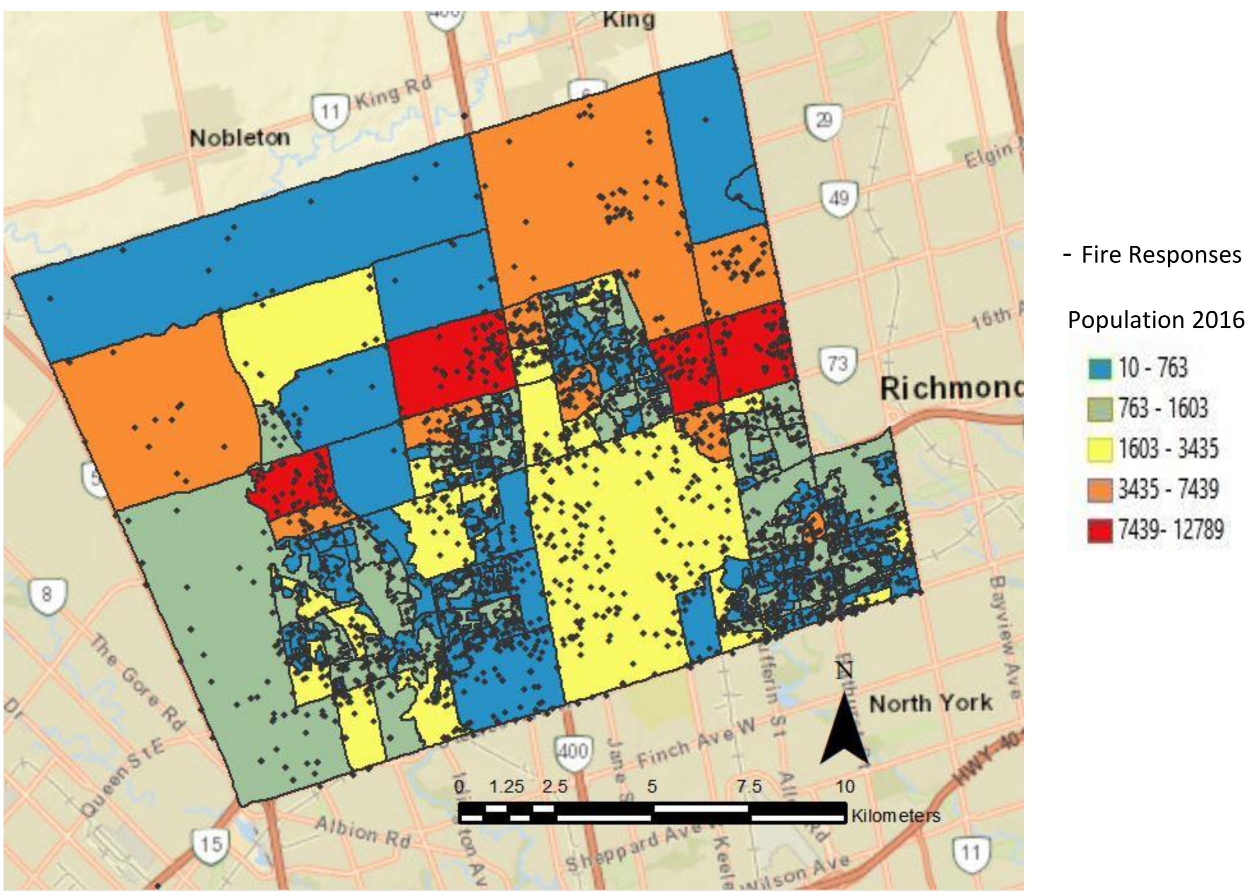


Figure 36 City of Vaughan, All responses locations during December 20th to 31st for years 2009 to 2016

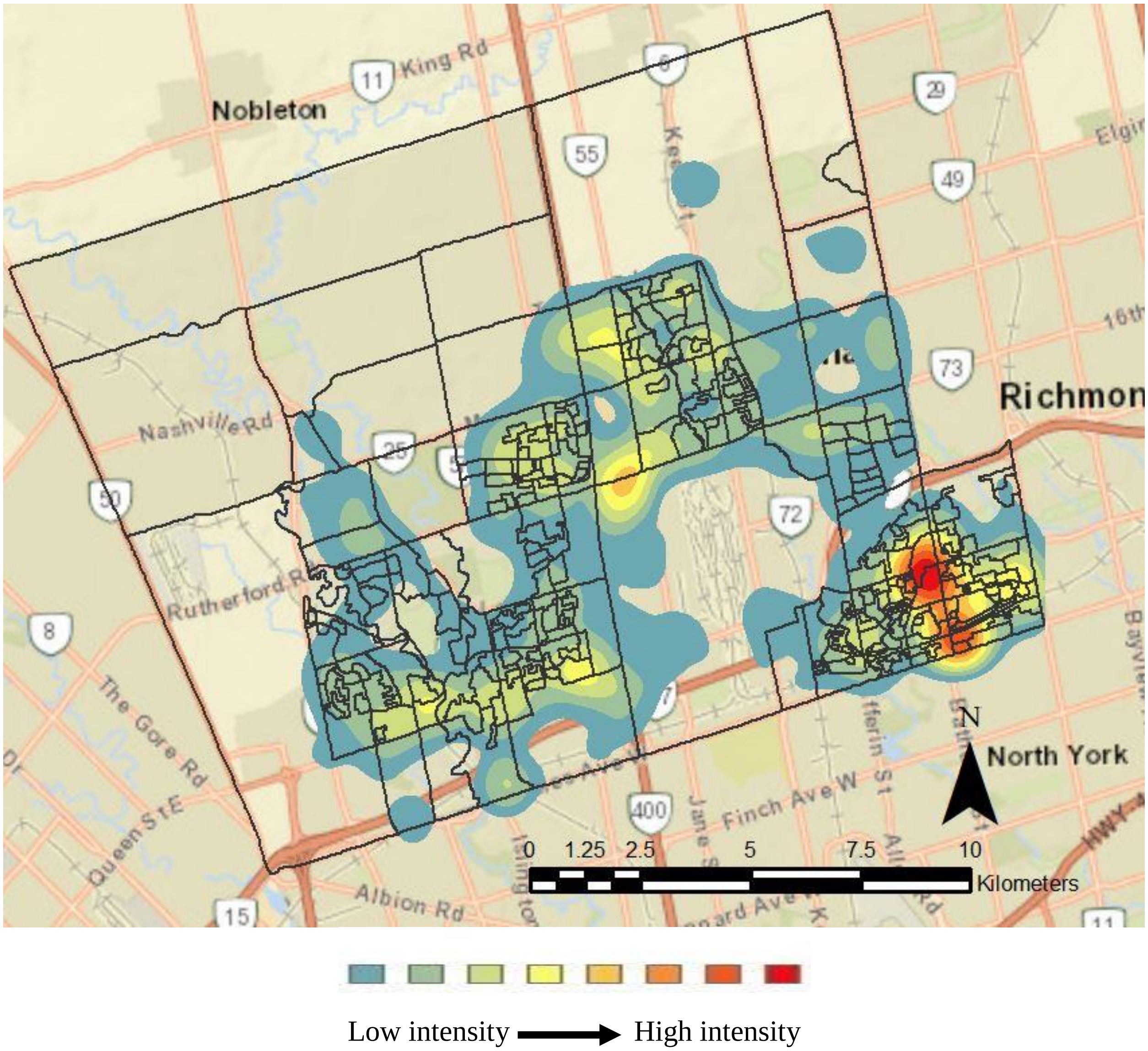
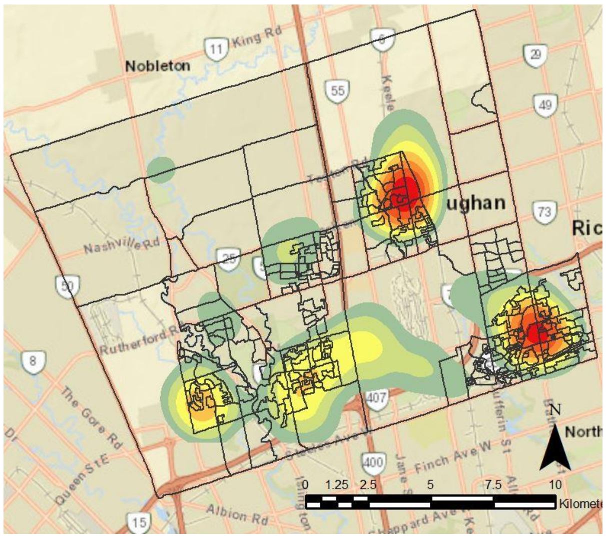


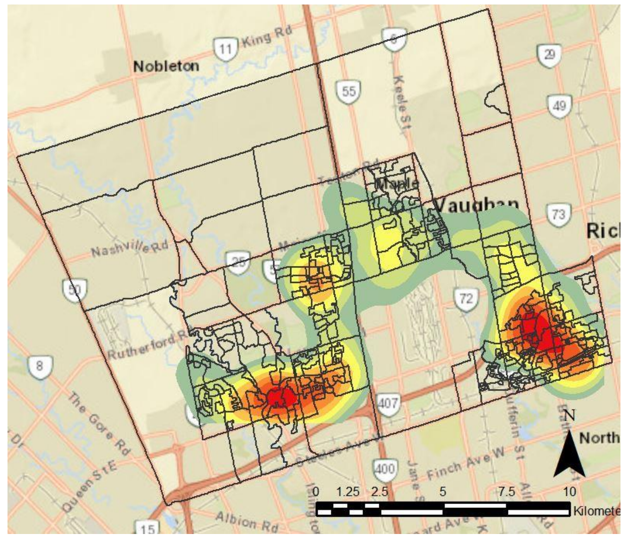
Figure 37 Spatial pattern of All responses happened during December 20th to 31st for years 2009 to 2016

6.1 Spatial Analysis of different type of response

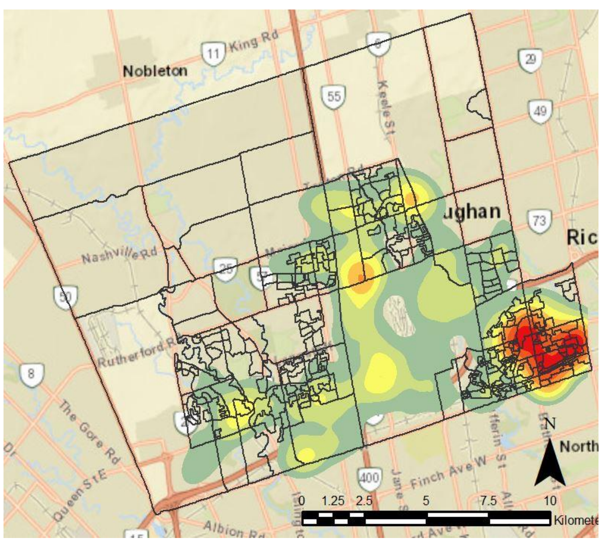
Figure 38 shows the kernel density map for different type of responses provided during the study period. The spatial pattern of different type of responses have noticeable differences in terms of hot zones. Fire responses mostly provided to two areas: Southeast of the City, between Steels avenue and Centre Street and the other area is close by Major Mackenzie Drive and Teston Rd. There were some moderate zones in the Southwest side of city. For all Pre-Fire Reponses, the geographical pattern was slightly different compared to fire responses. The density of responses in two areas were significantly high.



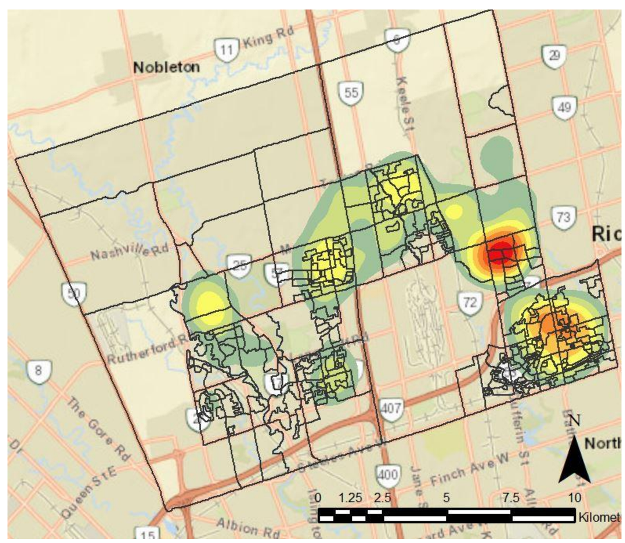
a. All Property Fires (category 1)



b. All Pre-Fire Conditions (category 3)

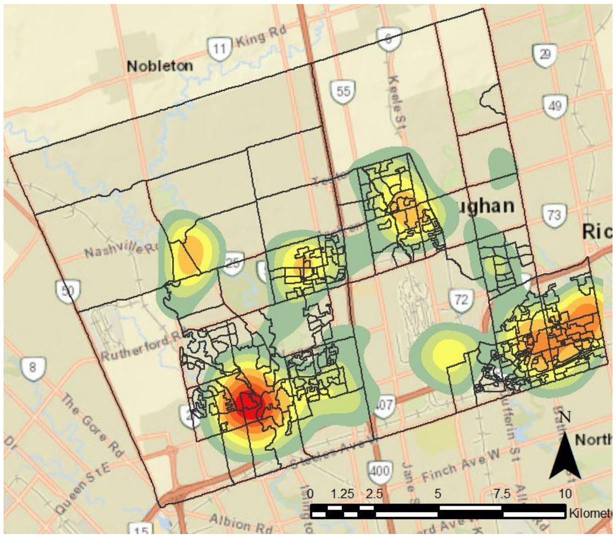


c. All False Fire calls (category 5)

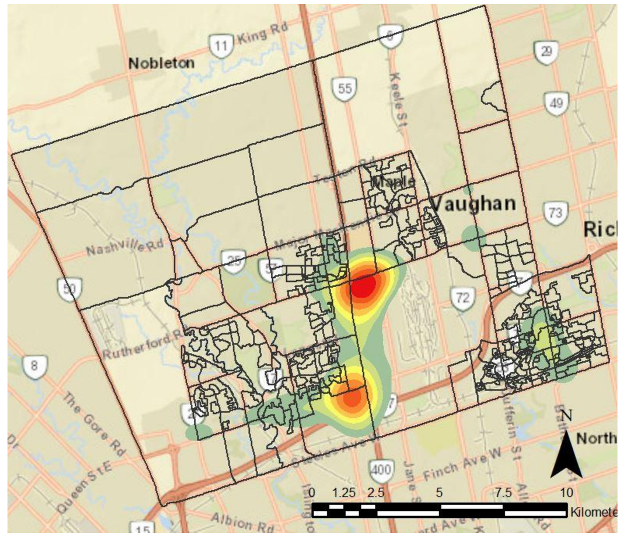


d. All CO False calls (category 6)

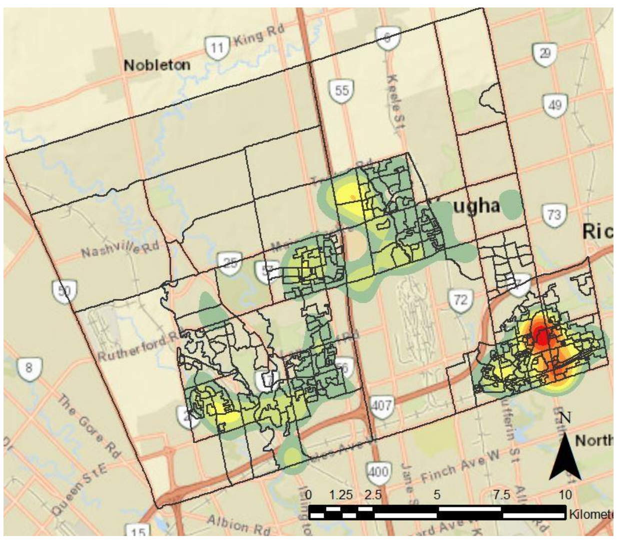
Figure 38 Spatial pattern of Different type of Responses happened during December 20th to 31st for years 2009 to 2016



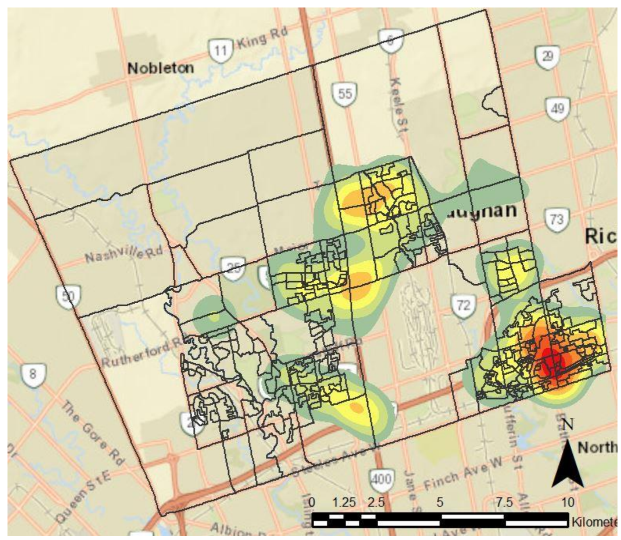
e. All Public Hazards (category 7)



f. All Rescue (category 8)



g. All medical Responses (category 9)



h. All other Response (category 10)

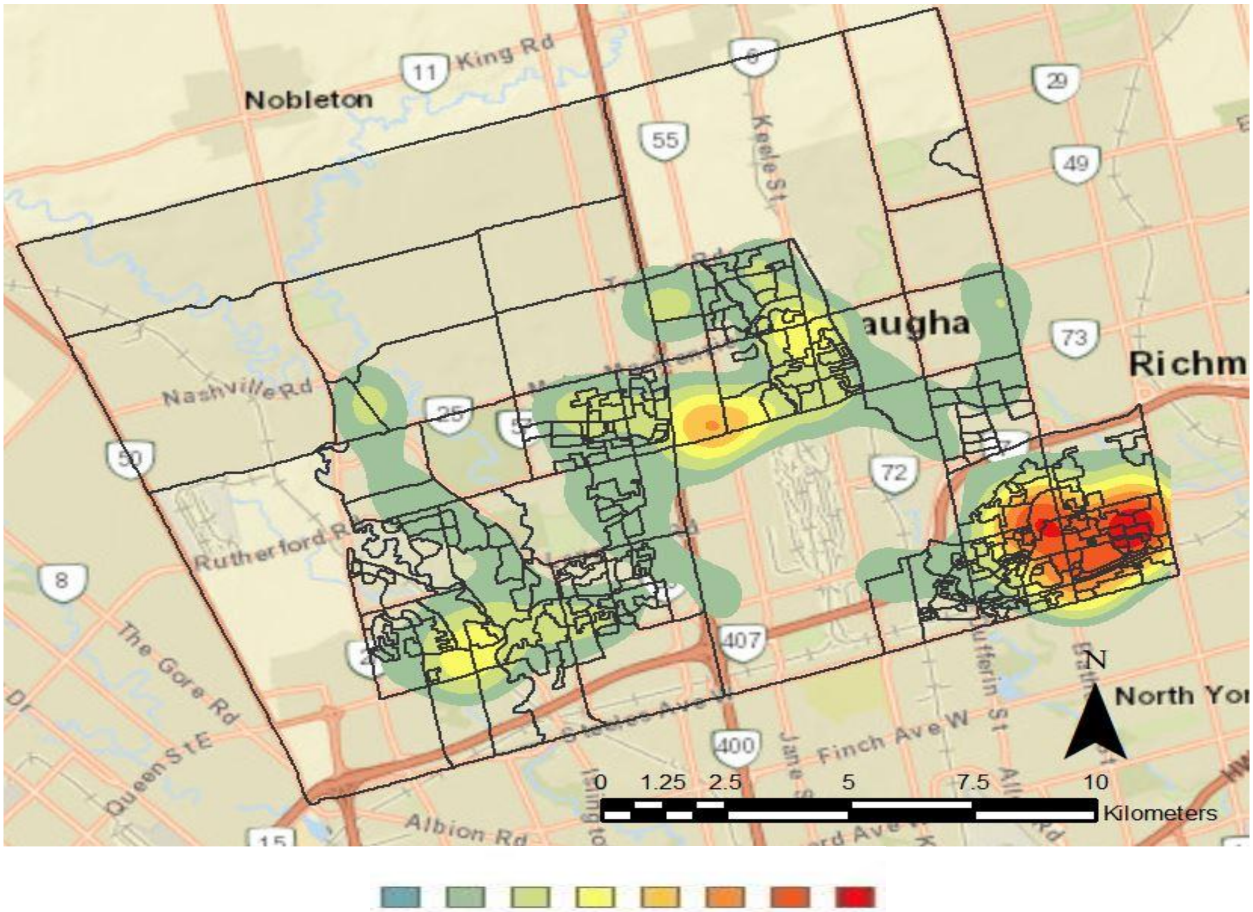
Low intensity ⟶ High intensity

(Continued) Spatial pattern of Different type of Responses happened during December 20th to 31st for years 2009 to 2016

6.2 Spatial Analysis of Responses during the 2013 ice storm

False fire responses mostly occurred in the southeast area of the city. On the other hand, it is noticeable that the location of most of the CO false calls, were concentrated near the Centre Street on the Southeast of the City of Vaughan. Most of the Public Hazard responses have been provided to the southwest area of the city, although, the southeast area experienced this type of response as well. More than 90% of the rescue responses were related to car accidents and these incidents mostly occurred across the Highway 400. There are two main areas, one is close to the intersection of highways 407 and 400 and the other area is located around the Rutherford Rd and highway 400 junction. The medical calls spatial pattern shows the highest intensity at Southeast of City of Vaughan. Finally, most other responses have been carried out at southeast area, and some areas across the Highway 400.

The spatial pattern of responses during the 2013 ice storm are displayed in Figure 39. The high intensity area is located at the Southeast of City of Vaughan. To examine how the ice storm affected the spatial pattern of daily responses from December 21st to December 31st, 2013, Figure 40 would be informative.



Low intensity ⟶ High intensity

Figure 39 All Responses conducted during the 2013 ice storm

It is noticeable that incidents and responses were more frequent at the southeast area in most days except for December 20th and 26th. As it was mentioned in the temporal analysis section, most of the responses have occurred on December 22nd. There are three areas which received the most responses on that day: southeast, southwest and north of Rutherford Rd. Also, on December 27th, fire stations have been providing responses to four main areas. Therefore, although there are some similarities in spatial pattern on daily basis, some days have exhibited significant differences.

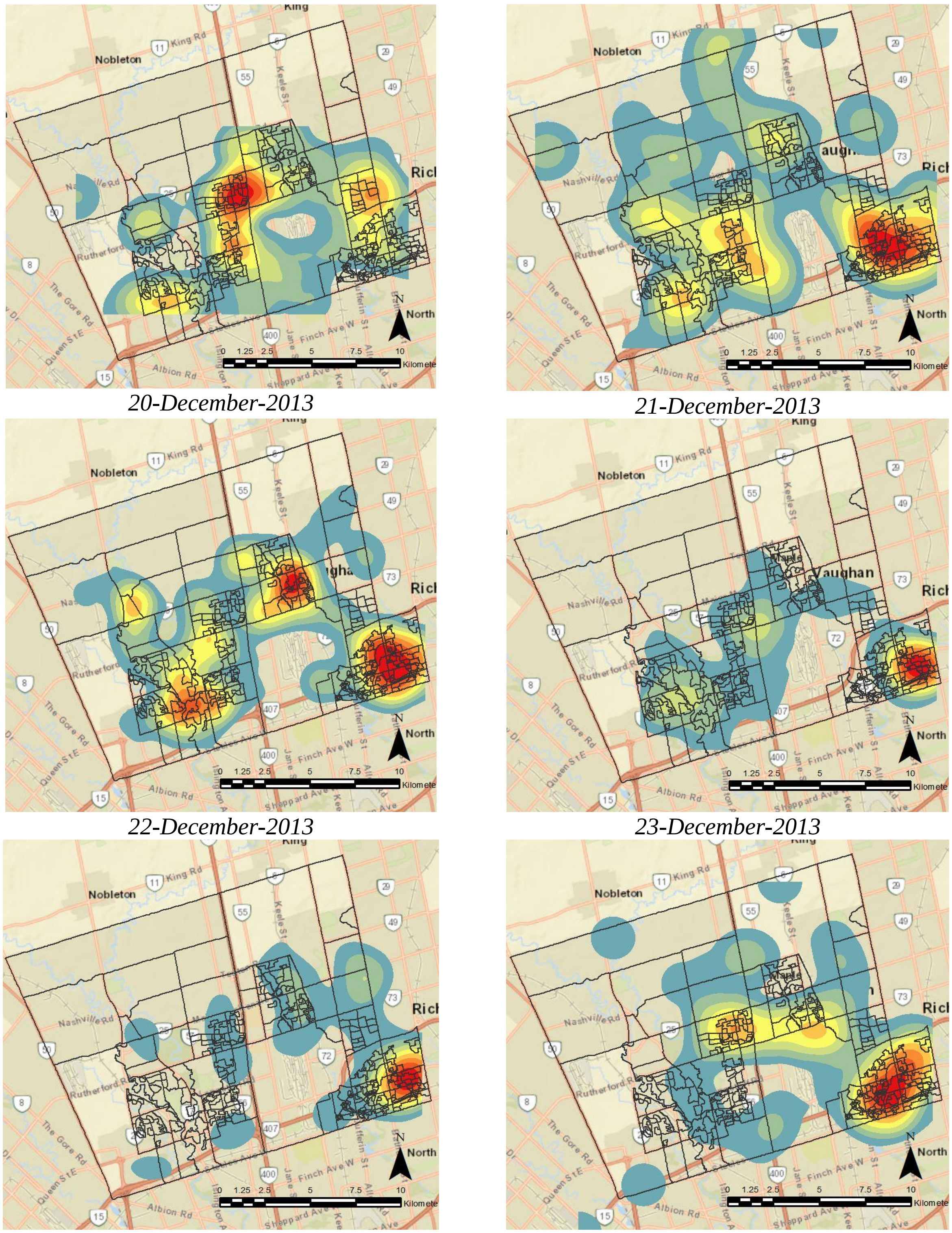
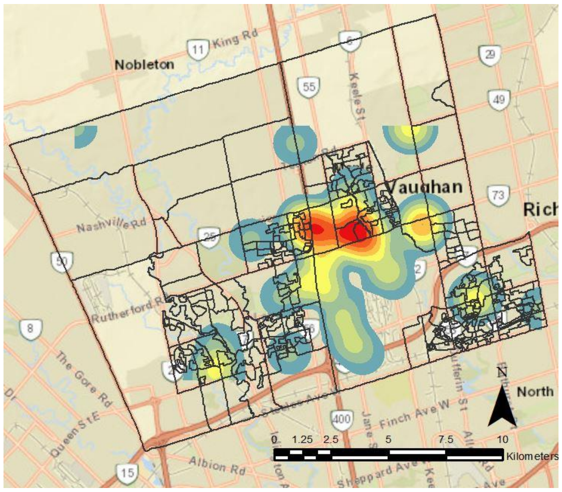
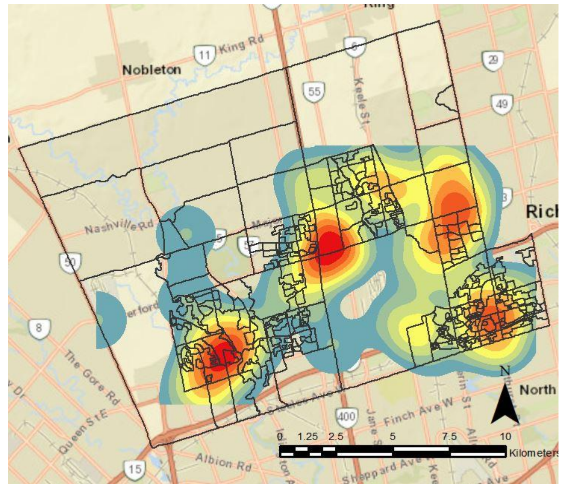


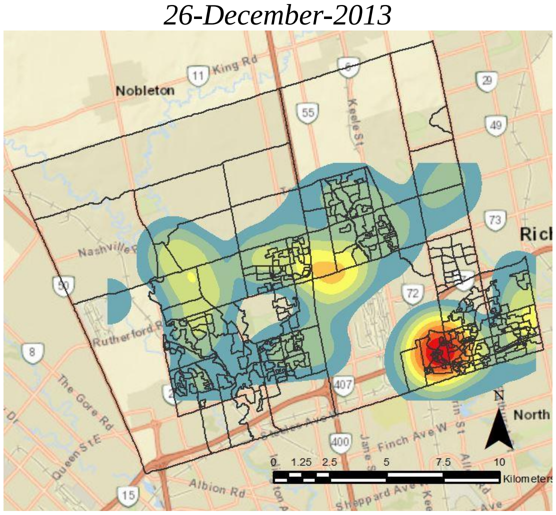
Figure 40 Spatial pattern of Daily Responses during the 2013 ice storm



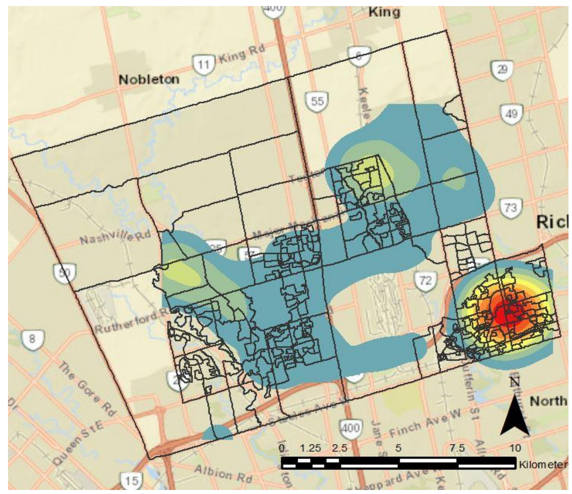
26-December-2013



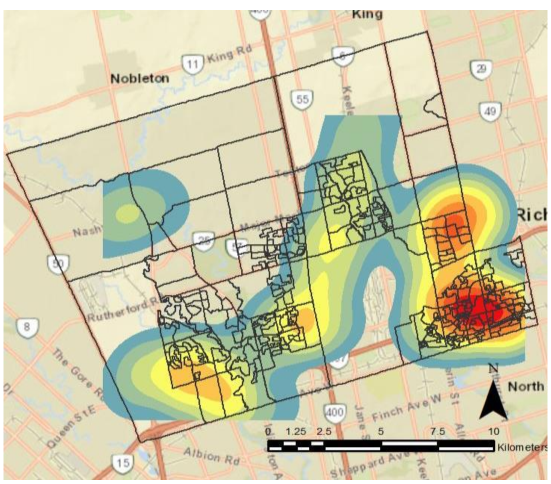
27-December-2013



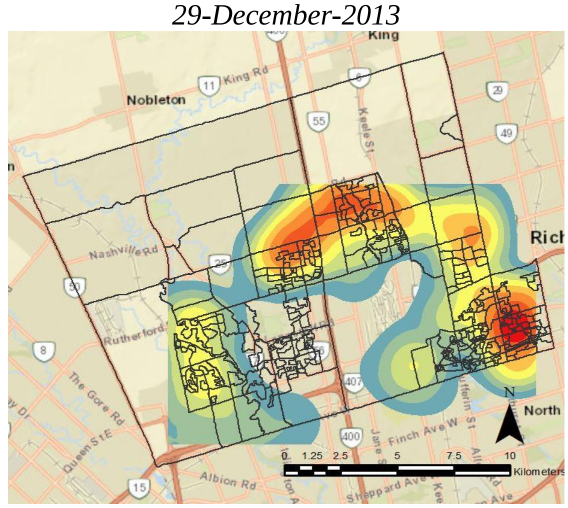
28-December-2013



29-December-2013



30-December-2013



31-December-2013

Low intensity ⟶ High intensity

(Continued) Spatial pattern of Daily Responses during the 2013 ice storm

6.3 Spatial Analysis of Different Properties

As the analyses in the previous chapter show, Group C and Group G properties received most of the responses during the study period. Therefore, kernel density analysis has been applied to these two groups only.

Figure 41 displays the kernel density maps for responses provided to *Detached-Semi-Attached residential* (Group C) during the study period and the ice storm separately. There was significant difference between these two maps related to high intensity areas. During the ice storm, most of the responses to this type of property have been provided to the southeast. On the other hand, during the study period, the geographical pattern of properties received responses were accumulated in four main areas.

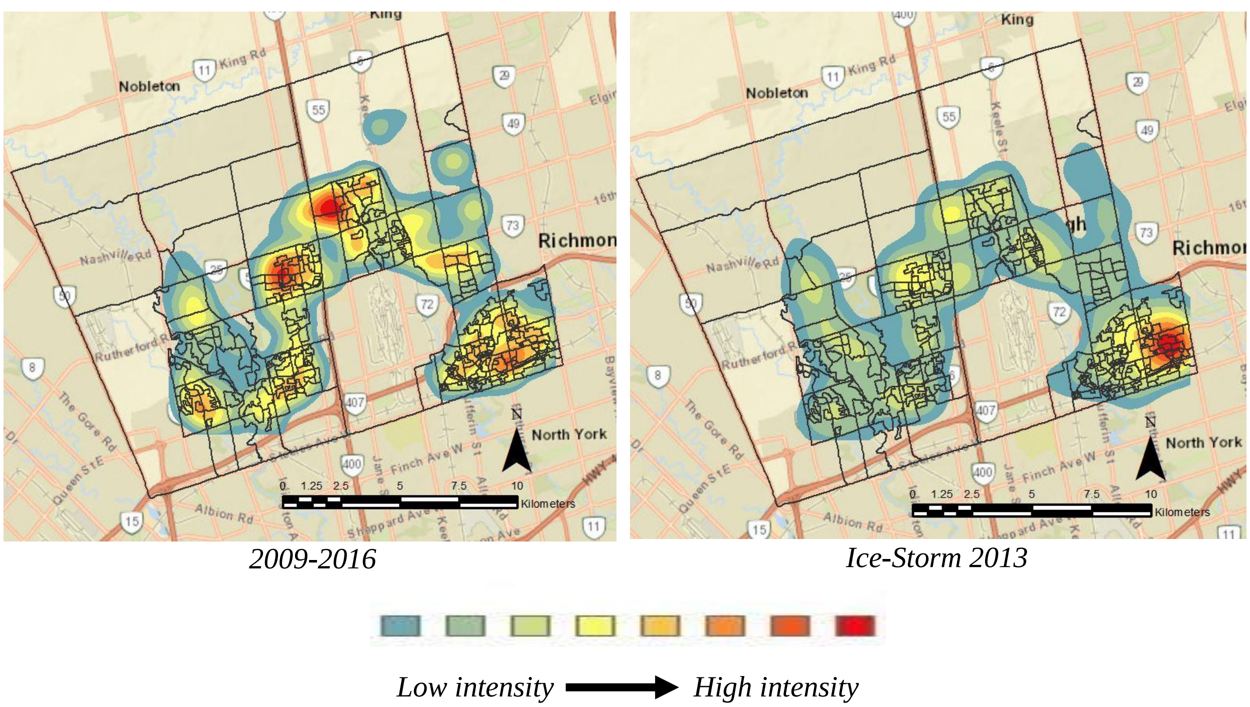
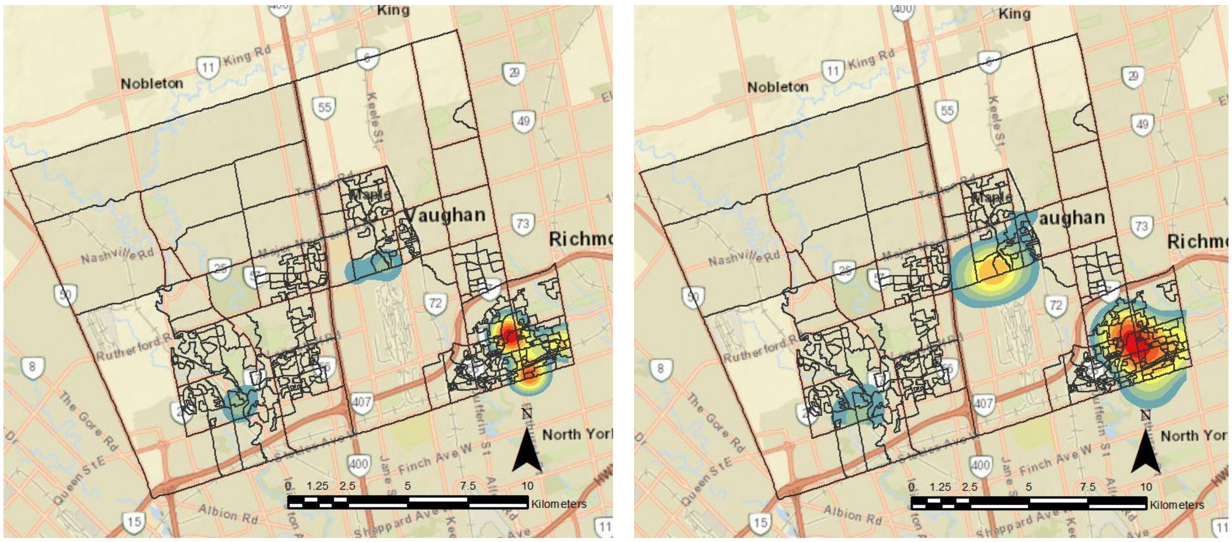


Figure 41 Comparison of Spatial patterns of responses to Dethatched-Semi-Attached Residential (Group C Properties) during ice storm with December 20th to 31st for 2009 to 2016

Figure 42 shows the result of kernel density analysis for responses implemented at *Multi Unit Dwelling* (Group C) during the study period and the ice storm independently. Although there is a slight variation in these maps, it can be concluded that the spatial patterns are very similar.

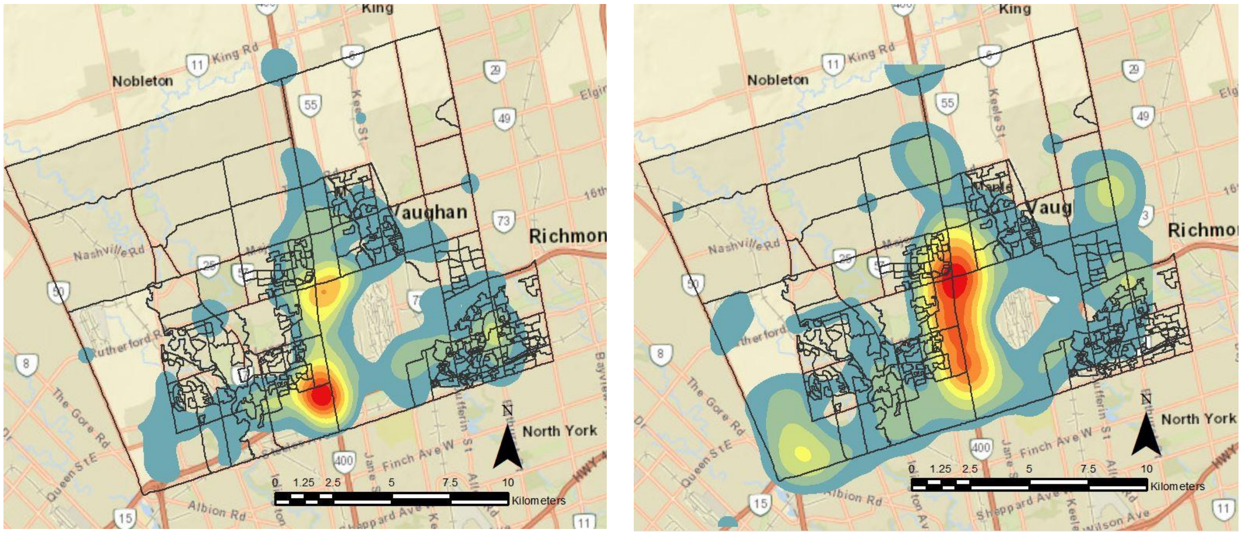


2009-2016 *The 2013 ice storm*

Low intensity ⟶ *High intensity*

Figure 42 Comparison of Spatial patterns of responses to Multi unit Dwelling (Group C Properties) during ice storm with December 20th to 31st for 2009 to 2016

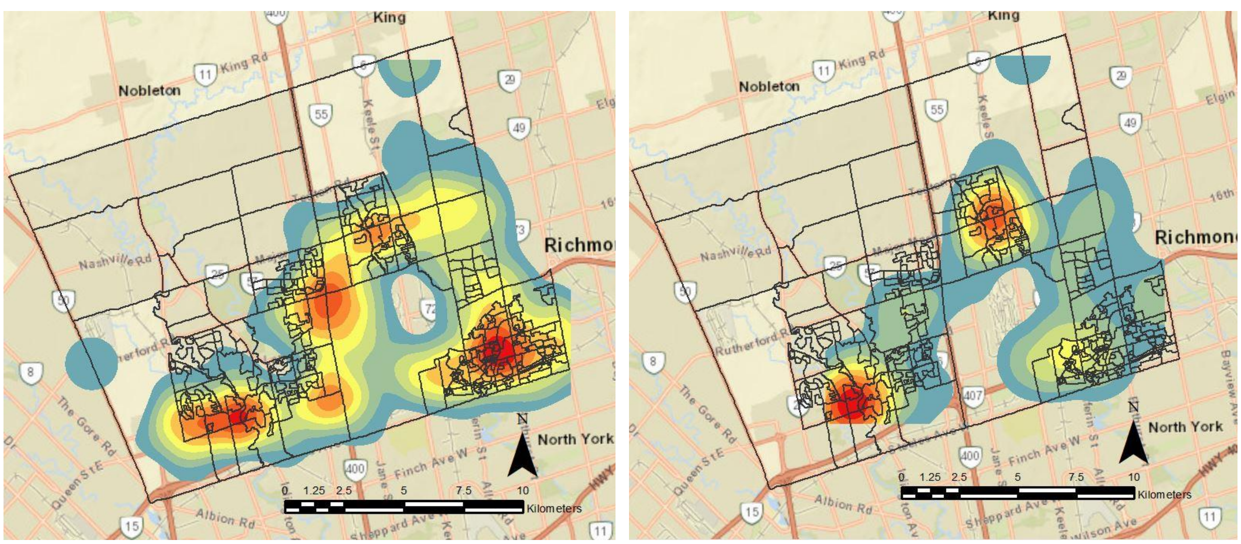
Figure 43 displays the geographical pattern of responses related to vehicles (Group G) during the ice storm and the study period separately. Between 2009 to 2016, majority of the incidents occurred at the south area of the Highway 400, but during the 2013 ice storm, the high intensity area shifted to the north, around the Highway 400 and the Rutherford Rd intersection. Also, it is notable that that majority of the incidents have taken place along the Highway 400, between Highway 407 and the Rutherford Rd in 2013.



2009-2016 The 2013 ice storm

Low intensity → *High intensity*

Figure 43 Comparison of Spatial patterns of responses to Road Vehicles (Group G Properties) during ice storm with December 20th to 31st for 2009 to 2016



2009-2016 Ice Storm

Low intensity → *High intensity*

Figure 44 Comparison of Spatial patterns of responses to Sidewalk, Street, Roadway (Group G Properties) during ice storm with December 20th to 31st for 2009 to 2016

Finally, Figure 44 compares the spatial pattern of responses received at *sidewalk- street-roadways* (Group G) during the ice storm and the study period. Although, the number of responses provided to the southeast of the City was significant between 2009 to 2016, the same pattern was not observed during the ice storm. All in all, there was a significant difference between the spatial patterns during these two periods.

6.4 Spatiotemporal Analysis

As the previous results have shown thus far, the responses during the study period as well as the ice storm has not been evenly spread spatially and temporally. Examining the spatiotemporal pattern of responses can reveal some useful insights.

Figure 45presents the univariate comap of all responses provided between 2009 to 2016 conditioned by hour, illustrates a change in responses over time and space. By moving from early morning hours to the late evening hours, the intensity of responses across North of Rutherford Rd and across the Highway 400 changes. There is not a significant difference in southeast area throughout the day.

Finally, the univariate comap of all responses provided during the 2013 ice storm conditioned by hour, Figure 46, shows the intensity of the responses changes over time and space. By following maps from early morning to the late evening, the intensity of responses changes, especially during late hours of the day.

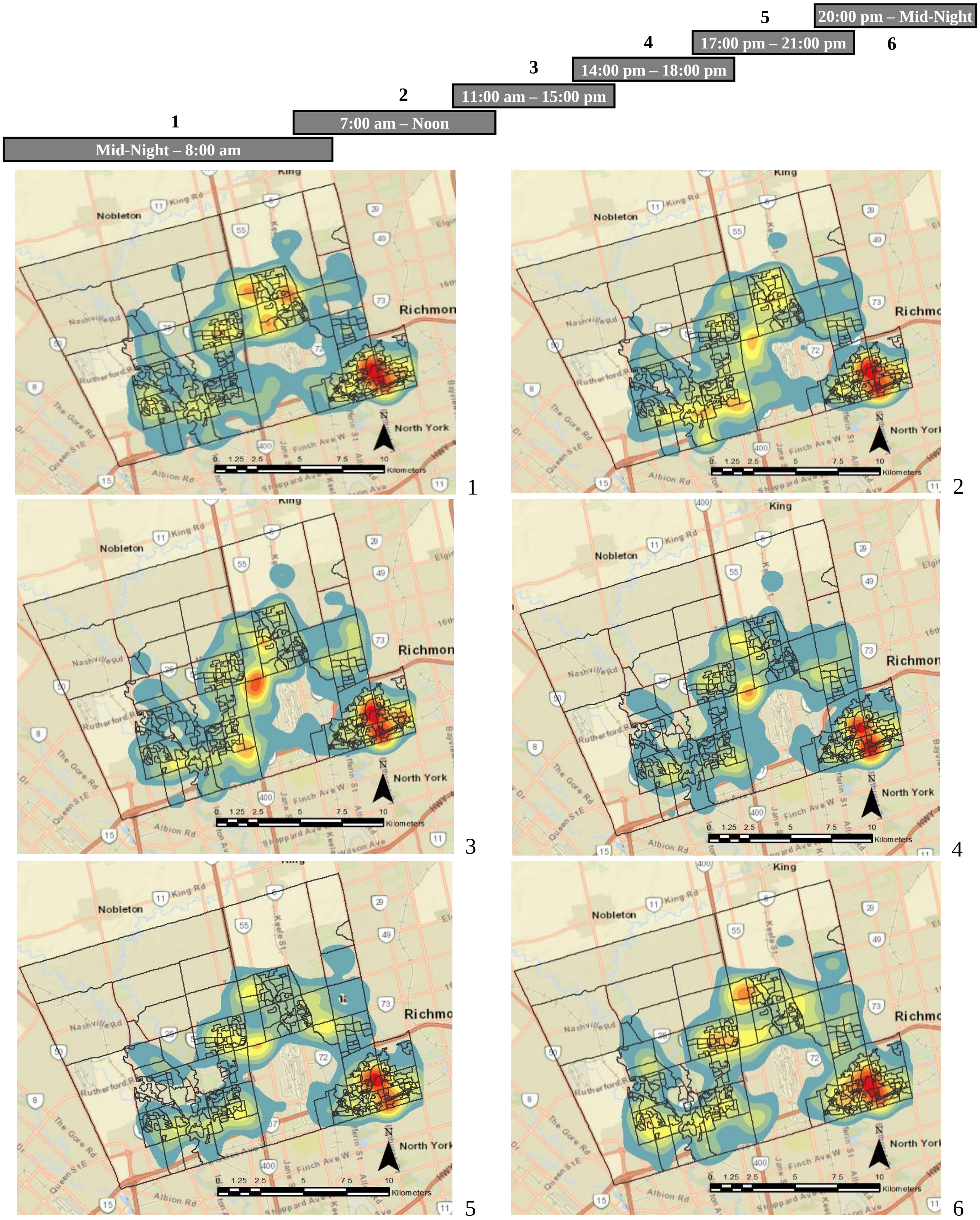


Figure 45 Univariate co-map for all responses occurred between December 20th to December 2016 for 2009 to 2016(by hour)

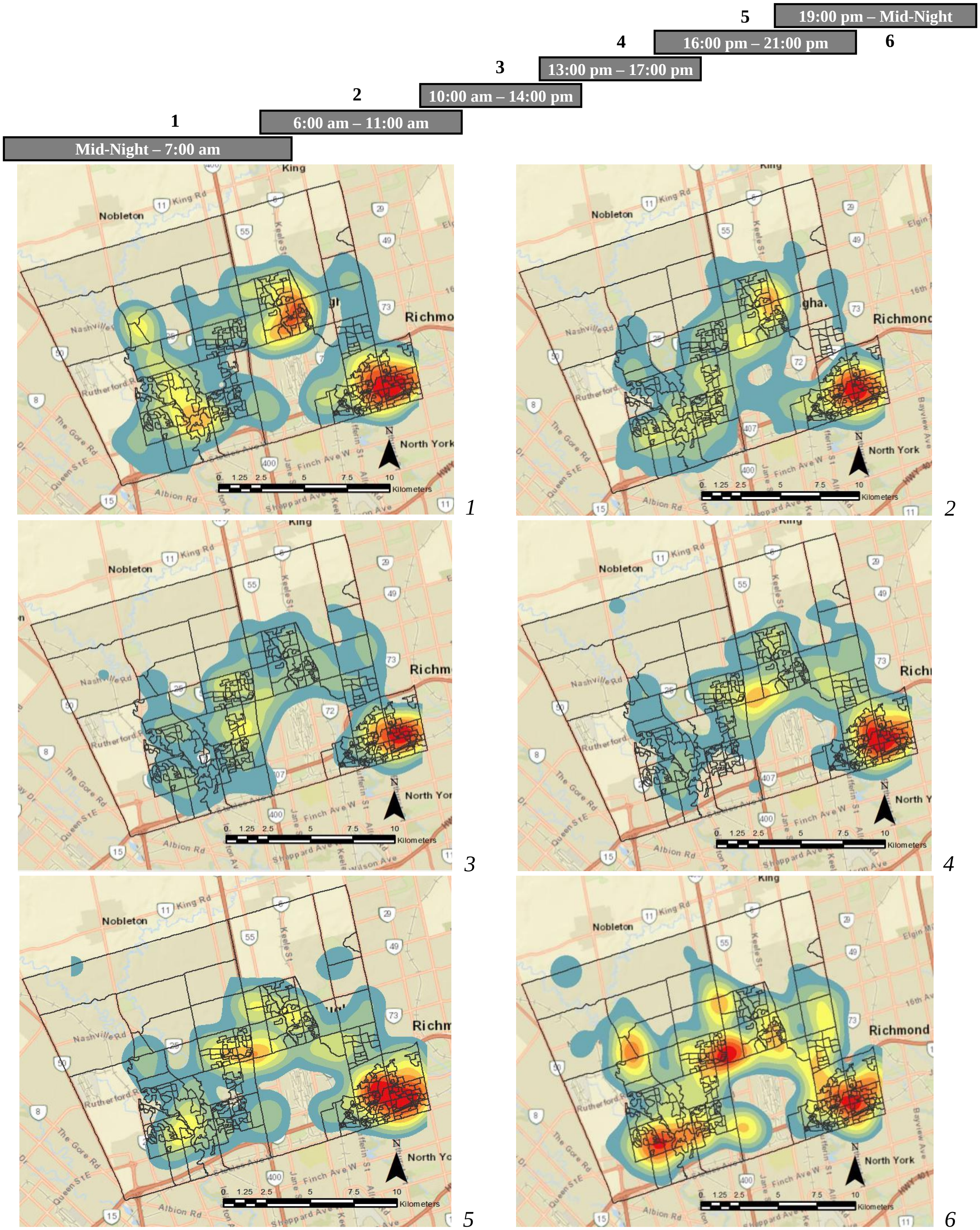


Figure 46 Univariate co-map for all responses occurred during the 2013 ice storm (by hour)

6.5 Spatial Analysis Discussion

The rate and number of fire incidents are correlated with many factors such as age of housing, housing tenure and socioeconomics status (Chandler & Chapman, 1984). The spatial and spatiotemporal analyses have been conducted in this section to investigate the important factors in responses provided by VFRS during the 2013 ice storm. The results of the analyses showed that the responses vary in both time and space. Also, these variations have shown meaningful relationship to the type of the call during the unique situation of the 2013 ice storm.

The spatial analysis has shown that the intensity of the responses was higher in three main areas of Vaughan which are:

- The southeast area. This area is Thornhill neighborhood which is the oldest and the most populated area in Vaughan with relatively high average housing age.
- The southwest area. This area is Woodbridge neighborhood which is the second oldest area in Vaughan.
- The Highway 400 and Rutherford road area. This area consists of relatively new neighborhood in Vaughan which has high population with relatively newer buildings compared to the two other areas.

The intensity of the responses has shown a strong direct correlation with the population density and the housing age in each area. For instance, the southeast area has the highest intensity in all response categories except in Category 8, all rescues, which is responses to vehicle extrication and vehicle collision. In fact, Category 8 showed the highest intensity in Highways 400 and 407 intersection area and Highway 400 and Rutherford road intersection area which are the busiest highways and road in Vaughan. Also, the intensity of the response for the Category 5, false fire calls, and Category 6, CO false calls were highest in the south east of the city were the housing age is the oldest and the smoke detectors and CO detectors can be older. The old or expired detector can be faulty and resulted in false alarm.

The results have shown a noticeable increase in the rate of responses to multi unit dwelling, e.g. apartment buildings, during the 2013 ice storm compare to the 2009 to 2016 period. This increase is more evident in the southeast of the city which has more residential buildings. Also, during the 2013 ice storm the responses to the road vehicles showed high intensity all along the Highway 400 whereas the same response intensity was high during 2009 to 2016 only in Highway 400 and 407 intersection area. Interestingly, the results showed that the distribution of response to side walk, roadway was dramatically changed during 2013 ice storm compare to 2009-2016 period and it was more concentrated in the main three areas mentioned before. This could be caused due to change in commute habits of the people and reduction of unnecessary trips during the ice storm.

The spatiotemporal analysis results showed that the intensity of the responses has increased in period of the midnight to mornings during the 2013 ice storm that may be result of power outage and cold weather. Use of improper heating methods during the cold nights can be a major reason for this change. This pattern is also apparent during the early night period between sunset and midnight.

As discussed here, the response pattern has correlation to factors such as population density and housing age. However, some unique factors have had significant effect during the 2013 ice storm compare to the other times such as un-conventional heating method and change in the commuting habits of the people in the city.

7. Conclusion and Recommendation

This study is the first to provide temporal, spatial and spatiotemporal information regarding the emergency Calls Responded by the Vaughan Fire and Rescue Service (VFRS) during the 2013 ice storm.

- The 2013 ice storm affected the number of responses on daily basis significantly, however, it was not an even impact on all days during the ten-day period. The number of responses on December 22nd 2013 increased 6 times compared to the same day for the same days in 2009 to 2016. Also, the hourly pattern of fire responses showed a significant change during the ice storm compared to other years.

- Alarms received by means of 911, telephone from civilian, from monitoring agencies and from police services increased notably. Although 40% of the alarms received from ambulances, during the ice storm, the number of this type of alarms did not show any difference compared to the other years. This illustrates that during the ice storm, the fire stations were notified by some other sources. This result may have important implications for fire stations' as it shows how the type of receiving alarm can change during major emergencies. Therefore, fire stations may need to allocate alternative resources to receive the alarms promptly.

- The 2013 ice storm did not affect City of Vaughan's fire stations activity uniformly. The number of responses provided by station 71, 72, 73,74, 78, 79 and 710 increased. Also, during the ice storm, responding to the districts other than the assigned district showed a huge increment, but this pattern was not noticed for station 71 activities. In terms of daily responses during the ice storm, all stations have been affected significantly on December 22nd 2013.

- City of Vaughan's fire stations had to assist medical related calls for more than 47% of the received calls during the 2009-2016. However, the number of medical calls did not increase during the ice storm compared to the other years. Although the number of some other type of responses increased remarkably. There was a 9-time increase in public hazard incidents which were mostly related to downed power lines. Extreme weather conditions, including high humidity, freezing temperatures, and ice storms can cause ice to form on power lines. Ice weight can put a lot of stress on power lines and damage equipment. Also, during ice storms, water can build up and freeze on tree limbs and other vegetation. The excess weight of the ice combining with wind can create hazardous conditions. Heavier branches can fall and damage power lines. Therefore, VFRS may need to be prepared for this type of responses for probable future ice storms. Also, the number of incident related to CO has increased. As several power outages happened during the ice storm, some of these CO incidents were the result of burning charcoal or propane inside the houses. Therefore, VFRS may need to provide public awareness beforehand to prevent these types of emergencies during ice storms.

- The number of responses related to false fire calls doubled and most of the alarms were related to alarm system equipment malfunction and other types of false fire calls. Also, the number of CO false calls increased for both codes, equipment malfunction and false perception of CO emergency. VFRS may need to investigate why these malfunctions increased during the ice storm and how they can assign more accurate sensors to prevent those malfunctions in the future emergencies. Although the ice storm did not affect number of vehicle incidents compared to the other years significantly, incidents related to people trapped in elevator increased four times.

- The hourly pattern of different type of responses showed some differences and this result may have important implication for VFRS further planning in terms of better preparedness during the peak times and allocating resources in a more insightful manner.

- In terms of properties which received responses, 60% of the properties were residential and 20% were related to vehicles. This pattern did not change significantly during the ice storm.

- The spatial analysis has displayed areas of the city that experienced more incidents and responses during the ice storm and during the whole study period. The spatial pattern of responses could help the fire stations to investigate the vulnerable areas in the city of Vaughan. As different type of responses did not show similar spatial pattern, future researches may be needed to find out what the root causes of this unevenness are and how factors such as socioeconomic, age of housing and median age of the residents can participate to intensity the number of responses in different areas. Also, spatiotemporal GIS analysis is very valuable, as it shows the vulnerable areas. In terms of fire management, this result should be useful in identifying areas with high demand for fire response.

- All in all, although the present findings could offer useful insights according to temporal, spatial and spatiotemporal patterns of different attributes of emergency calls during the 2013 ice storm and for years 2009 to 2016, further investigation is clearly required to validate the results as well as finding the root causes of the problems. Also, to mitigate the probable effects of hazards such as ice storms in future and to be more prepared, researchers, public and fire safety decision makers should cooperate effectively to reduce the loss of lives and property damage.

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Appendix:

I. Population Growth of Top 20 Canadian Cities (Census 2016)

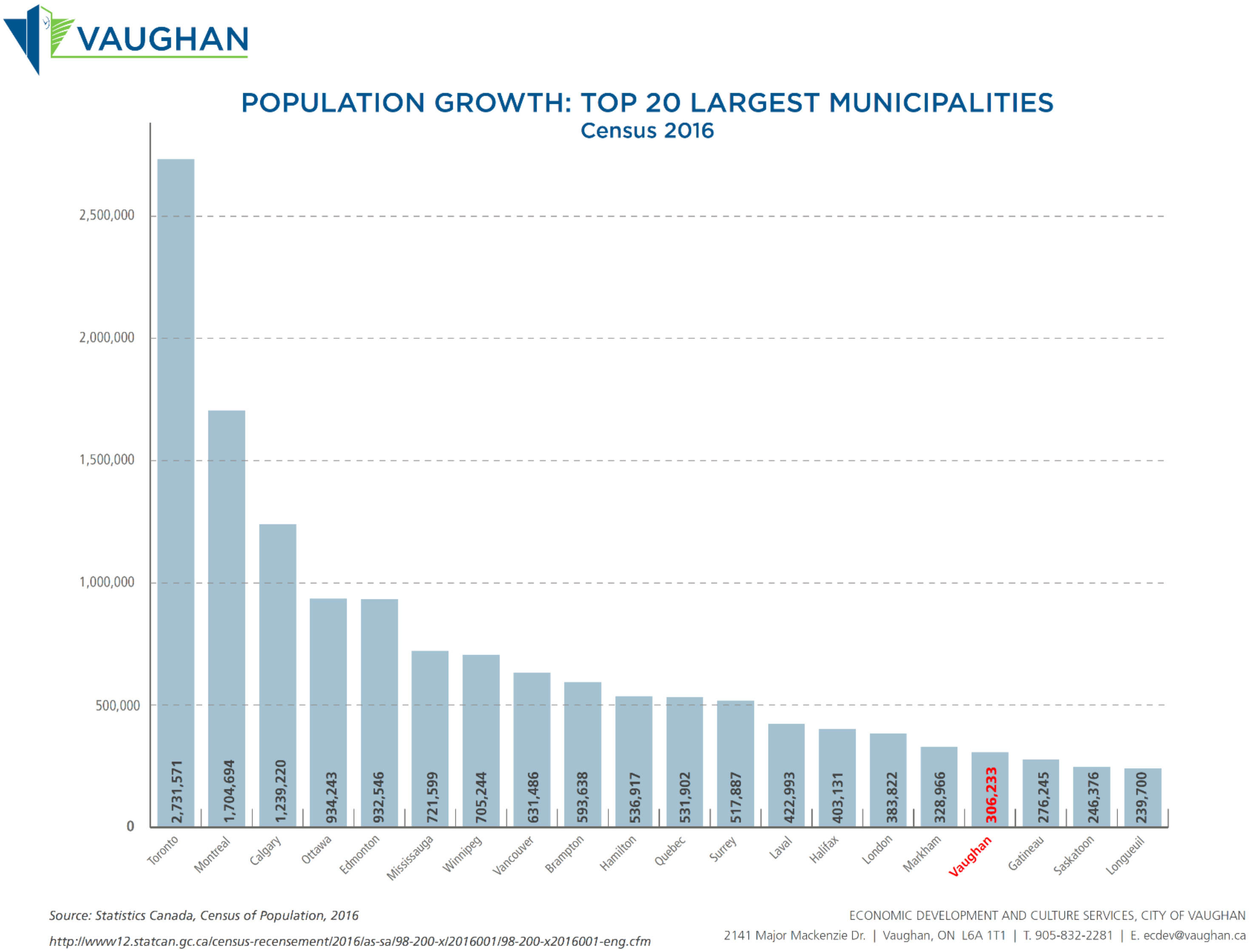
II. Employment Areas Key Map 2015

III. Age Characteristics Population (Census 2016)

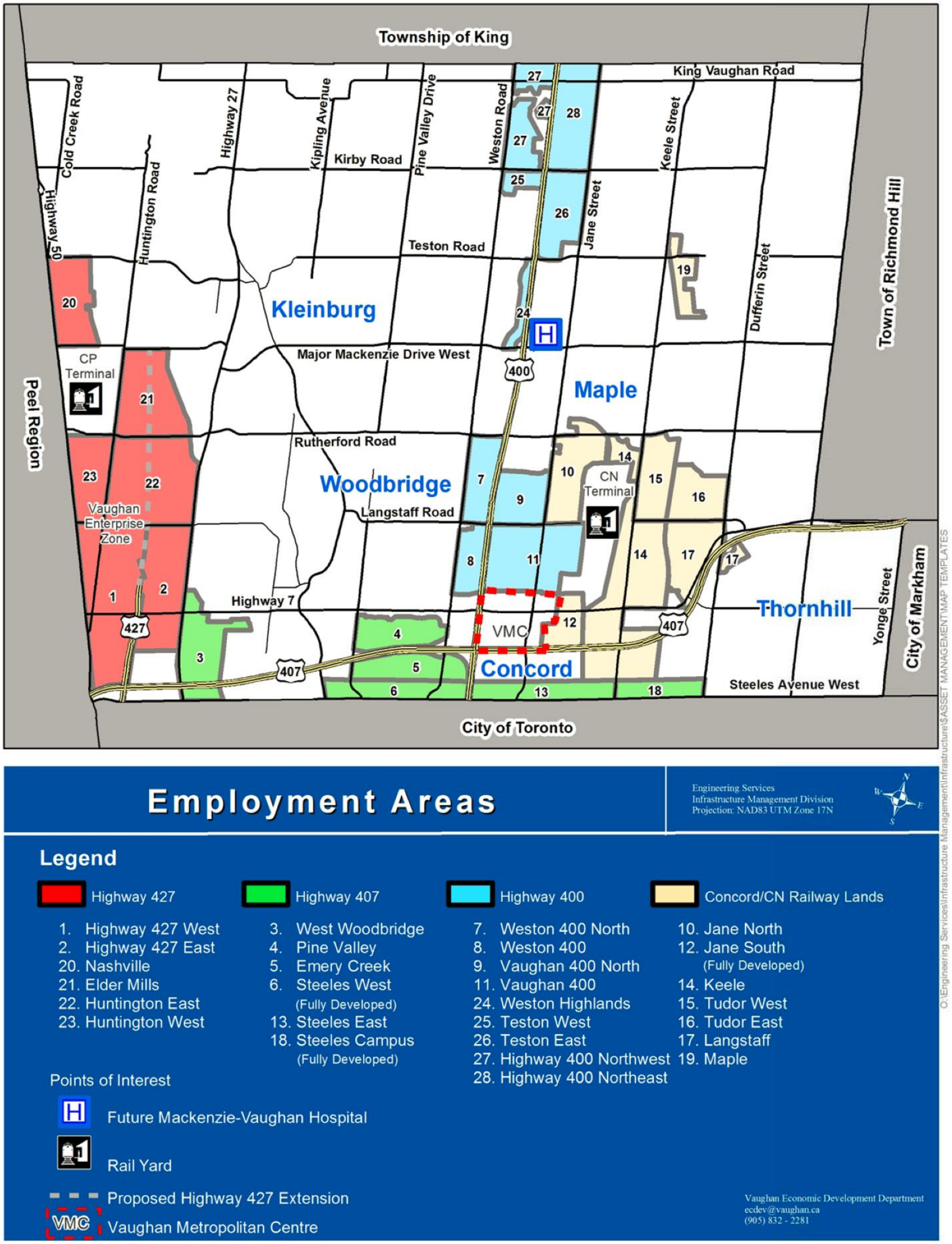
IV. Top Languages in City of Vaughan (Census 2016)

V. Standard Incident Report Codes List

Appendix I: Population Growth of Top 20 Canadian Cities (Census 2016)



Appendix II: Employment Areas Key Map 2015



Appendix III: Age Characteristics Population

VAUGHAN

POPULATION: AGE CHARACTERISTICS
Census 2016

AGE GROUP	GRAND TOTAL	TOTAL	
		MALE	FEMALE
0 to 4 years	16,265	8,265	8,000
5 to 9 years	19,965	10,250	9,720
10 to 14 years	21,300	10,870	10,425
15 to 19 years	21,280	10,830	10,450
20 to 24 years	20,285	10,470	9,810
25 to 29 years	17,105	8,500	8,605
30 to 34 years	16,825	7,980	8,845
35 to 39 years	19,430	8,875	10,550
40 to 44 years	23,345	10,905	12,440
45 to 49 years	25,440	12,185	13,255
50 to 54 years	24,480	11,970	12,515
55 to 59 years	20,805	10,085	10,715
60 to 64 years	16,250	7,650	8,595
65 to 69 years	14,645	7,015	7,630
70 to 74 years	9,645	4,670	4,975
75 to 79 years	8,165	3,855	4,310
80 to 84 years	5,680	2,625	3,055
85+ years	5,340	2,065	3,275
Total Population[1]	306,230	149,055	157,175
Median Population Age[2]	39.2	38.4	39.9
% of Population 0 to 14 years	18.8%	19.7%	17.9%
% of the Population 15 to 64 years	67%	66.7%	67.3%
% of the Population 65 years and over	14.2%	13.6%	14.8%
% of the Population 85 years and over	1.7%	1.4%	2.1%

Source: Statistics Canada. 2017. Vaughan, CY [Census subdivision], Ontario and York, RM [Census division], Ontario (table). Census Profile. 2016 Census. Statistics Canada Catalogue no. 98-316-X2016001. Ottawa. Released May 3, 2017.

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Appendix IV: Top Languages in City of Vaughan

TOP NON-OFFICIAL LANGUAGE MOTHER TONGUES IN VAUGHAN, 2016

MOTHER TONGUE	TOTAL	% OF TOTAL POPULATION
Italian	37,400	12.28%
Russian	20,685	6.79%
Mandarin	8,860	2.91%
Spanish	7,365	2.42%
Persian (Farsi)	6,605	2.17%
Cantonese	6,305	2.07%
Urdu	5,120	1.68%
Punjabi	4,760	1.56%
Tagalog	4,600	1.51%
Hebrew	4,525	1.49%

Source: Census 2016

Appendix IV: Standard Incident Report Codes List