Fire Department Equipment Allocation for Emergency Response: City of Saskatoon Case Study

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Abstract. All fire related incidents may require a standard fire engine, but some circumstances (high rise buildings, hazardous materials, etc) requires a specific fire engine and/or special apparatus. Special apparatus includes a "ladder-equipped" fire engine, a "decontamination" fire engine etc. it is clearly important for a city's fire and emergency services to have a well-organized and efficient allocation of fire and emergency equipment. The allocation of resources must take into account changing patterns of fire and emergency incidents, and changes in the city's size and development.

Limited resources often present major challenges in allocation. This study analysed response times to fire incidents that require a specific fire engine. The initial results suggest that Saskatoon Fire Department may need more resources such as ladders, tankers, etc. to respond efficiently. Saskatoon Fire Department's target response time is six minutes. Travel time accounts for four of the six minutes. The study developed a spatio-temporal response zone (based on realistic road conditions and travel times) and found that some fire incidents requiring specific resources lay outside the four minute zone. The analysis suggests that specific types of fire engines could be better allocated to fire stations with the most fire incidents requiring those engines. Better allocation of resources could help improve fire and emergency services delivery save lives and property.

INTRODUCTION

Problem Statement

A Fire Department's equipment allocation is usually based on two major factors, time and distance. When placing fire engines and associated fire equipment within the city, the Fire Department has a major challenge allocating the equipment to the fire stations. Over the years as the city grows, residential, commercial and industrial areas develop and it becomes necessary to re-evaluate the allocations of fire equipment to fire stations.

The primary objective of a Fire Service Department is to prevent fires from occurring and to reduce the loss of life and property due to fire Incidents (John et al.,2002).The Fire Department usually responds to all fire related incidents with a standard fire engine located in all fire stations. In other special fire incidents, the Fire Department respond with specific types of fire engines which are not located in all the fire stations. The location of fire stations equipped with fire engines with special features for specific types of incidents is therefore the foundation for efficient fire service delivery in emergency response.

Different types of fire equipment are used in emergency response; examples are; engines, ladders, tankers, brush, decontamination, rescue boats, etc. The different types of equipment perform different functions during fire prevention. For example, the City of Saskatoon Fire Department responds to a fire incident in a high-rise building with a "Ladder-equipped" engine. This engine carries a ladder device to rescue people and fight fire in high-rise buildings. If there is a fire incident in an industry that generates toxic, caustic, pollutant, or unhealthful or damaging substance, a "decontamination" engine is used to control the harmful emissions. It is clearly important to have a well-organized allocation of the different types of specialized equipment in the city.

The availability of emergency services response to an incident depends on the location of the emergency service, the travel time to the incidents and the fastest route to the incident. (B. Ntiamoah, 2009). Emergency response always requires an efficient response and dispatch of fire equipment to incidents within a city. It is therefore important to determine the travel time for each type of equipment.

Emergency response time to an incident is defined as the interval between the time at which an emergency vehicle is dispatched and the time at which the vehicle arrives at the location of the emergency (J. Mayer, 1980).The Saskatoon Fire Department target response time to an incident is within six minutes. The six minutes includes one minute for emergency call handling time (i.e., 911 call), one minute of fire fighters' preparation time, and four minutes of journey time.

The location of a fire station and equipment allocation depends on the spatial environment. This is because emergency services are always delivered to a geographical point. The combination of spatial, social, and economic factors, then contributes to the fire response capability of a fire department (Sanli et al., 1990). These factors determine the nature of fire incidents, the effective delivery of a fire service, and the location of fire stations. Although, the exact location of an incident cannot be predicted, we can say that on most occasions the situation at the incident will get worse with the passage of time. (Chen et al., 2010).

Periodically, certain service areas of a fire station may experience a series of fire incidents, or a new developing neighbourhood may experience fire incidents and will therefore require fire protection. A neighbourhood with a previous history of a high level of incidents may then exhibit lower levels of fire incidents as the neighbourhood changes. A fire station may need to have a new or special fire engine that has specific functionality to respond rapidly to emergencies. (K. Rider, 1974).

These issues raise concerns as to where to locate specific types of fire engine and special equipment. Should fire equipment be located at a station that has periodic changes in the level of incidents? Should the equipment be located in another station with a high level of a specific fire incident type that requires a specific fire engine? Should a new fire engine be purchased for such a station?

This paper presents a study of the Saskatoon Fire Department's emergency response apparatus and a visualization of fire station response to an incident using (GIS) service area analysis. The goal of this study is to use service area analysis and response time as a tool to help in decision making regarding fire equipment allocation among fire stations in order to maximize effective emergency response and fire protection within the city.

Study Objectives

The objectives of this study are to help improve emergency services, in particular, the Fire Department's emergency services. There are two main objectives;

1. To develop service areas for fire stations. As some types of incidents may require a fire engine equipped with a specific functionality in solving such incidents, service area analysis is used to identify service areas for equipment allocation purposes.

2. To develop a response time analysis for fire stations with specific engine functionality. This analysis is aimed to further support the Fire Department's request to increase its resource capacity.

The study will establish the need to provide and allocate fire equipment for fire stations where high rates of certain types of incident require specific fire engines. Improved allocation of such equipment is expected to help improve safety and reduce property damage.

This paper includes the following sections; the Study area, which describes the City of Saskatoon and the Fire Department; the Method, which describes the descriptive data analysis and the service area analysis, the Results of Analysis; which presents the findings of the study; and the Discussion and Conclusion, which summarizes the findings and possible recommendations of the study.

BACKGROUND

Study Area

This study covers the City of Saskatoon which is centrally located in the province of Saskatchewan. Saskatoon is the largest city in the province with an estimated population of 254,000 as of June 30, 2014 and an area of 218 square kilometers.

The Saskatoon Fire Department is divided into four divisions, North, Central, East and West with nine fire stations and nine fire response districts situated strategically throughout the four divisions to provide effective response to all areas in the city. The nine fire stations function as community-based protection service centre (www.saskatoon.ca).

Saskatoon Fire Department Response Apparatus

Saskatoon Fire Department has 13 front line engines, two aerials (ladders), one heavy rescue truck, two tanker, two brush units, auxiliary trucks, specialty trailers, a command bus, a rigid hull jet boat and two inflatable boats. The fire department also has three reserve pumpers and one reserve aerial (ladder).There are 260 fire fighters and officer's staff in the nine fire stations. These fire fighters respond to fire emergencies and are also trained in special rescue operations (www.saskatoon.ca). Figure 1 shows the location of the nine fire stations and main response apparatus.

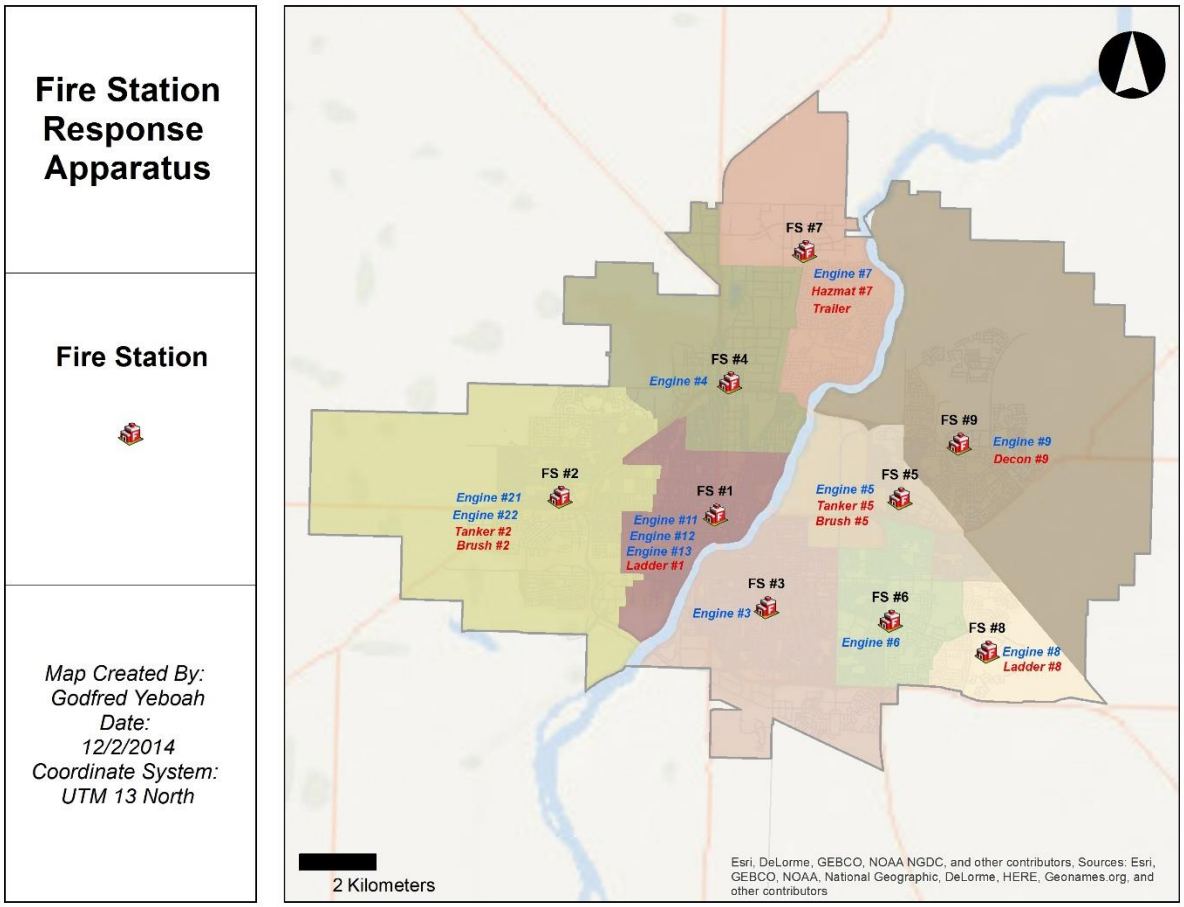

Figure 1 - Saskatoon's Fire Stations' Response Apparatus

A brief description of the role of the fire equipment operated by the Saskatoon Fire Department follows;

- **Engine:** This apparatus is located in every fire station. It is designed for fire attack. An engine has a pump, carries hose and water (usually about 500+ gallons), and also can carry three to four personnel. Engine are sometimes referred to as "Pumpers" .They can pump over 1500 GPM (gallons per minute). An engine also has the ability to supply fire retardant foam.
- **Ladder:** This apparatus carries a 100 feet articulating Sky-Arm aerial ladder device**.** It is equipped with a 300 gallon poly water tank. It is located in only two fire stations. Ladders are usually used to fight fires in high rise buildings and distant areas that cannot be easily accessed by the fire truck.
- **Tanker:** This apparatus is special fire equipment with the primary purpose of transporting large volumes of water to the fire during firefighting operations. A tanker can transport 3,000 gallons of water. It is located in only two fire stations. It has an on-board pumping system that is used to draw water into the tender from hydrants or other water sources.
- **Trailer (USAR):** This apparatus is known as the urban search and rescue (USAR) trailer. It is special apparatus for fire and rescue operations. It involves providing immediate on-scene medical help to people who have become trapped in confined spaces because of structural collapse, transportation accidents, trench collapses or natural disasters such as earthquakes, tornados, and hurricanes. It requires many different categories of equipment, some of which is quite bulky and heavy for an emergency vehicle.
- **Brush:** This is 4x4 truck apparatus. It is used to fight fires off-road, i.e., wild land or grass fires. It is located in only two fire stations. It is also known as a brush truck
- **Decontamination:** This apparatus is known as Decon. It is the used for the purpose of decontamination in the event of an industrial fire that generates toxic, infective, caustic, pollutant, or other unhealthful or damaging substances in the atmosphere. This apparatus is located in only one fire station.
- **Hazmat:** The hazmat apparatus unit is used to respond to Hazardous Materials. A hazmat unit is used to respond to incidents associated with chemicals and products spillage (eg, oil). The hazmat unit is located in only one fire station.

Saskatoon Incident Response Configuration

Incidents in the city are usually reported through 911 calls that are directed to the Fire Department. The Fire Department responds to both fire related and emergency medical (EMS) related calls.

The Saskatoon Fire Department response to different types of incident is based on incident Response Configuration. These Response Configurations are grouped according to incident reported calls. Incidents are grouped into Airport, Alarm, DG (Dangerous Goods), Fire, Bridge and Technical Rescue. Each of these configurations has sub-groups associated with a response apparatus.

For example, an incident reported as Alarm Level 1; will be responded to with equipment such as two Pump Engines and a Ladder. An incident reported as DG 1A; will be responded to with equipment such as an Engine, Hazmat and a Trailer. An incident reported as Fire 2; will be responded to with equipment such as a five Pump Engines, two Ladders and a Rescue truck (Saskatoon Fire Department, 2014).

The Response Configurations serve as a dispatch guide for responding to individual incidents with the appropriate equipment.

METHOD

Data Collection

The data used for this study was obtained from the Saskatoon Fire and Department. It consists of incident data covering 911 calls and response apparatus from 2009 to 2013. The data also includes documents showing, apparatus allocation by fire stations, alarm notification with fire neighbourhood districts, incident Response Configuration, incident response running cards, and automatic relocation guidelines. These documents serve as guidelines for the data processing. The Geographic Information System (GIS) data used for the study analysis was received from the City of Saskatoon.

Descriptive Data Analysis

The descriptive data analysis was carried out using R language. R is a statistical language for computing and graphically displaying data. It can display high quality plots that includes mathematical symbols and formulae. In this study, R was used for the descriptive charts showing fire incident report history and the use of incident response apparatus..

Multiple comma-separate values (cvs) files were created from Excel. R codes were written to display descriptive plots for all incident types and response apparatus.

GIS-Based Service Area Analysis

Service Area analysis is an ArcGIS network analysis extension tool that is used to find service areas around any location on a network. This analysis tool was used in this study. A Service Area is defined as a region that surrounds all accessible roads within a specified impedance. The impedance could be time or distance. For example, a 4-minute Service Area for a fire station on a network includes all the roadways and buildings that can be reached within four minutes from that fire station (ESRI, 2014). The Service Area analysis tool was used to determine the response area of the fire stations.

The application of GIS Service Area analysis is an established as a tool for solving a diverse range of problems in transportation engineering. For example, this tool was used by Steven (2003) to develop an algorithm to optimize a bus transit system serving streets within an area.

The Saskatoon Fire Department assumes a response zone based on road conditions and a travel time of 80% of the posted speed limit. This travel time takes into account the practical realities of reaching an incident, for example, turns at signalized/unsignalized intersections and random slowing down on roadways.

RESULTS

The results of the descriptive data analysis includes, total incidents, alarm incidents, fire incidents, response apparatus such as Ladder, Tanker, Trailer, Hazmat and Decontamination.

Total Incidents (2009 to 2013)

Figure 2 shows the total number of all incidents by year and by month from 2009 to 2013. The year 2009 shows a slightly higher number of incidents than the years 2010 to 2013. The months of April and May had the highest number of incidents.

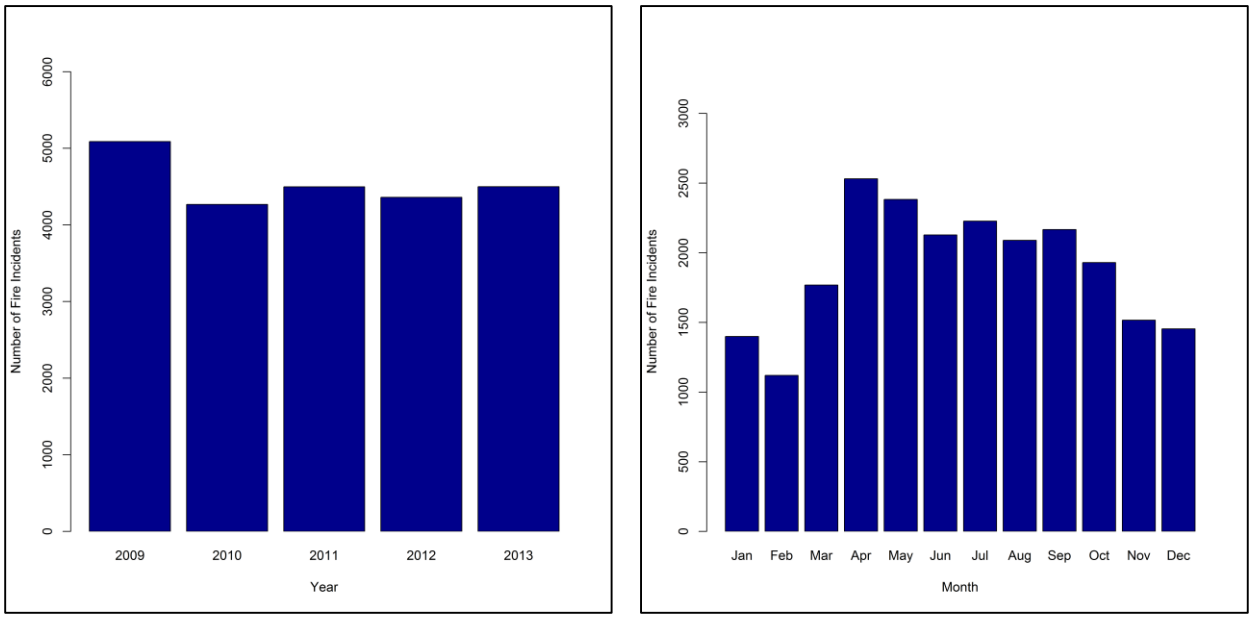

Figure 2 - Total Fire Incidents by Year and by Month

Figure 3 shows fire incidents by season and by day of the week. There were fewer incidents in winter. There is no clear pattern in the number of incidents by day of the week but Sundays tended to have slightly fewer incidents.

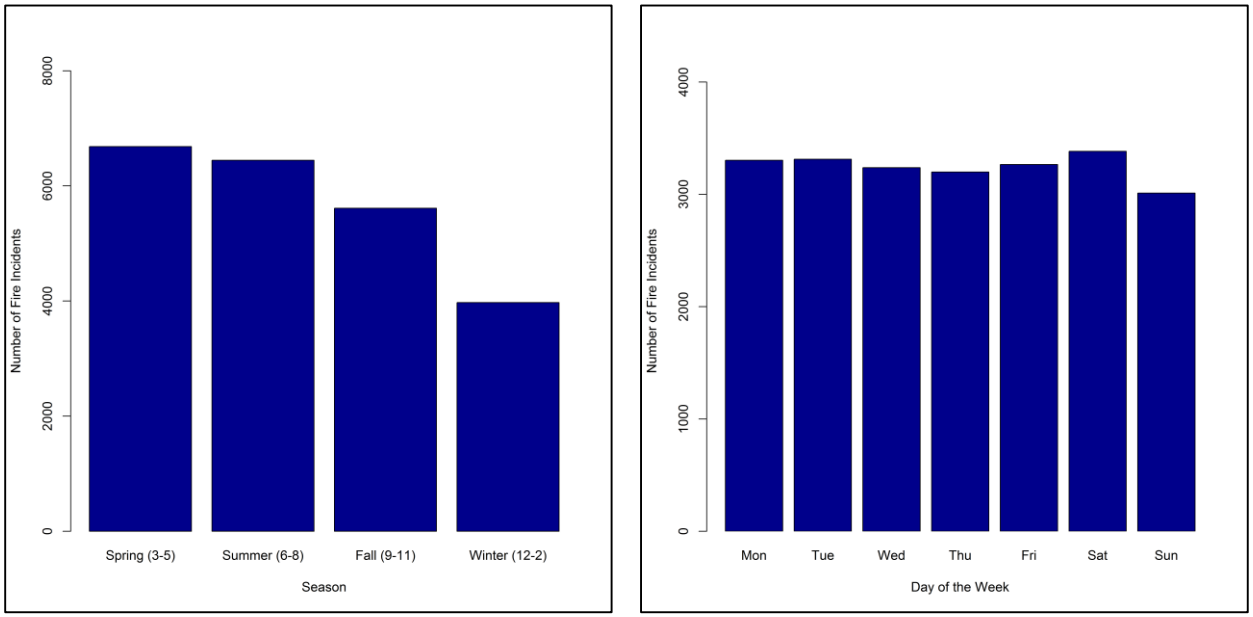

Figure 3 - Total Fire Incidents by Season and by Day of Week

Figure 4 shows a bar plot of fire incidents by hour of the day, and a clock plot of fire incidents by day of the week and hour of the day. Figure 4 shows that most fire incidents occurred between 1100hrs and 2000hrs.

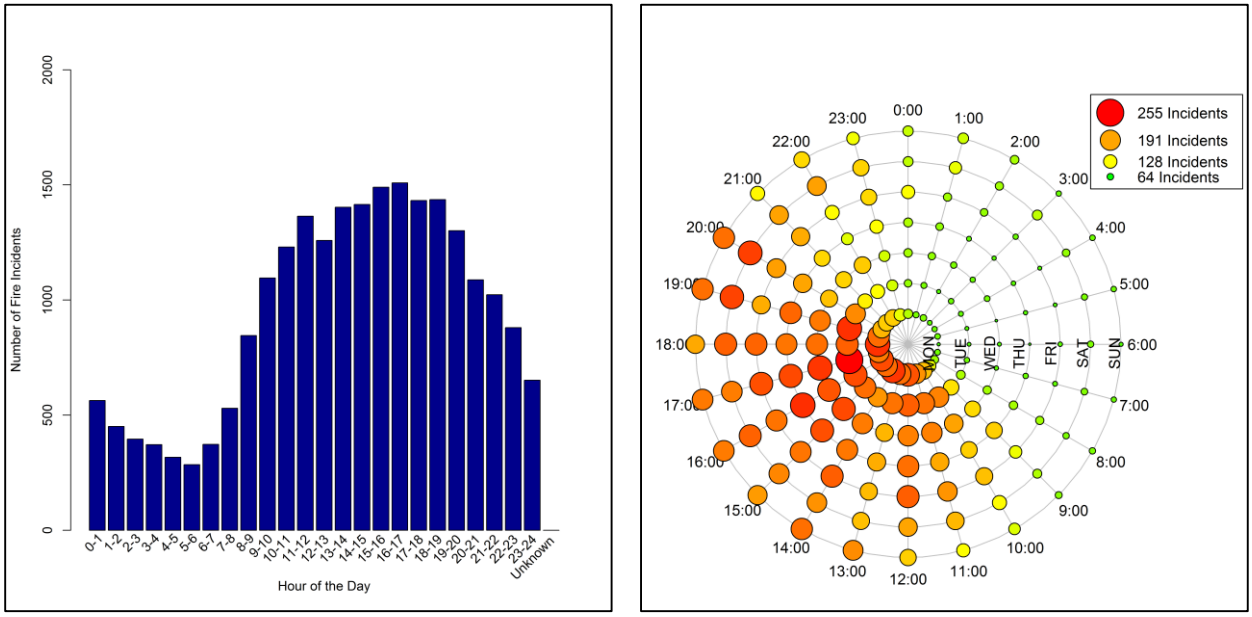

Figure 4 - Total Fire Incidents by Hour and by Day of Week and Hour

Alarm Incidents

Figure 5 shows bar plot incidents reported as Alarm by year and by day of the week and hour of the day. Figure 5 shows that the number of incidents reported as Alarm increased from 2011 to 2013. Most incidents occurred between 1000hrs and 2100hrs.

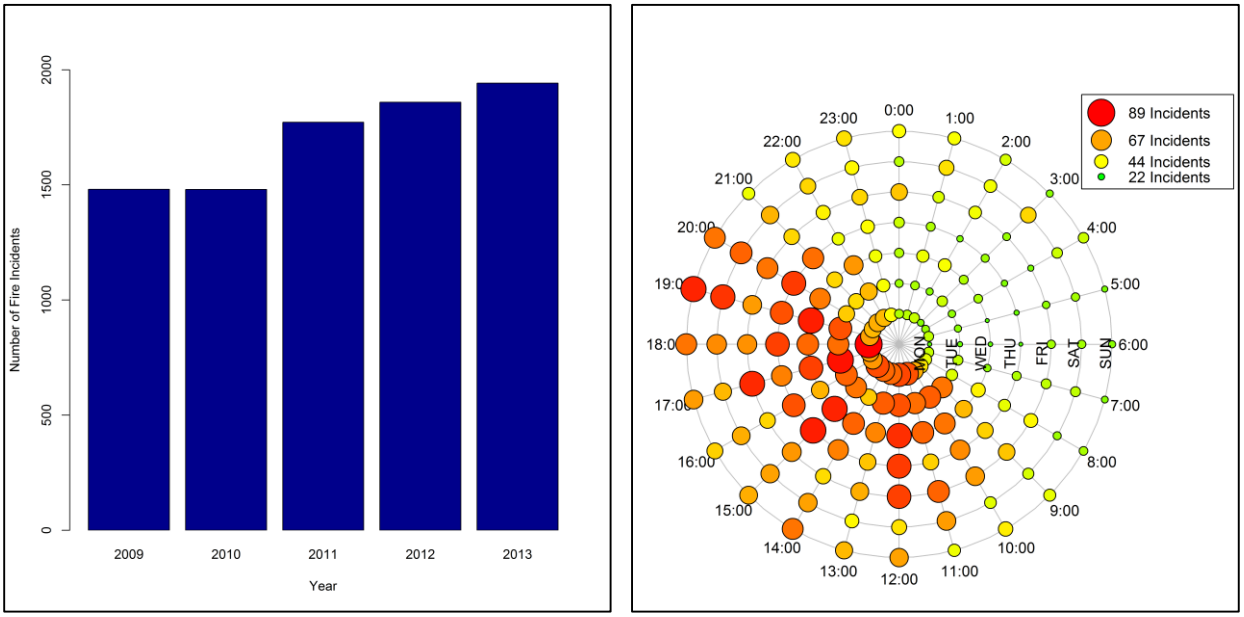

Figure 5 - Alarm Incidents by Year and by Day of Week and Hour

Fire Incidents

Figure 6 shows a bar plots of the number of incidents reported by fire by year and a clock plot by day of the week and hour of the day. Figure 6 shows that 2009 recorded the highest number of incidents reported by fire. There was also a small, but steady increase from 2010 to 2013.Most incidents reported by fire occurred on Saturday and Sunday between 1800hrs and 2300hrs.

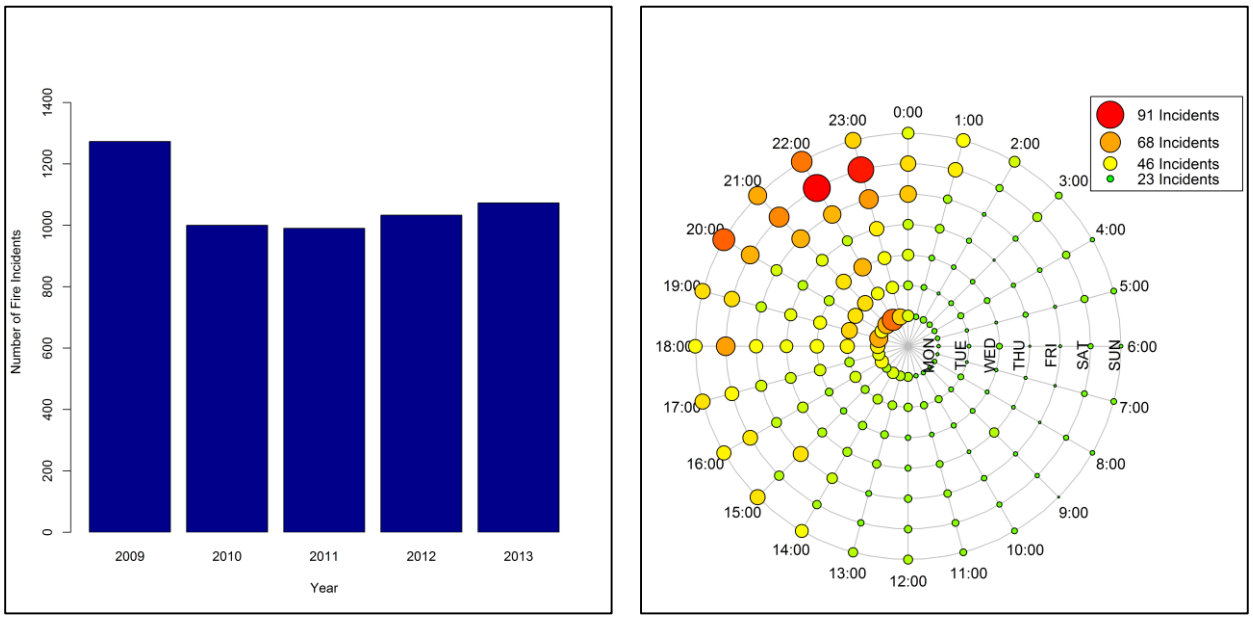

Figure 6 - Fire Incidents by Year and Day of Week and Hour

Dangerous Goods Incidents

Figure 7 shows a bar plots of Dangerous Goods incidents by year, and a clock plot of Dangerous Goods incidents by day of the week and hour of the day. Figure 7 shows that 2009 recorded the highest number of incidents. The number gradually decreased from 2010 to 2013.Most Dangerous Goods incidents occurred between 1000hrs and 1800hrs.

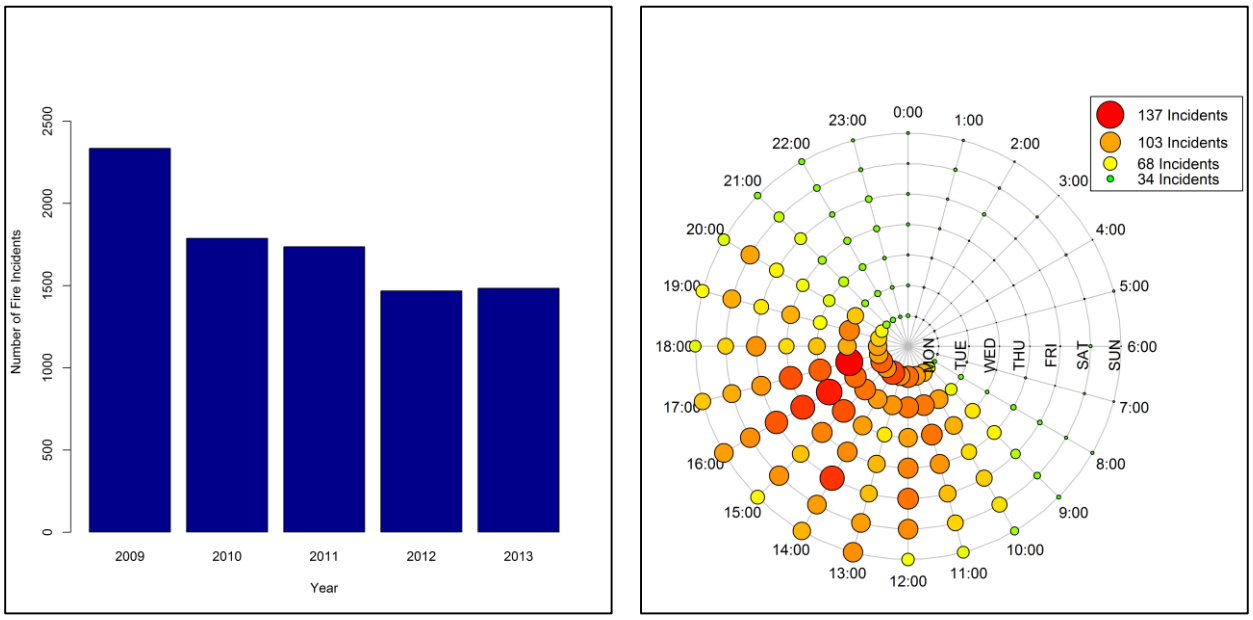

Figure 7 - Dangerous Goods Incidents by Year and Day of Week and Hour

Incident Responses by Apparatus

Figure 8 shows the number of incidents responded to by Tanker apparatus and by Ladder apparatus by year. Figure 8 shows that 2009 recorded the highest number of Tanker incidents. There was then a small increase from 2010 to 2013. Figure 8 shows that the number of incidents involving response by Ladder apparatus increased from 2009 to 2013.

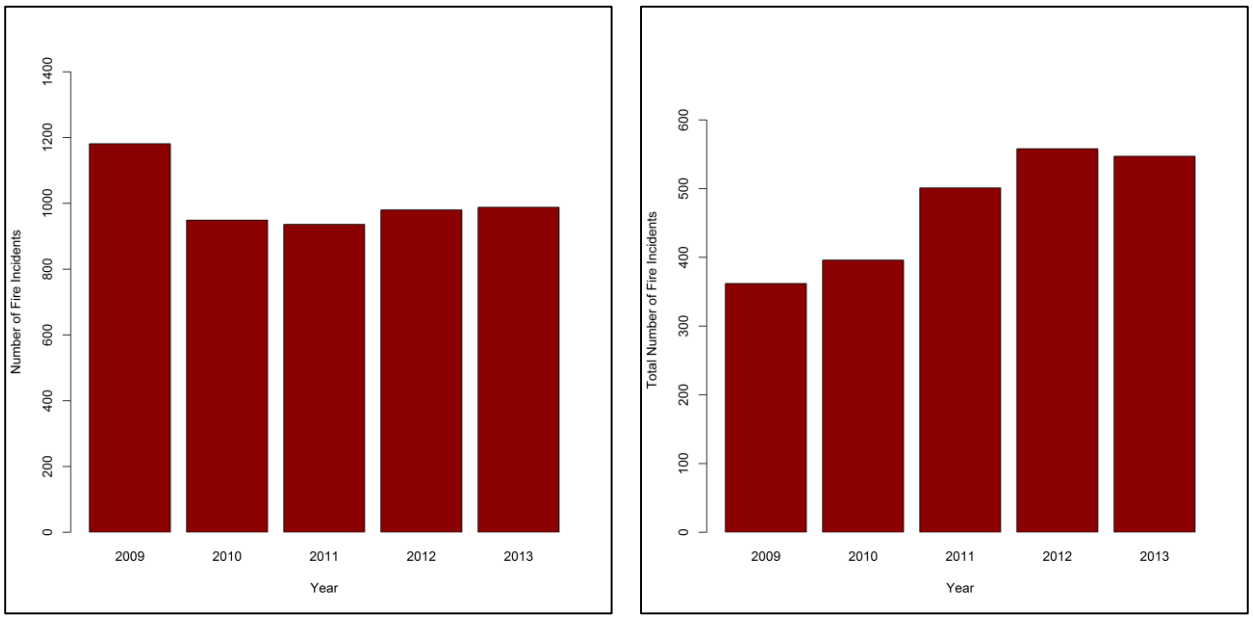

Figure 8 - Incident Responses by Tanker and by Ladder

Figure 9 shows the number of incidents responded to by Hazmat and Decontamination apparatus. Figure 9 shows that 2009 recorded the highest number of Hazmat incidents. There was then a small, but steady increase in Hazmat incidents from 2010 to 2013. Figure 9 shows that 2011 recorded the highest number of Decontamination incidents. Apart from 2011, the number of Decontamination incidents decreased from 2009 to 2013.

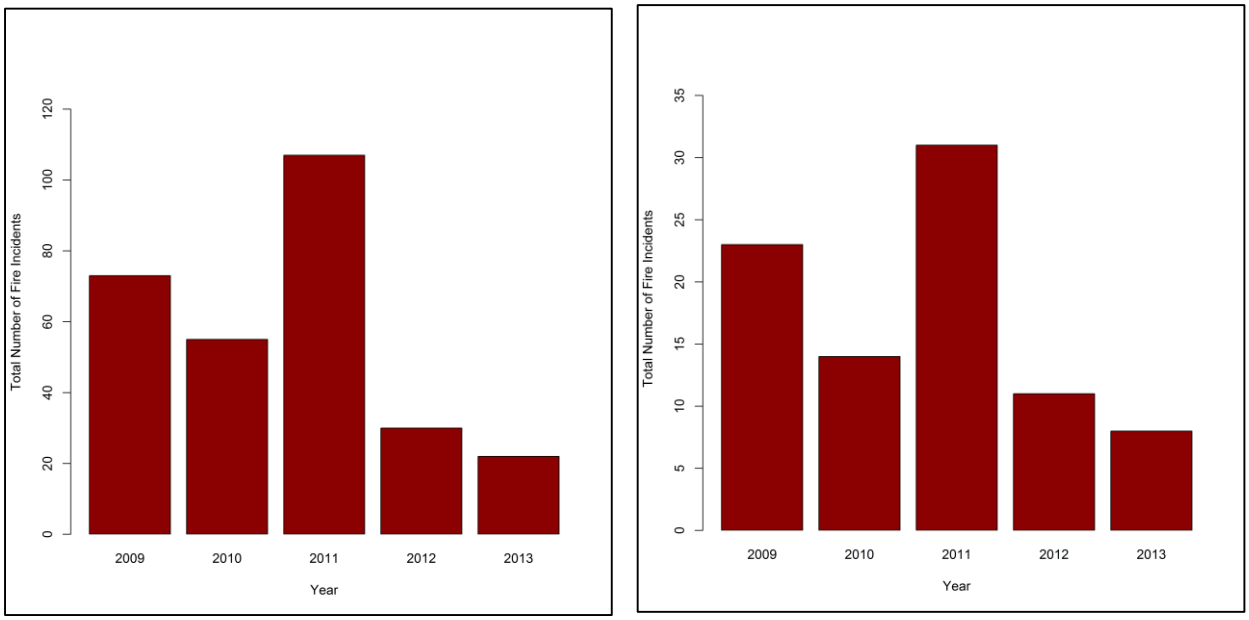

Figure 9 - Incident Responses by Hazmat and by Decontamination

Figure 10 shows the number of incident responses by Trailer. Figure 10 shows that 2011 recorded the highest number of Trailer incidents. Apart from 2011, the number of Trailer incidents tended to decrease from 2009 to 2013.

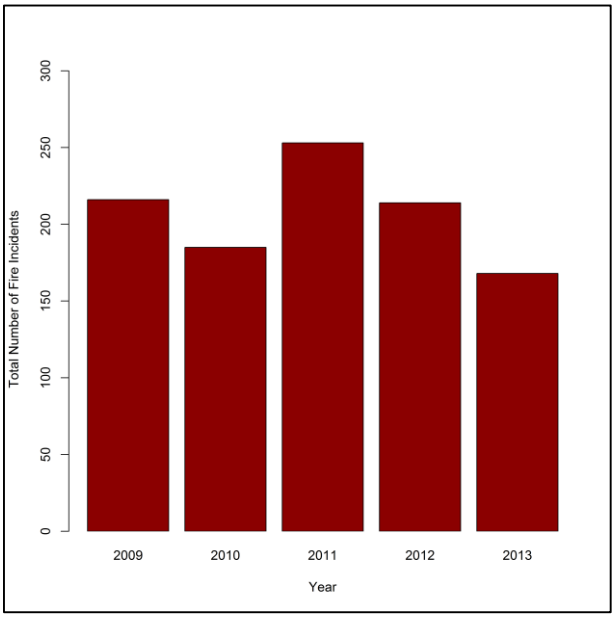

Figure 10 - Incident Responses by Trailer

Service Area Analysis for Response Apparatus

Tanker apparatus located at fire stations #2 and # 5. Tanker #2 responds to incidents requiring tanker apparatus in the central, north and west divisions. These divisions cover an estimated area of 101.64 km^2. Tanker #5 responds to incidents in the east division with an estimated area of 112.78 km^2.

Figure 11 shows the estimated Service Area for stations # 2 and #5. The four minute response time for Tanker dispatch from station #2 covers an area of 18.10 km^2 or 17.8 % of the estimated central, north and west division's area. The four minute response time for Tanker dispatch from station #5 covers an area of 19.6 km^2 or 17.4 % of the estimated east division area.

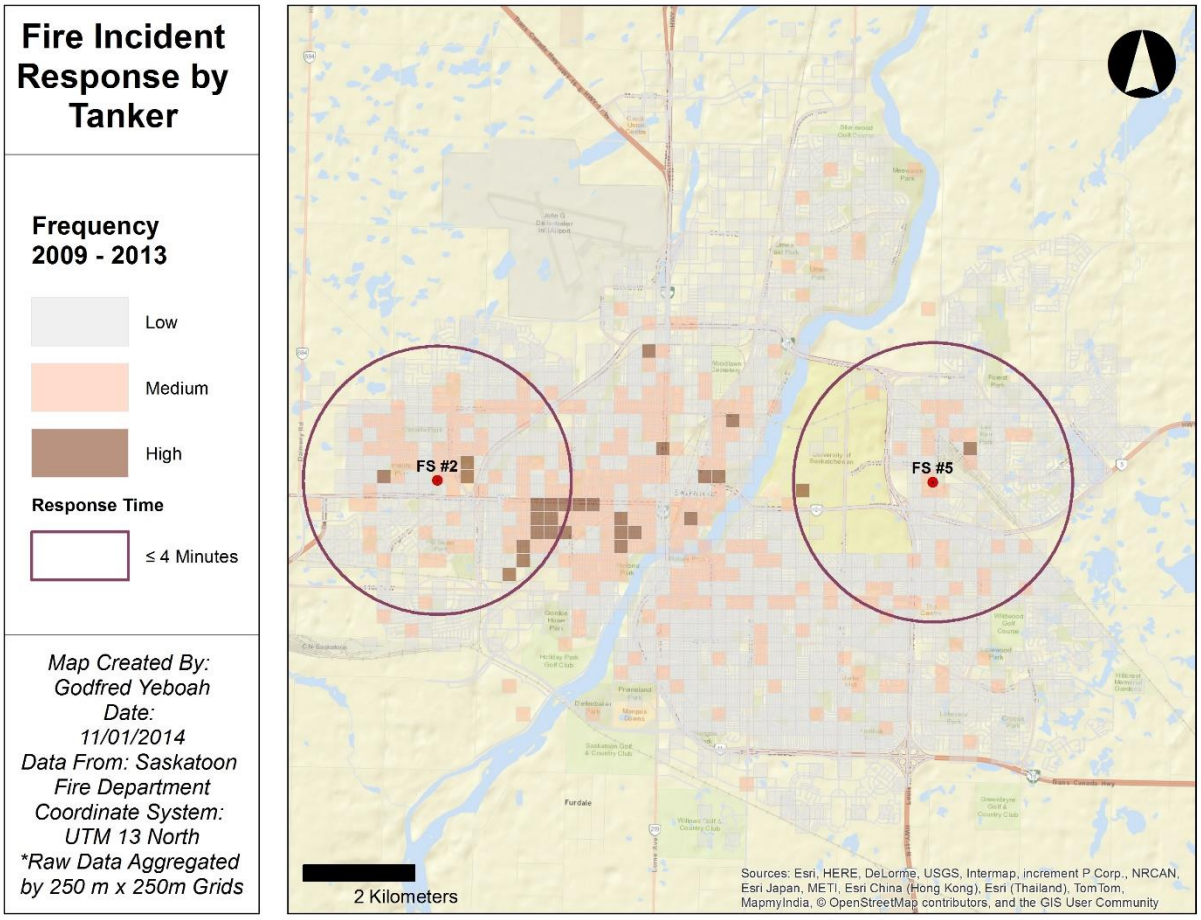

Figure 11 - Fire Stations # 2 and # 5 Service Area for Tanker Dispatch to Fire Incident

Ladders #1 and #8 are located at fire stations #1 and # 8 respectively. Ladder #1 responds to incidents requiring a Ladder in the central, north and west divisions. Ladder #8 responds to incidents in the east division.

Figure 12 shows the estimated Service Area for stations # 1 and #8. The four minute response time for Ladder dispatch from station #1 covers an area of 18.10 km^2 or 17.8 % of the estimated area of central, north and west division's area. The four minute response time for Ladder dispatch from station #8 covers an area of 12.60 km^2 or 11.2 % of the estimated east division area.

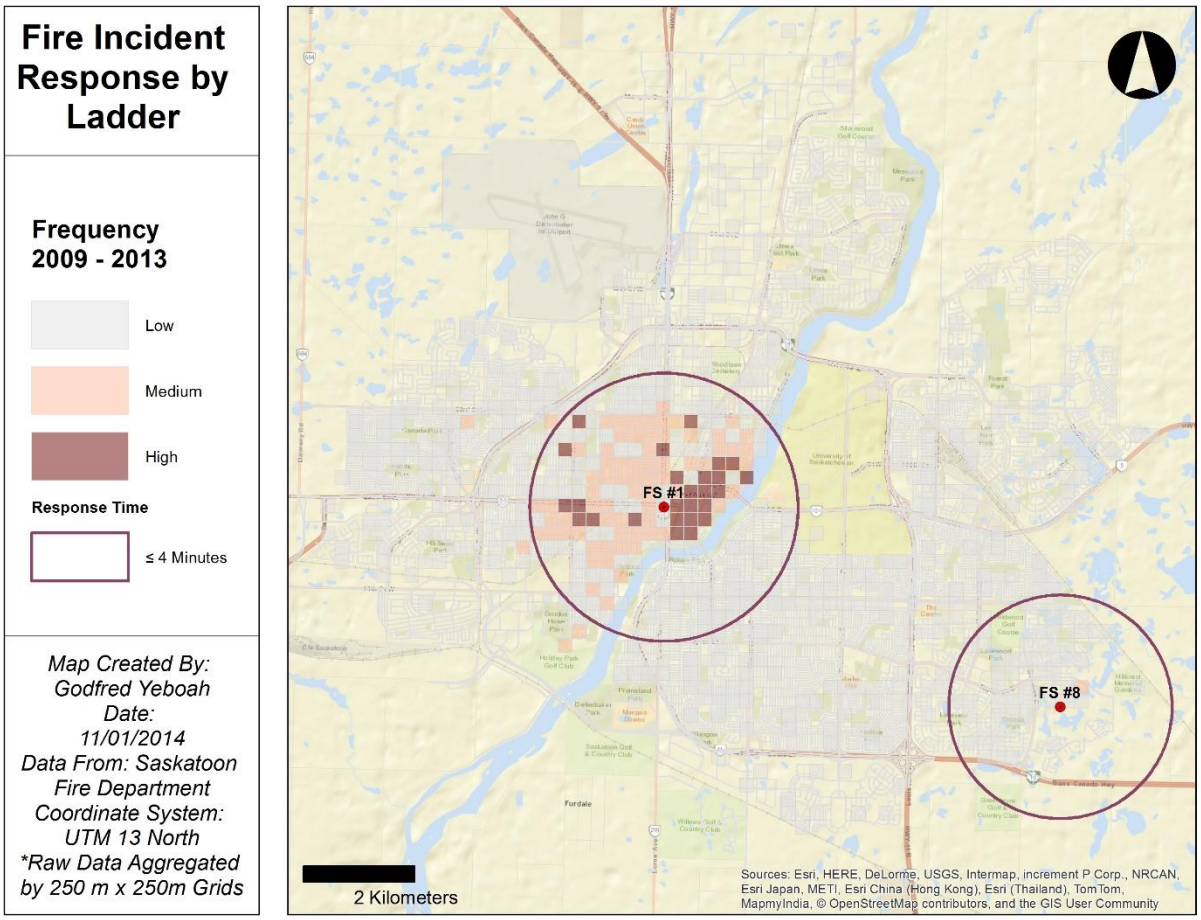

Figure 12 - Fire Station # 1 and # 8 Service Area for Ladder Dispatch to Fire Incident

The Decon apparatus is located at fire station #9. This apparatus responds to Decontamination related incidents in all four divisions.

Figure 13 shows the estimated Service Area for station #9.The four minute response time for Decon dispatch from station #9 covers an area of 16.6 km^2, or 7.7 % of the estimated area of all four divisions.

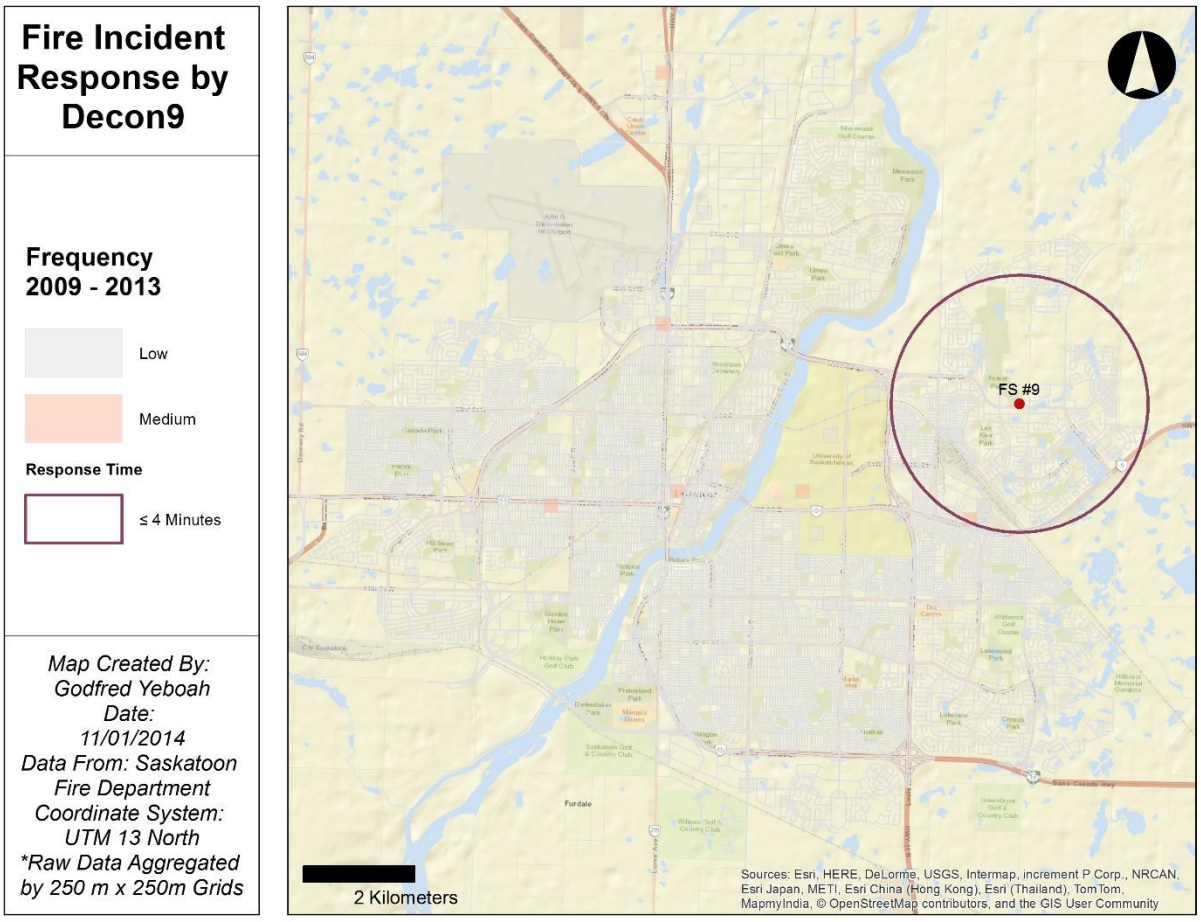

Figure 13 - Fire Station # 9 Service Area for Decontamination Dispatch to Fire Incident

Hazmat and Trailer apparatus are both located at fire station #7.The apparatus responds to Hazmat and Trailer related incidents in all four divisions.

Figures 14 show the estimated Service Area for station #7. The four minute response time for Hazmat and Trailer dispatch from station #7 covers an area of 9.10 km^2, or 4.2% of the estimated area of all four divisions.

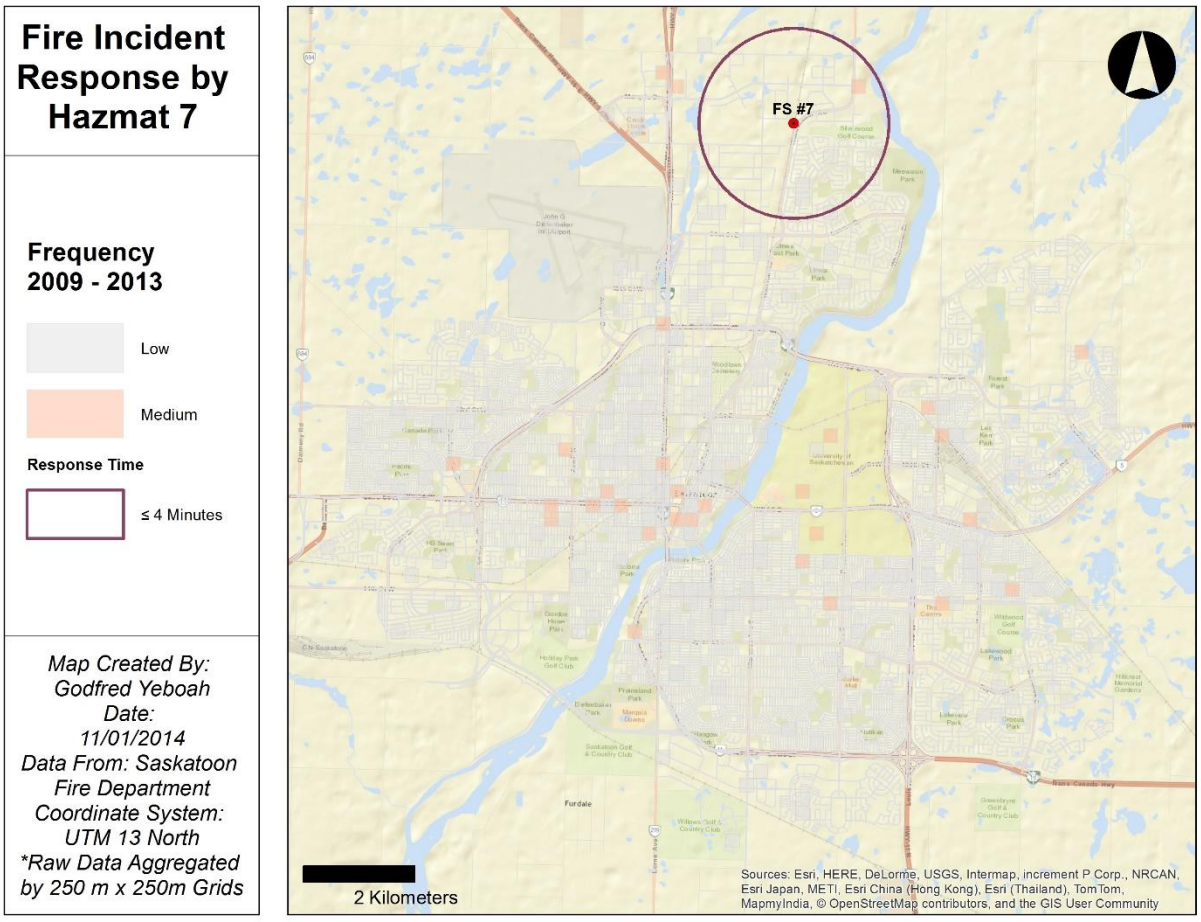

Figure 14a - Fire Station # 7 Service Area for Hazmat Dispatch to Fire Incident

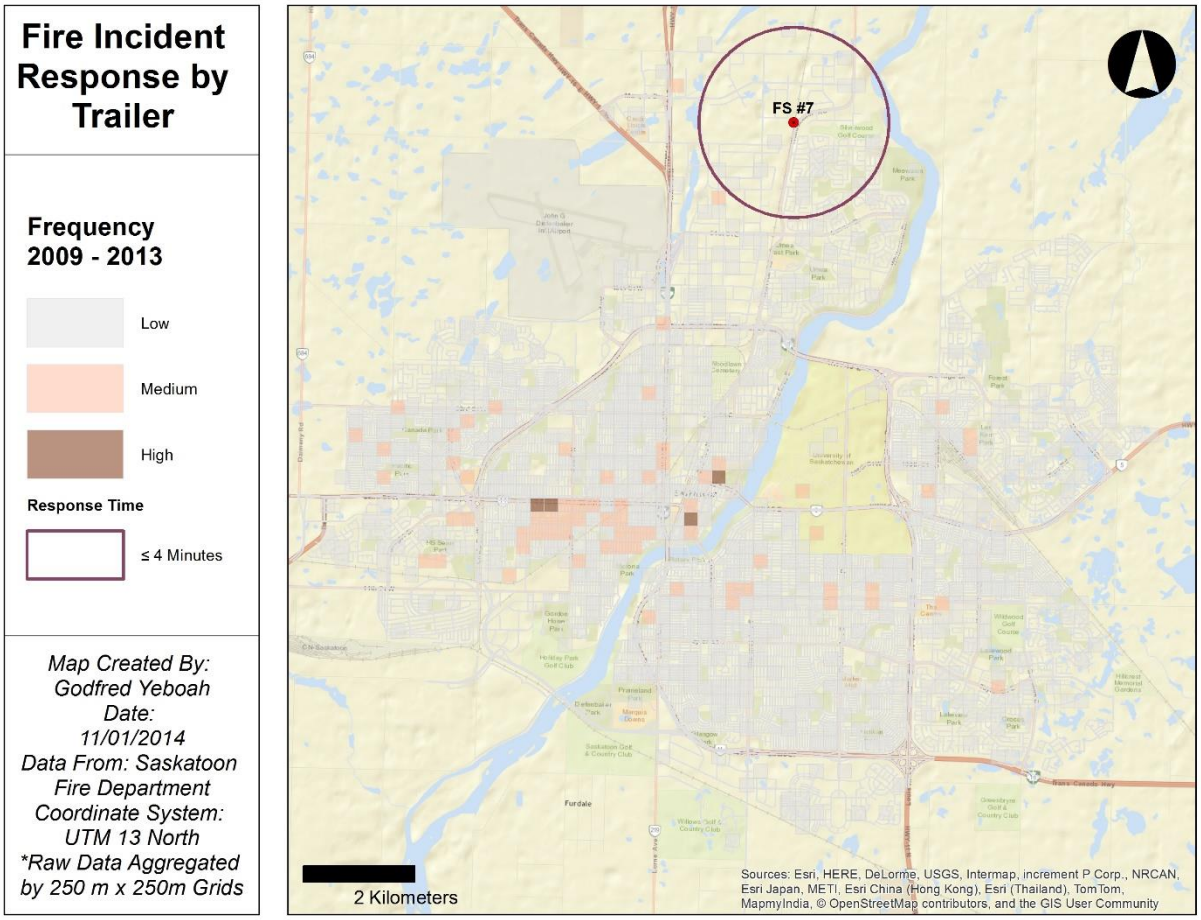

Figure 14b - Fire Station # 7 Service Area for Trailer Dispatch to Fire Incident

DISCUSSION AND CONCLUSION

The analyses in this study show an increase in fire incidents from 2009 to 2013.The Service Area analysis clearly shows that; approximately (80%) of incidents occur beyond the four minute target response time. This raises serious safety and security concerns. Given the number of incidents requiring Tanker and Ladder response in the four divisions, additional Tanker and Ladder apparatus could be allocated to fire station within the central and west divisions.

The Service Area analysis of fire stations #7and #9, which serve all the fire divisions for Hazmat, Trailer and Decon apparatus, shows that additional specific engines could be allocated to other fire stations to help improve response times. Specific fire equipment could be reallocated to other fire stations with higher incident rates to help improve response time.

This research shows the need for additional specific engines such as Tanker and Ladder to be allocated to other fire stations and also a possible need to relocate some Hazmat, Decontamination and Trailer apparatus to other stations. The study should be of value to decision makers, especially council members, dealing with fire equipment allocation and the purchase of additional response apparatus for the Saskatoon Fire Department. Ultimately, the best allocation of fire emergency equipment will help improve target response times and will save lives and property**.**

ACKNOWLEDGMENTS

Godfred Yeboah thanks the Saskatoon Fire Department and the Natural Sciences and Engineering Research Council of Canada for their financial assistance for this study. Special thanks go to Dr., Peter Y. Park, Jung Rak Wook and Emmanuel Ali Takyi for their help and guidance.

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