

**FIRST RESPONDERS' EMERGENCY RESPONSE TIME ANALYSIS:  
CITY OF SASKATOON CASE STUDY**

A Thesis Submitted to the  
College of Graduate and Postdoctoral Studies  
In Partial Fulfillment of the Requirements  
For the Degree of Master of Science  
In the Department of Civil, Geological and Environmental Engineering  
University of Saskatchewan  
Saskatoon

By

**GODFRED YEBOAH**

## **PERMISSION TO USE**

In presenting this thesis in partial fulfillment of the requirements for a Postgraduate degree from the University of Saskatchewan, I hereby agree that, the University Libraries may make it freely available for inspection. I further agree that permission for copying of this thesis in any manner, in whole or in part, for scholarly purposes may be granted by the professor who supervised my thesis, or, in his absence, by the Head of the Department or the Dean of the College in which my thesis was done. It is understood that any copying or publication or use of this thesis or part thereof for financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and to the University of Saskatchewan in any scholarly citation of any material in my thesis.

Request for permission to copy or to make other use of material in this thesis in whole or part should be addresses to:

Head of the Department of Civil, Geological and Environmental Engineering  
University of Saskatchewan  
Engineering Building  
57 Campus Drive  
Saskatoon, Saskatchewan S7N5A9  
Canada

## **ABSTRACT**

Emergency response time is very important to first responders. In an emergency, there are many factors that can affect the response time. This research focuses on three of the many factors that contribute to delays in reaching an incident within the four minute target travel time. Highway-railway grade crossings, fire equipment allocation and multiple incident occurrences in a fire district can have significant impact on emergency response time.

The operations of slow or stationary freight trains at highway-grade crossings, for instance, can lead to delays. This situation is common in Saskatoon, Saskatchewan. Even though grade separation can be the best alternative to solve this problem, it cannot be justified for most grade crossings. Using a grade crossing monitoring system (GCMS), real-time information can be communicated to local emergency dispatchers when a grade crossing is blocked. The benefit of installing a monitoring system was investigated to help improve emergency response time. In this research, Geographical Information System (GIS) based service area and network analysis was used to investigate the dynamic changes in the service area with or without grade crossing blockage and to estimate the benefit of installing GCMS to reduce first responders' emergency response time. The research analyses show significant time saved in emergency response times. The Saskatoon examples show; the assumption that a road is blocked and having to take long detours when GCMS indicates that the crossing is not blocked and when GCMS also indicates that waiting at a blocked crossing would be more efficient than taking a detour route could help save valuable time in emergency response.

All fire related incidents require a standard fire engine. However, some fire outbreaks that involve high rise buildings, hazardous materials, and the like, require a special fire engine and/or special equipment in addition to the standard fire engine. Special equipment includes a "ladder-equipped" fire engine, and a "decontamination" fire engine. It is important for a city to have a well-structured and efficient strategy to allocate fire and emergency equipment. The allocation of resources must take into account changing patterns of fire and emergency incidents.

This research analyzed response times to fire incidents that require a specific fire engine with special features. The results suggest that Saskatoon Fire Department (SFD) may need additional resources such as ladders and tankers in order to respond efficiently. Saskatoon Fire Department's target response time is six minutes. Travel time accounts for four of the six minutes.

The research developed a spatio-temporal response zone 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 districts with more fire incidents requiring those engines.

In Saskatoon, the fire department experiences frequent and multiple emergency calls in some of its fire districts which normally have an impact on the response time to individual incidents. The potential occurrence of multiple incidents in more than one fire district, makes it important for Saskatoon Fire Department to predict the periods during which a particular fire district may require an additional fire engine. When multiple calls occur, response times may increase due to the lack of a fire engine or secondary fire engine with the required equipment to handle more than one emergency call. The pre-emptive reallocation of a fire engine refers to the systematic reallocation of a secondary fire engine and its associated fire fighters in a way that temporarily transfers the services of the secondary fire engine from its original fire district to another fire district when a high number of service calls is expected in the other district. Pre-emptive reallocation of fire engines for pre-set short-term periods could be a promising way to respond to multiple concurrent incidents.

This research develops a novel, data-driven and scientific approach to assist decision making relating to the pre-emptive reallocation of one or more specific types of fire engines for fire departments where multiple fire or other emergency incidents may be expected to occur concurrently in the fire districts. Pre-emptive reallocation could be a very useful tactic particularly for some fire districts in Saskatoon, where the fire stations lack a secondary fire engine and have difficulty meeting the important six-minute rule. The approach to pre-emptive reallocation is designed to strengthen overall fire services in a region by using existing fire service resources more effectively and more efficiently.

Survival data analyses were used to develop a set of statistical models designed to determine the possible time window for fire engine pre-emptive reallocation from fire district (FS) #2 or FS #8 to FS #9 to handle multiple fire incidents in fire district #9. The results from the analyses show that there are high chances of risk for an Alarm reported incident occurring during peak hours, summer season and on weekends in fire district #9. Fire district #8 provides the possible alternate chances to pre-empt reallocation of one of its fire engine to district #9.

The result from this research demonstrates the benefit and importance of having GCMS and reallocation of fire engines with special features to improve emergency response time. This research would help enhance emergency response delivery during multiple incidents occurring in district#9, that requires pre-emptive reallocation of a fire engine. The outcome of this thesis will help save lives, property damage and improve security and safety.

## **ACKNOWLEDGEMENTS**

I am most grateful to my supervisor, Dr. Peter Park, for his unflinching support in helping make this research possible. His valuable guidance, advice and academic experience has deepened my understanding of transportation engineering. I would forever be grateful for his contribution in this research and my career goals. I would also thank my academic advisors, Dr. Leon Wegner and Dr. Mohamed Boulfiza for their tremendous advice and contributions in helping put together this thesis. My profound appreciation also goes to Emmanuel Takyi, Seun Oluwajana, Wook Rak Jung and Shah Tayyab for their academic assistance in this research. A special thanks to my parents, wife, kids and siblings for their support in perusing this goal. I would also like to express many thanks to George Eguakun for his support and friendship.

I would like to thank the City of Saskatoon, the Saskatoon Fire Department, the Natural Sciences and Engineering Research Council of Canada (NSERC), the Saskatchewan Centre of Excellence for Transportation and Infrastructure (SCETI), and MORR Transportation Consulting for their financial assistance and other support for this research.

## TABLE OF CONTENTS

PERMISSION TO USE .....	i
ABSTRACT .....	ii
ACKNOWLEDGEMENTS .....	v
LIST OF TABLES .....	viii
LIST OF FIGURES .....	ix
CHAPTER 1: INTRODUCTION.....	1
1.1. Background .....	1
1.2. The Study Area.....	12
1.3. Research Goal .....	15
1.4. Objectives.....	15
1.5. Benefit of Research .....	15
1.6. Scope .....	16
1.7. Layout of Thesis.....	16
CHAPTER 2: LITERATURE REVIEW.....	17
2.1. Emergency Response Time.....	17
2.2. Geographic Information System .....	18
2.3. Survival Data Analysis.....	20
2.4. Chapter Summary.....	21
CHAPTER 3: STUDY DATA .....	23
3.1. Spatial Data .....	23
3.2. Incident Data .....	24
3.3. Data Integration.....	28
3.4. Chapter Summary.....	31
CHAPTER 4: METHODOLOGY.....	32
4.1. GIS-Based Data Analysis.....	32
4.1.1. Service Area Analysis .....	32
4.1.2. Network Analysis .....	33
4.2. Survival Data Analysis.....	36
4.2.1. Kaplan-Meier Estimator .....	37
4.2.2. Cox Proportional Hazards Model Estimation.....	38
4.3. Chapter Summary.....	38

CHAPTER 5: ANALYSIS RESULTS.....	40
5.1. Descriptive Data Analysis.....	40
5.1.1. Incident Statistics.....	40
5.1.2. Incident Statistics per Fire District.....	47
5.1.3. Response Time Statistics per Fire District.....	64
5.2. Case Study 1: GIS-Based Data Analysis Results.....	68
5.2.1. Grade Crossing Blockage due to Stationary Train.....	68
5.2.2. Service Area Analysis.....	68
5.2.3. Network Analysis.....	69
5.2.4. Grade Crossing Blockage due to a Slow Moving Train.....	73
5.2.5. Service Area Analysis.....	73
5.2.6. Network Analysis.....	74
5.2.7. Fire Response Equipment Allocation.....	76
5.3. Case Study 2: Survival Data Analysis Results.....	83
5.3.1. Cox Proportional Hazard Model Estimate for Fire District #9.....	84
5.3.2. Cox Proportional Hazard Model Estimate for Fire District #2 and #8.....	86
5.4. Chapter Summary.....	89
CHAPTER 6: DISCUSSIONS AND CONCLUSION.....	91
6.1. Case Study 1: GIS-Based Data Analysis.....	91
6.2. Case Study 2: Survival Data Analysis.....	93
6.3. Future Work.....	94
REFERENCES.....	95
APPENDIX A.....	101
APPENDIX B.....	102
APPENDIX C.....	110



## LIST OF TABLES

Table 3-1. Saskatoon's ArcGIS Shape File Information on Road Network Segment (COS, 2014) .....	23
Table 3-2. Saskatoon's ArcGIS Shape File Information on Railway Segment (COS, 2014) .....	24
Table 3-3. Incident Location Table (SFD, 2014) .....	28
Table 3-4. Response Equipment (APPARATUSRESPONDING) table (SFD, 2014) .....	28
Table 3-5. Intersection of Road and Railway table (COS, 2014) .....	29
Table 3-6. Integrated Total Incident Number of Incident Table (SFD, 2014) .....	30
Table 3-7. Integrated Total Incident Number of Incident and Response Equipment Table (SFD, 2014) .....	30
Table 5-8. Test of Equality over Strata .....	83
Table 5-9. (a) Testing Global Null Hypothesis: $\beta=0$ for Fire District #9 (b) Analysis of Maximum Likelihood Estimates for Fire District #9.....	85
Table 5-10. (a) Testing Global Null Hypothesis: $\beta=0$ for Fire District #2 (b) Analysis of Maximum Likelihood Estimates for Fire District #2 .....	87
Table 5-11. (a) Testing Global Null Hypothesis: $\beta=0$ for Fire District #8 (b) Analysis of Maximum Likelihood Estimates for Fire District #8 .....	88

## LIST OF FIGURES

Figure 1-1. Total Number of Fire Incidents in Saskatoon by (a) Year (b) Month (c) Season and (d) Day of Week .....	2
Figure 1-2. Response Time for Incidents in all Fire Districts .....	4
Figure 1-3. Doppler Rader Detector and Installation of Grade Crossing Monitoring System. Source: (ITS Canada, 2014).....	7
Figure 1-4. Railway Crossing Status Display from a Grade Crossing Monitoring System. Source: (ITS Canada, 2014).....	8
Figure 1-5. Total Number of Multiple Incidents by Year.....	9
Figure 1-6. Saskatoon Fire Services' Response Districts and Number of Fire Engines .....	12
Figure 1-7. Saskatoon's Railway Routes, Grade Crossings, and Fire Stations' Response Districts.....	13
Figure 3-8. Map Showing Total Number of Incidents.....	25
Figure 3-9. Maps Showing Incidents Reported as (a) Alarm (b) Fire (c) Dangerous Goods .....	27
Figure 5-10. Total Number of Incidents by (a) Year (b) Season (c) Month (d) Day of Week and (e) Hour of Day .....	41
Figure 5-11. Alarm Reported Incidents by (a) Year (b) Season (c) Month (d) Day of Week (e) Hour of Day.....	43
Figure 5-12. Fire Reported Incidents by (a) Year (b) Season (c) Month (d) Day of Week and (e) Hour of Day .....	45
Figure 5-13. Dangerous Goods Reported Incidents by (a) Year (b) Season (c) Month (d) Day of Week and (e) Hour of Day .....	47
Figure 5-14. Number of Incidents Response per Fire District.....	48
Figure 5-15. Fire District #1 Incidents by (a) Year (b) Season (c) Month (d) Day of Week and (e) Hour of Day .....	49
Figure 5-16. Fire District #2 Incidents by (a) Year (b) Season (c) Month (d) Day of Week and (e) Hour of Day .....	51
Figure 5-17. Fire District #3 Incidents by (a) Year (b) Season (c) Month (d) Day of Week and (e) Hour of Day .....	53
Figure 5-18. Fire District #4 Incidents by (a) Year (b) Season (c) Month (d) Day of Week and (e) Hour of Day .....	55
Figure 5-19. Fire District #5 Incidents by (a) Year (b) Season (c) Month (d) Day of Week and (e) Hour of Day .....	57

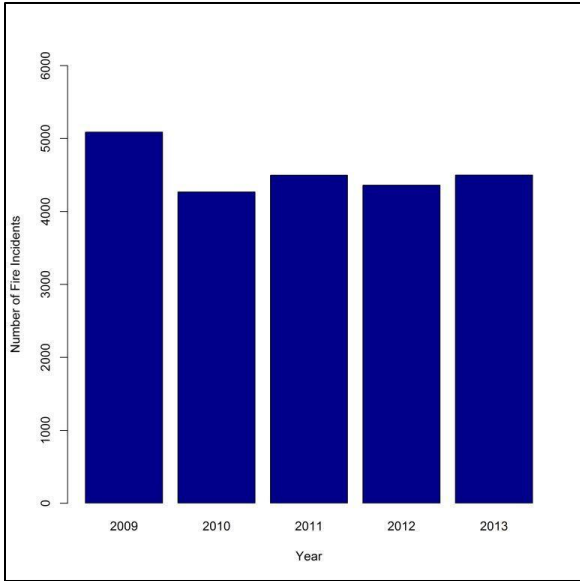
Figure 5-20. Fire District # 6 Incidents by (a) Year (b) Season (c) Month (d) Day of Week and (e) Hour of Day .....	58
Figure 5-21. Fire District #7 Incidents by (a) Year (b) Season (c) Month (d) Day of Week and (e) Hour of Day .....	60
Figure 5-22. Fire District # 8 Incidents by (a) Year (b) Season (c) Month (d) Day of Week and (e) Hour of Day .....	62
Figure 5-23. Fire District #9 Incidents by (a) Year (b) Season (c) Month (d) Day of Week and (e) Hour of Day .....	64
Figure 5-24. Response Time for Incidents in (a) Fire District #1 and (b) Fire District #2.....	65
Figure 5-25. Response Time for Incidents in (a) Fire District #3 and (b) Fire District #4.....	65
Figure 5-26. Response Time for Incidents in (a) Fire District #5 and (b) Fire District #6.....	66
Figure 5-27. Response Time for Incidents in (a) Fire District #7 and (b) Fire District #8.....	67
Figure 5-28. Response Time for Incidents in Fire District #9 .....	67
Figure 5-29. Fire Station #2's Varying Service Area Due to Stationary Train .....	69
Figure 5-30. Fire Engine Dispatch Routes to Montgomery with no Grade Crossing Blockage: without GCMS and with GCMS.....	71
Figure 5-31. Fire Engine Dispatch Routes to Montgomery with Grade Crossing Blockage: without GCMS and with GCMS.....	72
Figure 5-32. Fire Station #1's Varying Service Area Due to Slow Moving Train.....	74
Figure 5-33. Fire Engine Dispatch Routes in Saskatoon Downtown Area.....	76
Figure 5-34. Fire Station #2 and #5 Service Area for Tanker Dispatch to Fire Incidents .....	78
Figure 5-35. Fire Station #1 and #8 Service Area for Ladder Dispatch to Fire Incidents .....	79
Figure 5-36. Fire Station #9 Service Area for Decontamination Dispatch to Fire Incidents.....	80
Figure 5-37. Fire Station #7 Service Area for (a) Hazmat and (b) Trailer Dispatch to Fire Incidents .....	82
Figure 5-38. KM Survival Probabilities Curve for (a) Peak/nonpeak Hours (b) Days of the Week (c) Seasons and (d) Type of Incident for Fire District #9 .....	84

## CHAPTER 1: INTRODUCTION

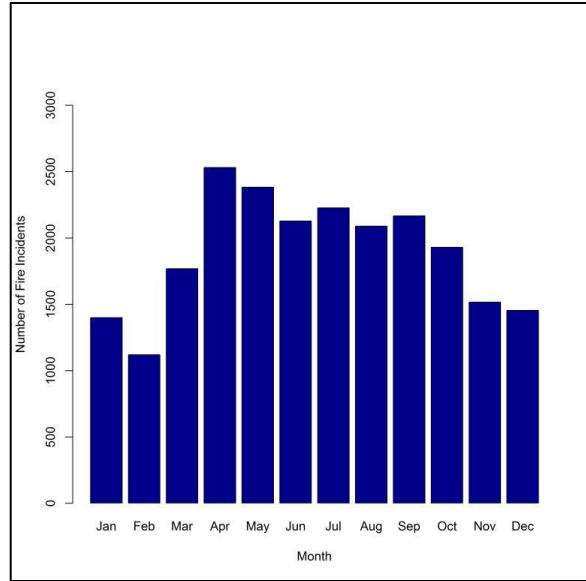
### 1.1. Background

First responders such as members of the Fire Department, render essential emergency services that provide immediate response to emergency situations in a community or the city. The goal of every fire department is to avert or limit as much as possible the loss of lives and property damage as a result of fire outbreaks. For this reason, a delay in emergency response time can significantly affect the effort of first responders, because the success of every emergency response is always measured in minutes and seconds. According to the Council of Canadian Fire Marshals and Fire Commissioners (CCFM/FC) report on fire losses in Canada, there were 42,753 fires (structural, vehicle and outdoor) recorded for 2007 from British Columbia, Alberta, Manitoba, Ontario, New Brunswick and Nova Scotia; for 2008 from Saskatchewan; and for 2003 to 2007 from Northwest Territories. These incidents resulted in 224 deaths and more than one billion dollars' worth of property damage. The CCFM/FC analysis shows that 54% of the 42,753 fires were related to structural fires (e.g., fires associated with the structural components of residential, commercial or industrial buildings), 19% were related to vehicle collisions, and 25% were related to outdoor fires (e.g., wildfires) (CCFM/FC, 2011).

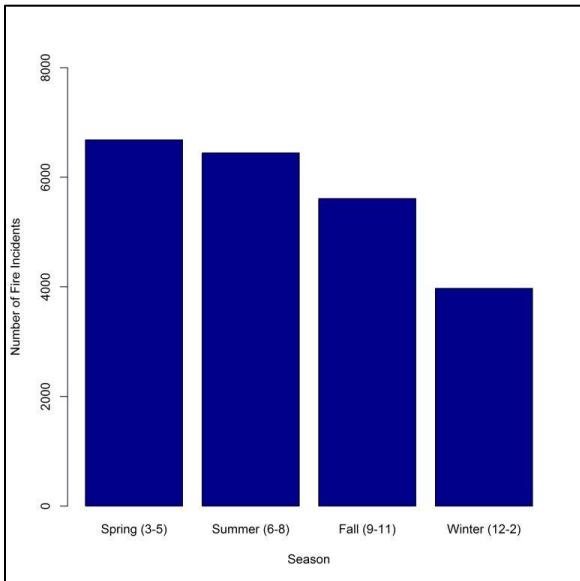
In Saskatoon, Saskatchewan (SK), a total of 22,618 incidents were experienced between 2009 and 2013. During this five-year period, 39% of the incidents were recorded as dangerous goods related incidents (motor vehicle accident clean up, needle disposal, spills and leaks, carbon monoxide detector warnings), 38% recorded as alarm incidents (alarm bells ringing: commercial and residential structures, alarm carbon monoxide detector sound) and 23% recorded as fire incidents (fire smoke in commercial and residential structures, fire in vehicle engine, outdoor fire). **Figure 1-1a** and **1-1b** show the total number of all reported incidents by year and by month from 2009 to 2013. The year 2009 shows a slightly higher number of incidents than years 2010 to 2013. The months of April and May had the highest number of incidents. **Figure 1-1c** and **1-1d** show seasonal and daily fire incidents. There were fewer incidents in winter. There was no clear pattern in the number of incidents by day of the week but Sundays tended to have slightly fewer incidents.



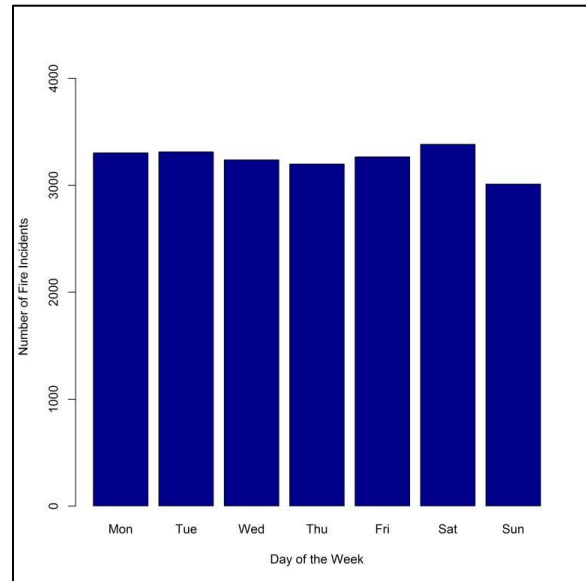
(a)



(b)



(c)



(d)

**Figure 1-1. Total Number of Fire Incidents in Saskatoon by (a) Year (b) Month (c) Season and (d) Day of Week**

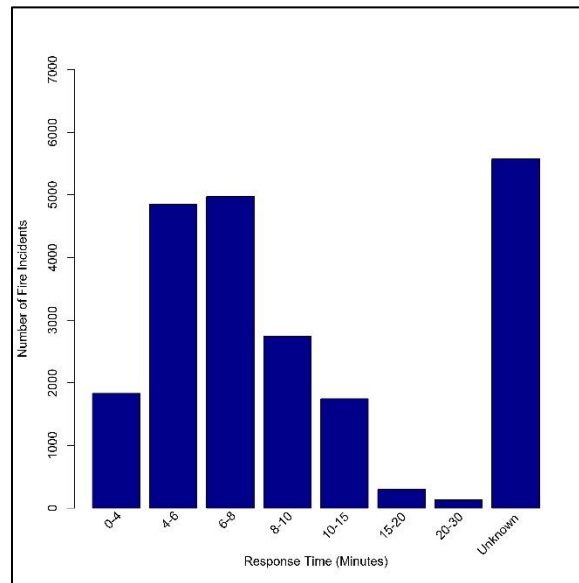
The response time to these incidents is very critical to the fire department in order to ensure the efficient delivery of quality and effective fire prevention. The emergency response time to an incident can be defined as the duration between the time at which an emergency call is received at the fire station, and the time at which an emergency vehicle arrives at the location of the incident (Haghani and Yang, 2007). The recommended target emergency response time by the International Association of Fire Fighters, for most jurisdictions in North America and other European countries, reads “... *the fire department shall establish a time objective of four minutes (240 seconds) or less for the arrival of the first arriving engine company at a fire suppression incident...*”(NFPA, 2002).

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. This target response time is in accordance with the NFPA specific standard on response time. In Saskatoon, when an emergency situation arises, there are a number of factors that prevent the fire department from meeting the four minute target journey time. These factors are: traffic congestion, fire equipment allocation (i.e., the assigning of fire equipment in fire stations for effective emergency response), grade crossing blockage, weather conditions, construction work zones, the location of an incident and multiple incident occurrences in the same fire district. This research will focus on three of these factors to investigate how they contribute to delays in reaching an incident for first responders. These factors include:

- Grade crossing blockage,
- Fire equipment allocation
- Multiple incident occurrences that requires pre-emptive reallocation of fire engines from different fire districts.

This research analysed the impact of grade crossing blockage and fire equipment allocation on emergency response time and the risk in chances of occurrence of multiple incidents that require pre-emptive reallocation of fire engines. **Figure 1-2** shows that the response time to most incidents in Saskatoon was between 6 and 8 minutes during the study period (2009-2013). The number of incidents recorded within the four-minute target response time were 1,832 (8.3%). The following paragraphs discuss an overview of the impact of grade crossing blockage and fire equipment

allocation on emergency response time and the risk of multiple incident occurrences that requires pre-emptive reallocation of fire engines.



**Figure 1-2. Response Time for Incidents in all Fire Districts**

The first factor that affects emergency response time is grade crossing blockage. In North America and other jurisdictions, railway crossing blockage is a major cause of delay to emergency response vehicles. There are approximately 261,000 at-grade public rail crossings in North America and 33,000 in Canada. In Saskatoon, there are 58 at-grade crossings. A public grade crossing refers to an intersection of a railway track and road at the same level which is designed for public use and opened or maintained by a road authority. What are the consequences for emergency first responders’ response time when trains block these crossings? Delays at blocked grade crossings can clearly have a major impact on first responders.

The US Federal Railroad Administration (FRA) does not set a maximum time that slow moving or stationary trains can block traffic at grade crossings (FRA, 2008), but many states have their own legislation and/or administration code. In the state of Washington, for instance, the Washington Administration Code (WAC) 480-62-220 states that “...*railroad companies must not block a grade crossing for more than ten consecutive minutes...*” A ten-minute limit is also applied in a number of other states, including Texas (Texas Transportation Code, 1999) and Nebraska

(NDOR, 2013). No state currently allows trains to block a grade crossing for more than 20 minutes (FRA, 2008).

In Canada, according to the Canadian Rail Operating Rule (CROR) 103(d) that governs the time a train may block a railway crossing: “...*no part of a movement may be allowed to stand on any part of a public crossing at grade, for a longer period than five minutes, when vehicular or pedestrian traffic requires passage. Switching operations at such crossing must not obstruct vehicular or pedestrian traffic for a longer period than five minutes at a time...*” (Transport Canada, 2013). In practice, however, Canadian provincial railway officials are well-informed that it is not rare for vehicles to have to wait 20 minutes or longer at grade crossings in Canadian cities, which violates CROR’s five-minute limit.

The City of Saskatoon, for example, frequently experiences the passage of trains on a daily bases. This usually creates long delays, especially when these trains are on spur lines; the delays often far exceed five minutes. Spur lines are used mainly for loading, unloading or marshalling trains (Global News, 2014). Delays are longest for trains (usually freight trains) longer than 9,500 feet (2.8 km). Freight trains can block more than one grade crossing simultaneously. This situation forces first responders and busy and/or impatient drivers to take long detours.

In Saskatoon, there are tendencies to assume that blockages at level crossings contribute to only a small percentage of emergency response delays, but in reality, trains delay first responders on a weekly and daily basis. This situation is common in other North American cities and in various cities across the world (FRA, 2006). Delays caused by train blockages can have major consequences on the response time to an incident. For example, Tank (Star Phoenix, 2014) reported the outcome of a fire incident at a tire warehouse in February 2014, when first responders were blocked by a slow moving train in Sutherland, Saskatoon. The delay resulted in extensive damage. This situation took fire fighters from different fire districts, 15 consecutive hours with 32 equivalent fire engines to resolve the fire due to delay in the response time by a blocked crossing. There may be examples of similar delays at grade crossings in many cities on other continents as well, but unfortunately this investigation was beyond the scope of this research.

Grade separation provides a permanent solution to this problem but it requires massive construction, traffic delays during the construction period, and a great cost. Considering the many



at-grade crossings in Canada, grade separation cannot be justified as the most affordable and cost-effective solution in most Canadian and North American jurisdiction (Easa et al., 1987).

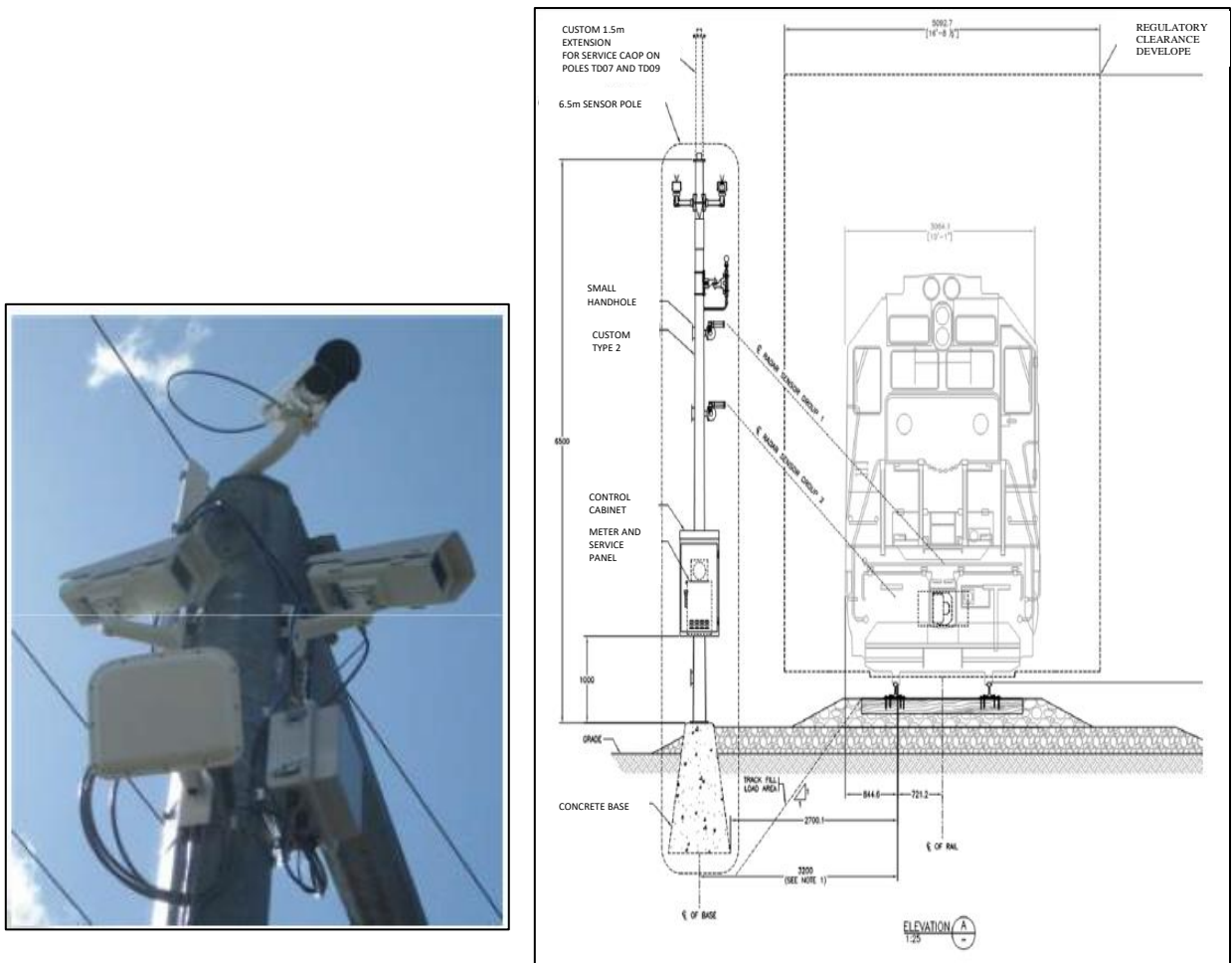
An alternative approach is a system that could provide real-time information on train movement and location. This system is known as “Grade Crossing Monitoring System (GCMS)”. A grade crossing monitoring system (GCMS) is a system designed to detect the presence of train, length of train, speed of train and the direction of the train. The monitoring system can also detect the times a crossing gate is closed through an interface of traffic preemption signal relays. The system aims at providing emergency dispatchers such as the Fire Department and other Emergency Services with a real-time train crossing blockage and positioning information system that will reduce emergency response time. With this information, emergency dispatchers will be aware of crossing times and gate closure times, which will help inform them on alternative routes to use to respond to emergencies quickly.

In recent years, the design of a train crossing monitoring system for emergency dispatchers has been of much importance in transportation engineering. In 2001 and 2003, two similar projects were developed by Texas Department of Transportation (TxDOT) and Texas Transportation Institute (TTI). The Texas Transportation Institute (TTI) prototypes made use of two external train detection technologies coupled with CCTV to collect train traffic information. These technologies can collect other information such as speed, train travel direction, and train length, to provide real-time information on grade crossings using automatic vehicle identification (AVI) transponders and Doppler radar devices. Goolsby et al., (2003) accomplished this by using a traffic signal cabinet with an interface of a signal preemption relay circuit, which was activated by the railroad’s equipment controlling the active crossing protection systems (gates and flashers) at the grade crossing. Monitoring of the warning systems provided a positive indication of train presence at grade crossings to supplement train detection/projection data provided by the detection devices. (Ruback and Balke, 2001). The Doppler radar detector installation at a grade crossing and railway crossing status information display are shown in **Figures 1-3** and 1-4.

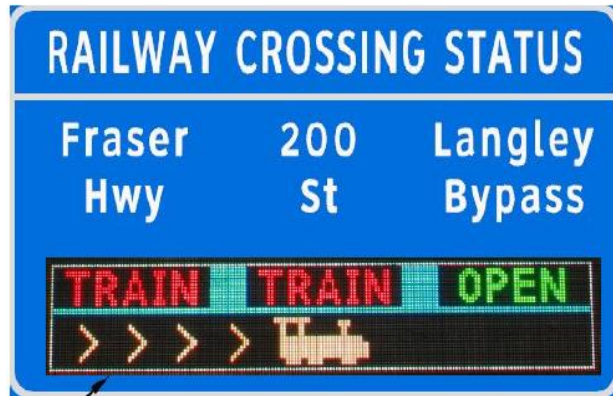
A conceptualized framework was carried out by Cisco, which uses wireless communication network system made up of IP networks, routers, switches, and surveillance cameras to help inform emergency response and public safety vehicles in emergency situations. The system aims to use GPS to guide emergency responders to emergency situations and also inform them on train

locations with a help of wireless communication signal to transmit information on train movement (www.cisco.com).

Goolsby et al., (2004) and FRA (2006) investigated the impact of grade crossing blockages on first responders and suggested that GCMS would be beneficial, but both studies relied mainly on surveys of first responders and neither undertook any rigorous response time analysis of the issues. This research will develop emergency response time analysis to determine the potential impact grade crossing blockages and the benefit of installing a grade crossing monitoring system for first responders.



**Figure 1-3. Doppler Rader Detector and Installation of Grade Crossing Monitoring System. Source: (ITS Canada, 2014)**



**Figure 1-4. Railway Crossing Status Display from a Grade Crossing Monitoring System.**  
**Source: (ITS Canada, 2014)**

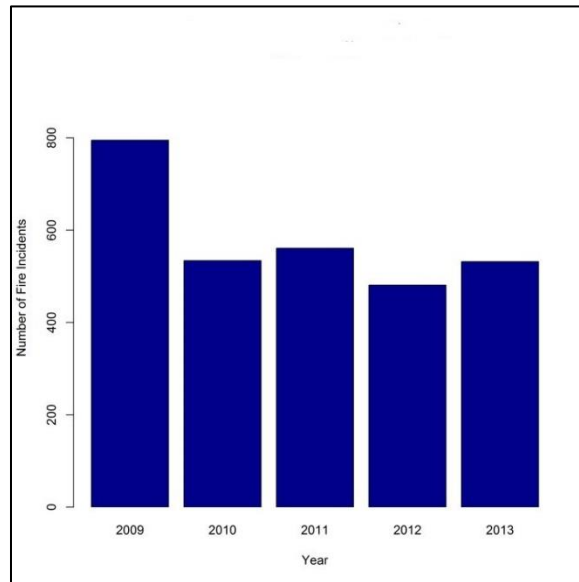
The second factor that influences emergency response time is fire equipment allocation. A Fire Department usually responds to all fire related incidents with a standard fire engine at least one of which is located in each fire district. In other special fire incidents, the Fire Department respond with specific types of fire engines which are not located in all the fire districts. The location of fire districts equipped with fire engines that have 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 include; engines, ladders, tankers, brush, decontamination, rescue boats, etc.

These different types of equipment perform different functions during fire fighting. 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. If there is a fire incident in an industry that generates toxic, caustic, pollutant, or unhealthful or damaging substances, a “decontamination” engine is used to control the harmful emissions. The location of these different types of fire equipment has an effect on emergency response time. It is clearly important to have a well-organized allocation of the different types of specialized equipment in the city.

There are periods when the demand for a special type of fire engine in a new developing neighborhood may rise, and will therefore require additional fire protection support. A neighborhood with previous history of a high level of incidents may experience low records of fire incidents over a period of time. The fire district may require a new or special fire engine that has

special features to respond rapidly to emergencies (Rider, 1974). This research presents Saskatoon’s Fire Department emergency response fire equipment and a visualization of fire district response time to an incident considering all fire stations equipped with special fire engines.

The third factor that affects emergency response time is the risk in occurrence of multiple incidents in a fire district which require pre-emptive reallocation of a fire engine. Multiple emergency situations (e.g., multiple 911 calls) in one or more fire districts are not uncommon. In Saskatoon there were 2,904 (13%) multiple incidents that occurred within 30minutes during the study period. **Figure 1-5** shows a steady trend of approximately 500 multiple incidents per year from 2010 to 2013.



**Figure 1-5. Total Number of Multiple Incidents by Year**

**Figure 1-6** shows Saskatoon’s fire stations (shown as FS #1 to FS #9) and the number of fire engines allocated to each fire station in 2013. FS #9, for instance, is located on the east side of Saskatoon and responds to fire related incidents occurring in an area of 58.8 square kilometers (see **Figure 1-6**); it normally experiences multiple 911 calls. When Saskatoon Fire Services dispatches a secondary fire engine from FS #2 or FS #8 to resolve multiple emergency situations in fire district #9, fire districts #2 and #8 maybe adversely affected by multiple emergency situation arising in their own fire district. This usually affects the response time to these incidents.

Ideally, each fire station would have multiple fire engines and the number of fire fighters needed to operate the fire engines, but budget restrictions limit six of the fire stations to a primary fire engine only. FS #1 has three fire engines because it serves the high density downtown area. The many high-rise buildings of downtown in Saskatoon generate a much higher number of calls for service, particularly during the daytime, than do the other fire districts. It is therefore difficult to reallocate FS #1's fire engines to other fire districts as backup. The only other fire stations with more than one fire engine is FS #2, FS #8 has a standard engine and a ladder equipped engine which can also perform duties of a standard engine. These fire engines in FS #2 and FS #8 are available for dispatch to other fire districts when needed.

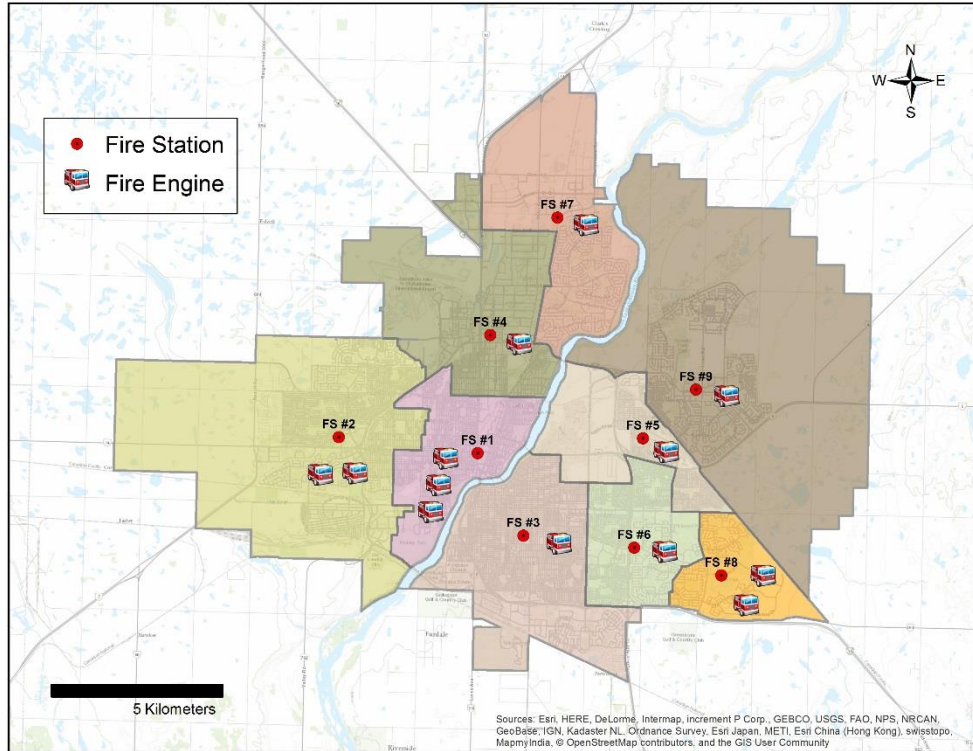
For example, two distinct fire incidents (Dunlop Street and Central Avenue) occurred in fire district #9 on June 6, 2013. These incidents required a secondary fire engine to be dispatched from FS #2 to Central Avenue in fire district #9. While the secondary engine was operating in fire district #9, two separate incidents occurred in fire district #2 (Diefenbaker Drive and Maxwell Crescent). These incidents also required a secondary fire engine (Saskatoon Fire Department, 2014).

The potential occurrence of multiple incidents in more than one fire district makes it very important for the Saskatoon Fire Department to a) predict the time periods during which a particular fire district may require an additional fire engine, and b) ensure that multiple incidents do not adversely affect fire services of other fire districts. Since it is not financially feasible to purchase a secondary fire engine for all nine fire stations, the next best possible approach is to share the existing secondary fire engines stored in FS #2 and FS #8 as efficiently as possible when multiple incidents occur in one or more fire districts.

To provide a high quality fire service, a fire department must provide the appropriate type of fire engines and the appropriate number of fire fighters to every incident within the department's fire district. The International Association of Fire Fighters (IAFF) developed an operational standard for most countries in North America and Europe in 2002. This standard is known as the National Fire Protection Association 1710 (NFPA 1710). It highlighted the important functions of fire department emergency services and specified the response capabilities and resources, response times, levels of service, etc. required to maximally save both the lives of residents and fire fighters themselves.

NFPA 1710 also strongly encouraged fire departments to analyze and evaluate the number and type of fire incidents occurring at the various locations within a fire district (high-rise buildings, manufacturing companies, schools, hospitals, etc.), and ensure that additional fire engines and/or fire fighters were available to fire districts that needed additional resources to avoid delays in emergency response. This kind of incident evaluation and forward planning is particularly important when multiple fire incidents occur concurrently. This research aims at using a pre-emptive reallocation method in allocating fire engines during multiple incidents in a particular fire district.

Pre-emptive reallocation of a fire engine refers to the systematic reallocation of a secondary fire engine and its associated fire fighters in a way that temporarily transfers the services of the secondary fire engine from its original fire district to another fire district when a high number of service calls is expected in another fire district. Fire engine pre-emptive reallocation is designed to strengthen overall fire services in a region as it uses existing fire service resources more efficiently. The database of all reported incidents from 2009 to 2013 were analysed to develop a model to determine the period of risk of multiple incidents occurring in a fire district and the period for pre-emptive allocation of a fire engine to multiple incidents risk locations.



**Figure 1-6. Saskatoon Fire Services' Response Districts and Number of Fire Engines**

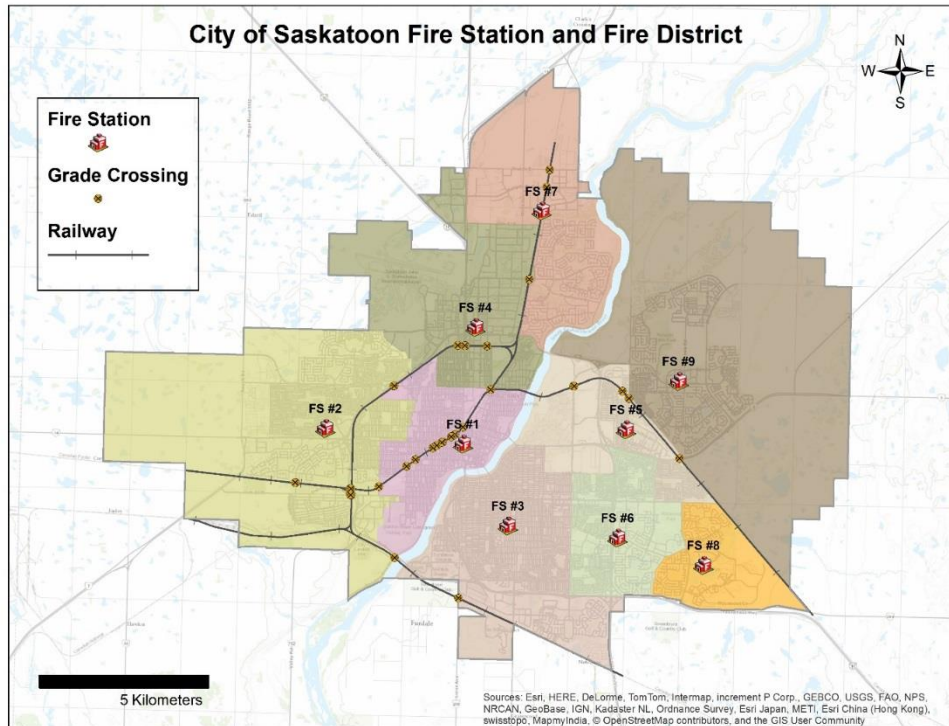
## 1.2. The Study Area

The City of Saskatoon is located in the province of Saskatchewan, Canada. Saskatoon Fire Department has nine fire stations that serve nine fire districts. The fire districts are divided into four divisions, North, Central, East and West. These fire districts serve as a community-based protection service and provide emergency response to an estimated population of 304,975 within an area of 218 square kilometers. Saskatoon has two major rail hubs that provide rail services in the city, Canadian Pacific Railway (CPR) and Canadian National Railway (CNR). CPR was the first rail service in Saskatoon established in the late 1880s, and with the continuous demand for freight trains, CNR soon also added its services in Saskatoon.

The rail system handles mainly agricultural produce (wheat), mining (coal, sulfur, potash, oil) and industrial products. The agricultural produce are distributed nationally to the west through Alberta, to the east through Manitoba and internationally through Montana and North Dakota (Landry, 1990.; MacKay, 1992). The existence of these two large rail yard tracks in the city has contributed to a large number of grade crossings across the city. There are currently 58 at grade



crossings on the three mainline railway routes that pass through the city. **Figure 1-7** shows Saskatoon's major railways routes, fire stations and fire response districts.



**Figure 1-7. Saskatoon's Railway Routes, Grade Crossings, and Fire Stations' Response Districts**

The Saskatoon Fire Department has 13 front line engines, two aerials (ladders), one heavy rescue truck, two tankers, 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 districts. These fire fighters respond to fire emergencies and are also trained in special rescue operations. All fire districts have one primary engine except districts #1, #2 and #8. Fire district #1 has three fire engines and since it serves the downtown and central part of the city, it is usually difficult to reallocate one of its engines as a secondary fire engines to other locations. For this reason, fire districts #2 and #8 dispatch one of their engines as a secondary engine to other locations during multiple emergency calls in other locations (City of Saskatoon, 2014).



A brief description of some major fire equipment operated by the Saskatoon Fire Department are as follows:

**Engine:** This equipment is located in every fire station. It is specially designed and equipped for fire attack. An engine usually carries three to four fire fighters and it is equipped with a pump, water hose and a water tank that can store about 500 to 600 gallons. A fire Engine can also be referred to as “Pumpers”. An engine also has the ability to supply fire retardant foam.

**Ladder:** This is a fire engine that carries more than 100 feet articulating Sky-Arm aerial ladder device. A ladder engine can carry about 300 gallons of water. 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 equipment is a special type of fire equipment with the primary purpose of transporting large volumes of water to a fire location during firefighting operations. A tanker can transport about 3,000 gallons of water. It is located in only two fire stations. It is equipped with an on-board pumping system that is used to draw water into a tank from hydrants or other water sources.

**Trailer (USAR):** This apparatus is known as the urban search and rescue (USAR) trailer. It is special equipment that is used to carry many different types of equipment, some of which is quite bulky and heavy for an emergency vehicle during an immense fire and rescue operation. It is equipped with various medical and fire protective accessories to provide immediate on-scene medical help to victims trapped in a major structural collapse, motor accidents, or natural disasters such as earthquakes and hurricanes.

**Brush:** This is 4x4 truck equipment 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 equipment is known as Decon. It is used for the purpose of decontamination in an event of industrial fire that generates toxic pollutant, or other unhealthful and damaging substances in the atmosphere. This apparatus is located in only fire district #9.

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.

### **1.3. Research Goal**

The goal of this research is to improve first responders' emergency response time by developing a response time analysis to demonstrate the impact of grade crossing blockage and the benefit of installing a Grade Crossing Monitoring System. This research goal also includes investigating the response area for locations of specialized fire engines and the possibility of fire engine preemptive reallocation for preset short-term periods when multiple fire incidents may be expected to occur in a certain fire district.

### **1.4. Objectives**

To achieve this research goal, four specific objectives were addressed:

1. To establish how grade crossing blockage information available from a GCMS changes first responders' response times and service area;
2. To develop service area and response time analysis for fire stations with fire engines equipped with special features;
3. To develop a statistical model that can predict the time window when there is a high risk of multiple fire incidents in a fire district that has only a primary fire engine. (Fire district #9 was used as a sample district); and
4. To develop a statistical model to determine the time window when a fire district that has more than one fire engine can dispatch a secondary fire engine for the purpose of preemptive reallocation. (Fire districts #2 and #8 were used as sample districts).

### **1.5. Benefit of Research**

This research demonstrates the serious impact of grade crossing blockages and the benefit of installing a grade crossing monitoring system to improve emergency response time for the Saskatoon fire department. It will also establish the need to provide and reallocate fire equipment

to fire districts with high risk of multiple incident occurrences that require fire engines with special features and preemptive allocation of fire engines from other districts. The outcomes of this research are expected to help decision makers and emergency response agencies to introduce GCMS and the provision of fire equipment to improve emergency response time to reduce loss of lives and property damage.

## **1.6. Scope**

This research was focused on the City of Saskatoon Fire Department. The study developed response time analysis using five-year incident data from the Saskatoon fire department from 2009 and 2013. Geographic Information System (GIS) street map from the City of Saskatoon was used to display visually the impact of grade crossing blockage, the benefit of installing a GCMS and to show response time and service areas for high incident areas that require allocations of fire equipment. Survival data analysis was used to develop a set of statistical models designed to determine the possible time window for fire engine pre-emptive reallocation from FS #2 or FS #8 to FS #9 to handle multiple fire incidents in fire district #9.

## **1.7. Layout of Thesis**

Chapter two presents literature review of existing research on first responders' emergency response time analysis, fire equipment allocation and the use of response time to an event analysis to determine the risk in occurrence of incidents in order to provide pre-emptive allocation of a fire engine. Chapter three discusses the data used for the research and data integration. Chapter four discusses the methods used in carrying out the objectives of this research. Chapter five discusses the analysis results and interpretation. Chapter six presents the conclusions with major recommendations.

## CHAPTER 2: LITERATURE REVIEW

### 2.1. Emergency Response Time

First responders' emergency response time (or travel time) has been considered by numerous research studies with various purposes and objectives. A complex mathematical model known as the "inverse square root laws" was used by Kolesar and Blum (1973) to describe the relationship between average response distance and average number of response units (e.g., fire stations) assigned to an area. This model was developed to help solve emergency management decision problems in a fire department. Another mathematical model was developed by Kolesar et al., (1975) to illustrate the relationship between fire engines' response time and travel distance. Kolesar et al. (1975) showed very small difference in response time by time of day (i.e., peak hour and non-peak hours). Comparing the response time during peak hour and non-peak hours, the increase in response time was not as great as expected by Kolesar et al., (1975).

The models developed by both research studies used response time data collected in New York City through field experiments. Both studies were used to help determine the optimal number and emergency response units' locations in New York City. The study by Green and Kolesar (2004) examined how earlier studies in the 1970s, including the two Kolesar studies, have had a great impact on management science for emergency response units in an area. Over the years, there have been numerous follow-up studies using different approaches to investigate the maximum number and/or (re)location of emergency response units for a given area.

In recent years, there have been few studies made by fire departments, using mathematical models to improve fire station location, allocation of equipment and response times, although earlier studies that used complex mathematical models (e.g., linear optimization) to investigate and enhance emergency response plan and policy decisions were successful. For example, a recent study in modelling the allocation of emergency vehicles considering secondary incidents used a system of integrated mathematical model to allocate emergency vehicles on freeways during a secondary incident regardless of the location of the incident. The analytical model by Park et al., (2015) was based on the probabilities of a primary and secondary incidents over a time period to plan on dispatching an emergency vehicle to a secondary incident. This means that emergency

vehicles will need to remain at the location of a resolved primary incident without returning to its original location in anticipation of the occurrence of a secondary incident.

One reason that prevents fire officials and other decision makers from adopting mathematical models is the problem of understanding and applying the models (Green and Kolesar, 2004). Another reason may be the failure of the models to consider important real-world constraints. For example, a linear optimization model was developed by some researchers to allocate multiple dispatchers. This model was used to optimize the total response time of fire engines and the number of emergency locations that could be reached from a fire station within the four-minute journey time. (Yang et al., 2005; Aktas et al., 2013; Murry et al., 2013).

Many of these mathematical models unfortunately did not clearly take into consideration other various factors that may be even more important to the fire department's service tactics and strategies than the response time. These factors include the number of fire fighters and workload in each fire station, the spatial and temporal road network changes that affect traffic conditions on the road network, number and type of fire engines in each fire station, and the annual operational budget available to a fire department. A good example of spatial and temporal road network changes is blockages at grade crossings. Emergency response issues that are associated with train blockages pose a major challenge to researchers when using mathematical models.

The difficulties associated with understanding and interpreting some of these complex mathematical models and the problems of including so many factors in a mathematical model has resulted in many fire departments turning to the visual display of output available from a Geographic Information System (GIS) for their decision making processes. Studies by Derekenaris et al., (2001) and Malowidzki et al., (2013) show conceptual frameworks that integrate GIS/GPS/GSM technologies to provide a decision support tool to enhance emergency response agencies' dispatching routes.

## **2.2. Geographic Information System**

Geographic information system (GIS) can be defined as ...*“a system of integrated data, software, and computer hardware for analyzing, managing, capturing, and displaying all forms of geographically referenced information to provide a proper interpretation and visualization of the*

*relationships and patterns in the form of maps and charts for useful purposes...*" (ESRI, 2007). GIS is used to effectively manage and support emergency response operations by first responders.

GIS techniques has been widely used in different analyses on emergency response. For example, the spatial relationship between various types of fire incident and selected socio-economic, geographic and demographic data (e.g., property types, population dynamics, neighbourhood classification, etc.) was investigated using GIS spatial pattern analysis tool (Corcoran et al., 2013; Higgins et al., 2013). In recent years, a brief review of applications of GIS technologies to urban fire rescue management was carried out by Corcoran and Higgs (2013), but there are no studies found, to investigate the impact of spatial and temporal blockages on emergency response time and route selection using GIS techniques.

There are some transportation engineering studies that have investigated the most efficient (shortest or fastest) response route to fire incidents or traffic accidents, using simulation tools, such as CORSIM or ARENA. For example, a simulation model was developed by Haghani et al. (2013) to determine a non-congested routes for emergency vehicles. This model uses a system strategy to assign emergency vehicles using travel time information. Another study used the COSSIM traffic simulation tool to model effective hurricane evacuation routes using traffic and road network information for emergency planning strategies (Haghani et al., 2013; Sisiopiku, 2007; Zhang et al., 2009; Zhou & Liu, 2011).

There are merits in using simulation tools to search for the fastest/shortest response route to an incident considering the benefit of using traffic volume and traffic congestion information, but the size of the road network that can be simulated has been a major limitation. There are studies that have considered using a small and limited road network to determine the fastest/shortest route. The network in a study area, for example, might have restrictions on the arterials and freeways. The inclusion of every road segment and every intersection on a large road network remains a difficult technical challenge in a real city.

Emergency preemption systems installed at level crossings are designed to give priority to approaching trains to prevent collision between trains and road vehicles. Based on an intelligent transportation system (ITS) (Nelson and Bullock, 2000; Mirchandani and Lucas, 2004), the main purpose of emergency preemption systems installed at level crossings are designed to give priority not to emergency vehicles, but to approaching trains. This approach is not useful in reducing

emergency responders' response times. Specifically, preemption systems at grade crossings are not designed to reduce emergency response times nor to help with emergency vehicles routes. The use of GIS-based analysis offers a more straightforward approach and would be beneficial to the fire department to analyze the impact of spatial and temporal network restrictions on emergency response time and allocation of fire equipment. GIS-based analysis was used in this study.

In theory, simulation tools are useful in emergency response analysis, but practically, they do not offer the great computing power required when analyzing the entire road network of a large city. Apart from the discussions on GCMS in the Introduction, there have been no existing ITS techniques that have proven effective in reducing first responders emergency response times considering blockages at level crossings. This research approach is unique and different from other studies.

### **2.3. Survival Data Analysis**

Survival analysis (a.k.a., time to event or time to failure analysis) has been successfully used in a many disciplines for various types of event including death, divorce and disease (Smith et al., 2012, Williams, 2008., Anderson et al., 1991). The subject of survival analysis usually involves the time at which the target event occurs and/or the duration (length of time) between two successive target events. The length of time leading up to an event or the length of time between the two successive target events is known as the survival time. The usual time units in survival analysis are days, weeks, months or years. In survival analysis, the survival function ( $S(t)$ ) and hazard functions ( $h(t)$ ) are the two most important functions.

Approaches to the development of survival and hazard functions include non-parametric and parametric models (Cleves et al., 2004, Klein et al., 2003). Survival analysis techniques that are widely used in transportation engineering were selected: the Kaplan-Meier survival probability estimator, often simply called the Kaplan-Meier estimator; and the Cox hazard model. The Kaplan-Meier estimator, a non-parametric approach, was used to develop the survival function and the Cox hazard model was used to develop the hazard function.

Both the Kaplan-Meier estimator and the Cox hazard model have been used in various interesting and recent studies. Shi et al. (2014), for example, conducted a survival data analysis in

which they investigated the duration of traffic incidents on an expressway in Shanghai, China. They used the Kaplan-Meier estimator to estimate and categorize the main factors that contribute to traffic incident duration. Possible factors included type of incident, time of day (day and night), location of incident, number of lanes, etc. To determine how such factors influence traffic incident duration, Shi et al. used the Cox hazard model.

Masten and Foss (2010), for instance, used the Kepler Meier method, a non-parametric approach, to estimate survival probability. They defined survival probability as the probability of experiencing the first collision after obtaining one's first driving license before and after the implementation of a graduated driver licensing program in North Carolina. Using this approach, they demonstrated that the implementation of graduated driver licensing system on young teen drivers in North Carolina was successful since the young drivers who took the program are expected to take longer time to experience the first collision.

Masten and Foss (2010) used the Cox proportional hazard model to show the different collision risks of young drivers according to selected input variables such as age and gender. Xiaobao et al. (2012) also used the Cox proportional hazard model. They showed the impact of various traffic parameters (bus volume, passenger car volume, percentage of bicycles, etc.) on vehicles' travel time between bus stops. They used the model outcomes to plan and design bus stop locations. There have been very few studies in the use of survival analysis by fire departments' emergency response operations.

In this research, the Kaplan-Meier test and the Cox proportional hazard model was used to develop a survival function and hazard function respectively. The study developed a set of statistical models to predict the specific time of the day, season of the year, and type of fire incident associated with a higher risk of multiple simultaneous incidents in a fire district to determine the possible time window for fire engine preemptive reallocation.

## **2.4. Chapter Summary**

The literature in this chapter reviews studies by researchers on emergency response time for first responders. The review by earlier studies shows the use of mathematical models to describe the relationship between the response time and travel distance using data from field experiments. Even



though fire departments made little use of these models, the outcomes were useful in (re)allocating fire engines to a given area.

An alternative approach for fire departments to analyze emergency response time for fire engines without considering so many factors used in earlier mathematical models is a Geographic Information System (GIS). GIS provides a visual display of important information for fire departments to enhance emergency response delivery.

The literature reviewed different survival data analysis study approach on how the Kepler Maier and cox proportional hazard model was used to determine the probability and risk involved in the occurrence of an event considering selected input variables.

## CHAPTER 3: STUDY DATA

There were two types of data used to conduct this research: spatial data with road and railway network information from the City of Saskatoon and Incident data from the Saskatoon Fire Department.

### 3.1. Spatial Data

The spatial data for the City of Saskatoon was made up of a geographic information system (GIS) that is used to visually display, analyse and manage the current road and railway network. Two ArcGIS shape files were obtained with detailed information on all existing road and railway network in the City.

**Table 3-1** and **Table 3-2** show examples of the information from the road network and railway shape files provided by the City of Saskatoon. **Table 3-1** shows road location identifiers (ROAD\_ID), street location identifier (STREET\_NAM), street position (STREET\_POS), street name (ONLINE\_STR), posted speed limit (SPEED\_LIMI), number of lanes (LANE\_COUNT), etc. **Table 3-2** shows railway location identifiers (RL\_ID), railway ownership (OWNER), rail type (RTE\_TYPE), province (SK), rail position location code (CODE), railway feature (FEATURE), etc.

**Table 3-1. Saskatoon's ArcGIS Shape File Information on Road Network Segment (COS, 2014)**

ROAD _ID	STREET _NAM	STREET _POS	ONLINE _STR	SPEED _LIMI	LANE _COUNT
9203	T	N	Ave T N	50	2
9206	23rd	W	23rd St W	50	2
6576	S	S	Ave S S	50	2
6579	21st	W	21st St W	50	2
6586	R	S	Ave R S	50	2
6587	Q	S	Ave Q S	50	2
6618	P	S	Ave P S	50	2
6570	20th	W	20th St W	50	4

**Table 3-2. Saskatoon's ArcGIS Shape File Information on Railway Segment (COS, 2014)**

<b>RL_ID</b>	<b>OWNER</b>	<b>RTE_TYPE</b>	<b>PROV</b>	<b>CODE</b>	<b>FEATURE</b>
61568	CN	RL	SK	962	MAIN LINE
16630	CN	RL	SK	962	MAIN LINE
20105	Sidetrack	RL	SK	963	SIDETRACK
20185	Sidetrack	RL	SK	963	SIDETRACK
61548	CN	RL	SK	91	MAIN LINE - BRIDGE
2711	CPR	RL	SK	962	MAIN LINE
2410	CPR	RL	SK	962	MAIN LINE
61559	CPR	RL	SK	91	MAIN LINE - BRIDGE

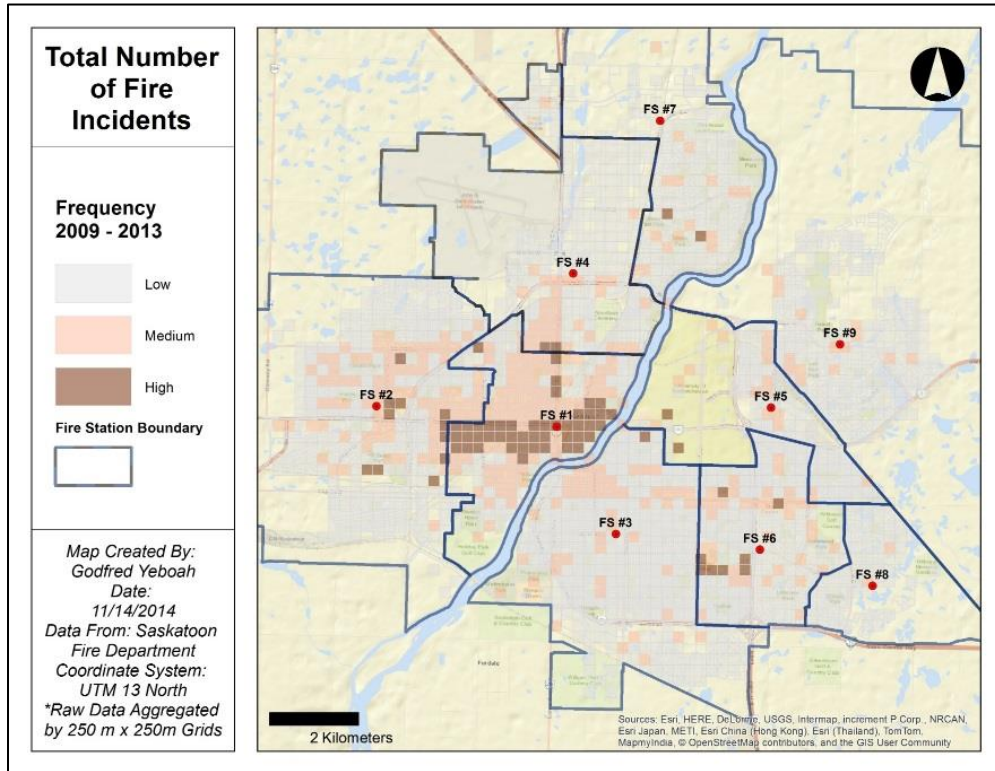
### **3.2. Incident Data**

Incident data for the study was provided by the Saskatoon Fire Department. The database involves two separate tables – Reported Incident location (INCIDENTS) table and Response (APPARATUSRESPONDING) table. The INCIDENT table includes information (e.g., incident begin time, incident end time, type of incident, location of incident, etc.) on all reported emergency calls that were responded to by the fire department. The APPARATUSRESPONDING table includes information (e.g., apparatus name, dispatch time, on route time, on scene time etc.) on all reported emergency calls responded by the fire department.

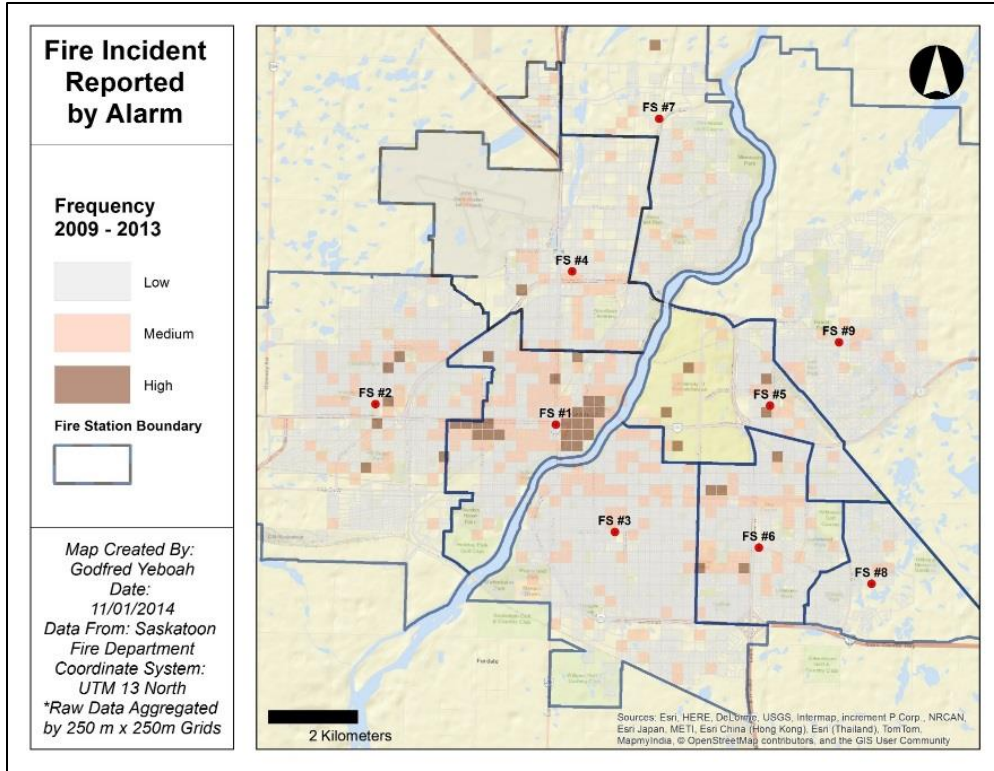
The department responded to a total of 22,618 incidents from 2009 to 2013. **Figure 3-8** shows a map of the frequency of incidents from 2009 to 2013. The frequency levels shown in the map legend are described as: *low*, this represents the average or below average number of incidents; *medium*, this represent above average and four times the average number of incident and *high*, this represent more than four times the average number of incidents. There were high number of incidents recorded in the central Saskatoon downtown area. The types of incidents the fire department responded were, Alarm, Fire and Dangerous goods incidents. **Figures 3-9a, 3-9b** and **3-9c** shows maps of the frequency of incidents reported as alarm, fire and dangerous good. Fire district #1 shows high number of incident frequency.

The classification of these incident types were based on the nature of the incident and the type of fire equipment used to respond to these incidents. For example, an incident referred to as Alarm (Level 1) is responded with two pump engines, rapid intervention team (RIT) and a ladder equipped engine. An incident referred to as Dangerous goods (DG 1A) is responded with a district

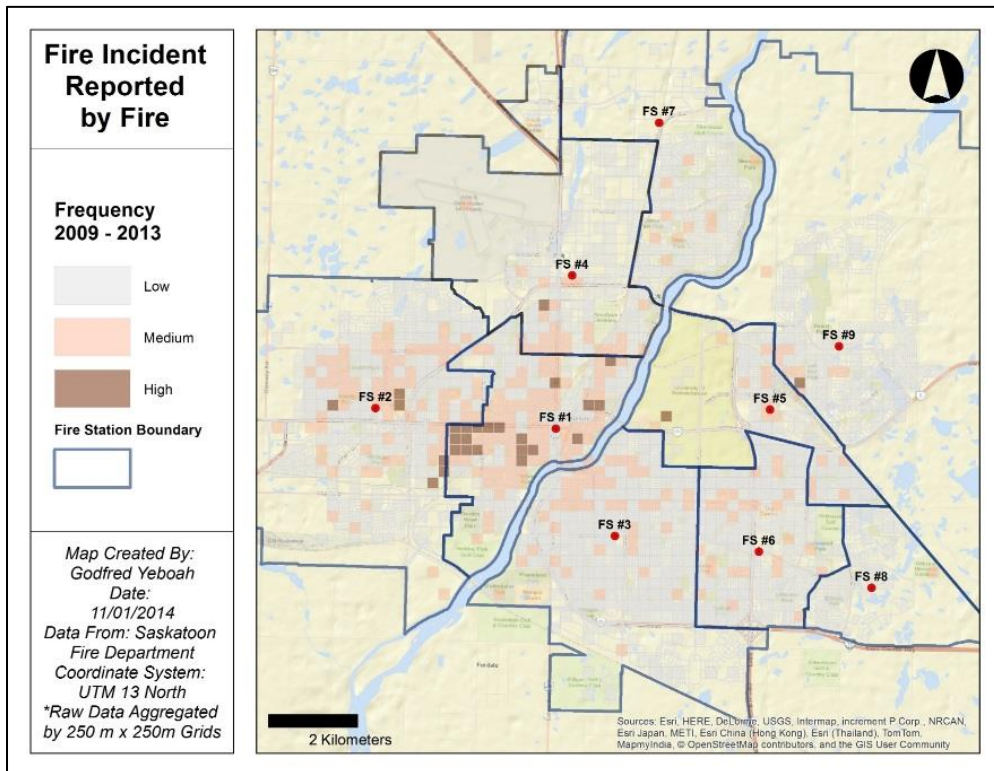
engine and a Hazmat with trailer on standby. An incident referred to as Fire (Fire 1+) is responded with a district engine and an extra pump.



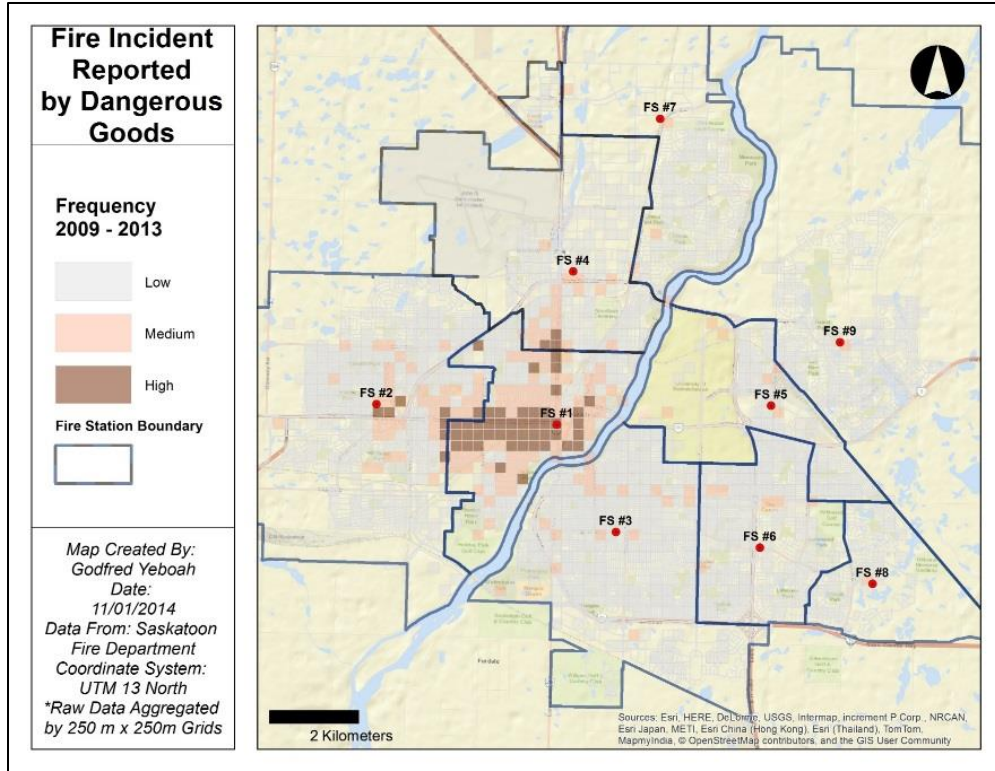
**Figure 3-8. Map Showing Total Number of Incidents**



(b)



(c)



(d)

**Figure 3-9. Maps Showing Incidents Reported as (a) Alarm (b) Fire (c) Dangerous Goods**

**Table 3-3** shows an example of the information in the INCIDENT table, it includes incident identification number (Incident Number (NFIRS)), incident begin time (INCIDENT BEGIN TIME), incident end time (INCIDENT END TIME), location of incident (ADDRESS DISPLAY), type of incident, (INCIDENT TYPE DESCRIPTION), etc.

**Table 3-4** shows an example of information in the APPARATUSRESPONDING table, it includes incident identification number (Incident Number (NFIRS)), response equipment name (APPARATUS NAME), dispatch time (DISPATCH TIME), on route time (ON ROUTE TIME), on scene time (ON SCENE TIME), etc.

**Table 3-3. Incident Location Table (SFD, 2014)**

<b>INCIDENT NUMBER (NFIRS)</b>	<b>INCIDENT BEGIN TIME</b>	<b>INCIDENT END TIME</b>	<b>ADDRESS DISPLAY</b>	<b>INCIDENT TYPE DESCRIPTION</b>
10-13321	12/16/2010 18:19	12/16/2010 18:32	1608 8TH ST E	DG LEVEL 1A
09-11965	10/31/2009 16:08	10/31/2009 16:29	803 AVE L N	DG LEVEL 1B
09-11765	10/26/2009 6:48	10/26/2009 7:00	1840 ONT AVE	FIRE LEVEL 1
13-11061	8/24/2013 1:09	8/26/2013 14:43	809 50TH ST E	FIRE LEVEL 2
10-13169	12/11/2010 7:15	12/11/2010 7:34	241 5TH AVE N	ALARM

**Table 3-4. Response Equipment (APPARATUSRESPONDING) table (SFD, 2014)**

<b>INCIDENT NUMBER (NFIRS)</b>	<b>APPARATUS NAME</b>	<b>DISPATCH TIME</b>	<b>ON ROUTE TIME</b>	<b>ON SCENE TIME</b>
10-13321	Engine 03	12/16/2010 18:22	12/16/2010 18:24	12/16/2010 18:29
11-06764	Engine 04	7/3/2011 11:42	7/3/2011 11:44	7/3/2011 11:51
11-06765	Engine 11	7/3/2011 12:11	7/3/2011 12:12	7/3/2011 12:31
12-05920	Engine 03	5/7/2012 19:49	5/7/2012 19:50	5/7/2012 20:04
12-05921	Engine 01	5/7/2012 20:09	5/7/2012 20:10	5/7/2012 20:24

### 3.3. Data Integration

The spatial and incident databases were processed and revised for the analysis. The spatial data with information on the road and railway network were modified to identify all the intersection of road and railway in Saskatoon. **Table 3-5** shows an example of the information in the road and railway intersection table. It includes railway ownership (OWNER), rail position location code (CODE), railway location identifiers (RL\_ID), road location identifiers (ROAD\_ID), street name (ONLINE\_STR), etc.

The road network attribute table was also modified to be capable of being used for the ArcGIS network and service area time-based analysis. The ArcGIS field calculator tool was used to add the fields; LENGTH (kilometers), TIME (minutes) and TIME\_80 (minutes). These fields were very vital in determining the time and distance covered for every network route and service area covered.

Incident databases/tables (INCIDENT and APPARATUS RESPONDING) needed to be integrated together to generate a single database. Quality control was performed on each database



to ensure that there were no duplicates incidents recorded using Microsoft Excel Pivot Table tool. ArcGIS join table tool was used to merge the two Incident databases/tables to generate the integrated database. The integrated database was used to determine the total number of incident responded by the Saskatoon Fire Department. Based on the integrated database, additional columns were created to add lacking data (day of week, hour, month, season, year, duration of incident, response time, journey time, type of incident and response equipment classification) needed to create histograms to describe the trend of the incident data.

The classification of the incident types and response equipment were based on the fire department’s response configuration manual. This manual serves as a guideline in identifying the type incident they are responding to and also the appropriate equipment and personnel to be dispatched. **Table 3-6** and **3-7** shows an example of the information from the integrated database that represent the “Total Number of Incidents” with response equipment.

**Table 3-5. Intersection of Road and Railway table (COS, 2014)**

<b>OWNER</b>	<b>CODE</b>	<b>RL_ID</b>	<b>ROAD_ID</b>	<b>ONLINE_STR</b>
CPR	962	61564	869905	Preston Ave N
CPR	962	2411	18528	Central Ave
CPR	962	2488	872370	Idylwyld Dr N
CPR	962	2488	903835	22nd St W
CPR	962	2488	7304	Ave C N
CN	962	2537	997637	11th St W
CN	962	2538	997547	Dundonald Ave
CN	962	2406	891224	33rd St E



**Table 3-6. Integrated Total Incident Number of Incident table (SFD, 2014)**

INCIDENT NUMBER(NFI)	INCIDENT BEGIN	INCIDENT END TIME	YEAR	MONTH	SEASON	DAYofWEEK	HOUR	SREET	DURATION (min)	STATION#	INCIDENT Type	JOURNEY TIME (min)	RESPONSE TIME (min)
09-00099	1/4/2009 11:03	1/4/2009 11:18	2009	January	Winter	Sunday	12	1ST AVE S	15	1	ALARM	3	5
10-00072	1/2/2010 21:39	1/2/2010 22:16	2010	January	Winter	Saturday	23	22ND STW	37	1	FIRE	6	8
12-01614	2/8/2012 16:53	2/8/2012 17:20	2012	February	Winter	Wednesday	18	COLLEGE DR	27	5	ALARM	10	11
13-00275	1/8/2013 12:59	1/8/2013 13:20	2013	April	Winter	Tuesday	14	COLLEGE DR	21	5	DANGEROUSGOODS	5	6
09-00137	1/5/2009 18:31	1/5/2009 18:48	2009	January	Winter	Monday	19	33RD STW	17	2	ALARM	7	8
09-00237	1/8/2009 16:31	1/8/2009 16:33	2009	January	Winter	Thursday	17	37TH STW	2	4	DANGEROUSGOODS	1	2
11-00188	1/6/2011 22:24	1/6/2011 22:50	2011	January	Winter	Thursday	23	104STW	26	5	FIRE	10	12
09-01159	2/13/2009 18:41	2/20/2009 10:51	2009	February	Winter	Friday	11	SAGUENAY DR	250	7	FIRE	10	732

**Table 3-7. Integrated Total Incident Number of Incident table and Response Equipment (SFD, 2014)**

INCIDENT NUMBER(NFIRS)	INCIDENT BEGIN TIME	INCIDENT END TIME	YEAR	MONTH	SEASON	DAYofWEEK	HOUR	SREET	DURATION (min)	INCIDENT Type	RESPONSE EQUIPMENT
09-01206	2/15/2009 15:58	2/15/2009 16:27	2009	February	Winter	Sunday	17	AVE M S	29	DANGEROUSGOODS	HAZMAT
09-01835	3/8/2009 23:21	3/8/2009 23:54	2009	March	Spring	Sunday	24	AVE I S	43	DANGEROUSGOODS	HAZMAT
11-00188	1/6/2011 22:24	1/6/2011 22:50	2011	January	Winter	Thursday	23	104ST STW	26	FIRE	TANKER
13-00535	1/15/2013 21:03	1/15/2013 21:17	2013	January	Winter	Tuesday	22	COLLEGE DR	14	ALARM	LADDER
13-00539	1/16/2013 01:53	1/16/2013 02:03	2013	February	Winter	Wednesday	3	CAMPUS DR	10	ALARM	LADDER
09-08984	8/16/2009 05:09	8/16/2009 05:34	2009	August	Summer	Sunday	6	22ND STW	25	DANGEROUSGOODS	DECON
13-09700	7/30/2013 11:44	7/30/2013 11:47	2013	July	Summer	Tuesday	12	106TH STW	3	FIRE	BRUSH
13-09736	7/30/2013 19:05	7/30/2013 19:13	2013	July	Summer	Tuesday	20	CENTRAL AVE	8	FIRE	BRUSH

### **3.4. Chapter Summary**

This chapter contains the different types of data received from the City of Saskatoon and the fire department. The chapter also includes the data management processes on the data. The data for the research was made up of a spatial data and incident data. The spatial data contains geographic information on the road and railway network in Saskatoon. These spatial data were shape files with detailed information on all existing road and railway network. The road and railway network data was modified to identify all the grade crossings in Saskatoon. This was very useful for the GIS-based analyses.

The incident data was made up of two tables with information on all reported incidents and the types of equipment that were used to respond to each incident. A total of 22,618 incidents were recorded by the fire department from 2009 to 2013. The types of incidents responded to by the department are incidents associated with alarm, fire and dangerous goods. The two tables were integrated into one database using ArcGIS join table tool. The integrated data was imported into ArcGIS to visually display the total incidents and types of fire related incidents on the map. R-Language was used to create histogram charts to describe the trend and nature of the incident data.

## CHAPTER 4: METHODOLOGY

### 4.1. GIS-Based Data Analysis

To determine the impact of grade crossing blockages and the allocation of fire equipment on emergency response time, two ArcGIS-based spatial data analysis tools were used. These spatial data analysis tool are both similar and quantitative but distinct in how the results are visually displayed. The analyses were:

- Service area analysis; and
- Network analysis

The service area analysis (SAA) was used to investigate the impact of a grade crossing blockage on the service area in a fire district and to determine the response area of fire stations equipped with fire engines with special features. The response area covered within a fire district and the changes in service area, with/without grade crossing blockage was determined using a fire station's service area. The network analysis (NA) was then used to investigate the network route when there was no train blockage at grade crossings (i.e., default circumstance). The network analysis was used to compare two situations where dispatchers may assume that a route is blocked but it is actually open (without GCMS) and where dispatchers know (with GCMS) that there is a blocked crossing and can plan their route accordingly. The NA was used to compare route(s) available to dispatchers with/without GCMS when multiple grade crossings are blocked simultaneously by a train.

#### 4.1.1. Service Area Analysis

The Service Area (SA) is an ArcGIS Network Analyst. In this study SAA was defined as...“*a type of network analysis for determining the region that encompasses all accessible streets - streets that lie within a specified impedance (e.g., time or distance)...*” (Gomersall, 2003). The Service Area (SA) can be described as the geographic area in which an expected level of service is provided and fulfilled. (Indriasaria et al., 2010; Murray & O’Kelly, 2002). When determining a fire station’s SA, the time taken to reach an incident is considered rather than the physical distance covered. In this study, the accessibility of streets was measured in terms of time. For example, a four-minute

SA for a fire station on a network includes all the roadways and buildings that can be reached within four minutes from that fire station. This study used ArcGIS SAA algorithm known as Dijkstra's algorithm to determine a SA using the shortest path (Dijkstra, 1959).

GIS-based SAA is used widely used in transportation engineering, especially in public transit studies to determine the walking distance to/from public transit stations (e.g., to/from light rail stations in downtown Sacramento, CA (Upchurch et al., 2004) and to/from metro stations in Minneapolis–Saint Paul, MN (Lee et al., 2013)). There are numerous studies that have used SAA to determine the response area of fire stations (Lee et al., 2013; Forkuo and Quaye-Ballard, 2013; ESRI, 2007). SAA has been used in some studies to determine the location of a number of fire stations in a large study area in the possible future. These studies seek to maximize the area of coverage as efficiently as possible (Indriasaria et al., 2010; Liu et al., 2006).

#### **4.1.2. Network Analysis**

GIS-based NA is an ArcGIS Network Analyst tool designed to find the fastest route on a road network from one or multiple origins (fire stations) to one or multiple destinations (incidents). In NA, all the possible routes to an incident are considered to determine the fastest and most efficient route(s) available to one or more fire stations. There are previous studies that have used Dijkstra's algorithm to find the fastest route on a road network to an incident for different emergency service agencies (Forkuo and Quaye-Ballard, 2013; Kai et al., 2014).

The analysis in this study assumed travel speed of fire engines which is a very essential factor in the network routes. In a study analysis of an area near the University at Buffalo North Campus, NY, Henchey et al., (2014) it was assumed that emergency vehicles (EMS vehicles) travel 10 mph faster than the posted speed limit. A micro-simulation tool known as Rockwell ARENA was used for the study analysis. A study by Holm et al. (2007) proposed the “10 mph rule” and designed a micro-simulation tool (the CORSIM model) to investigate the impact on traffic flow on a road network, emergency vehicles and regular cars by different travel speed. The “10 mph rule” proposed by Henchey et al. (2014) and Holm et al. (2007) for EMS vehicles was not adequately justified.

The Saskatoon Fire Department assumes that fire engines travel at 80% of the posted speed limit when planning or considering emergency policy decisions. The choice of the speed takes into account real world travel conditions of reaching an incident: slowing down on roadways with different geometric and environmental restrictions (e.g., roundabouts), slowing down to avoid collision with conflicting vehicles, cyclists and/or pedestrians right-of-way, making turns at signalized/unsignalized intersections. The speed is also based mainly on dispatchers' knowledge of response times in Saskatoon and long years of experience. In this study analysis, the assumption that fire engines travel at 80% of posted speed limits was used. This approach is more applicable in the study area than the "10 mph rule".

The potential for delay due to traffic congestion is very limited in Saskatoon and it is worth noting that dispatchers are not subject to the kind of recurrent traffic congestion which is typical of large cities. For this reason, this study was not focused on delays caused by traffic congestion but an unexpected event such as a grade crossing blockage and the availability of fire equipment when finding the fastest and shortest route to an incident.

The Fire Department takes into account several factors before responding to an emergency in a fire district. These factors were considered to determine the impact of grade crossing blockages and the allocation of fire equipment with special functionality on emergency response time. These factors includes the type of incident (eg., fire alarm, oil spill, vehicle collision, etc), the location of the incident (high-rise building, wild grass fire, industrial, etc), the type of fire engine required and the availability of fire engines due to other secondary incidents. The Fire Department responds to every incident with a different approach depending on the circumstances. For example, in the case of an intense fire in a high-rise building, two to four fire engines are dispatched simultaneously with a ladder equipped engine regardless of the response districts. The following assumptions and decisions were made in carrying out this analysis:

1. The response area analysis of fire equipment allocation was based mainly on fire districts that have fire engines equipped with special features such as Ladder, Hazmat, Tanker, etc. These fire engines are not located in all fire districts, therefore the SFD usually dispatches these special fire engines to other fire districts during an emergency situation that requires these special fire engines.

2. The study analysis was limited to incidents within the response district of a fire station, as a majority of incidents occurs within the response district and this provide a valuable basis for analysis.
3. The analysis of response times assumed that the SFD's response team dispatches fire engines from the nearest fire station, but in reality, the type of fire engine dispatched to an incident is dependent on the type of incident. For example, in Saskatoon, dispatchers respond to a fire incident in an industry that generates toxic, unhealthful or damaging substance, with a "decontamination" fire engine to control the harmful emissions, which is located in FS #9. This means that, there are situations where fire engines dispatched to an incident location may not be directly dispatched from the nearest fire station.
4. The incidents used in the analysis to test the impact of blocked grade crossings were assumed to be normal emergencies not requiring many fire engines from different fire stations.
5. This research did not use any field work to collect data on actual response times and dispatch routes, although some research has been based on the field collection of actual response times and dispatch routes (Kolesar and Blum, 1973; Kolesar et al., 1975). The study did not consider concerns of the possibility of an unforeseen adverse consequence (e.g., a road accident). Instead, the study adopted the most recent approaches, using GIS techniques, and assumed dispatch routes and travel speeds.
6. The Saskatoon Fire Department does not keep records of their travel route and distance traveled to incidents, as is the case in New Zealand (Claridge and Spearpoint, 2013). A secure radio communication system is used by fire fighters driving to an incident to communicate with 911 call dispatchers to ensure that both sides can be up-to-date with any unforeseen changes in route that arise due to unexpected roadway events such as level crossing blockages, construction work zones, traffic accidents, roadways covered in snow, etc. These unforeseen delays in routes puts fire fighters in a difficult position to report the

increase in total response time accurately and quantitatively. For this reason, it was not appropriate to use response times reported by the Fire Department for a scientific analysis.

7. Two different situations were analyzed in Saskatoon to test the impact of blocked crossings on response time and the benefit of GCMS. Montgomery area is notable for blockages due to stationary trains, while Downtown Saskatoon normally experiences blockages due to slow moving trains. GCMS can be used to calculate the speed of trains and duration at each crossing due to a slow moving train. This additional information can be used to refine the choice of dispatch route.

#### **4.2. Survival Data Analysis**

Survival data analysis was used to develop simple statistical models that can predict the time window when there is a high risk of multiple fire incidents in a fire district that has only a primary fire engine, and when a fire district that has more than one fire engine can dispatch a secondary fire engine for the purpose of pre-emptive reallocation.

The survival time in this study is defined as the time between two successive incidents that occur in a single fire district within an hour. The study's unit for time analysis is minutes. This is because every minute in an emergency is crucial to saving lives.

In this study, the Kaplan-Meier test and the Cox proportional hazard model was used to develop the survival function and hazard function, respectively. The SAS Ver.9.4 was used to develop all the statistical models for the survival analysis.

Fire district #2 and fire district #8 were our supplier fire districts as they were the only fire districts with a secondary fire engine. We selected fire district #9 as our demand fire district. These three Saskatoon fire districts together recorded 6,571 incidents during the study period, 29% of the total for Saskatoon. In the case of the supplier fire districts, fire district # 2 had 5,237 incidents with 1,208 of these incidents defined as multiple incidents (23% of the district's total) and fire district #8 had 271 incidents (23 multiple incidents (8%). The demand fire district, fire district #9, had 1,063 incidents (141 multiple incidents (13%).

#### 4.2.1. Kaplan-Meier Estimator

The Kaplan-Meier (KM) estimator is a nonparametric estimate of the survival function  $S(t)$ , which is used to indicate the probability of surviving up to a certain time  $t$  (i.e., survival time). Suppose there are a set of events with unique time interval which can be interpreted as the observed survival times,  $t_1, \dots, t_k$ , where  $k$  is the number of distinct events under observation (an event is defined as the time interval between two successive incidents),  $n_j$  presents the number of chances that an event may be experienced up to a given time period  $t_j$ , and  $d_j$  is the number of occurrences of events experience during that period of time  $t_j$ , then the KM estimate at any given time  $t$  is given as;

$$\hat{S}_{(t)} = \prod_{j:t, j \leq t} \left[ 1 - \frac{d_j}{n_j} \right] \quad \text{Equation [4-1]}$$

As there is no event occurrence at  $t = 0$ , the Kaplan-Meier estimator is typically presented in the form of a step function that starts at 1 (100% chance of survival). The estimator then decreases as more and more events occur. In summary, the Kaplan-Meier estimator is an estimate of survival probability as a function of time (Efron, 1988).

The Kaplan-Meier estimator was used to provide an indication of the time periods when fire district #9 was most likely to experience multiple incidents and therefore need assistance from fire district #2 and/or fire district #8. Three time periods were considered as input variables: 1) time of the day (two categories were compared, peak hours (10 am to 11 pm) and non-peak hours (11 pm to 10 am)); 2) season of the year (four categories were compared, spring, summer, fall, and winter); and 3) day of the week (two categories were compared, weekdays with weekends).

The Log-Rank and Wilcoxon tests were used to decide whether the differences shown in the Kaplan-Meier estimator's results for the different time periods and different type of incident were significant at the 95% confidence level. Three goodness of fit tests were used: the likelihood ratio test, the score test and the Wald test (Lee and Wang, 2003). The 95% confidence level was used in all our analyses.



#### 4.2.2. Cox Proportional Hazards Model Estimation

The Cox hazards model shows the statistical relationship between the various input variables  $x_i$  (e.g., season of the year and type of incident) and the survival time between multiple incidents. The hazards models are developed to represent the risk of occurrence of multiple incidents in a particular fire district. The hazard at a period of time  $t_i$  is defined as:

$$h_i(t) = h_0(t) \times \exp\{\beta_1 X_{1i} + \beta_2 X_{i2} + \dots \dots \dots \beta_n X_{ik}\} \quad \text{Equation [4-2]}$$

*Taking natural logarithms of both sides:*

$$\ln \left\{ \frac{h_i(t)}{h_0(t)} \right\} = \beta_1 X_{1i} + \beta_2 X_{i2} + \dots \dots \dots \beta_n X_{ik} \quad \text{Equation [4-3]}$$

where,  $h_i(t)$  is the hazard at a given period of time  $t_i$ ,  $h_0(t)$  is the baseline hazard, and  $\beta_i$  is the risk of multiple incidents occurring in a fire district.  $\beta$  is also used to obtain the hazard ratios. If  $\beta_i = 0$ , the input variable  $x_i$  has no statistically significant relationship with the occurrence of multiple incidents in the subject fire district. If  $\beta_i \neq 0$ , the input variable  $x_i$  has a statistically significant relationship with the occurrence of multiple incidents.

If  $\beta_i$  is positive, the risk of an event occurrence due to the associated input variables is high. If  $\beta_i$  is negative, the risk of an event occurrence due to the associated input variables is low. The hazard ratio is the exponential of  $\beta_i$  and is defined as the relative hazard corresponding to a unit change in the associated input variables. As a result, if the hazard ratio of an input variable is less than 1, the input variable has little influence on the risk an event occurrence, but if the hazard ratio of an input variable is greater than 1, the input variable has considerable influence on the risk of event an occurrence (Xiaobao et al., 2012).

In this study, three separate Cox hazards models were developed to estimate the risk of multiple incidents, one model for the demand fire district (fire district #9) and one model for each of the two supplier fire districts (fire districts #2 and #8).

#### 4.3. Chapter Summary

To achieve the objectives of this research, two ArcGIS-based spatial data analyses tools were used. The tools were used to determine the impact of grade crossing blockages and the allocation of fire equipment on emergency response time. Two survival data analyses technique were used to

develop models that can predict the time window when there is a high risk of multiple fire incidents in a fire district that has only a primary fire engine. The data analyses tools were also used to ascertain when a fire district that has more than one fire engine can dispatch a secondary fire engine for the purpose of pre-emptive reallocation.

The two ArcGIS-based spatial data analyses were used to test the impact of GCMS on emergency response time for blockages due to stationary trains in Montgomery and slow moving trains in Saskatoon Downtown. These spatial analyses are service area analysis (SAA) and Network analysis (NA). The service area analysis was used to investigate the changes in a fire station's service area with or without a grade crossing blockage. The service area was used to develop four-minute response time service area for fire station's equipped with special features. The network analysis (NA) was used to investigate the network route taken by dispatchers when there is train blockage and no blockage at grade crossings with GCMS) and without GCMS. The network analysis was used to demonstrate the benefit of installing a grade crossing monitoring system to improve emergency response time.

The Kaplan-Meier test and the Cox proportional hazard model were used to develop models to predict the time window when there is a high risk of multiple fire incidents in fire district #9 and also to determine the possible time window for fire engine pre-emptive reallocation from FS #2 or FS #8 to FS #9 to handle multiple fire incidents in fire district #9. The Cox proportional hazard model was used to predict variables such as the specific time of the day, season of the year, and type of fire incident that may be associated with a high risk of multiple incidents in fire district #9 and an overlapping time window of lower risk of multiple simultaneous incidents in fire districts #2 and #8.

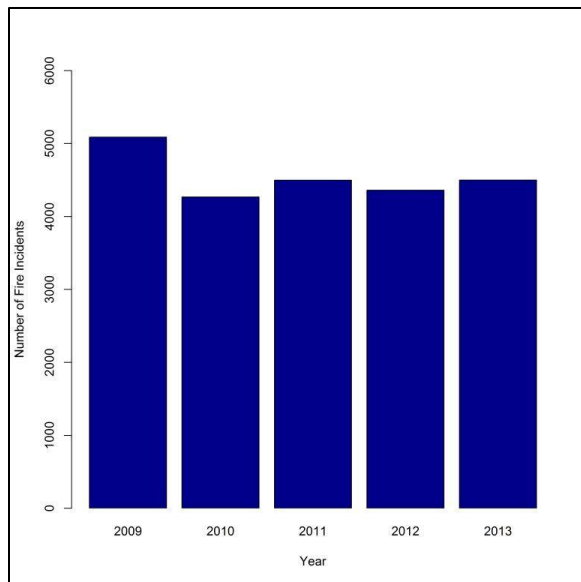
## CHAPTER 5: ANALYSIS RESULTS

### 5.1. Descriptive Data Analysis

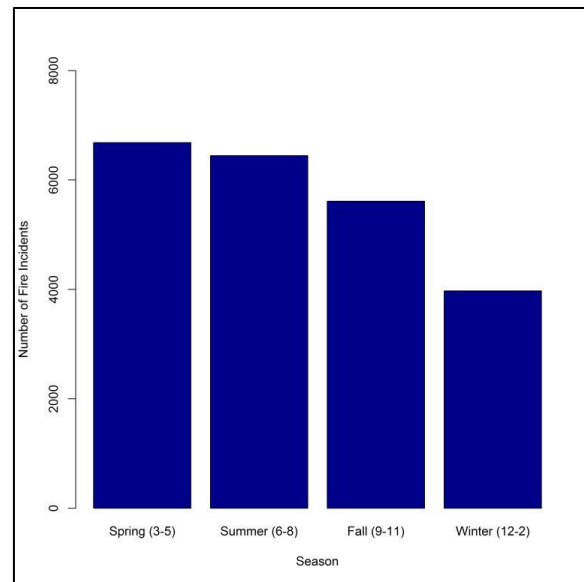
The integrated incident data were converted into multiple comma-separated values (csv) files and imported into R-Language to generate various charts to represent the trend and nature of the data received.

#### 5.1.1. Incident Statistics

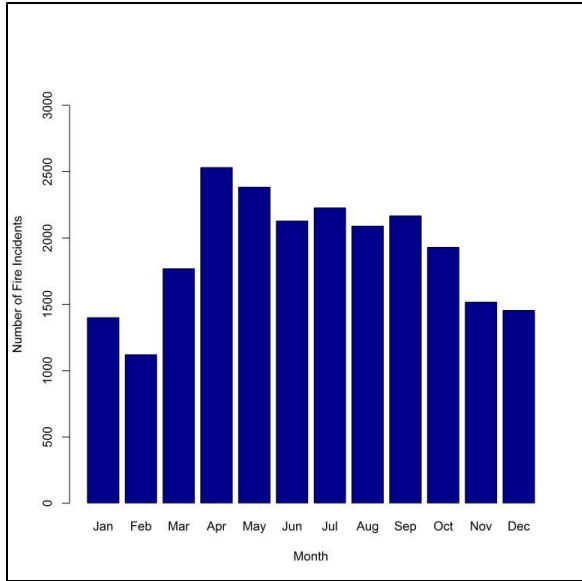
The bar plot in **Figure 5-10a** and **5-10b** shows the total number of incidents by year and season with a steady trend from 2009 to 2013. There were an average of 4,542 incidents per year with fewer incidents recorded in winter. **Figure 5-10c** shows April and May as the peak months for incidents recorded. The bar and clock plot in **Figure 5-10d** and **5-10e** shows incident by day of week and hour of the day. Most incidents occurred between 1100hrs and 2200hrs.



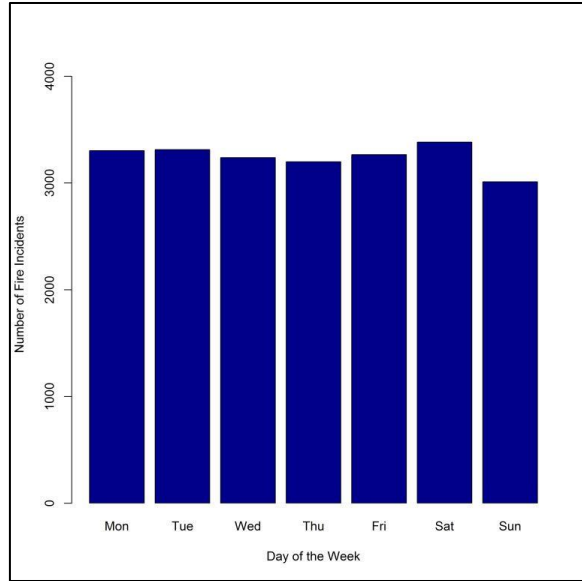
(a)



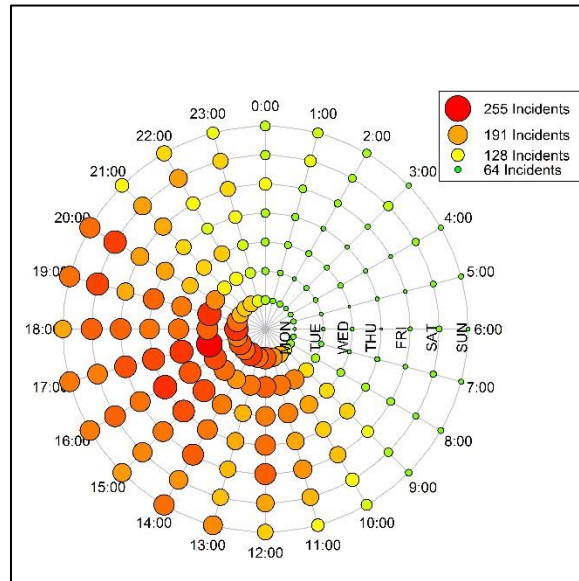
(b)



(c)



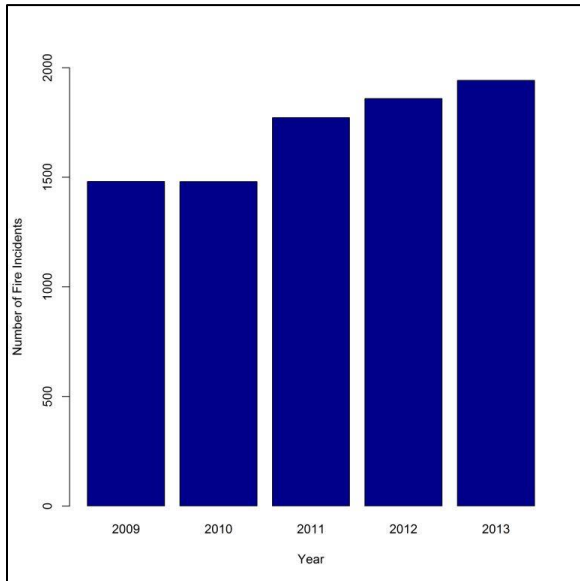
(d)



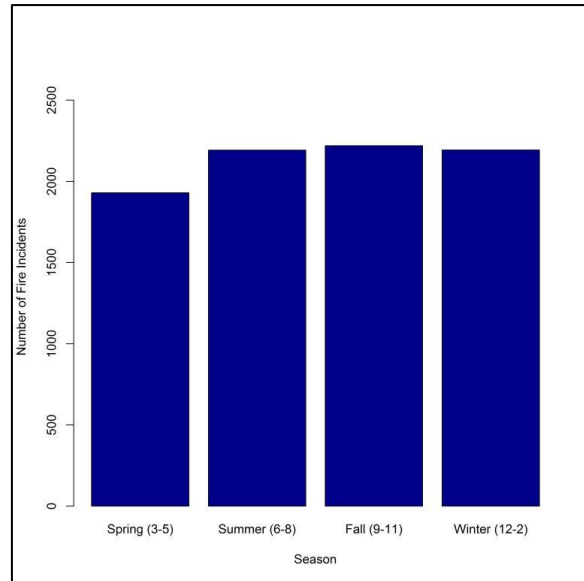
(e)

**Figure 5-10. Total Number of Incidents by (a) Year (b) Season (c) Month (d) Day of Week and (e) Hour of Day**

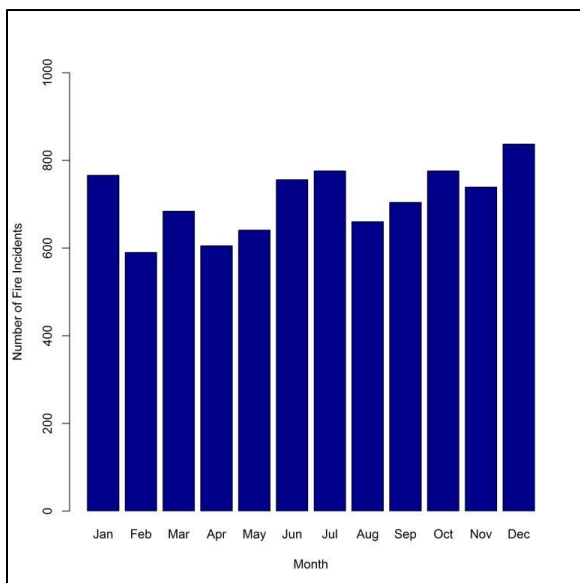
Alarm incidents recorded an increasing trend from 2010 to 2013 as shown in **Figure 5-11a** with an average of 1,707 incidents per year. There were no clear peak seasons for alarm incidents. **Figure 5-11c** and **5-11d** show no clear peak number in Alarm incidents per month and days of week. **Figure 5-11e** shows clock plot of Alarm incident by hour of the day. Most incidents occurred between 10am and 9pm



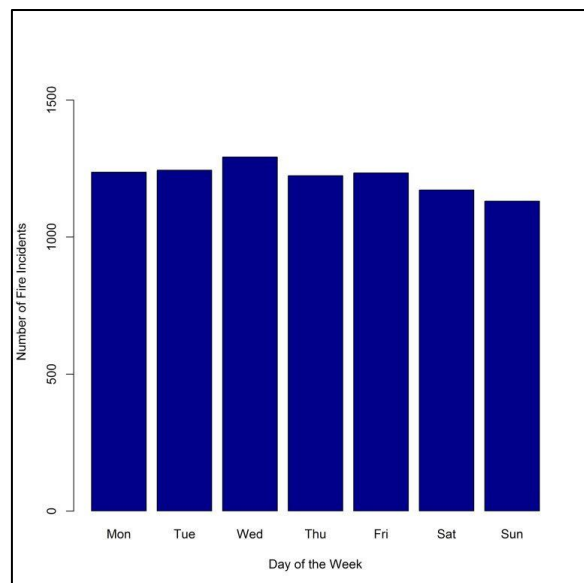
(a)



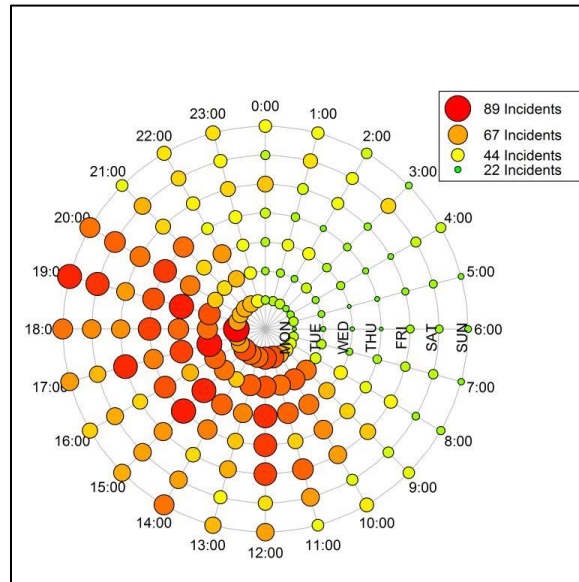
(b)



(c)



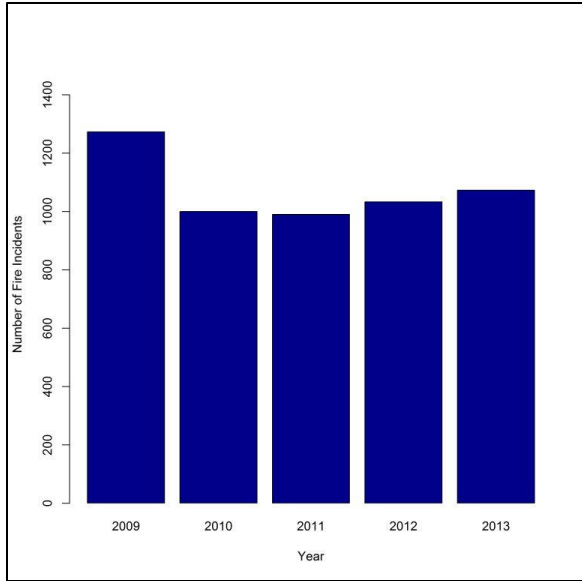
(d)



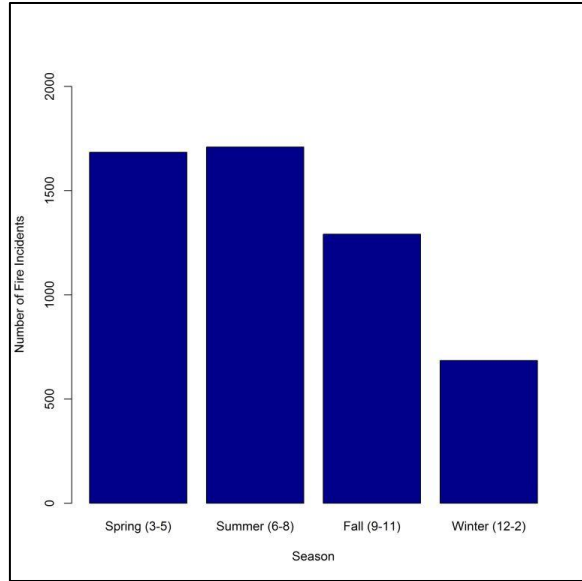
(e)

**Figure 5-11. Alarm Reported Incidents by (a) Year (b) Season (c) Month (d) Day of Week (e) Hour of Day**

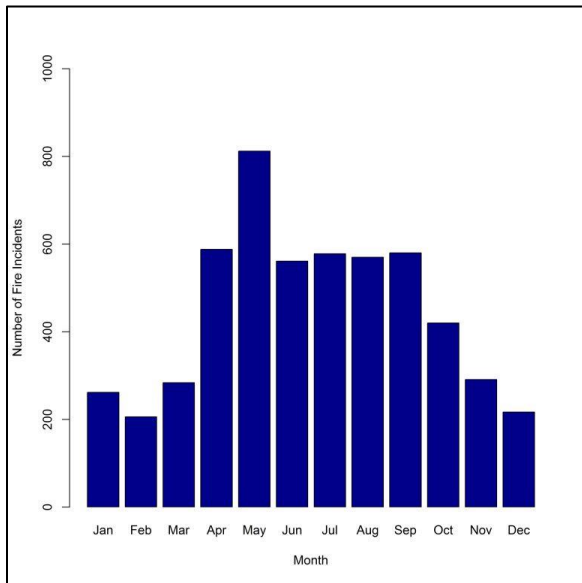
As shown in **Figure 5-12a** 2009 recorded the highest number of incidents reported as Fire with an average of 1,073 incidents per year. Spring and summer season recorded the highest number of incidents. **Figure 5-12c** shows that May recorded the highest number of Fire reported incident. Saturday and Sunday recorded the highest number of incidents as shown in **Figure 5-12d**. **Figure 5-12e** shows clock plot of Fire incident by day of week and hour of the day. Most incidents occurred between 8am and 11pm.



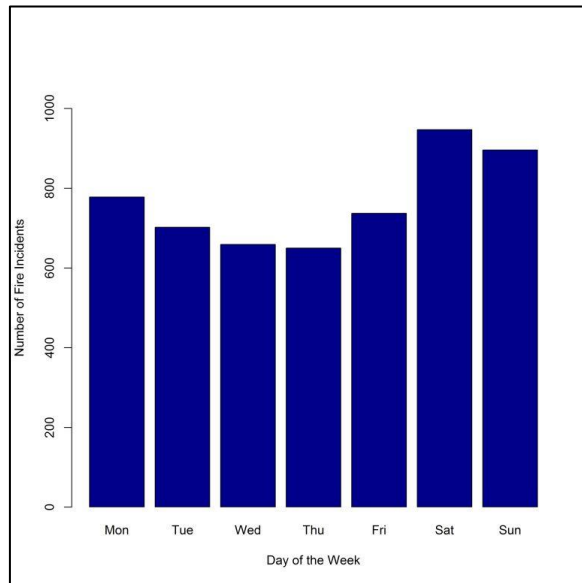
(a)



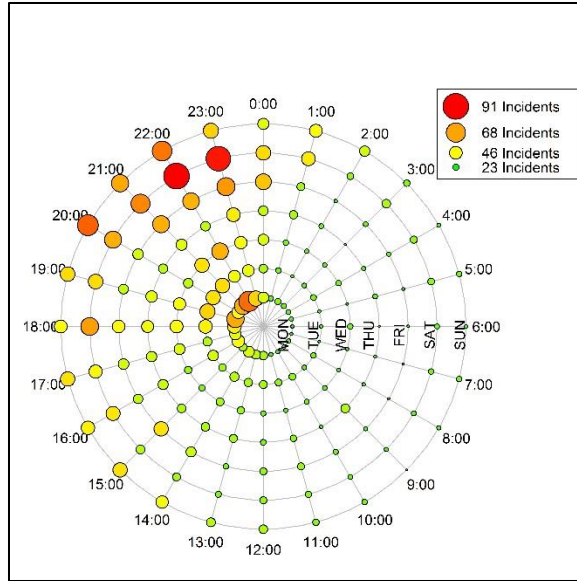
(b)



(c)



(d)

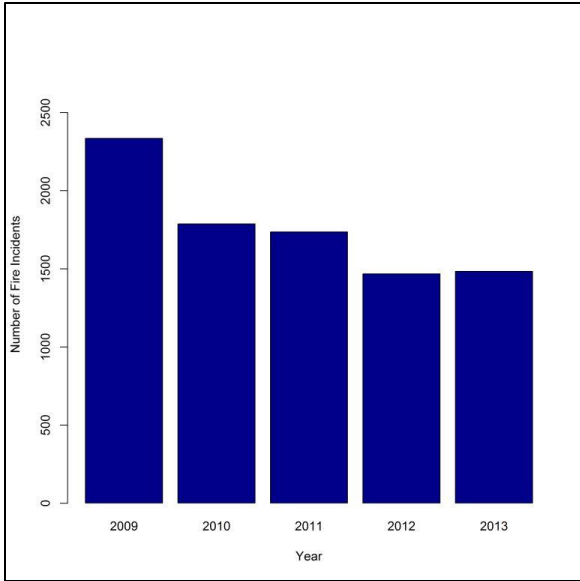


(e)

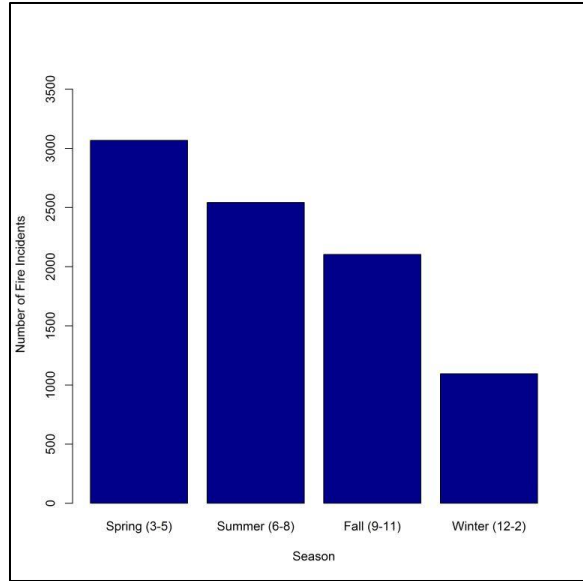
**Figure 5-12. Fire Reported Incidents by (a) Year (b) Season (c) Month (d) Day of Week and (e) Hour of Day**

As shown in **Figure 5-13a** there was a decrease in trend from 2009 to 2013 for Dangerous goods incidents with an average of 1,761 incidents per year. Spring shows the highest number of incidents recorded for Dangerous goods incident. **Figure 5-13c** shows that April recorded the highest number of Dangerous goods Incidents. There were few incidents recorded on Sundays in **Figure 5-13d**. **Figure 5-13e** shows clock plot of incident by hour of the day. Most dangerous goods incidents occurred between 11am and 8pm.

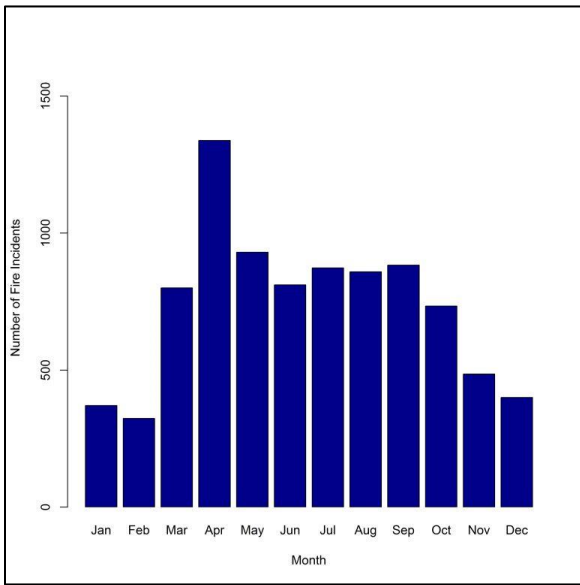




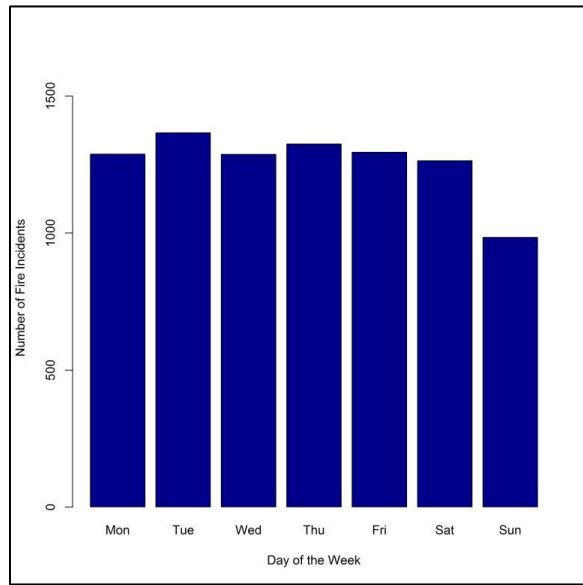
(a)



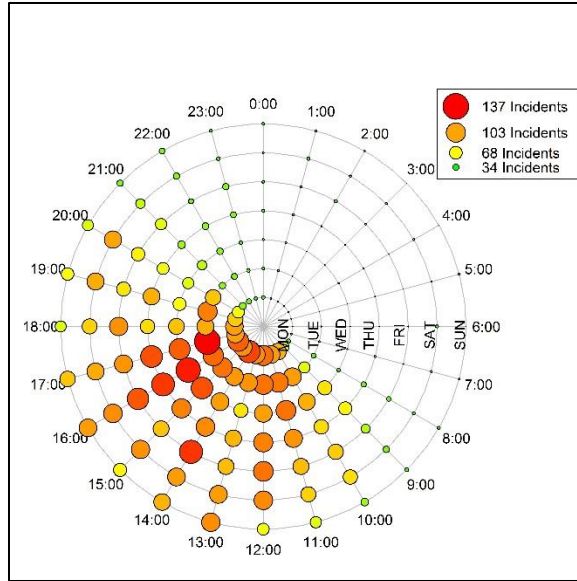
(b)



(c)



(d)



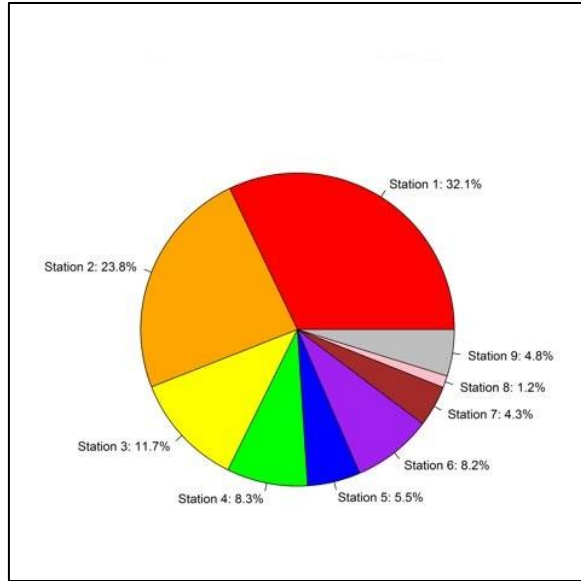
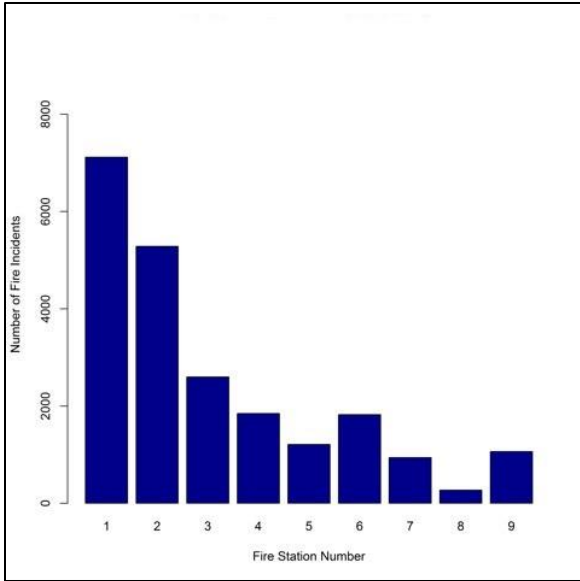
(e)

**Figure 5-13. Dangerous Goods Reported Incidents by (a) Year (b) Season (c) Month (d) Day of Week and (e) Hour of Day**

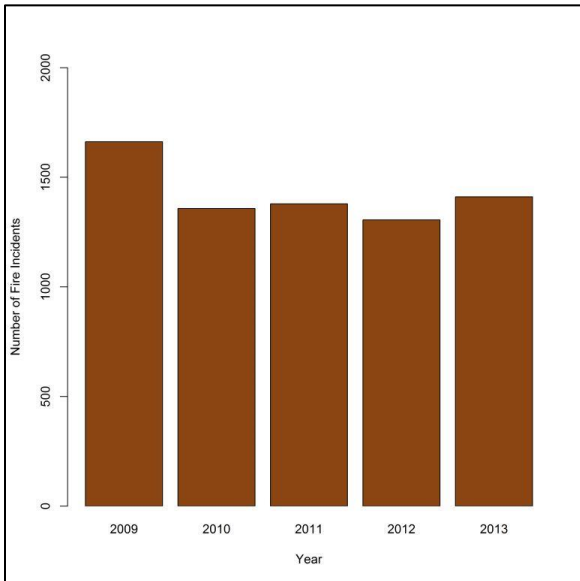
### 5.1.2. Incident Statistics per Fire District

The total number of incidents response per fire district are shown in **Figure 5-14**. There were at an average of 2,523 incidents per fire district. Fire district #1 recorded the highest number of incidents representing 32.1% of the total incidents.

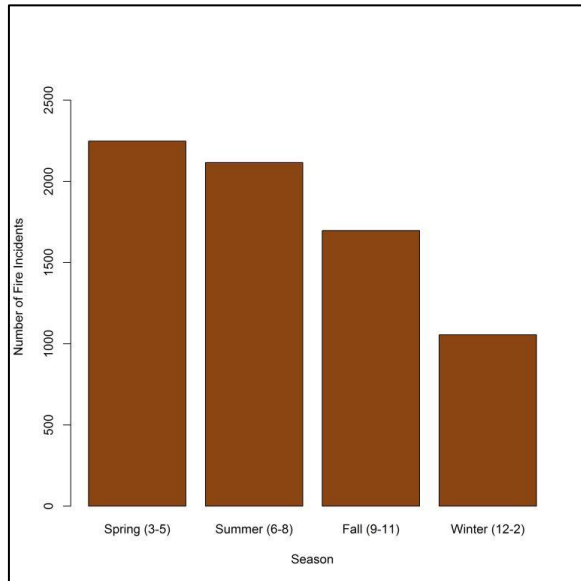
**Figure 5-15a** and **5-15b** shows fire district #1 incidents by year and season. There were at an average of 1,423 incidents per year with fewer incidents recorded in winter. As shown in **Figure 5-15c** the month of April recorded the highest number of incidents and fewer incidents in February. There was a steady trend in the number of incidents by day of the week. **Figure 5-15e** shows most incidents occurred between the hours from 9am to 8pm.



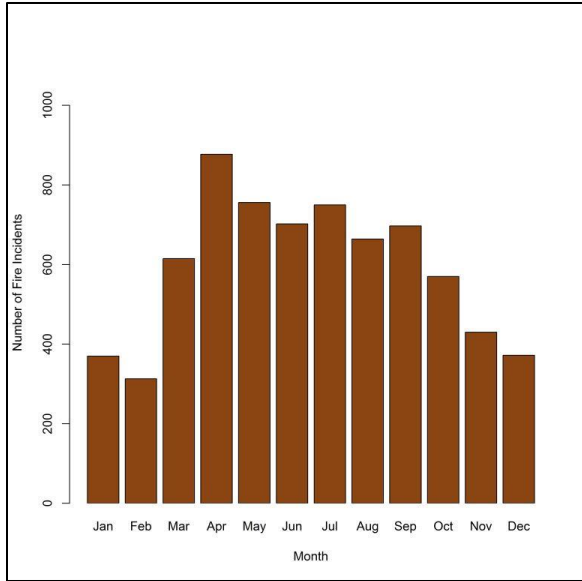
**Figure 5-14. Number of Incidents Response per Fire District**



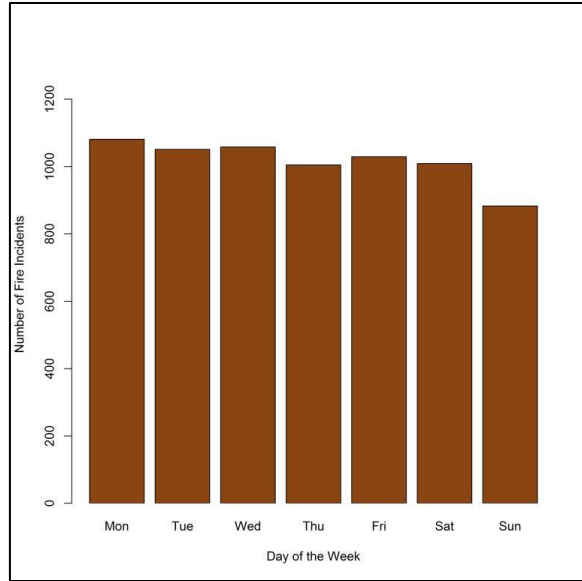
**(a)**



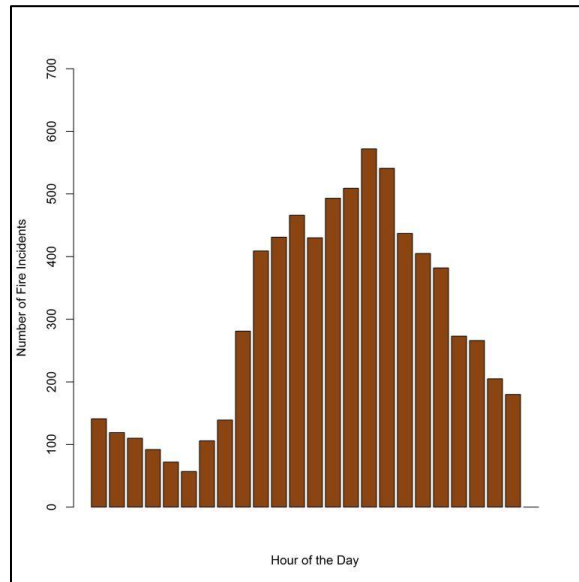
**(b)**



(c)



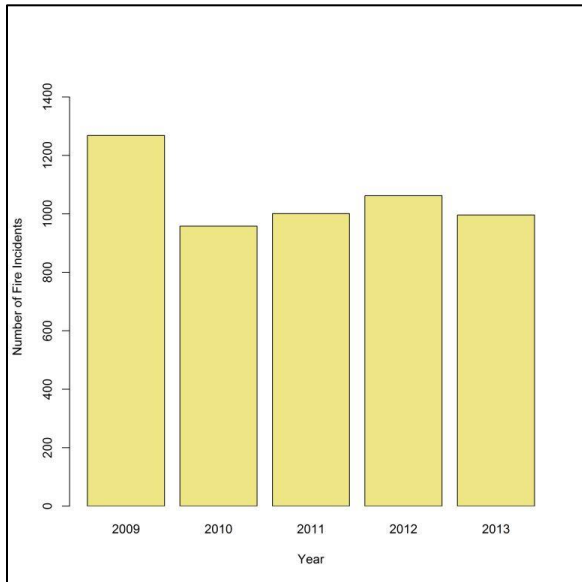
(d)



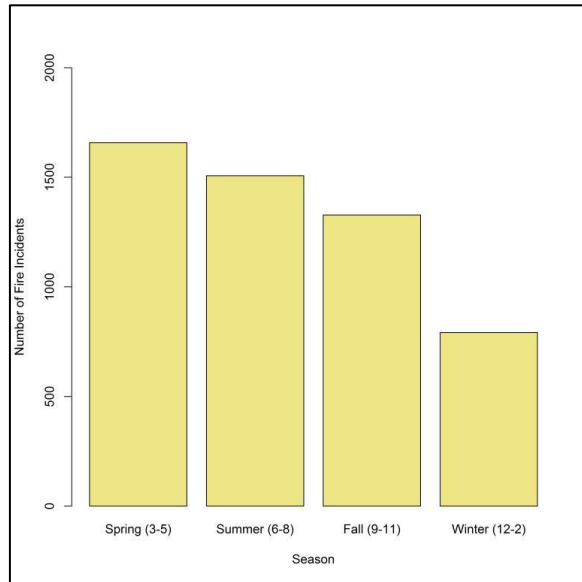
(e)

**Figure 5-15. Fire District #1 Incidents by (a) Year (b) Season (c) Month (d) Day of Week and (e) Hour of Day**

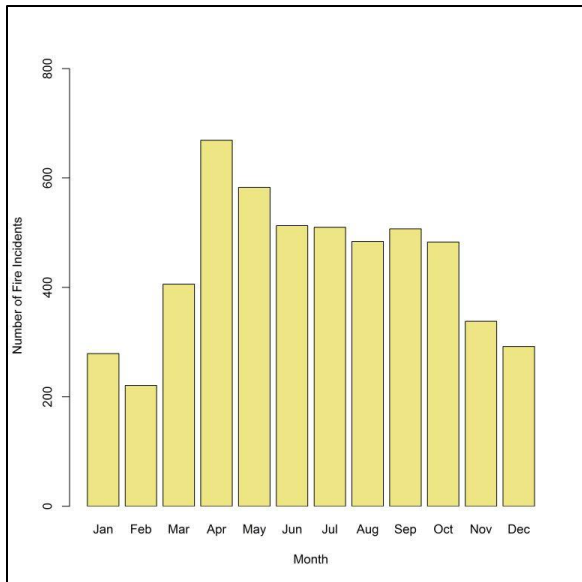
As shown in **Figure 5-16a**, fire district #2 recorded a steady trend from 2010 to 2013 with an average of 1,057 incidents per year. There were fewer incidents in winter compared to other seasons. **Figure 5-16c** shows the Month of April with the highest number of incidents. There was a steady trend in the number of incidents by day of the week. **Figure 5-16e** shows that most incidents in fire district #2 occurred between 10am to 9pm.



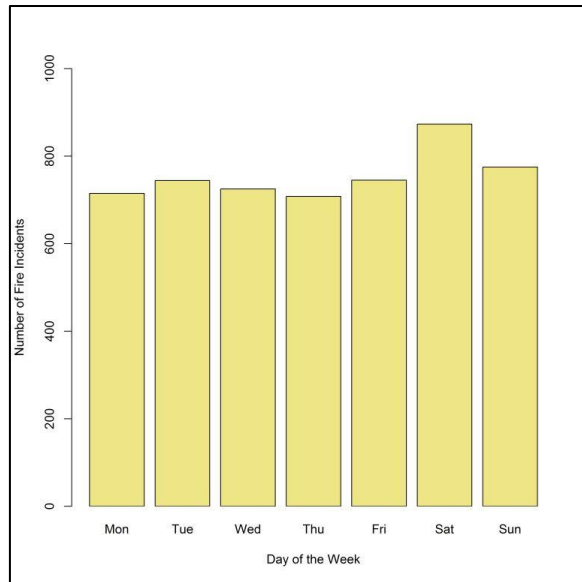
(a)



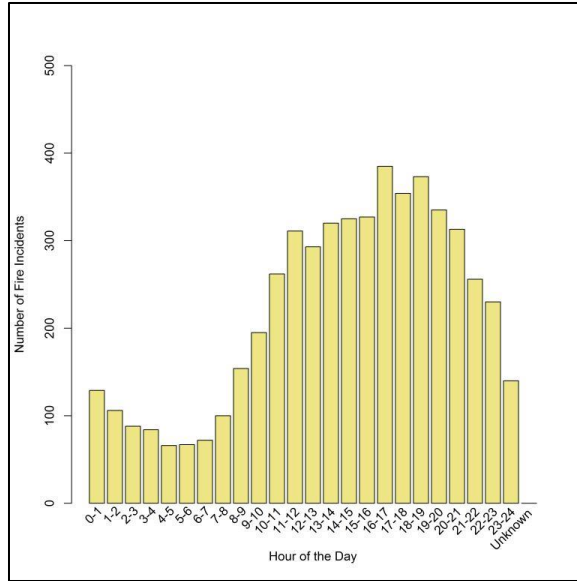
(b)



(c)



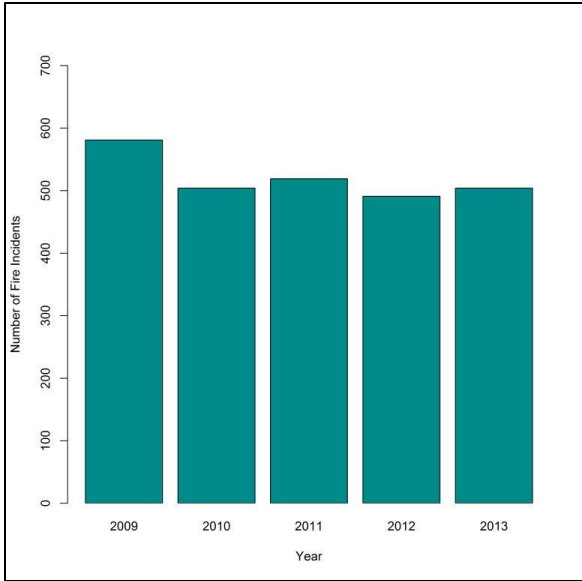
(d)



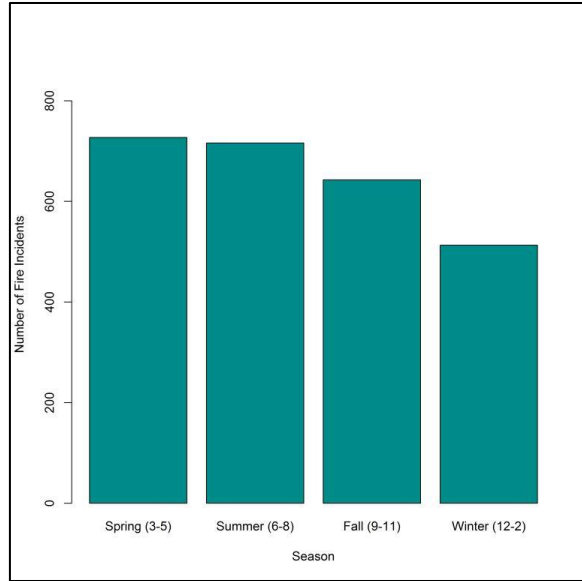
(e)

**Figure 5-16. Fire District #2 Incidents by (a) Year (b) Season (c) Month (d) Day of Week and (e) Hour of Day**

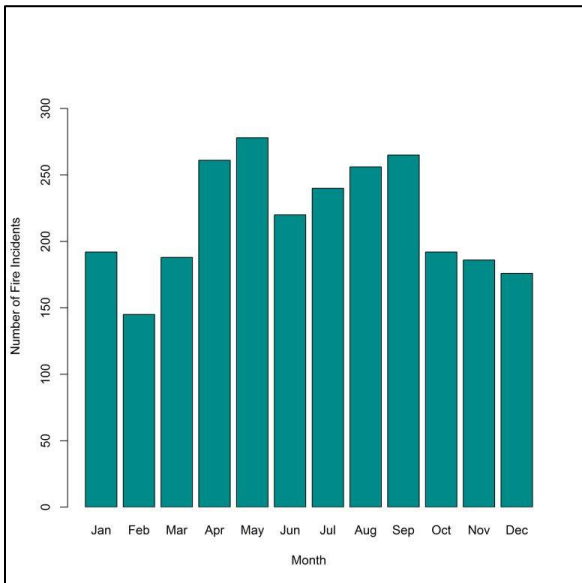
**Figure 5-17a** shows a steady trend from 2009 to 2013 and an average of 519 incidents per year in fire district #3. There were fewer incidents in winter compared to other seasons. **Figure 5-17c** shows the April and May recorded the highest number of incidents. There was a steady trend in the number of incidents by day of the week as shown in **Figure 5-17d**. **Figure 5-17e** shows that most incidents occurred between 9am to 11pm.



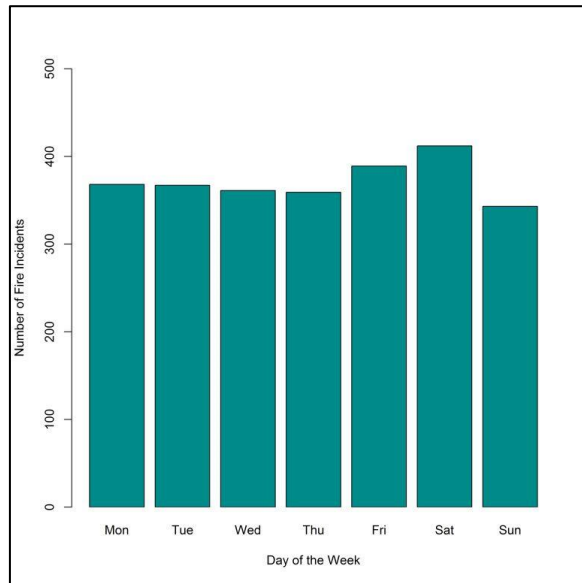
(a)



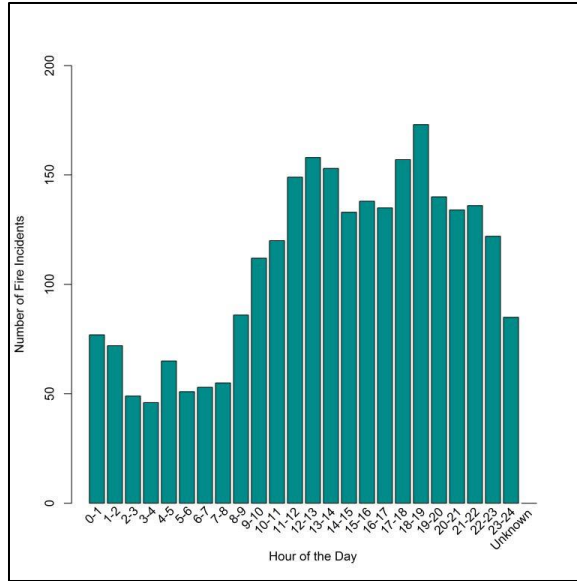
(b)



(c)



(d)

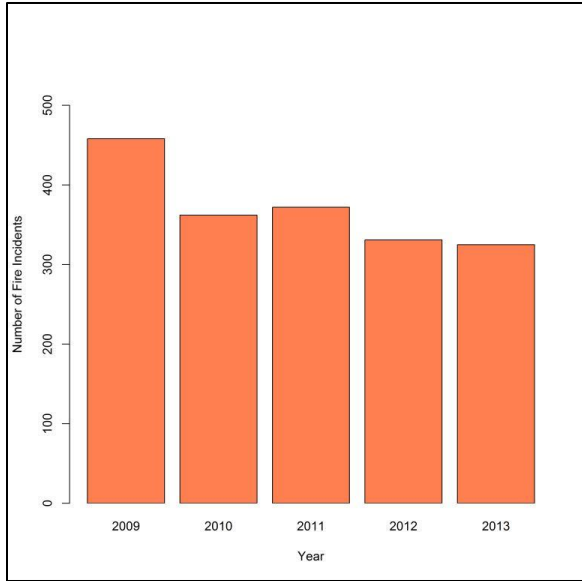


(e)

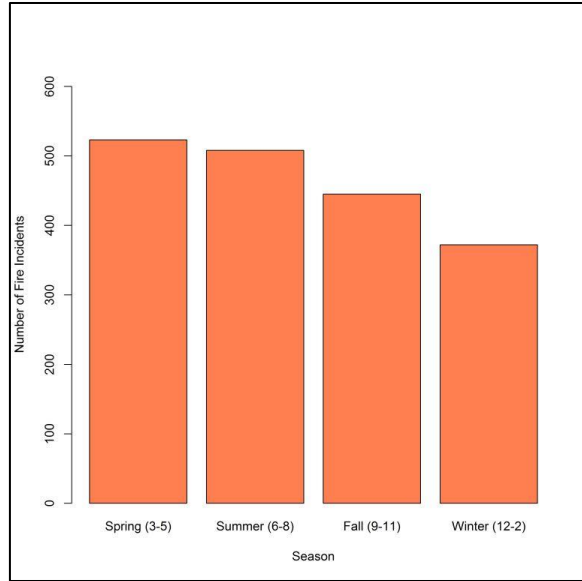
**Figure 5-17. Fire District #3 Incidents by (a) Year (b) Season (c) Month (d) Day of Week and (e) Hour of Day**

As shown in **Figure 5-18a**, fire district # 4 recorded a steady trend from 2010 to 2013 with an average of 370 incidents per year. There were fewer incidents in winter compared to other seasons. **Figure 5-18c** shows the Month of April with the highest number of incidents. There was a steady trend in the number of incidents by day of the week. **Figure 5-18e** shows that most incidents in fire district #4 occurred between 8am to 9pm.

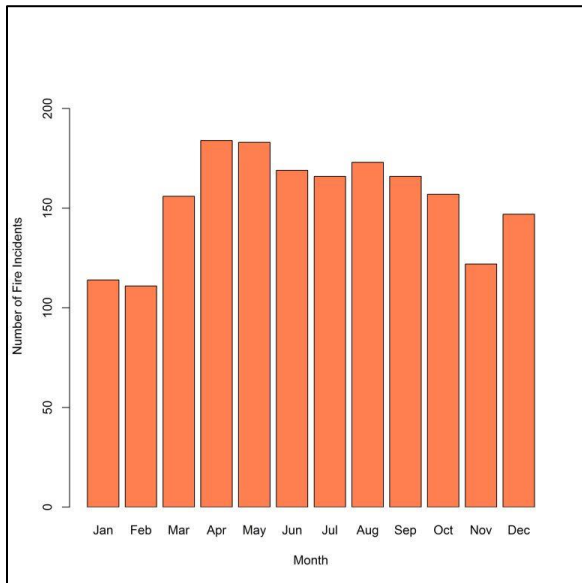




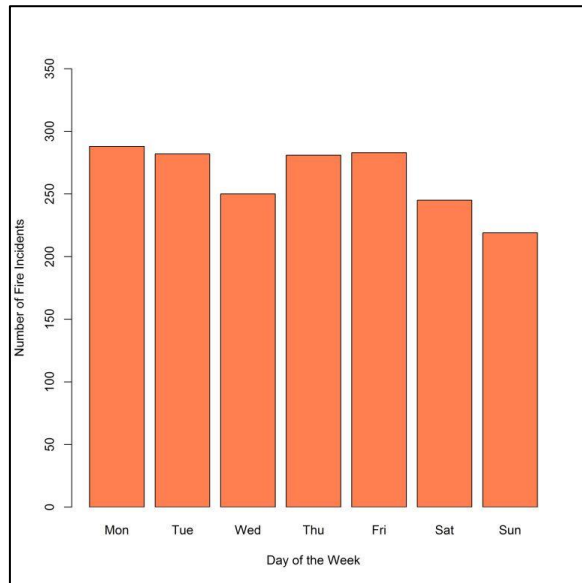
(a)



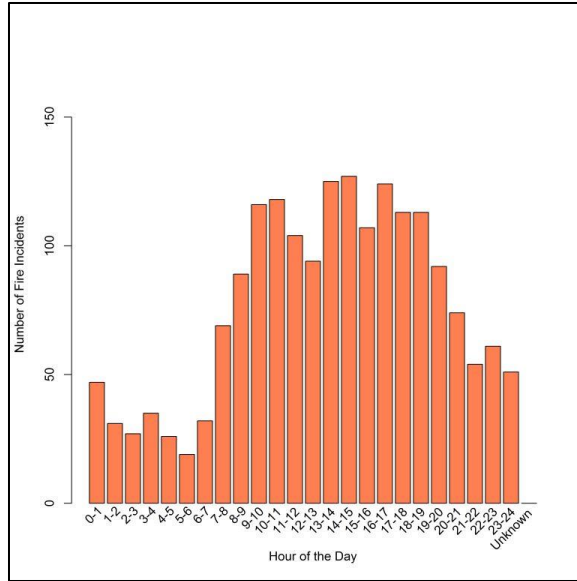
(b)



(c)



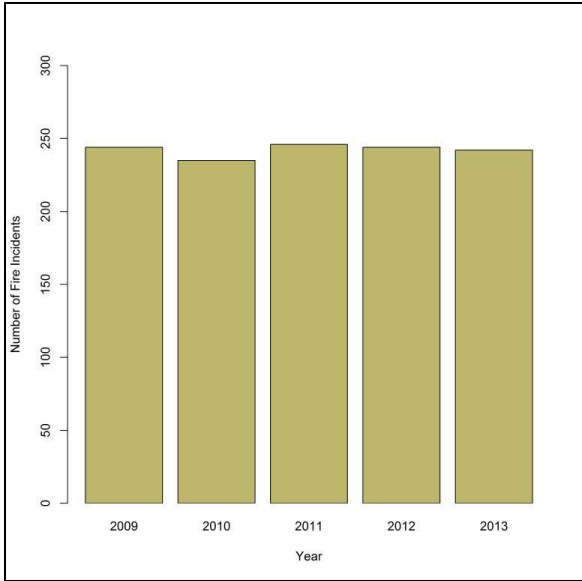
(d)



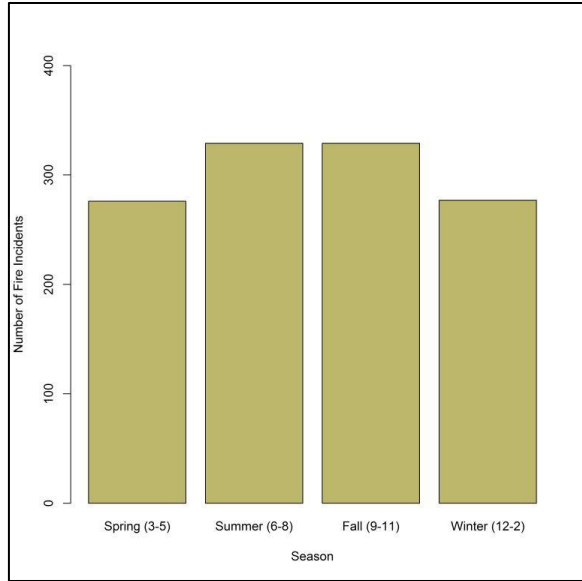
(e)

**Figure 5-18. Fire District #4 Incidents by (a) Year (b) Season (c) Month (d) Day of Week and (e) Hour of Day**

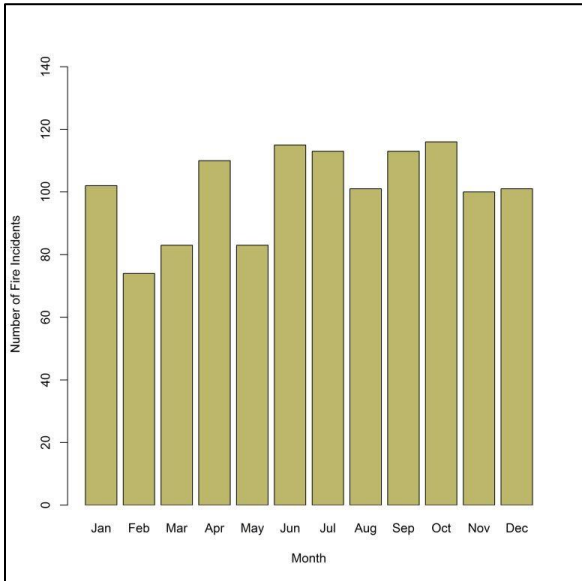
**Figure 5-19a** shows a steady trend from 2009 to 2013 and an average of 242 incidents per year in fire district #5. Summer and fall recorded the highest number of incidents compared to other seasons. **Figure 5-19c** shows a steady trend in number of incidents by months. Tuesday and Wednesday recorded the highest number of incidents compared to other days of the week. **Figure 5-19e** shows that most incidents occurred between 9am to 12am.



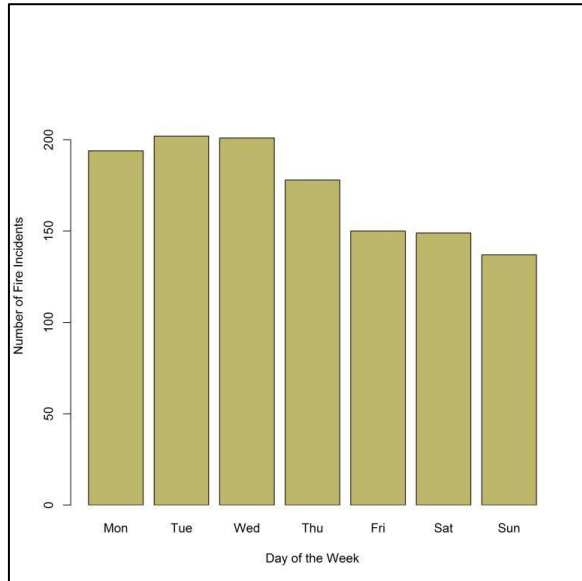
(a)



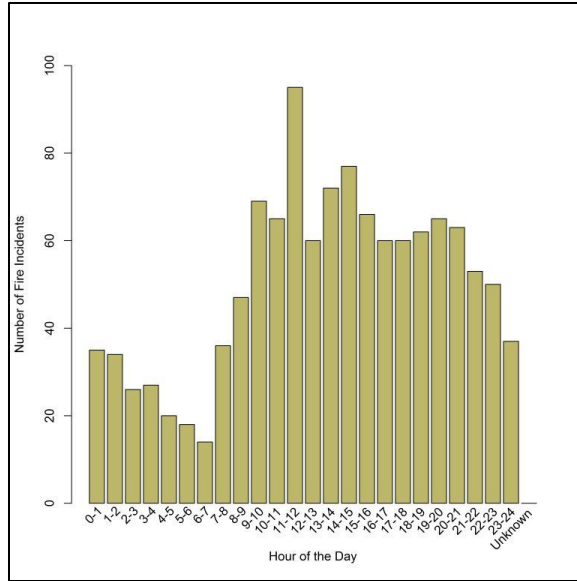
(b)



(c)



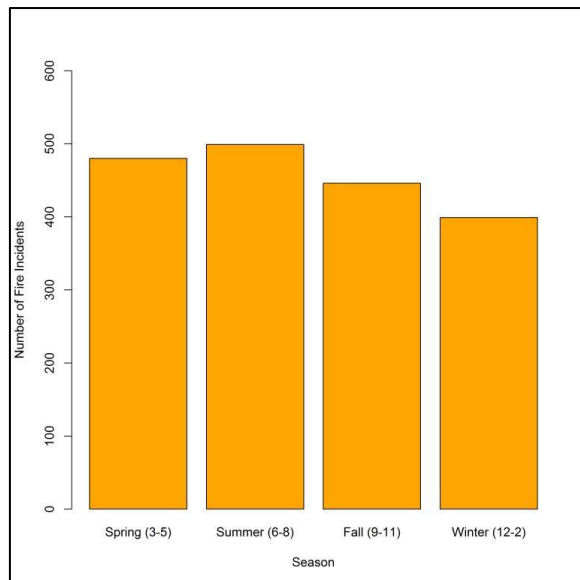
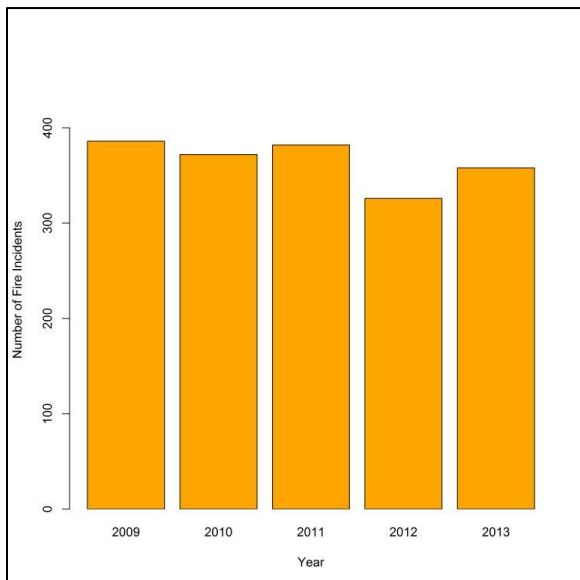
(d)



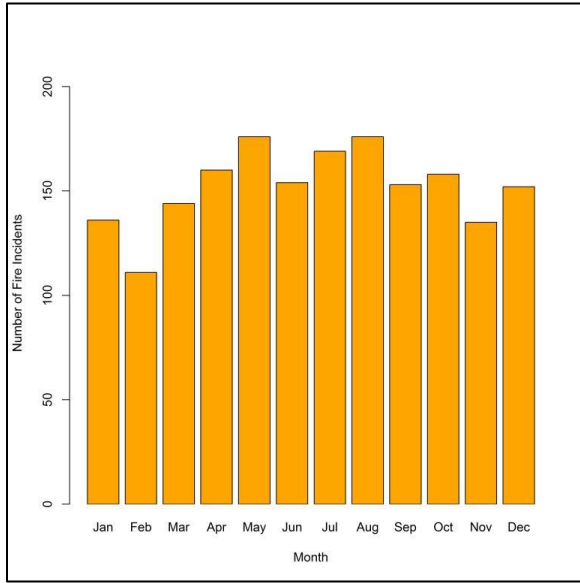
(e)

**Figure 5-19. Fire District #5 Incidents by (a) Year (b) Season (c) Month (d) Day of Week and (e) Hour of Day**

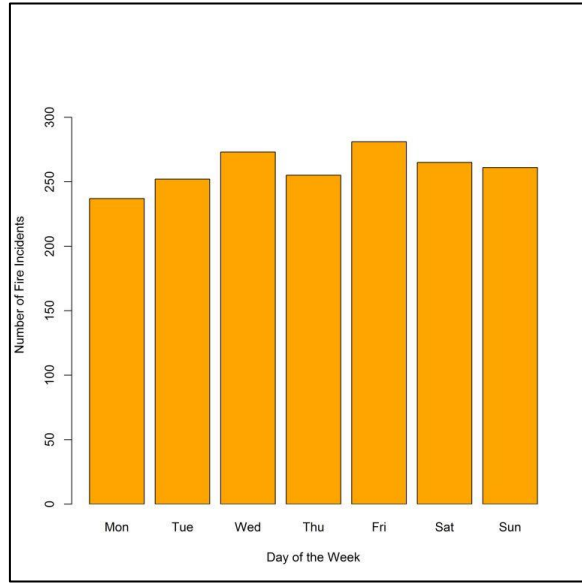
**Figure 5-20a** shows a steady trend from 2009 to 2013 and an average of 364 incidents per year for fire district #6. Spring and summer recorded the highest number of incidents compared to other seasons. **Figure 5-20c** shows a steady trend in the number of incidents by month and by day of the week. **Figure 5-20e** shows that most incidents in fire district #6 occurred between 11am to 10pm.



(a)

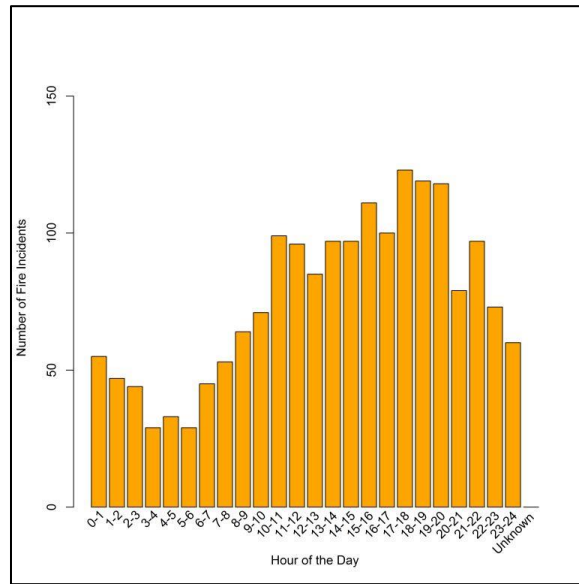


(b)



(c)

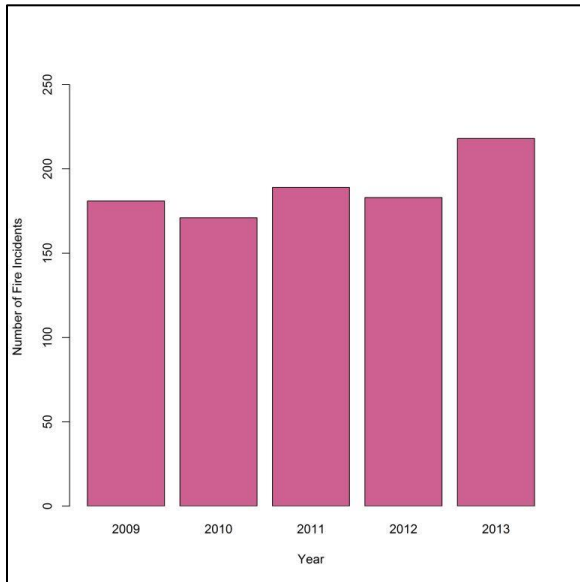
(d)



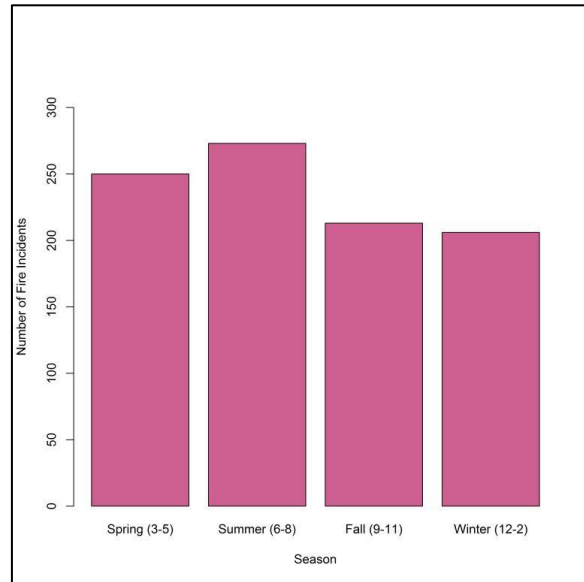
(e)

**Figure 5-20. Fire District # 6 Incidents by (a) Year (b) Season (c) Month (d) Day of Week and (e) Hour of Day**

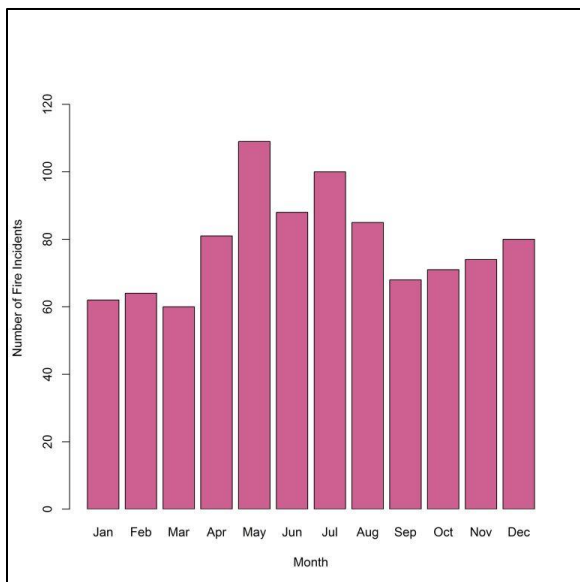
As shown in **Figure 5-21a**, 2013 recorded the highest number of incidents and an average of 188 incidents per year in fire district #7. Spring and summer recorded the highest number of incidents compared to other seasons. **Figure 5-21c** shows May and July recorded the highest number of incidents. There were fewer incidents recorded on Sunday compared to other days of the week. **Figure 5-21e** shows that most incidents occurred between 8am to 11pm.



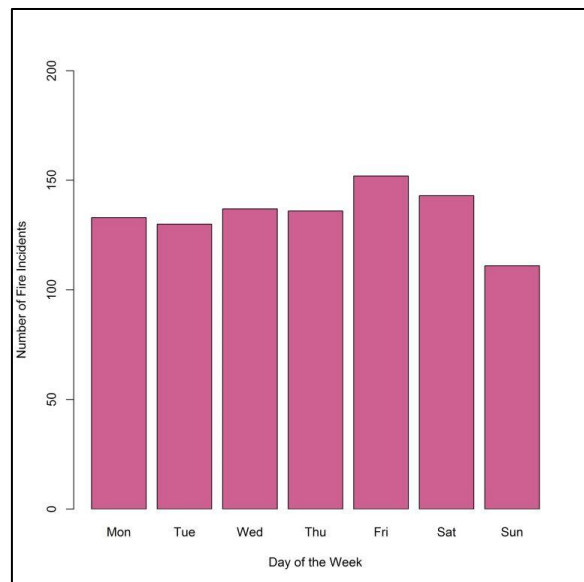
(a)



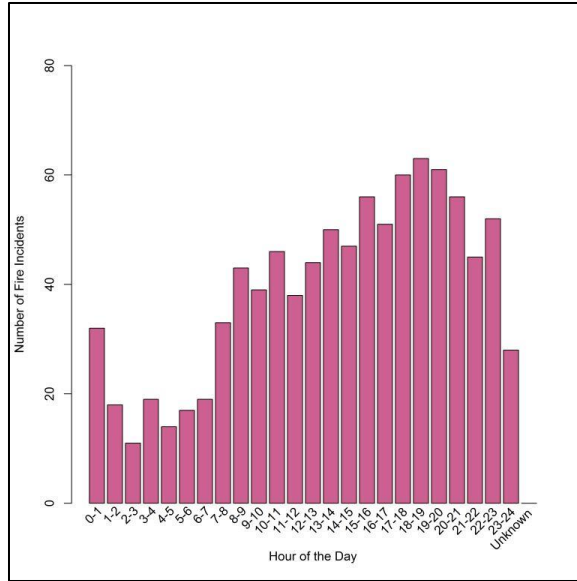
(b)



(c)



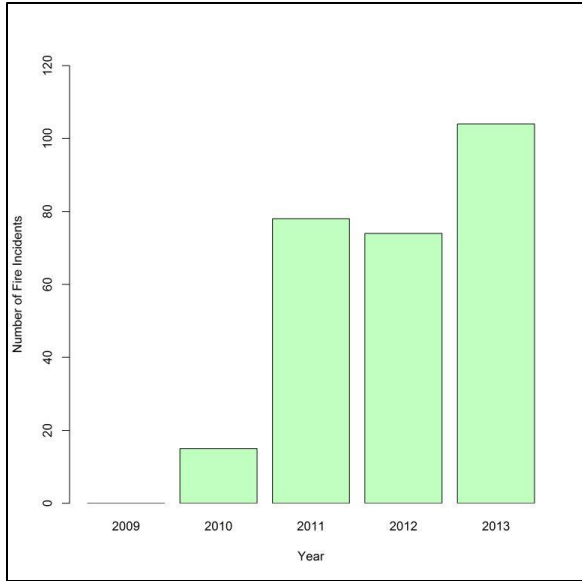
(d)



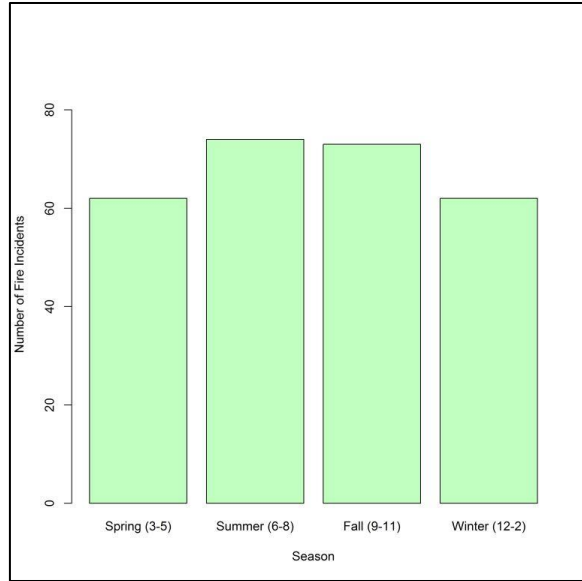
(e)

**Figure 5-21. Fire District #7 Incidents by (a) Year (b) Season (c) Month (d) Day of Week and (e) Hour of Day**

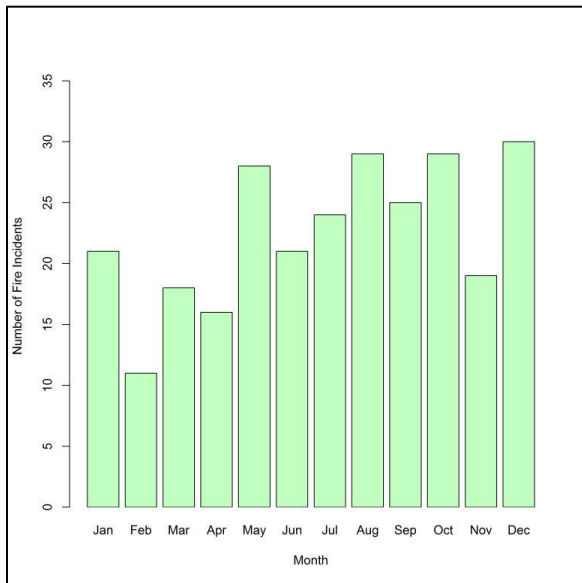
As shown in **Figure 5-22a** 2013 recorded the highest number of incidents and an average of 54 incidents per year for fire district #8. Summer and fall recorded the highest number of incidents compared to other seasons. **Figure 5-22c** shows May, August, October and December recorded the highest number of incidents. **Figure 5-22d** shows Monday, Thursday and Sunday recorded the highest incidents. **Figure 5-22e** shows that most incidents in fire district #8 occurred between 8am to 11pm.



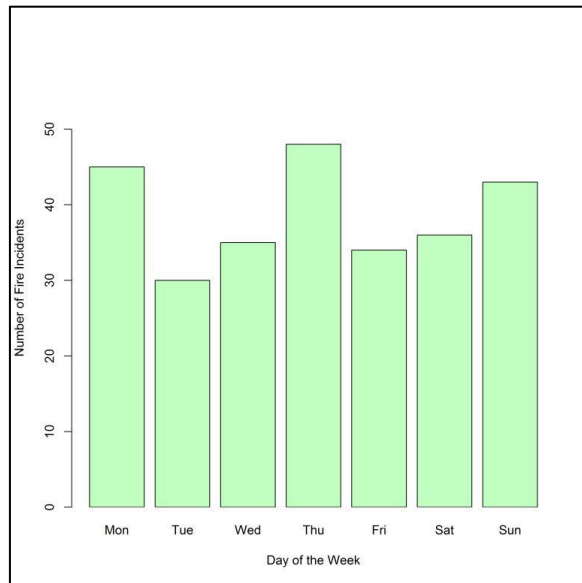
(a)



(b)

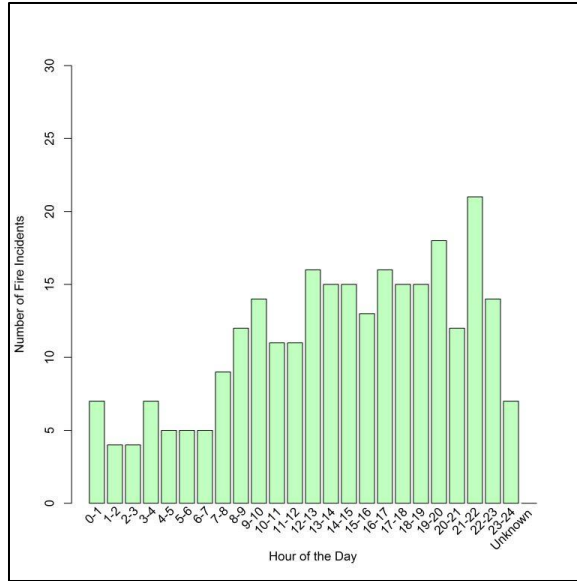


(c)



(d)

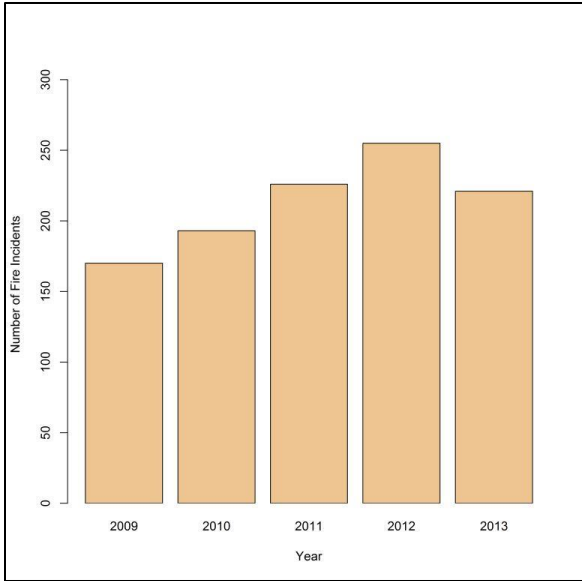




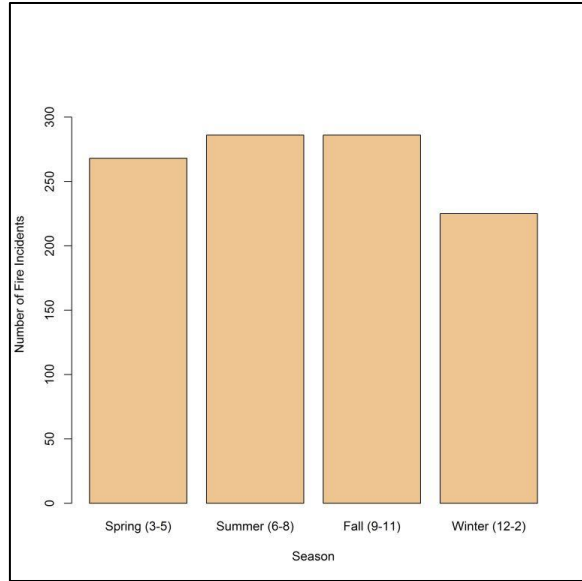
(e)

**Figure 5-22. Fire District # 8 Incidents by (a) Year (b) Season (c) Month (d) Day of Week and (e) Hour of Day**

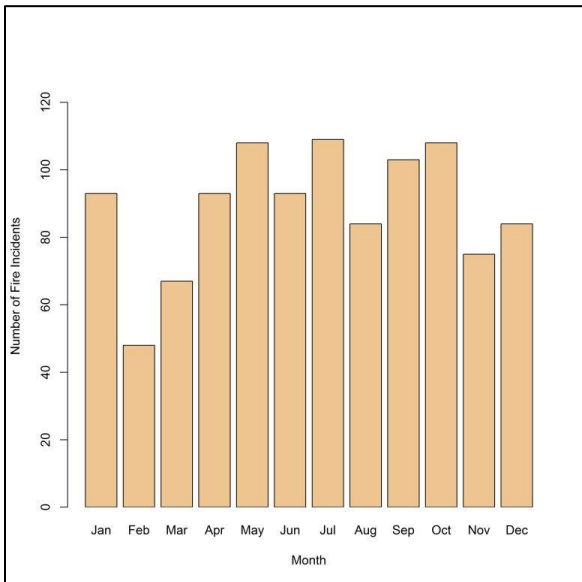
As shown in **Figure 5-23a**, there was an increasing trend in incidents from 2009 to 2013 and an average of 213 incidents per year in fire district #9. Summer and fall recorded the highest number of incidents compared to other seasons. **Figure 5-23c** shows no clear peak months in number of incidents recorded. There was a steady trend in the number of incidents by days of the week. **Figure 5-23e** shows that most incidents occurred between 9am to 12am.



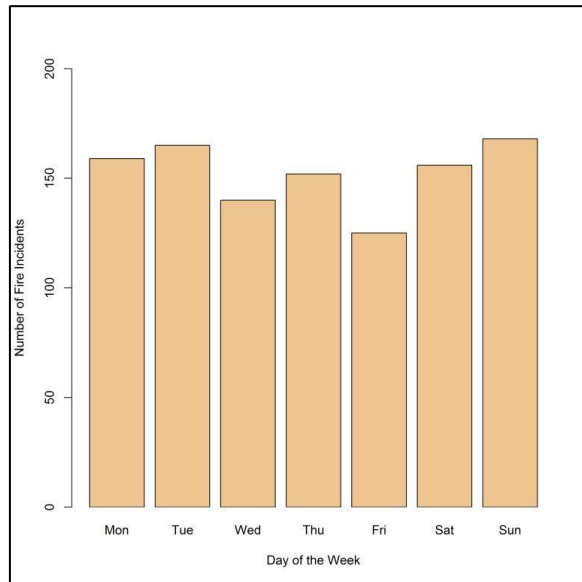
(a)



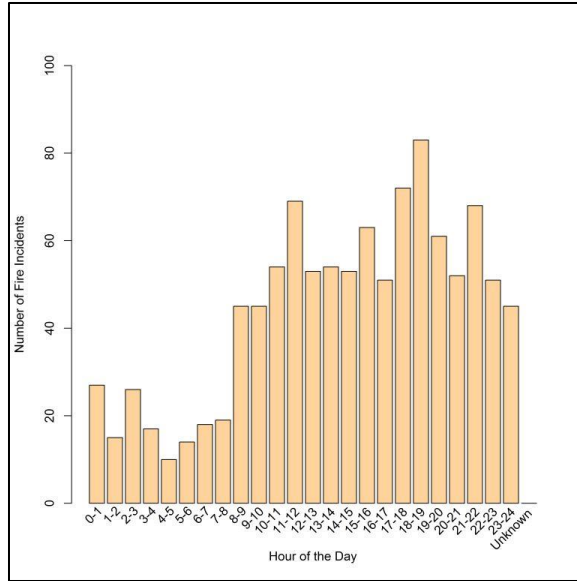
(b)



(c)



(d)



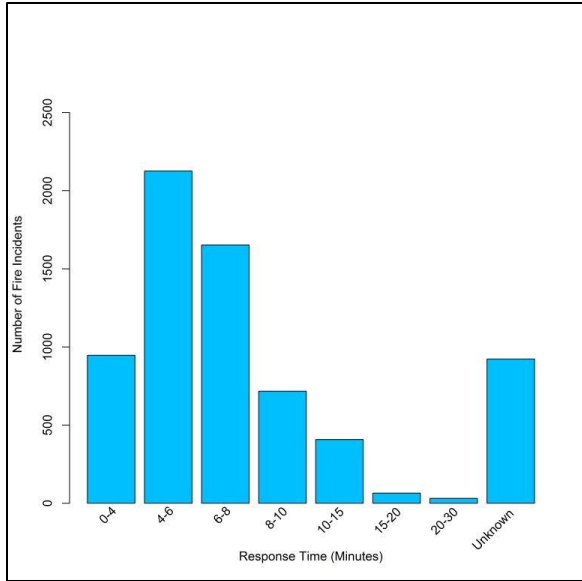
(e)

**Figure 5-23. Fire District #9 Incidents by (a) Year (b) Season (c) Month (d) Day of Week and (e) Hour of Day**

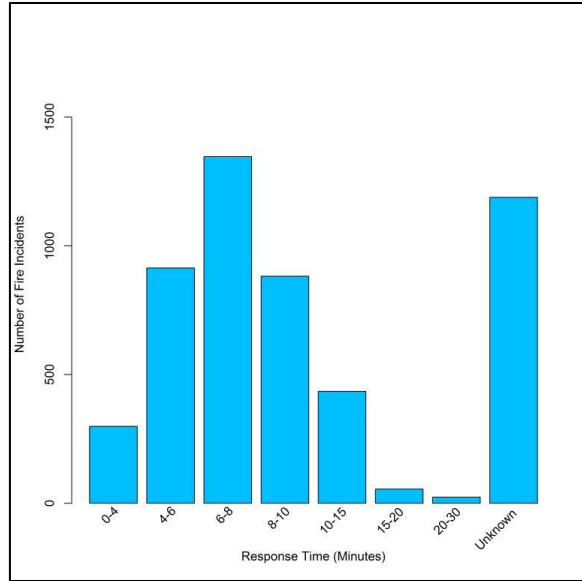
**5.1.3. Response Time Statistics per Fire District**

The response time shown in **Figure 5-24a** for most incidents in fire district #1 was 4 - 6 minutes. The number of incidents recorded within the four-minute target response time was 1,170 (16%). **Figure 5-24b** shows the response time for most incidents in fire district #2 was 6 - 8 minutes. The number of incidents recorded within the four minutes’ target response time’ was 432 (8%).

As shown in **Figure 5-25a**, the response time for most incidents in fire district #3 was 4 - 6 minutes. The number of incidents recorded within the four-minute target response time was 221 (8%). **Figure 5-25b** shows the response time for most incidents in fire district #4 was 6 - 8 minutes. The number of incidents recorded within the four minutes’ target response time was 126 (6%).

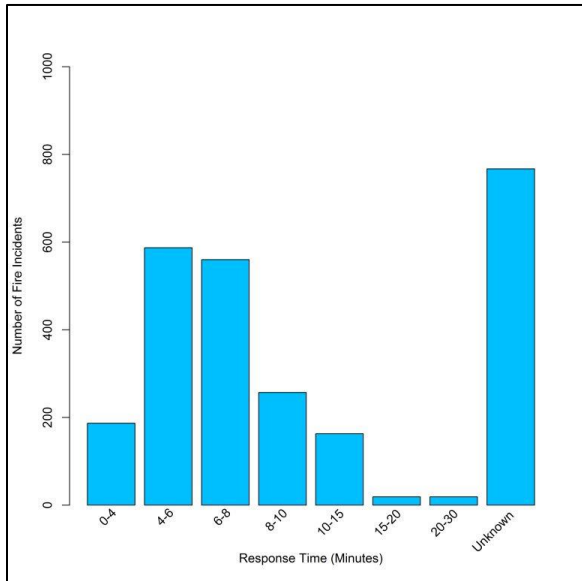


(a)

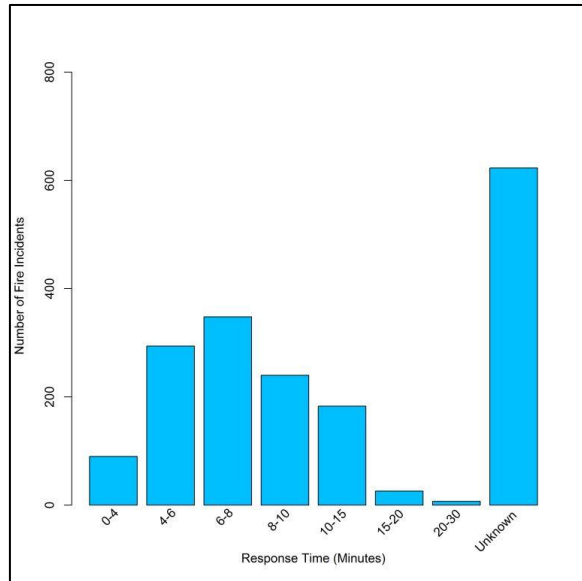


(b)

**Figure 5-24. Response Time for Incidents in (a) Fire District #1 and (b) Fire District #2**



(a)



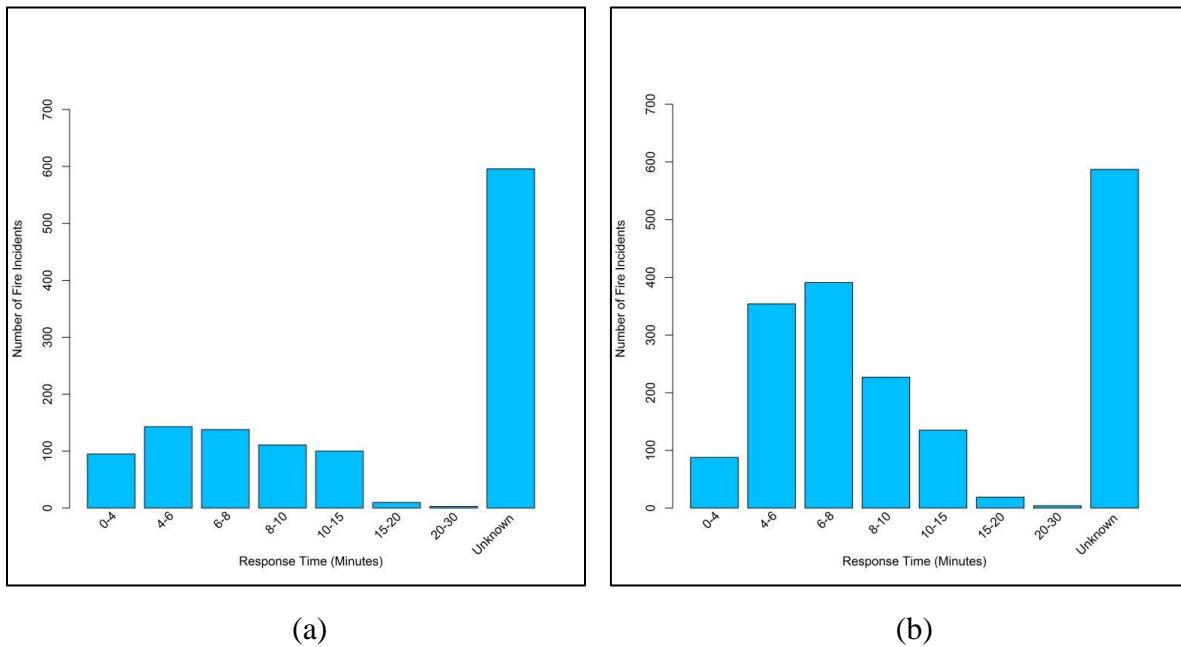
(b)

**Figure 5-25. Response Time for Incidents in (a) Fire District #3 and (b) Fire District #4**

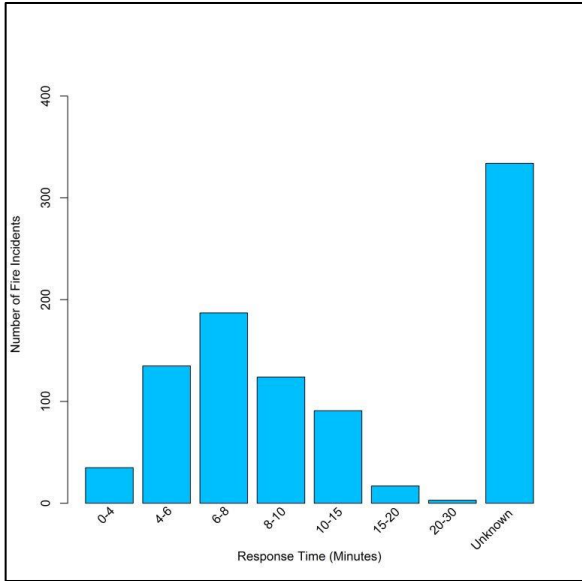
**Figure 5-26a** shows the response time for most incidents in fire district #5 was 4 - 6 minutes. The number of incidents recorded within the four-minute target response time was 107 (8%). **Figure 5-26b** shows the response time for most incidents in fire district #6 was 6 - 8 minutes. The number of incidents recorded within the four minutes' target response time was 105 (6%).

**Figure 5-27a** shows the response time for most incidents in fire district #7 was 6 - 8 minutes. The number of incidents recorded within the four minutes' target response time was 50 (5%). **Figure 5-27b** shows the response time for most incidents in fire district #8 was 4 - 6 minutes. The number of incidents recorded within the four minutes' target response time was 31 (11%).

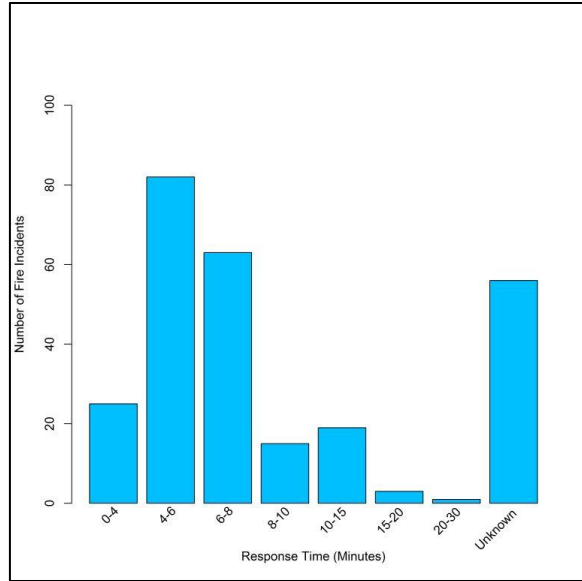
**Figure 5-28** shows the response time for most incidents in fire district #9 was 6 - 8 minutes. The number of incidents recorded within the four minutes' target response time was 66 (6%).



**Figure 5-26. Response Time for Incidents in (a) Fire District #5 and (b) Fire District #6**

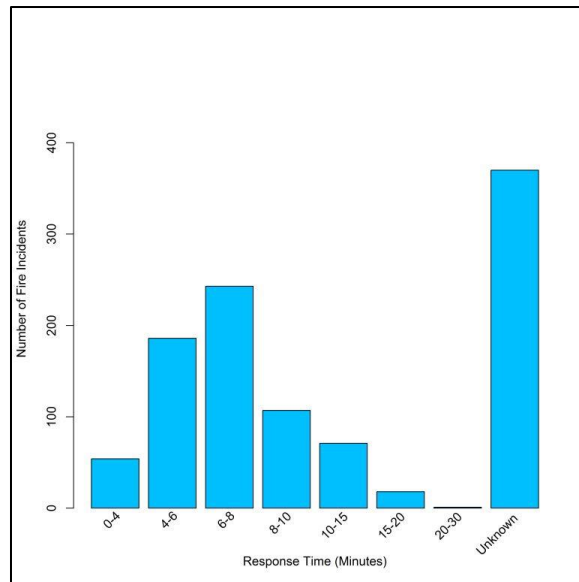


(a)



(b)

**Figure 5-27. Response Time for Incidents in (a) Fire District #7 and (b) Fire District #8**



**Figure 5-28. Response Time for Incidents in Fire District #9**

The analysis result on investigating the impact of grade crossing blockage, fire equipment allocation and multiple incident occurrences on emergency response time were grouped under two case studies. Case study 1 shows GIS-based data analysis results and Case study 2 shows survival data analysis results.

## **5.2. Case Study 1: GIS-Based Data Analysis Results**

To investigate the impact of GCMS on emergency response time, the research study analyzed two different situations: Grade crossing blockages due to stationary trains and blockages due to slow moving trains. Montgomery and Saskatoon downtown were chosen as typical subjects of blockages due to stationary trains and slow moving trains, respectively.

GIS-based service area (SA) and network analysis (NA) spatial data were used. SAA was used to investigate the dynamic impact of a grade crossing blockage on the service area. The NA was used to examine the network when there is no train blockage at grade crossings and when there is blockages. This analysis compares the network route(s) available to dispatches with or without GCMS. The results are as follows.

### **5.2.1. Grade Crossing Blockage due to Stationary Train**

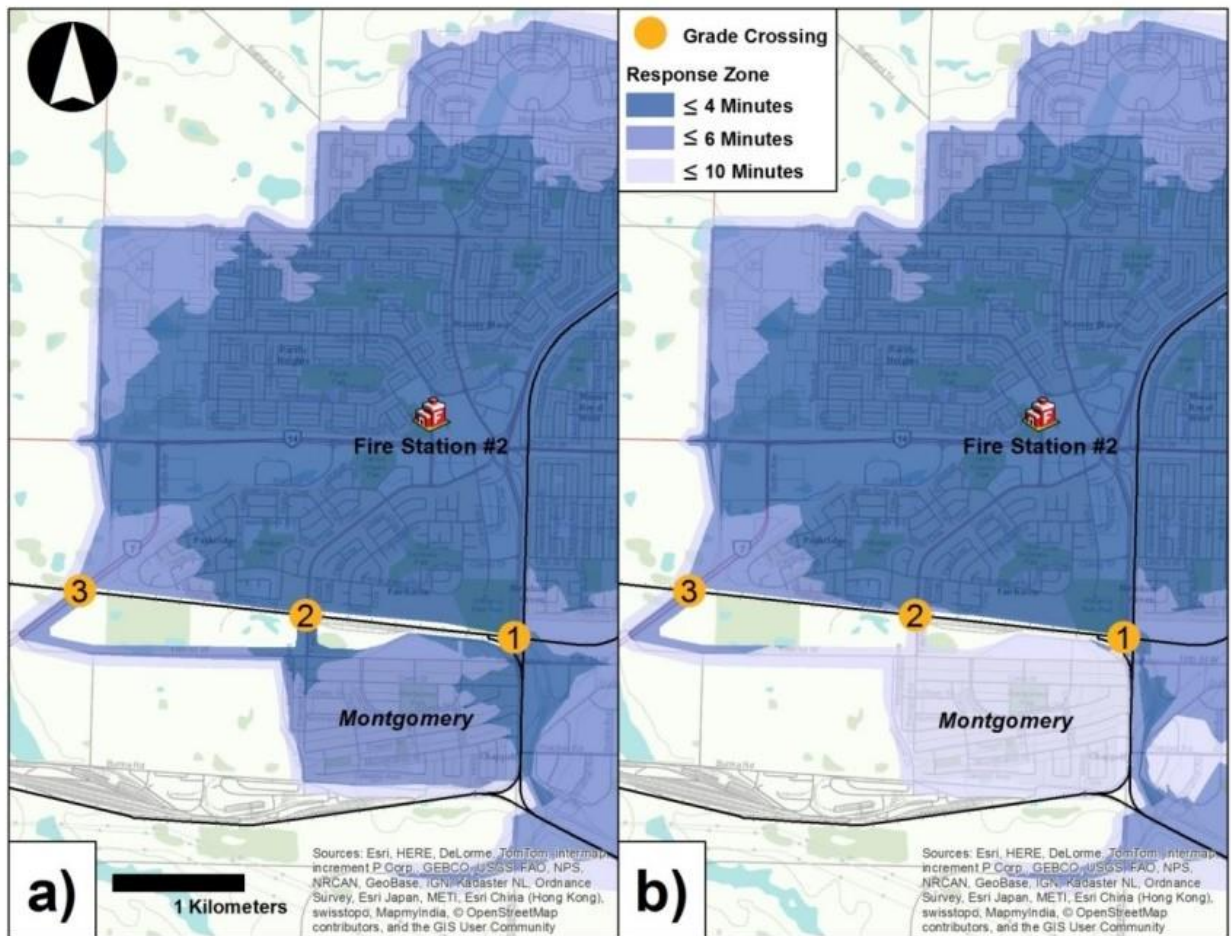
**Figure 5-29** shows Fire Station (FS) #2 and its response district. FS #2 has the primary responsibility for incidents in Montgomery. To reach an incident in Montgomery, the station's fire engines must cross at least one of the three grade crossings, as shown in **Figure 5-29**.

### **5.2.2. Service Area Analysis**

**Figure 5-29a** shows the estimated SA for FS #2 when there is no grade crossing blockage (default circumstance). As shown in **Figure 5-29a**, Montgomery area is 3.57 km<sup>2</sup> of which only 0.97 km<sup>2</sup> (27%) can be reached within four minutes (dark blue). The remaining 2.60 km<sup>2</sup> (73%) of Montgomery can be reached in four to six minutes.

**Figure 5-29b** shows the SA for FS #2 when there is a train blockage at one or more than one grade crossing. The distance between grade crossing 1 and 2 is 1.6 km, and these two crossings are sometimes blocked simultaneously by a long freight train. **Figure 5-29b** shows the estimated SA when grade crossing 1 and 2 are blocked simultaneously. Most of Montgomery now lies within

a six to ten minute response time (light blue) representing 2.63 km<sup>2</sup>. The four-minute response zone has disappeared (reduced from 0.97 km<sup>2</sup> to 0.00 km<sup>2</sup>). Fire engines from FS #2 take the long detour via grade crossing 3. As a result, most Montgomery residents must wait more than six minutes and possibly up to 10 minutes for a FS #2 fire engine to arrive at an emergency. This clearly is a serious safety and security issue for Montgomery area.



**Figure 5-29. Fire Station #2's Varying Service Area Due to Stationary Train**

### 5.2.3. Network Analysis

**Figure 5-30** shows FS #2 fire engine dispatch routes to Montgomery are without grade crossing blockage (the default circumstance). **Figure 5-30a** shows the route without GCMS information and **Figure 5-30b** shows the routes with GCMS information. The primary route (PR) (dotted red



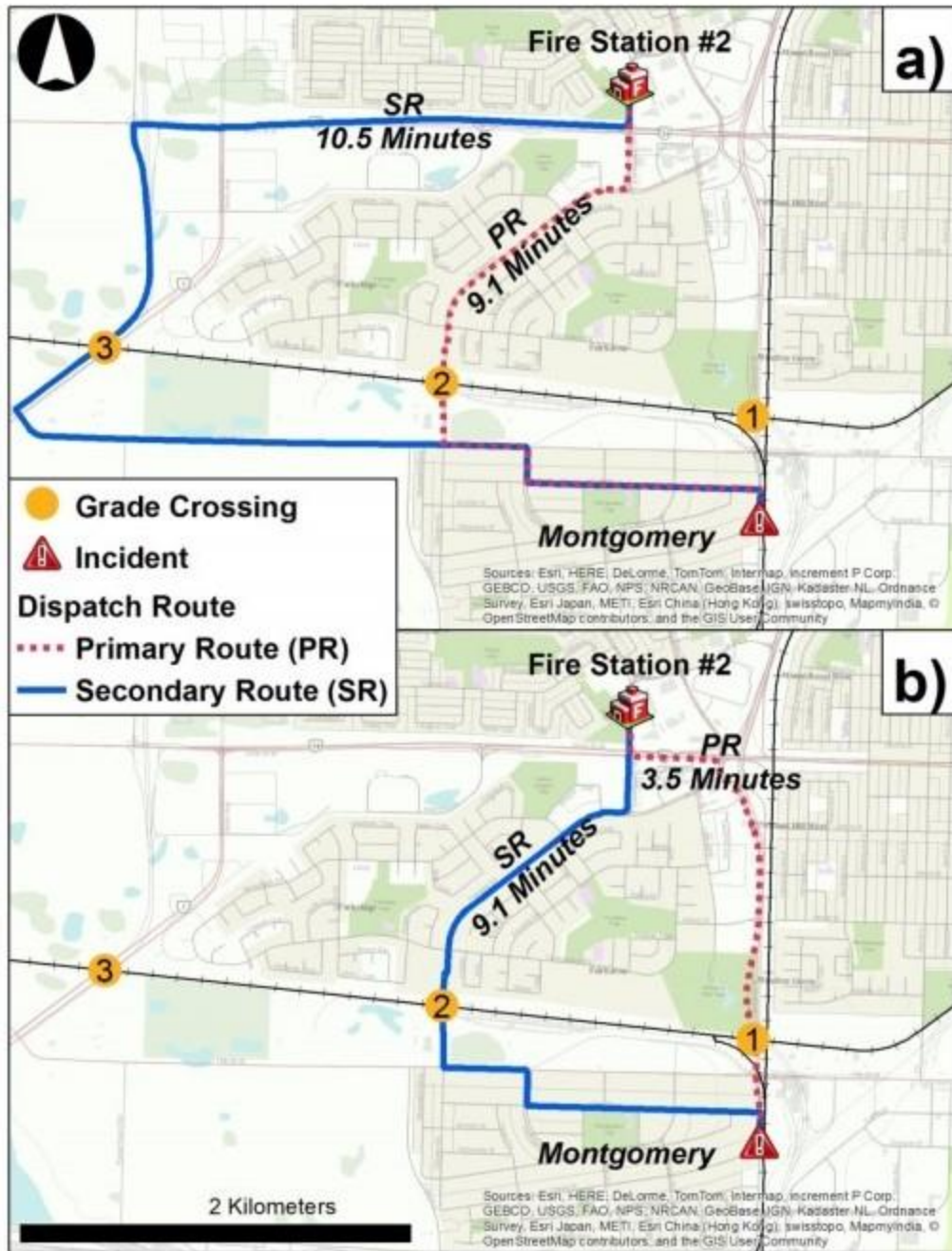
line) represents the first fire engine dispatched and the secondary route (SR) (blue line) represents the second fire engine dispatched. Due an unknown crossing blockage, it is standard practice for the SR to take a different route to avoid a delay on the PR route.

FS #2 dispatchers anticipate that grade crossing 1 is frequently blocked due to marshaling of trains and therefore do not dispatch fire engines through grade crossing 1 to Montgomery. Assuming there is no grade crossing blockage and no GCMS, **Figure 5-30a** shows that the PR (the first fire engine) takes 9.1 minutes. The SR (the second fire engine) takes 10.5 minutes.

**Figure 5-30b** shows the change in dispatch routes with a real-time GCMS information showing that the assumption that grade crossing 1 is blocked by a stationary train is inaccurate as there is actually no blockage at the crossing. The PR now use grade crossing 1 and takes 3.5 minutes. FS #2 fulfills the target response time of 4 minutes and saves 5.6 minutes, arriving 60% faster than when there is no real-time GCMS information. The SR uses grade crossing 2 and takes 9.1 minutes. GCMS reduces the total response time by 35.7%, when there is no grade crossing blockage on the network. This shows a significant reduction in response time for first responders.

**Figure 5-31** shows FS #2 fire engine dispatch routes to Montgomery when there is a grade crossing blockage. **Figure 5-31a** shows what the dispatch routes when FS #2 dispatchers have no real-time GCMS information and two fire engines are dispatched. The engines use the routes shown in **Figure 5-31a**, but the PR engine realizes that grade crossing 2 is blocked and has to take a long detour, taking a total of 11.8 minutes to reach the incident.

The SR engine is not affected. The total time for the PR and SR routes is 22.3 minutes. **Figure 5-31b** shows the result when dispatchers have real-time GCMS information that grade crossing 2 is blocked before the first engine is dispatched from the station. Dispatchers can then use the routes shown in **Figure 5-31b**. With a blockage at grade crossing 2, the total time for the PR and SR routes is now 17.0 minutes, a saving of 5.3 minutes (23.7%) due to the GCMS.



**Figure 5-30. Fire Engine Dispatch Routes to Montgomery with no Grade Crossing Blockage: without GCMS and with GCMS**

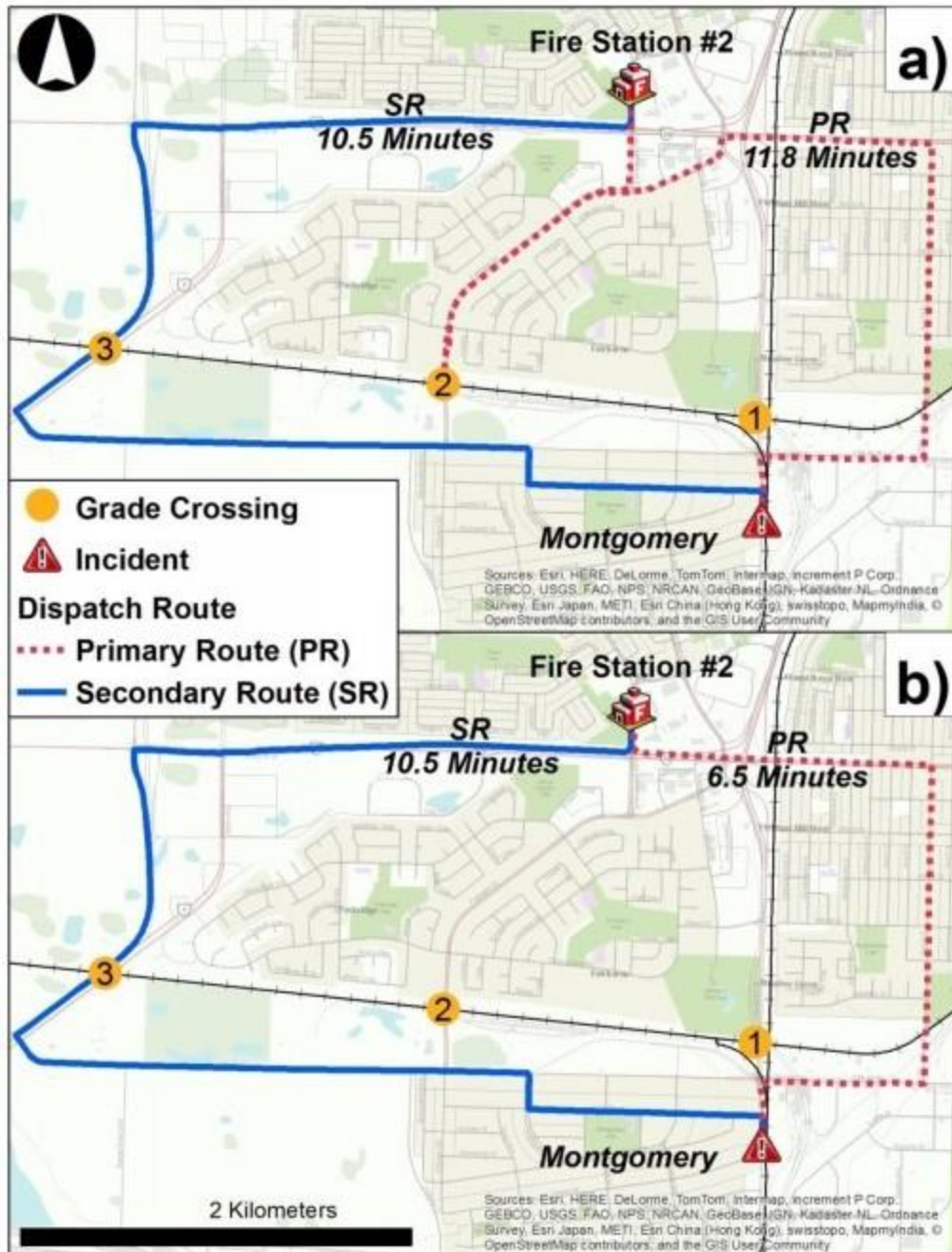


Figure 5-31. Fire Engine Dispatch Routes to Montgomery with Grade Crossing Blockage: without GCMS and with GCMS

#### 5.2.4. Grade Crossing Blockage due to a Slow Moving Train

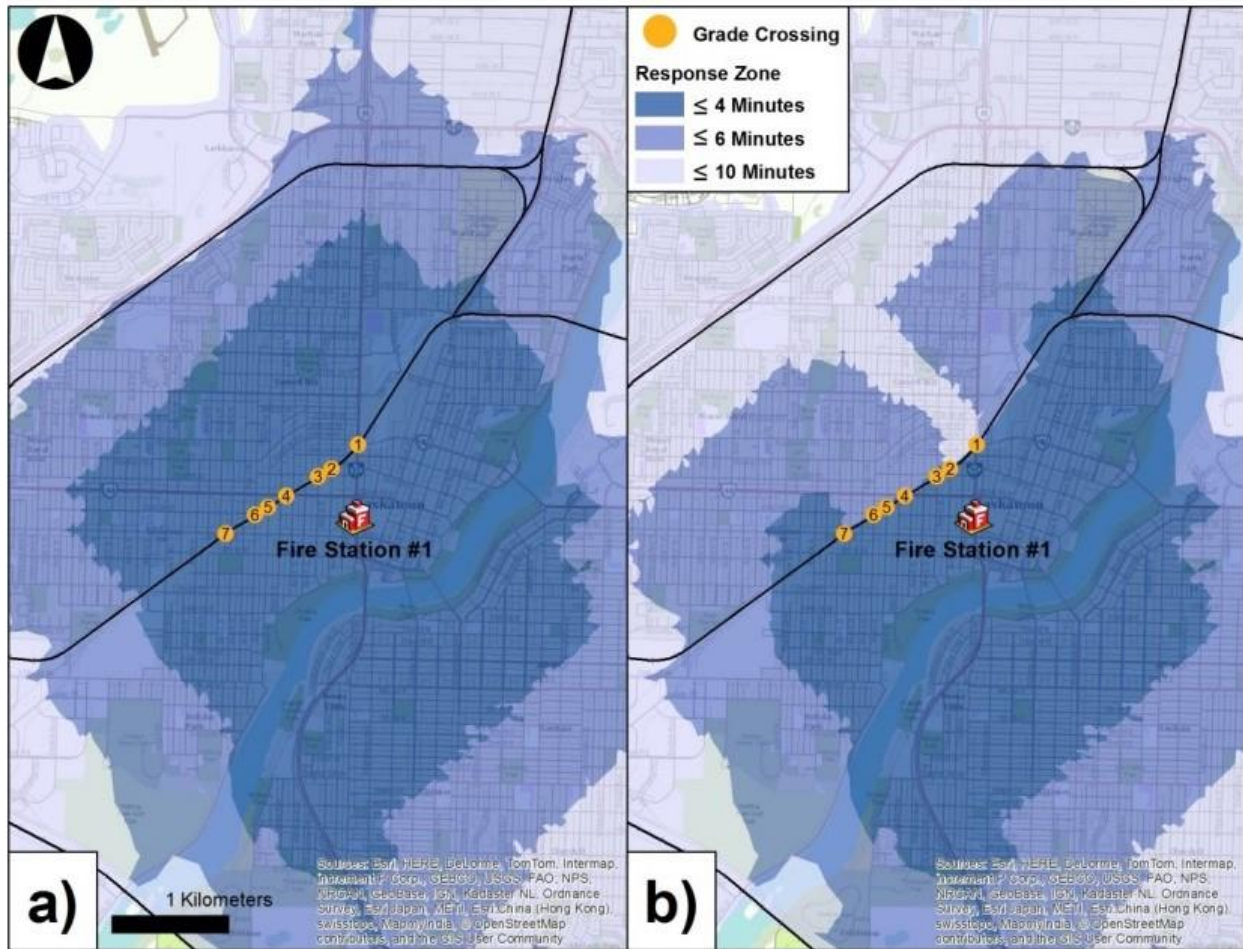
**Figure 5-32** shows the location of FS #1 in Saskatoon's downtown business and commercial area. The Saskatoon downtown main rail line tracks are usually notable for blockages due to slow moving trains rather than stationary trains. **Figure 5-32** shows the seven grade crossings, all to the north west of the fire station. It is assumed that a 2.2 km long freight train is moving at 40 km/h. The average length of a freight train is 2.2 km, and the usual speed of a freight train in Saskatoon is 40 km/h.

#### 5.2.5. Service Area Analysis

**Figure 5-32a** shows the estimated SA of FS #1 when there is no grade crossing blockage (the default scenario). During blockage, the four-minute target response area (dark blue) is about 4.7 km<sup>2</sup> (i.e., northwest of the mainline rail track). The response area for the four to six minutes (medium blue) is about 7.2 km<sup>2</sup>.

**Figure 5-32b** assumes that all crossings are between grade crossing 1 and 7 are simultaneously blocked by a slow moving freight train. The distance between grade crossing 1 and grade crossing 7 is only 1.4 km and can be blocked simultaneously by a freight train. When a train arrives at grade crossing 1, it takes only a few minutes to reach grade crossing 7 from grade crossing 1 and first responders at FS #1 know that all seven crossings will be blocked (It takes approximately 3.3 minutes at 40 km/h.). The four-minute response area is only 0.5 km<sup>2</sup> (reduced by 90%) when the crossings are blocked. The response area for the six minute is only 5.8 km<sup>2</sup> (reduced by 19%).





**Figure 5-32. Fire Station #1's Varying Service Area Due to Slow Moving Train**

### 5.2.6. Network Analysis

In the NA for the downtown area, the focus is only on the primary dispatch route while a secondary route is not considered. In the downtown area, there are many similar alternative routes available (unlike Montgomery the secondary route can be very different from the primary route because alternative routes are limited). **Figure 5-33a** shows a possible primary dispatch route (blue line) to an incident northwest of the fire station from FS #1 when there is no grade crossing blockage (the default circumstance).

The fastest route to an incident with or without a GCMS is the same, as dispatchers can use Idylwyld Drive (a major arterial) which provides a relatively fast and suitable driving environment for emergency dispatches to an incident. The route takes 3.2 minutes and satisfies the four-minute target both with and without GCMS.

**Figure 5-33b** shows how the dispatch route changes without GCMS (dotted red line) and with GCMS (green line). When there is no real-time GCMS information, the FS #1 fire engine travels 650 m north on Idylwyld Drive (one minute), but dispatchers notice that grade crossing 1 is blocked by a slow moving train. Dispatchers knows that routes to the west are also blocked by the train and then has to detour to the east. The journey takes six minutes (2.8 minutes longer than when there is no grade crossing blockage).

With real-time GCMS information on blockage times, however, the fire engine dispatcher may for example, be notified that two minutes after the fire engine is dispatched from the station, grade crossing 1 will be reopened. In this situation, the engine can wait at grade crossing 1 for one minute and then proceed to the incident on the shortest route (the green line) reaching the incident in 4.2 minutes (3.2 minutes travel time plus one minute waiting time).

The responders arrive in slightly longer time than the four-minute target response time, but save 1.8 minutes (30%) compared with the six minutes without real-time GCMS information. The 1.8minute gain can be useful when lives are at stake, time saved in response could make a tremendous difference.

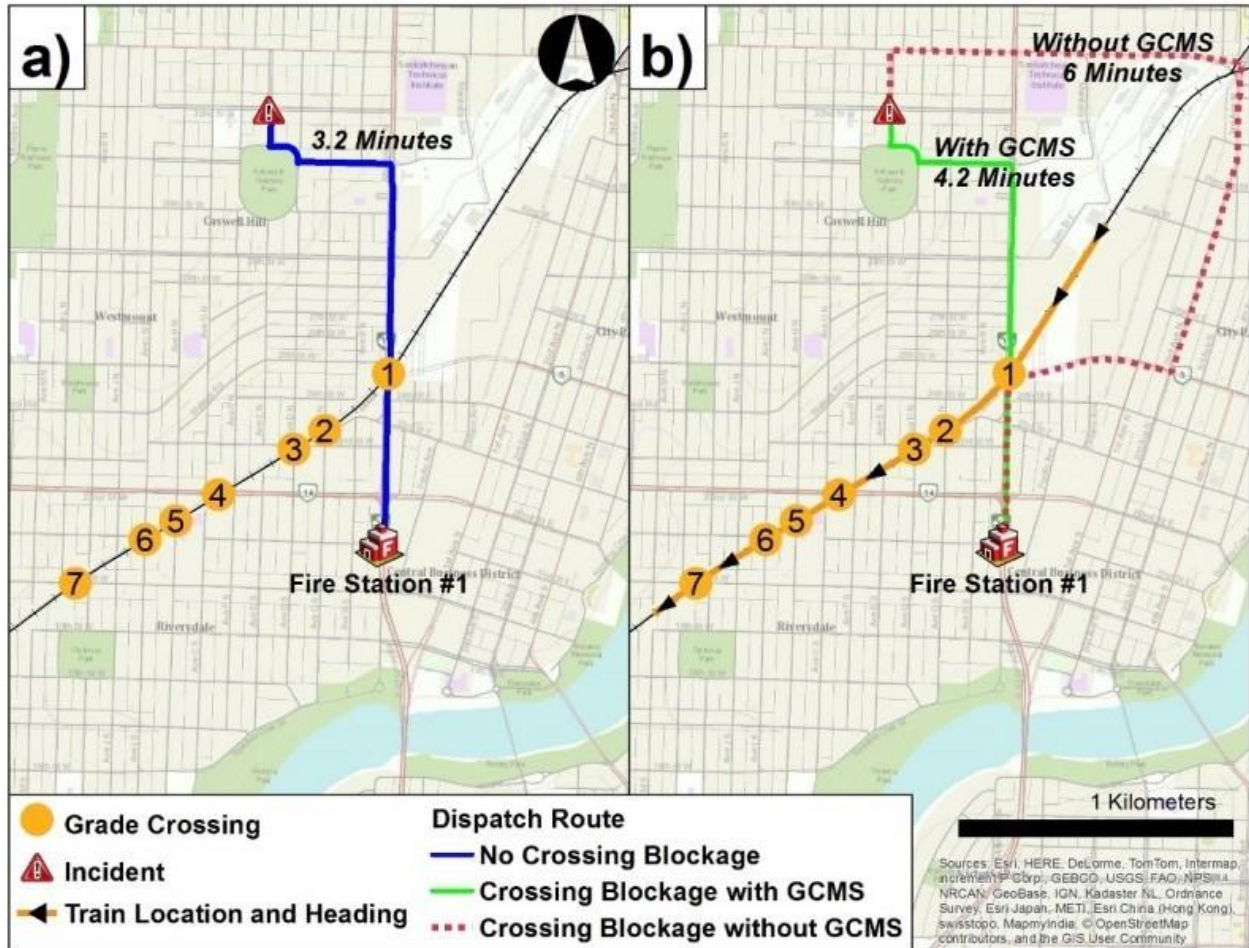


Figure 5-33. Fire Engine Dispatch Routes in Saskatoon Downtown Area

### 5.2.7. Fire Response Equipment Allocation

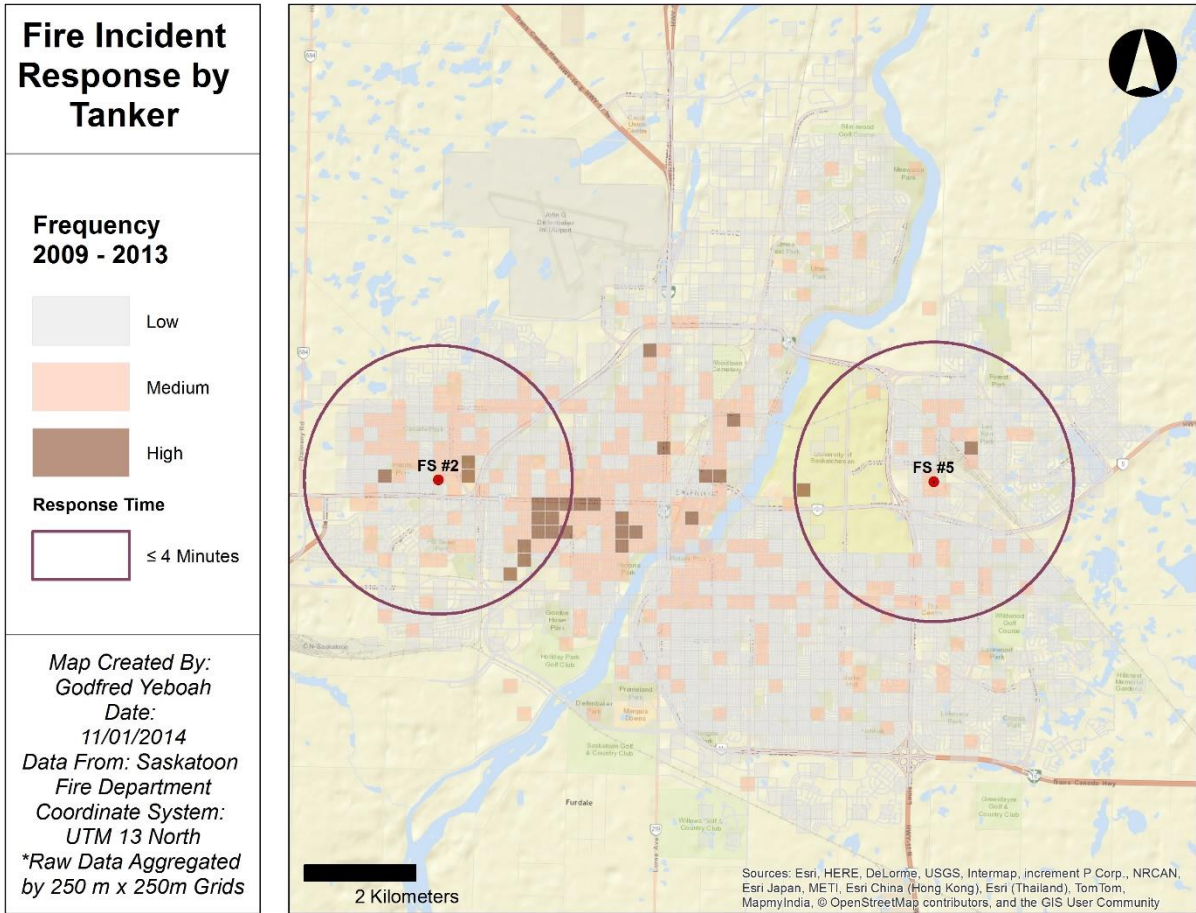
Tanker apparatus are located at fire stations #2 and #5. Tanker #2 responds to incidents requiring tanker apparatus in the central, north and west divisions. These divisions cover an estimated area of 101.64 km<sup>2</sup>. Tanker #5 responds to incidents in the east division with an estimated area of 112.78 km<sup>2</sup>. **Figure 5-34** 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<sup>2</sup> 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 19.6 km<sup>2</sup> or 17.4 % of the estimated east division area.

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 5-35** 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<sup>2</sup> 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<sup>2</sup> or 11.2 % of the estimated east division area.

The Decontamination (Decon) apparatus is located at fire station #9. This apparatus responds to Decontamination related incidents in all four divisions. **Figure 5-36** 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<sup>2</sup>, or 7.7 % of the estimated area of all four divisions.

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 5-37a** and **5-37b** 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<sup>2</sup>, or 4.2% of the estimated area of all four divisions.





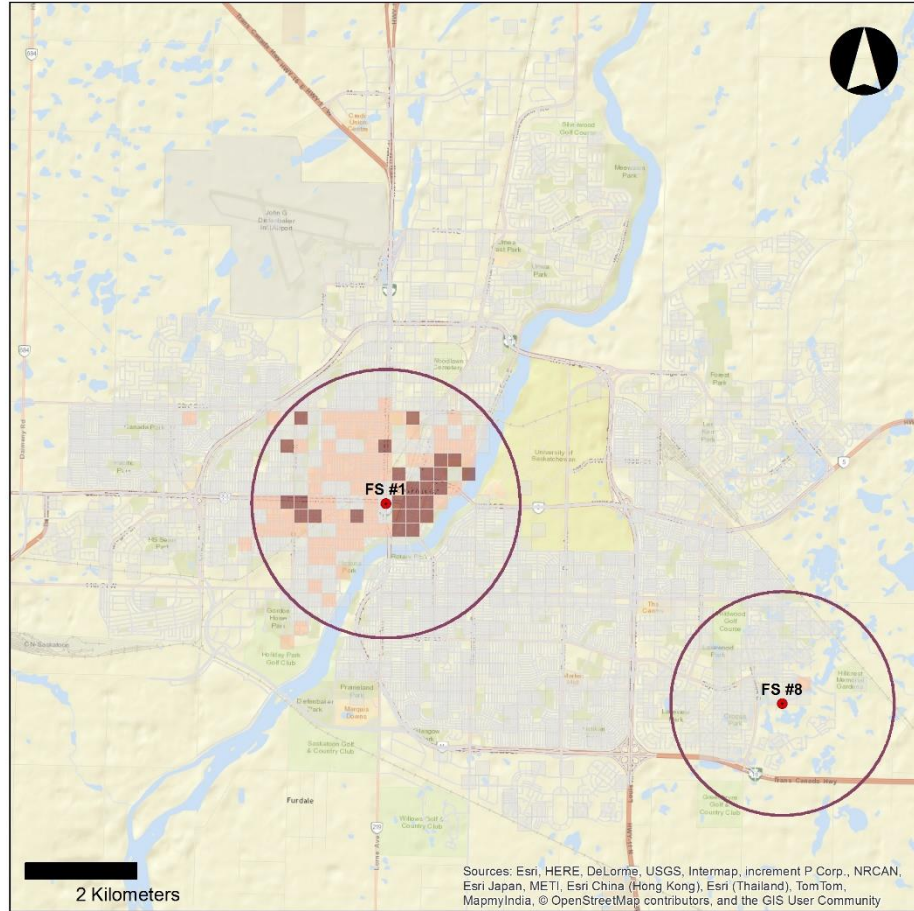
**Figure 5-34. Fire Station #2 and #5 Service Area for Tanker Dispatch to Fire Incidents**

# Fire Incident Response by Ladder

Frequency  
2009 - 2013



Map Created By:  
Godfred Yeboah  
Date:  
11/01/2014  
Data From: Saskatoon  
Fire Department  
Coordinate System:  
UTM 13 North  
\*Raw Data Aggregated  
by 250 m x 250m Grids



**Figure 5-35. Fire Station #1 and #8 Service Area for Ladder Dispatch to Fire Incidents**

**Fire Incident Response by Decon9**

**Frequency 2009 - 2013**

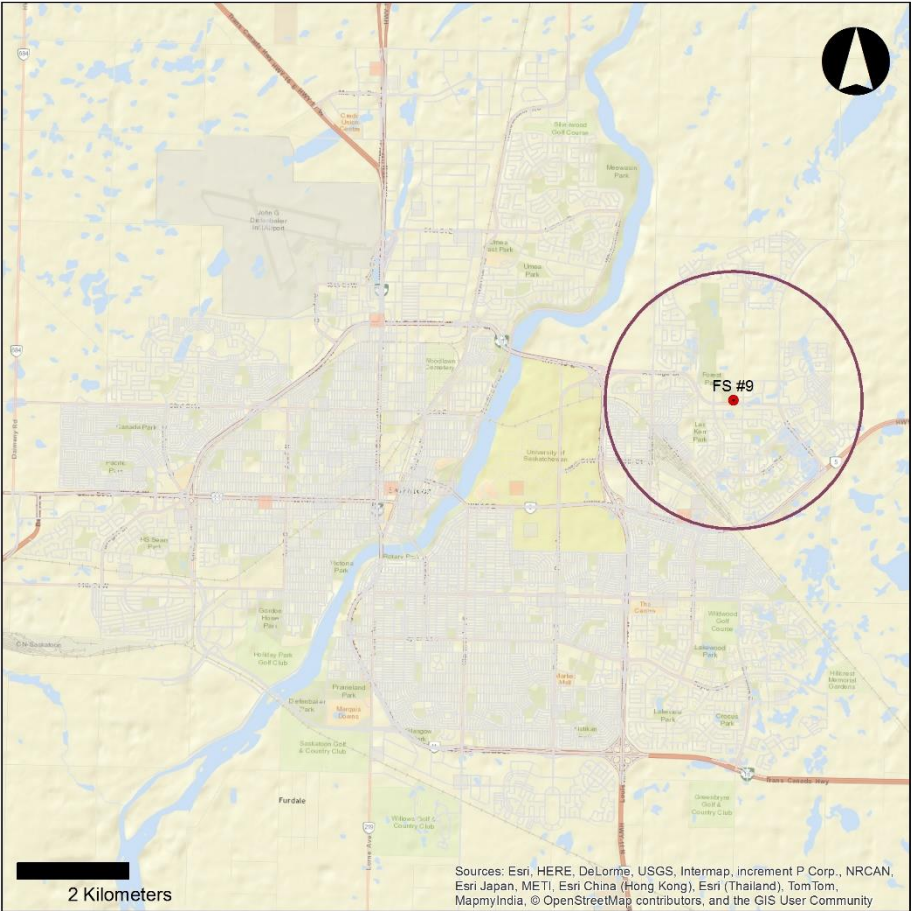
Low

Medium

**Response Time**

≤ 4 Minutes

*Map Created By:  
Godfred Yeboah  
Date:  
11/01/2014  
Data From: Saskatoon  
Fire Department  
Coordinate System:  
UTM 13 North  
\*Raw Data Aggregated  
by 250 m x 250m Grids*



**Figure 5-36. Fire Station #9 Service Area for Decontamination Dispatch to Fire Incidents**



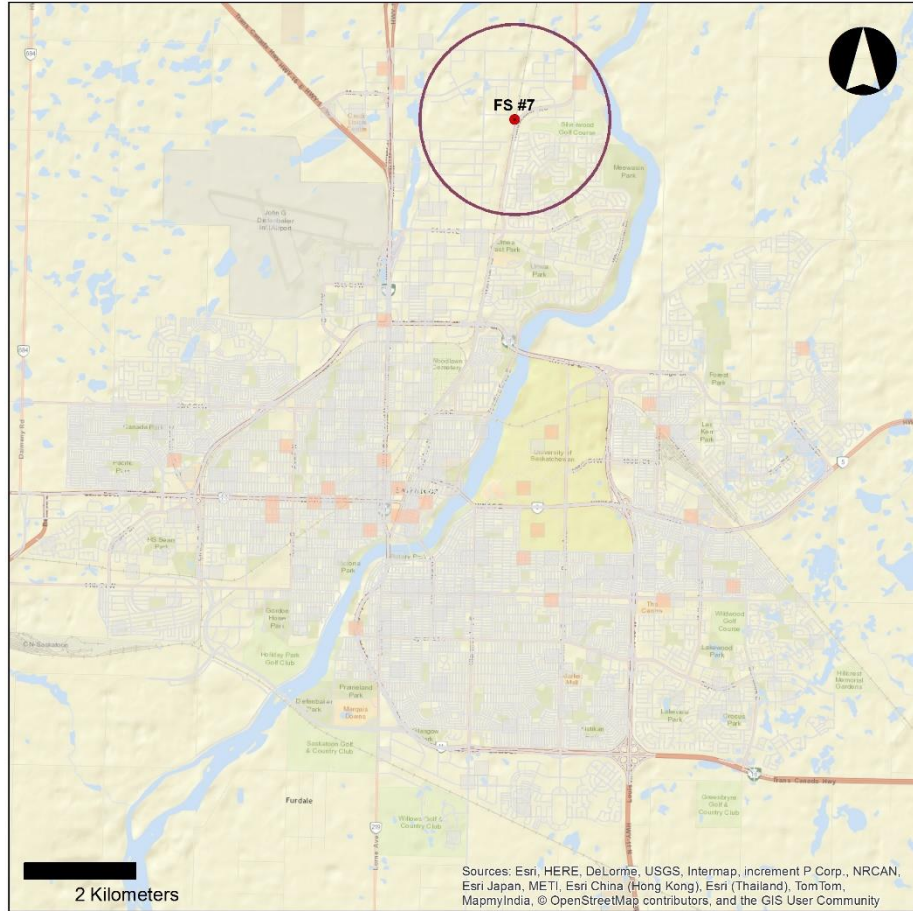
# Fire Incident Response by Hazmat 7

**Frequency  
2009 - 2013**

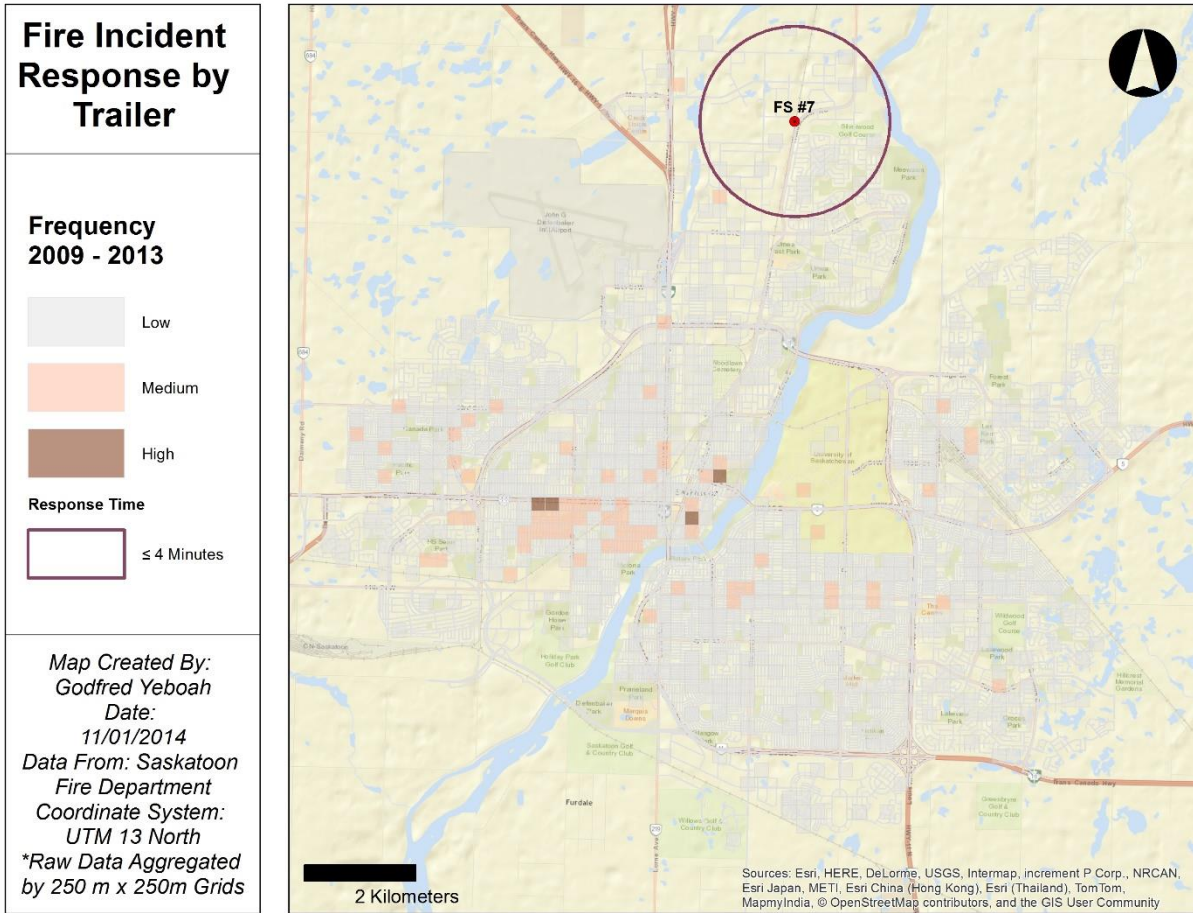


**Response Time**  
 ≤ 4 Minutes

*Map Created By:  
 Godfred Yeboah  
 Date:  
 11/01/2014  
 Data From: Saskatoon  
 Fire Department  
 Coordinate System:  
 UTM 13 North  
 \*Raw Data Aggregated  
 by 250 m x 250m Grids*



(a)



(b)

**Figure 5-37. Fire Station #7 Service Area for (a) Hazmat and (b) Trailer Dispatch to Fire Incidents**

### 5.3. Case Study 2: Survival Data Analysis Results

This analysis was used to predict the time periods with a relatively high risk of multiple incidents in fire district #9, the demand fire district. The analysis also considered the type of incident most likely to occur during a set of multiple incidents. First, the Kaplan-Meier estimators were used to check whether the different categories of the input variables used were statistically significant. The Log-Rank and Wilcoxon tests were used. **Table 5-8** presents the results. As the p-values for both test statistics were less than 0.05, it can be concluded that there were statistically significant differences between the Kaplan-Meier estimators for the categories of each input variable considered.

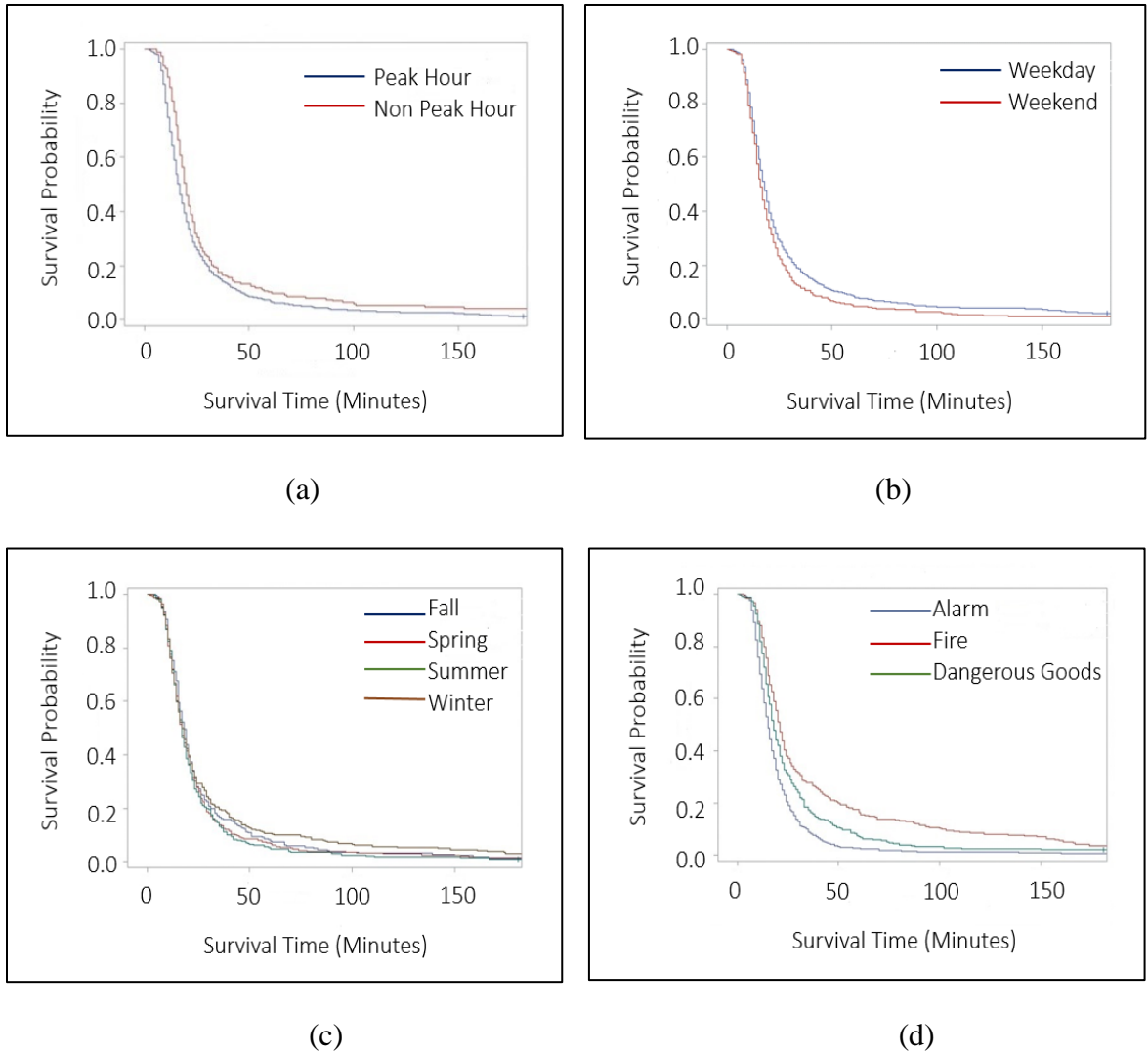
The Kaplan-Meier survival estimate curves in **Figure 5-38** show the probability of multiple incidents occurring in fire district #9. The survival probabilities decrease over time. **Figure 5-38** shows the Kaplan-Meier estimator curves for (a) peak/non-peak hours, (b) days of the week and (c) season of the year. **Figure 5-38d** shows the Kaplan-Meier estimator curves for the type of incident.

The lower or lowest curve in each of the four comparisons shows the higher or highest probability of multiple incidents. In **Figure 5-38a** for example, the comparison of the curves shows that multiple incident occurrences in fire district #9 are more likely during peak hours (blue curve) than during non-peak hours (red curve).

**Figure 5-38 (a), (b), and (c)** shows that the most likely times for multiple incidents to occur in fire district #9 are during peak hours, at the weekend and in summer. **Figure 5-38(d)** shows that when multiple incidents occur, the most likely type of incident is an alarm incident.

**Table 5-8. Test of Equality over Strata**

Test	Chi <sup>2</sup>	DF	p-value
Log-Rank	9.902	1	<b>0.001</b>
Wilcoxon	15.238	1	<b>&lt;.001</b>
-2Log(LR)	42.088	1	<b>&lt;.001</b>



**Figure 5-38. KM Survival Probabilities Curve for (a) Peak/nonpeak Hours (b) Days of the Week (c) Seasons and (d) Type of Incident for Fire District #9**

**5.3.1. Cox Proportional Hazard Model Estimate for Fire District #9**

To fit a Cox proportional hazard model, the Kaplan-Meier estimators for all four variables (peak hours, weekend, summer and alarm) which were statistically significant (**Table 5-8**), were added to the Cox hazard model. The purpose of the Cox hazard model analysis was to examine the impact of each of the four variables on the risk of multiple incidents occurring in fire district #9. The maximum likelihood estimation method was used to estimate the parameter values (i.e.,  $\beta_i$ ) of the model. **Equation 5-4** shows the hazards model developed for fire district #9.

$$\ln \left\{ \frac{h_i(t)}{h_0(t)} \right\} = 0.327X_{Peak Hour} + 0.143X_{Summer} + 0.212X_{Weekend} + 0.533X_{Alarm}$$

Equation [5-4]

where:

$X_{Peak Hour}$  = variable for peak hour;

$X_{Summer}$  = variable for summer;

$X_{Weekend}$  = variable for weekends; and

$X_{Alarm}$  = variable for alarm incidents.

**Table 5-9a** presents the results of the tests of statistical significance obtained from the Cox hazard model for fire district #9.

**Table 5-9a. Testing Global Null Hypothesis:  $\beta=0$  for Fire District #9**

Test	Chi <sup>2</sup>	DF	p-value
Likelihood Ratio	87.629	4	<.001
Score	88.271	4	<.001
Wald	87.063	4	<.001

**Table 5-9b. Analysis of Maximum Likelihood Estimates for Fire District #9**

Parameter	Parameter Estimate( $\beta$ )	Standard Error	Chi <sup>2</sup>	p-value	Hazard Ratio	95% Hazard Ratio Confidence Limits
Peak hour	<b>0.327</b>	0.083	15.586	<.001	<b>1.386</b>	1.179 1.630
Summer	<b>0.143</b>	0.071	4.104	<b>0.043</b>	<b>1.154</b>	1.005 1.325
Weekends	<b>0.212</b>	0.068	9.756	<b>0.002</b>	<b>1.236</b>	1.082 1.412
Alarm	<b>0.533</b>	0.064	68.759	<.001	<b>1.704</b>	1.503 1.933

**Table 5-9a** shows the results of the three goodness of fit tests. The p-value for each of the three test statistics is less than 0.05 which means that each goodness of fit test easily rejects the null hypothesis (that all  $\beta_i = 0$ ) at the 95% confidence level. **Table 5-9b** shows that the parameters estimated for peak hours (10 am to 11 pm), for summer, for weekend and for alarm incident are all statistically significant at the 95% confidence level. As each estimate is positive ( $\beta_i > 0$ ), we can conclude that all four contribute to an increase in the risk of multiple incidents occurring in fire district #9. For example, the Cox hazard ratio for peak hours is 1.386. This means that the risk



of multiple incidents occurring in district #9 during peak hours is 38.6% higher than during non-peak hours. Similarly, summer has a 15.4% higher risk than the other seasons, weekends have a 23.6% higher risk than weekdays, and alarm incidents have a 70.4% higher risk of occurring than do fire or DG incidents).

To summarize the analysis for fire district #9, multiple incidents are most likely to occur during peak hours (10 am to 11 pm), weekends and summer, and the most likely type of incident is an alarm incident.

### 5.3.2. Cox Proportional Hazard Model Estimate for Fire District #2 and #8

The study developed Cox proportional hazard model to predict the time periods when there is a relatively low risk of multiple incidents in fire districts #2 and #8, the supplier fire districts. The analysis also considered the type of incident most likely to occur during a set of multiple incidents.

In the analysis of the two supplier fire districts (districts #2 and #8), the analysis was focused on the time periods fire district #9 was most likely to need help (i.e., peak hours, summer, and weekends) and the type of incident most likely to occur during multiple incidents (i.e., alarm incidents). The study investigated whether one (or both) of the supplier fire districts has a relatively low risk of multiple alarm incidents during the target time periods. To do this, Cox hazards models were developed. **Equation 5-5** shows the Cox hazard model developed for supplier fire district #2.

$$\ln \left\{ \frac{h_i(t)}{h_0(t)} \right\} = -0.101X_{Peak Hour} + 0.242X_{Summer} + 0.110X_{Weekend} - 0.082X_{Alarm}$$

Equation [5-5]

where:

$X_{Peak Hour}$  = variable for peak hour;

$X_{Summer}$  = variable for summer;

$X_{Weekend}$  = variable for weekends; and

$X_{Alarm}$  = variable for alarm incidents.

**Table 5-10a** presents the results of the tests of statistical significance for the Cox hazard model for fire district #2.

**Table 5-10a. Testing Global Null Hypothesis:  $\beta = 0$  for Fire District #2**

Test	Chi <sup>2</sup>	DF	p-value
Likelihood Ratio	153.050	4	<b>&lt;.001</b>
Score	142.290	4	<b>&lt;.001</b>
Wald	139.888	4	<b>&lt;.001</b>

**Table 5-10b. Analysis of Maximum Likelihood Estimates for Fire District #2**

Parameter	Parameter Estimate( $\beta$ )	Standard Error	Chi <sup>2</sup>	p-value	Hazard Ratio	95% Hazard Ratio Confidence Limits	
Peak hour	<b>-0.101</b>	0.038	7.262	<b>0.007</b>	<b>0.904</b>	0.840	0.973
Summer	<b>0.242</b>	0.041	35.133	<b>&lt;.001</b>	<b>1.273</b>	1.176	1.379
Weekends	<b>0.110</b>	0.040	7.683	<b>0.006</b>	<b>1.116</b>	1.033	1.207
Alarm	<b>-0.082</b>	0.038	4.538	<b>0.033</b>	<b>0.921</b>	0.855	0.993

**Table 5-10a** shows that the results of all three goodness-of-fit test statistics for fire district #2 are statistically significant at the 95% confidence level (i.e., p-value < 0.05). This means that at least one  $\beta_i \neq 0$ . **Table 5-10b** shows that the parameter estimated for peak hours (10 am to 11 pm), for summer, for weekend and for alarm incident are all statistically significant at the 95% confidence level, but two of the parameter estimates (peak hours and alarm) are negative ( $\beta_i < 0$ ). The parameter estimates for summer and weekend are positive ( $\beta_i > 0$ ). It is therefore expected that for fire district #2, the risk of multiple incidents occurring during peak hours and involving an alarm incident is decreased while the risk of multiple incidents during the weekend and during summer is increased.

**Table 5-10b** also shows that the Cox hazard ratio for peak hours and alarm is 0.904 and 0.921 respectively. These results suggest that in fire district #2, there is a 9.6% lower risk of multiple incidents during peak hours than during non-peak hours, and a 7.9% lower risk of multiple incidents involving alarm incidents compared to the risk of multiple incidents involving fire or DG incidents. The risk of multiple incidents is however, 27.3% higher during the summer than during

the other seasons, and the risk of multiple incidents is 11.6% higher during the weekend than on weekdays.

**Table 5-11a** presents the results of the tests of statistical significance for the Cox hazard model for fire district #8. **Equation 5-6** shows the Cox hazard model developed for supplier fire district #8:

$$\ln \left\{ \frac{h_i(t)}{h_0(t)} \right\} = -0.152X_{Peak Hour} - 0.115X_{Summer} - 0.113X_{Weekend} - 0.264X_{Alarm}$$

Equation [5-6]

where:

$X_{Peak Hour}$  = variable for peak hour;

$X_{Summer}$  = variable for summer;

$X_{Weekend}$  = variable for weekends; and

$X_{Alarm}$  = variable for alarm incidents.

**Table 5-11a. Testing Global Null Hypothesis:  $\beta = 0$  for Fire District #8**

Test	Chi <sup>2</sup>	DF	p-value
Likelihood Ratio	14.695	4	<b>0.005</b>
Score	14.823	4	<b>0.005</b>
Wald	14.657	4	<b>0.006</b>

**Table 5-11b. Analysis of Maximum Likelihood Estimates for Fire District #8**

Parameter	Parameter Estimate( $\beta$ )	Standard Error	Chi <sup>2</sup>	p-value	Hazard Ratio	95% Hazard Ratio Confidence Limits	
Peak hour	<b>-0.152</b>	0.167	0.831	<b>0.005</b>	<b>0.859</b>	0.619	1.191
Summer	<b>-0.115</b>	0.040	8.319	<b>0.004</b>	<b>0.892</b>	0.825	0.964
Weekends	<b>-0.113</b>	0.147	0.592	<b>0.010</b>	<b>0.893</b>	0.670	1.191
Alarm	<b>-0.264</b>	0.155	2.888	<b>0.002</b>	<b>0.768</b>	0.566	1.041

**Table 5-11a** shows that the results of all three goodness-of-fit test statistics for fire district #8 are statistically significant at the 95% confidence level (i.e., p-value < 0.05). This means that

at least one  $\beta_i \neq 0$ . **Table 5-11b** shows that the parameter estimated for peak hours (10 am to 11 pm), for summer, for weekend and for alarm incident are all statistically significant at the 95% confidence level. Each parameter is negative. This means that all four contributed to reducing the risk of multiple incidents in fire district #8.

The Cox hazard ratios shown in **Table 5-11b** suggest that in fire district #8, the risk of multiple incidents is 14.1% lower during peak hours than during non-peak hours, 10.8% lower during the summer than during the other seasons, and 10.7% lower during the weekend than on weekdays. The risk of multiple incidents involving alarm incidents is 23.2% lower than the risk of multiple incidents involving fire or DG incidents

#### **5.4. Chapter Summary**

The analysis results from this research show how emergency response time is affected by grade crossing blockage, the allocation of fire equipment with special features and the risk in the occurrences of multiple incidents in fire district #9. The service area analysis in Montgomery area shows that out of a service area of 3.57 km<sup>2</sup>, only 0.97 km<sup>2</sup> can be reached by fire station #2 within the four-minutes target response time when there is no blockage. When there is a train blockage, no area in Montgomery can be reached within four-minutes target response time. Most parts of Montgomery area (2.63 km<sup>2</sup>) can now be reached from six to 10 minutes. This clearly shows the impact of grade crossing blockage.

The network analysis in Montgomery area shows the impact of grade crossing blockage on the response time with or without real-time information from a GCMS. When there is no blockage, since the fire department does not have a real-time information of the conditions at the crossing in Montgomery, they anticipate a blockage and it takes the primary route (the first fire engine) and secondary routes (the second fire engine) 9.1 minutes and 10.5 minutes respectively. With a real-time information from a GCMS, the assumption that there is a blockage by a train is incorrect and it takes 3.5 minutes for the primary route and 9.1 minutes for the secondary route, saving 5.6 minutes (62%) for the primary route and 1.4 minutes (13%) for the secondary route. These results clearly demonstrate the impact of grade closing blockage on emergency response time and the benefit of installing a grade crossing monitoring system to improve emergency response time.

The service area analysis for fire equipment that has special features show how the four-minute response time target is not achieved due to the allocation of special fire engines such as tanker, ladder, decontamination, hazmat and trailer. The four-minute response time for Tanker dispatch from station #2 and #5 covers only an area of 18.10 km<sup>2</sup> (17.8 %) of the estimated area for the entire west fire districts and 19.6 km<sup>2</sup> (17.4 %) for the east fire districts. The response area for Ladder #1 and #8 covers an area of 18.10 km<sup>2</sup> (17.8 %) of the estimated area west fire districts and 12.60 km<sup>2</sup> (11.2 %) of the estimated area for the east fire districts. The four-minute response time for Decontamination equipment covers an area of 16.6 km<sup>2</sup> (7.7 %) of the estimated area of all nine fire districts.

The survival data analysis was used to develop models designed to determine the time window of multiple incidents in fire district #9 and the overlapping time window for fire engine pre-emptive reallocation from FS#2 or FS#8 to FS#9. The survival analysis showed that fire district #9 (the demand district) may require the pre-emptive reallocation of an additional fire engine during peak hours (10 am to 11 pm), the summer and weekends. In addition, the analysis of fire district #9 showed that multiple incidents are more likely to involve alarm incidents than fire or DG incidents.

The survival analysis showed important differences between the two supplier fire districts analyzed. Both districts might be able to provide a secondary fire engine to fire district #9, but fire district #8 is the more promising district. During the time periods when fire district #9 is expected to experience a higher risk of multiple incidents (with alarm incidents being the most likely), fire district #8 is expected to experience a lower risk of multiple incidents. Fire district #2, however, is expected to have an increase in the risk of multiple incidents in the summer and at weekends

The output from the analysis shows that the fire department can pre-empt a fire engine from fire district #8 to fire district #9 because of the 23.0% less chances of an Alarm incident in fire district #8 compared to 70.4% in fire district #9. Fire station #8 is equipped with a ladder fire engine which is a required fire equipment for an Alarm incident.

## CHAPTER 6: DISCUSSIONS AND CONCLUSION

### 6.1. Case Study 1: GIS-Based Data Analysis

This research clearly demonstrates the impact of grade crossing blockages, fire equipment allocation and the risk of multiple incident occurrences on emergency response time. Grade crossing blockages increase first responders' response times and decrease the service area that can be reached within the four-minute target response time. The analysis of Saskatoon downtown and Montgomery area shows how stationary and slow moving trains affect the service area and increases response times, and how these response times could be considerably reduced by using a GCMS.

The Montgomery residential area analysis shows that, the fire station (FS #2) has four different routes available, but three of these routes pass through a grade crossing which are sometimes blocked. Two of these routes can be blocked simultaneously by a long freight train. When emergency dispatchers lack real-time grade crossing blockage information and the most direct route to Montgomery is frequently blocked, they assume that there is a blockage on these routes and automatically dispatch the first and second fire engines on the two longer routes. The network analysis examples in Montgomery show that the Fire Department is then unable to meet its target response time of four minutes. When there is no crossing blockage the response time is increased by 5.6minute relative to what it would have been if fire engines had been dispatched along the shortest routes. When there is a grade crossing blockage, lack of real-time information on blocked crossings means that the engine that dispatchers would have to be delayed by a further 5.3 minutes to detour.

Incidents located on the north-west side of the downtown area near FS #1 are affected by blockages on any of seven grade crossings caused by slow moving freight trains (see **Figure 5-32**). The network analysis shows that dispatchers would choose to wait at a crossing for a blockage to open when the GCMS indicates that waiting would be more efficient than taking a detour route. The Saskatoon downtown network analysis example shows a time saving of 1.8 minutes (30%) with a GCMS system.

The permanent solution to grade crossing blockages is grade separation, but it is very costly and cannot be justified at the great majority of level crossings in North America. Grade separation will not be feasible in the Central Saskatoon downtown due to the dense network. GCMS provides a promising alternative approach for emergency responders when choosing the fastest dispatch route to reach an incident.

The analysis results from this research cannot be directly transferred to other areas in Saskatoon, even though the analysis shows the benefits of a GCMS for two test locations in the city. First responders have their own approaches when dispatching a fire engine to an incident in an area and also every area has its own road and rail network. The study shows that GCMS can help reduce emergency response. It should be noted though that, the impact of grade crossing blockages on first responders' response times for different towns and cities vary.

The Service Area analysis on fire engines with special features clearly showed 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 stations within the central and west divisions.

The Service Area analysis of fire stations #7 and #9, which serve all the fire divisions for Hazmat, Trailer and Decontamination equipment, showed 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.

## 6.2. Case Study 2: Survival Data Analysis

The survival analysis approach used in this study were the Kaplan-Meier survival probability estimator to develop the survival function and the Cox hazard model to develop the hazard function. Both techniques are widely used in transportation engineering. The analyses was focused on four input variables: time of day (peak hours vs. non-peak hours), season, day of the week (weekdays vs. weekends), and type of incident (alarm vs. fire vs. DG incidents). All four variables selected were statistically significant at the 95% confidence level.

One of the study's objective was to develop a statistical model to predict the time of the day, of the week, season of the year, and type of fire incident associated with a higher risk of multiple incidents in a demand fire district. Saskatoon's fire district #9 was the demand district. Another objective was to develop statistical models to predict the time of the day, of the week, season of the year, and type of fire incident associated with a lower risk of multiple incidents in a supplier fire district. The study compared two supplier districts: fire districts #2 and #8. The aim of this analysis was to demonstrate the potential for pre-emptive reallocation by matching the time periods of increased risk for multiple incidents in the demand district to one or more supplier districts with a decreased risk for multiple incidents during the same time periods.

The study's findings clearly identified fire district #9's periods of greatest risk: peak hours (10 am to 11 pm), summer and weekends. The study also found that during these periods, there was an increase in the risk of alarm incidents (compared to the risk of fire or DG incidents). Fire district #8 emerged as the district most likely to be able to help fire district #9. Fire district #8 is expected to experience a lower risk of multiple incidents during each of the riskiest time periods for fire district #9. Fire district #2 is not suitable as a supplier district because fire district #2 is expected to have an increase in the risk of multiple incidents in the summer and at weekends.

The study's findings suggest that the Saskatoon Fire Department might wish to consider the pre-emptive reallocation of a ladder-equipped fire engine from fire district #8 to fire district #9 during summer weekends from 10 am to 11 pm. This pre-emptive reallocation would help the Saskatoon Fire Department to fulfill its standard of dispatching two pump engines, a rapid intervention team and a ladder-equipped fire engine to all alarm incidents. This approach taken in this study can help improve the response time during multiple emergencies.



### **6.3. Future Work**

This research was limited to investigating the benefit of installing GCMS to help improve response time without considering any analysis on the benefit/cost of installing a GCMS at selected grade crossings. The response area analysis on fire engines with special features was carried out based on the existing location of the fire engines with special features, and the analysis on risk in multiple incident occurrences was based on the Saskatoon Fire Departments' current concerns in fire district #9 without considering all other districts.

A rigorous analysis to determine the benefit/cost of installing a GCMS at a level crossing should be conducted. As transportation engineers, an analysis on how much it will cost to install, maintain and operate a specific GCMS system should be performed. When conducting analyses to estimate the benefits of reduced response times to incidents brought about by the introduction of the GCMS, an in-depth benefit/cost analysis is likely to raise significant challenges.

There are some studies that have discussed the estimated cost of fire incidents in an aggregated form (Hall, 2014; ODPM, 2004, 2006) and this approach may be helpful to policy-level decisions. Future research would consider producing more detailed estimates of the cost of fire damage, possibly by each type of fire incident. The more detailed approach could be used for the analysis benefit/cost of a fire department's operation and for more detailed fire service policy decisions (such as, does a city need a more complex 911 call dispatching system that provide real-time information on the blockage status of selected at-grade crossings in the city?).

The response area analysis on fire equipment allocation indicates that not all fire districts' service areas are covered within the four-minute target response time. There are instances where the four-minute response time service area of two or more fire districts can overlap while other service areas in the district are not covered. Future studies would consider an optimum allocation of some fire stations and fire engines with special features. This approach will ensure that a great part of each fire district service area can be covered within the four-minutes target response time.

Future research would consider analyses on multiple incident occurrences in all nine fire districts to determine which time window a fire district will require pre-emptive reallocation of a fire engine from other fire districts to help improve the response time.

## REFERENCES

- Aktas, E., Ozaydin, O., Bozkaya, B., and Sule Onsel, F.U., Optimizing Fire Station Locations for the Istanbul Metropolitan Municipality, *Interfaces*, Vol. 43 (3), 2013, pp. 240-255.
- Anderson, K. M., Odell, P. M., Wilson, P. W., Kannel, W. B., Cardiovascular disease risk profiles, *American Heart Journal*, Vol. 121(1), 1991, pp. 293-295.
- City of Saskatoon (COS), Saskatoon Fire Department, [www.saskatoon.ca](http://www.saskatoon.ca), 2014.
- City of Saskatoon (COS), Saskatoon Fire Department, Incident and Response Equipment Data, 2014.
- Cleves, M. A., Gould, W. W., Gutierrez, R. G., An introduction to survival analysis using strata, Revised Edition, Stata Press, College Station, Texas, 2004, pp. 1-10.
- Claridge and Spearpoint, New Zealand Fire Service Response Times to Structure Fires, *Procedia Engineering*, Vol. 62, 2013, 1063-1072.
- Council of Canadian Fire Marshals and Fire Commissioners (CCFM/FC), Fire Losses in Canada Year 2007 and Selected Years, Presented at the CCFM/FC Meeting – September 2011, Calgary, Alberta, Canada, pp. 3-5.
- Corcoran, J., Higgs, G., Brunson, C., Ware, A., and Norman, P., The Use of Spatial Analytical Techniques to Explore Patterns of Fire Incidence: A South Wales Case Study, *Computers, Environment and Urban Systems*, Vol. 31, 2007, pp. 623-647.
- Corcoran, J., and Higgs. G., Special Issue on Spatial Analytical Approaches in Urban Fire Management, *Fire Safety Journal*, Vol. 62, 2013, pp. 1-2.
- Derekenaris, G., Garofalakis, J., Makris, C., Prentzas, J., Sioutas, S., and Tsakalidis, A., Integrating GIS, GPS and GSM Technologies for the Effective Management of Ambulances, *Computers, Environment and Urban Systems*, Vol. 25 (3), 2001, pp. 267-278.
- Dijkstra, E.W., A Note on Two Problems in Connexion with Graphs". *Numerische Mathematik* 1, 1959, pp. 269–271.
- Easa, S.M., and D.R. McColl, Assessing Traffic and Emergency Benefits of Railroad Grade Separations, *Journal of Transportation Engineering*, Vol. 113 (6), 1987, pp. 593-608.
- Efron, B., Logistic Regression, Survival Analysis, and the Kaplan-Meier Curve, *Journal of the American Statistical Association*, Vol. 83, No. 402, Jun., 1988, pp. 414-420.

ESRI, GIS for Fire Station Locations and Response Protocol. Redlands, CA: ESRI, 2007, pp. 1-4.

Federal Railroad Administration (FRA), Trains Blocking Highway-Rail Grade Crossing Fact Sheet, Office of Public Affairs, US Department of Transportation, May 2008.

Federal Railroad Administration (FRA), Impact of Blocked Highway-Rail Grade Crossings on Emergency Response Services, August 2006.

Forkuo, E.K., and J.A. Quaye-Ballard, GIS Based Fire Emergency Response System, International Journal of Remote Sensing and GIS, Vol. 2 (1), 2013, pp. 32-40.

Gomersall, C. E., Access to Public Services: An Analysis of Fire Department Response Times in Cincinnati, Ph.D. Dissertation, Department of Geography, College of Arts and Science, University of Cincinnati, 2003.

Goolsby, M., Vickich, M., and A. Voigt, Railroad Grade Crossing Monitoring System. Houston, TX: Texas Transportation Institute, 2003.

Goolsby, M.E., Vickich, M.J., and A.P. Voigt, Evaluation of a railroad grade crossing monitoring system for first responders, ITE 2004 Annual Meeting and Exhibit, Lake Buena Vista, FL, August 1-4, 2004.

Gooley, T. A., Leisenring, W., Crowley, J., Storer, B. E., 1999. Estimation of failure probabilities in the presence of competing risks: new representations of old estimators. *Statistics in Medicine*, No. 18, John Wiley & Sons, Ltd, pp. 695-702.

Green, L.V., and Kolesar, P.J., Improving Emergency Responsiveness with Management Science, *Management Science*, Vol. 50 (8), 2004, pp. 1001-1014.

Haghani, A., and Yang, S., Real-Time Emergency Response Fleet Deployment: Concepts, Systems, Simulation & Case Studies, Chapter 7, University of Maryland, 2007, pp134.

Haghani, A., Tian, Q., Hu, H., Simulation Model for Real-Time Emergency Vehicle Dispatching and Routing, *Transportation Research Record, Journal of the Transportation Research Board*, No. 1882, 2004, pp. 176-183.

Hall J.R., Total Cost of Fire in the United States, National Fire Protection Association, Fire Analysis and Research Division, March, 2014.

Henchey, M.J., Batta, R., Blatt, A., Flanigan, M., and K. Majka, A Simulation Approach to Study Emergency Response, *Journal of Simulation* 8, 2014, pp. 115-128.

Higgins, E., Taylor, M., Jones, M., and Lisboa, P.J.G., Understanding Community Fire Risk - A Spatial Model for Targeting Fire Prevention Activities, *Fire Safety Journal*, Vol. 62, 2013, pp. 20-29.

Holm, P., Tomich, D., Sloboden, J., and L., Cheryl, Traffic Analysis Toolbox Volume IV: Guidelines for Applying CORSIM Microsimulation Modeling Software, Final Report, FHWA-HOP-07-079, US Department of Transportation, Federal Highway Administration, January 2007.

<http://www.cisco.com/c/en/us/solutions/industries/transportation/commercialvehicles/response.html>.

Indriasaria, V., Mahmudb, A.R., Ahmadc, N., and A.R.M. Shariffd, Maximal Service Area Problem for Optimal Siting of Emergency Facilities, *International Journal of Geographical Information Science*, Vol. 24 (2), 2010, pp. 213-230.

Kai, N., Zhang, Y.-T., and Y.-P. Ma, Shortest Path Analysis Based on Dijkstra's Algorithm in Emergency Response System, *TELKOMNIKA Indonesian Journal of Electrical Engineering*, Vol.12 (5), 2014, pp. 3476 – 3482.

Klein, J. P., Moeschberger, M. L., *Survival analysis techniques for censored and truncated data*, Second Edition, Springer-Verlag New York, Inc., New York, NY., 2003, pp. 21-50.

Kolesar, P., and Blum, E.H., Square Root Laws for Fire Engine Response Distances, *Management Science*, Vol. 19 (12), 1973, pp. 1368 – 1378.

Kolesar. P., Walker, W., and Hausner, J., Determining the Relation between Fire Engine Travel Times and Travel Distances in New York City, *Operations Research*, Vol. 23 (4), 1975, pp. 614-627.

Landry, N., The CNR and western settlement, 1925-1930, *The Archivist*, May-June, 1990, p.14.

Lee, E. T., Wang, J. W., *Statistical methods for survival data analysis*. Wiley Series in Probability and Statistics, Third Edition, John Wiley & Sons, Ltd, 2013, pp. 19-160.

Lee, S.G., Tong, D., and M. Hickman, Generating Route-Level Mutually Exclusive Service Areas Comparative Study of Alternative Methods, *Transportation Research Record: Journal of the Transportation Research Board*, No. 2350, Washington, D.C., 2013, pp. 37–46.

Liu, N., Huang, B. and M. Chandramouli, Optimal Siting of Fire Stations using GIS and ANT Algorithm, *Journal of Computing in Civil Engineering*, Vol. 20 (5), 2006, pp. 361-369.

MacKay, D., *The People's Railway: A History of Canadian National Railway*, Vancouver: Douglas and McIntyre, 1992.

Malowidzki, M., Mazur, M., Dalecki, T., and Berezinski, P., Traffic Routes for Emergency Services, in: Al Begain, K., Al Dabass, D., Orsoni, A., Cant, R., and Zobel, Z. (Eds.), 8th EUROSIM Congress on Modelling and Simulation, EUROSIM, IEEE – The Institute of Electrical and Electronics Engineers, Inc., Cardiff, Wales, UK, 2013, pp. 466–471.

Masten, S.V., Foss, R. D., Long-term effect of the North Carolina graduated driver licensing system on licensed driver crash incidence: A 5-year survival analysis, 2010, pp. 1-6.

Murray, A.T., Optimising the Spatial Location of Urban Fire Stations, *Fire Safety Journal*, Vol. 62, 2013, pp. 64-71.

Mirchandani, P. B., and Lucas, D. E., Integrated Transit Priority and Rail/Emergency Preemption in Real-Time Traffic Adaptive Signal Control. *Journal of Intelligent Transportation Systems*, 8(2), 2004, 101-115.

Murray, A.T., and M.E. O'Kelly, Assessing Representation Error in Point-Based Coverage Modeling, *Journal of Geographical Systems*, Vol. 4(2), 2002, pp. 171-191.

National Fire Protection Association, NFPA 1710 Standard on Fire Department Deployment and Operations: Implementation Guide, International Association of Fire Fighters, Second Printing, 2002.

National Fire Protection Association, NFPA 1710: Standard for the organization and deployment of fire suppression operations, emergency medical operations, and special operations to the public by career Fire departments, 2002, pp. 4.

Nebraska Department of Road (NDOR), Title 415, Chapter 7, Comprehensive Public Safety Program for Highway-Rail Grade Crossings, NE Code 74-1342, Nebraska Rail and Public Transportation Division, 2013.

Nelson, E.J., and Bullock, D., Impact of Emergency Vehicle Preemption on Signalized Corridor Operation: An Evaluation, *Transportation Research Record*, Journal of the Transportation Research Board, No. 1727, 2000, pp. 1-11.

Office of the Deputy Prime Minister (ODPM), *The Economic Cost of Fire: Estimates for 2004*, London, United Kingdom, 2006.

Park, H., Shafahi, A., Haghani, A., A stochastic emergency response location model considering secondary incidents on freeways. *IEEE Transactions on Intelligent Transportation Systems*, Vol.17, (9), 2016, pp. 1-9.

Park, Y. P, Jung, W. R., Yeboah, G., Rempel, G., Paulsen, D., Rempel, D., First responders' response area and response time analysis with/without grade crossing monitoring system, *Fire Safety Journal*, Vol. 79, 2016, Pages 100–110

Ruback, L., and K. Balke, *Integrating Train Information for Advanced Transportation Management*, College Station, TX: Texas Transportation Institute, 2001.

Rider, K. L., Introduction to a method for the allocation of fire Companies, *Fire Technology*, Vol. 11(2), 1974, pp. 4-11.

Simpson, N.C., and Hancock, P.G., Fifty Years of Operational Research And Emergency Response, *Journal of the Operational Research Society*, Vol. 60, 2009, pp. S126-S139.

Sisiopiku, V., Application of Traffic Simulation Modeling for Improved Emergency Preparedness Planning, *Journal of Urban Planning and Development*, Vol. 133, 2007, pp. 51-60.

Smith, A. J., Dieppe, P., Vernom, K., Porter, M., Blom, A. W., Failure rates of stemmed metal-on-metal hip replacements: analysis of data from the National Joint Registry of England and Wales. Vol. 379, 2012, pp. 1199.

Tank, P., Long Delays at Railway Crossings a Concern, Article, *The Star Phoenix*, April 23, 2014, Retrieved from:  
<http://www.thestarphoenix.com/Long+delays+railway+crossings+concern/9765933/story.html>,  
Date Accessed [July 10, 2014].

Texas Constitution and Statutes, Transportation Code, Title 6. Roadways, Subtitle Z. Subtitle Z. Miscellaneous Roadway Provisions, Chapter 471. Railroad and Roadway Crossings, September 1999.

Transport Canada, *Canadian Rail Operating Rules*, TC O 0-167 December 2013.

Transport Canada, *Stronger Ties: A Shared Commitment to Railway Safety - Review of the Railway Safety Act*, Railway Safety Act Review Secretariat, Ottawa, Canada, ISBN 978-0-662-05408-5, November, 2007.

Upchurch, C., Kuby, M., Zoldak, M., and A. Barranda, Using GIS to Generate Mutually Exclusive Service Areas Linking Travel On and Off a Network, Vol. 12(1), 2004, pp. 23-33.

Winiewski, W., City Concerned Train Delays Slowing Emergency Response Times, Article, Global News, April 23, 2014, Retrieved from: <http://globalnews.ca/news/1284974/saskatoon-fire-chief-concerned-train-delays-are-slowing-emergency-response-times/>, Date Accessed [July 10, 2014].

Williams, C.S., Durham, N.C., Survival analysis: an applied introduction. Proceedings of the South East SAS Users Group. St Pete Beach, FL, USA. SESUG. <http://analytics.ncsu.edu/sesug/2008/ST-147.pdf> (23 de junio de 2013), 2008, pp. 1-3.

XiaoBao, Y., ZiYou, G., HongWei, G., Mei, H., Survival analysis of car travel time near a bus stop in developing countries. Science China Technological Sciences, Vol. 55(8), 2012, pp. 2356-2360.

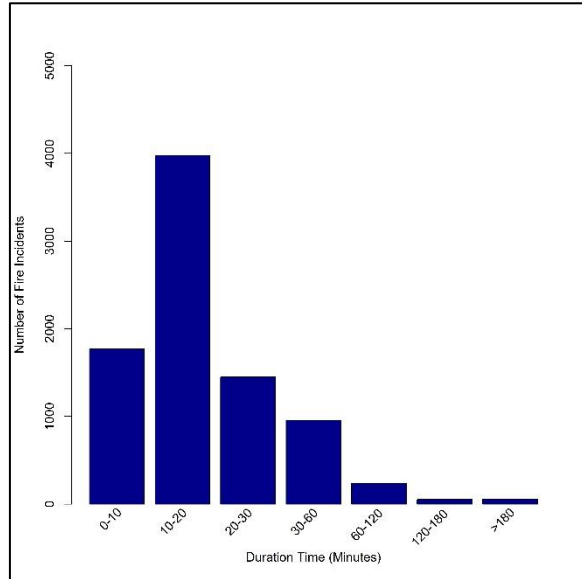
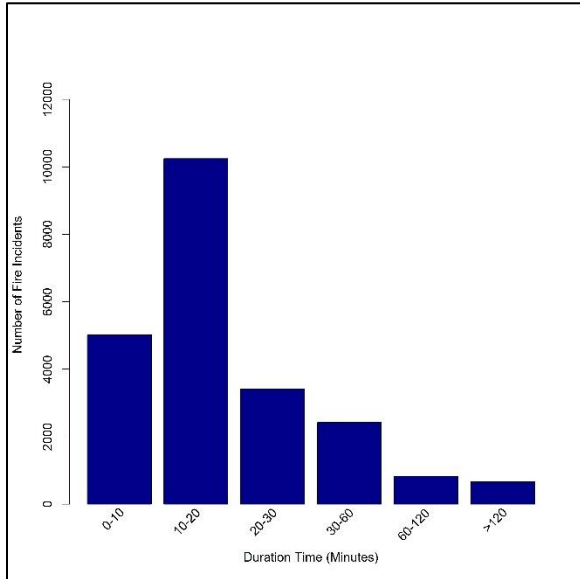
Yang, S., Hamed, M., and Haghani, A., Online Dispatching and Routing Model for Emergency Vehicles with Area Coverage Constraints, Transportation Research Record, Journal of the Transportation Research Board, No. 1923, 2005, pp. 1-8.

Zhang, L., Gou, J. Liu, K., McHale, G., Ghaman, R, and Li, L., Simulation Modeling and Application with Emergency Vehicle Presence in CORSIM, IEEE 70th Vehicular Technology Conference, Anchorage, AK, Fall, 2009, pp. 1-7.

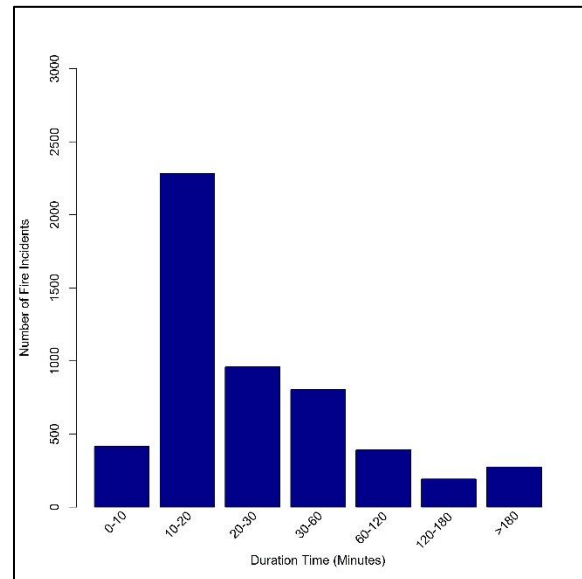
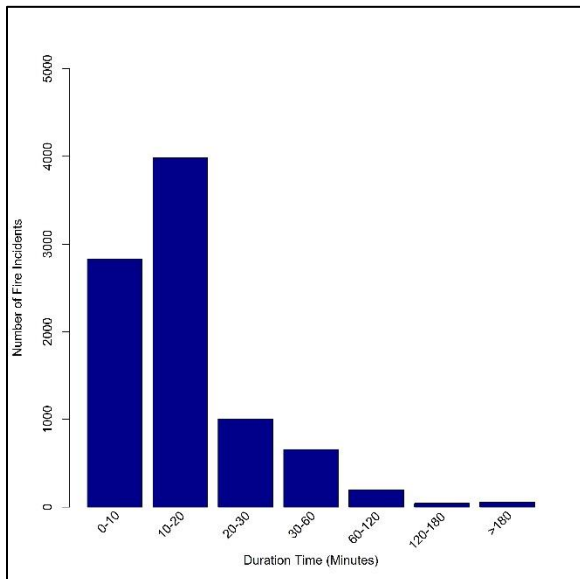
Zhou, Y., and Liu, M., An Intelligent System for Emergency Traffic Routing, Applied Informatics and Communication, International Conference, ICAIC 2011, Xi'an, China, August 20-21, 2011, Proceedings, Part V, pp. 429-436.

## APPENDIX A

### INCIDENT DURATION TIME



(a) (b)  
**Figure A-1. Duration Time for Incidents (a) Total and (b) Alarm**

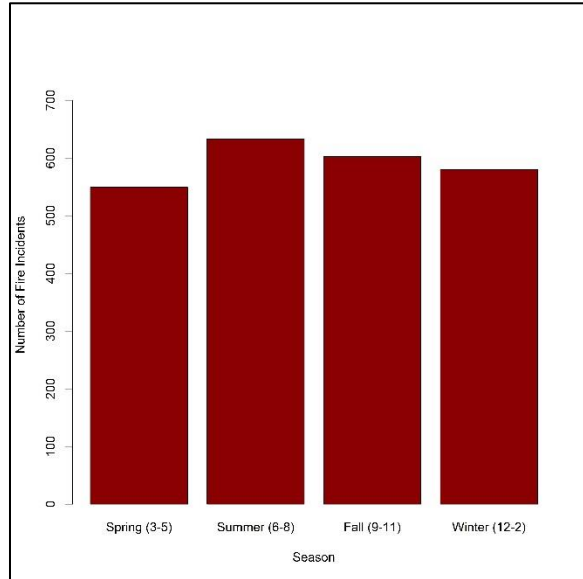
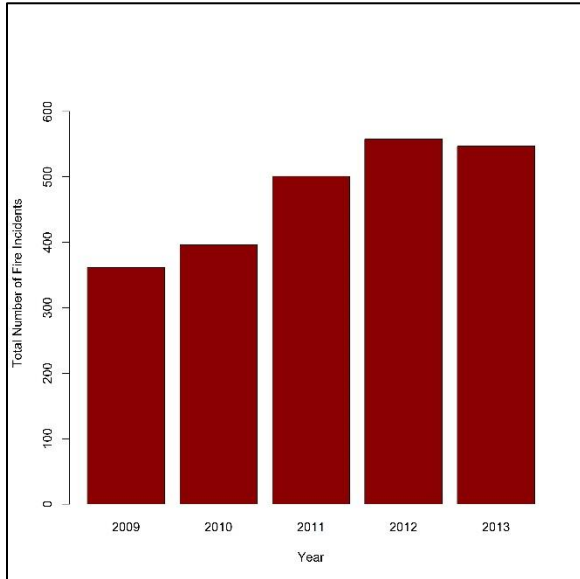


(a) (b)  
**Figure A-2. Duration Time for Incidents (a) Dangerous Goods and (b) Fire**



## APPENDIX B

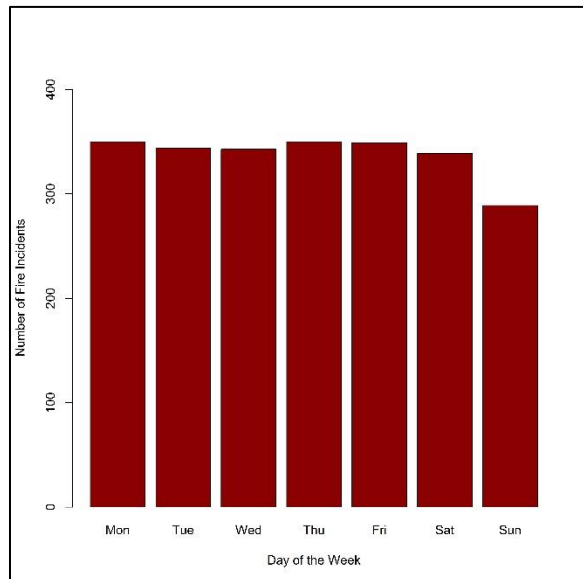
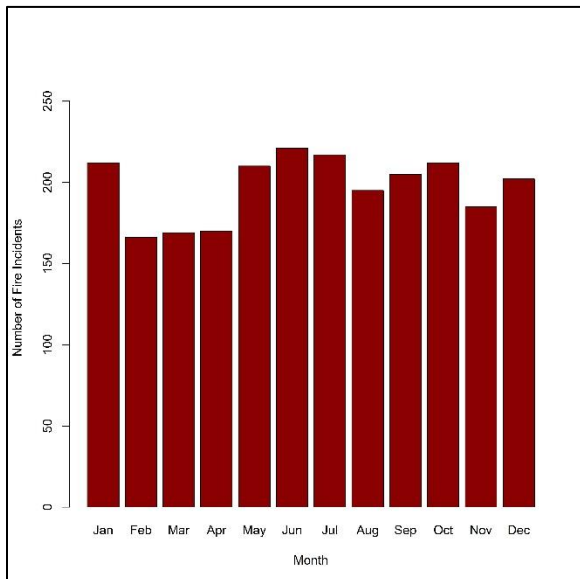
### INCIDENT RESPONSES BY FIRE EQUIPMENT WITH SPECIAL FEATURES



(a)

(b)

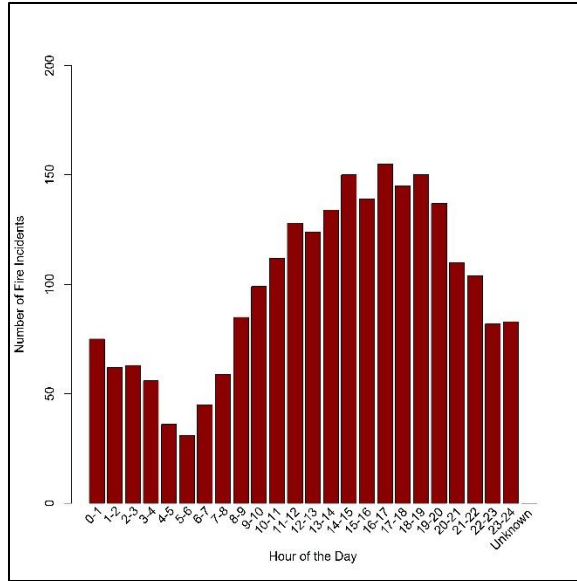
**Figure B-1. Incidents Responses with Ladder Equipment (a) Year and (b) Season**



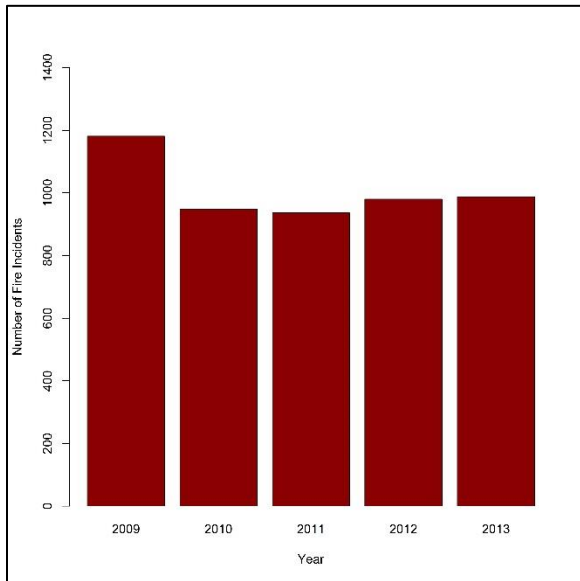
(a)

(b)

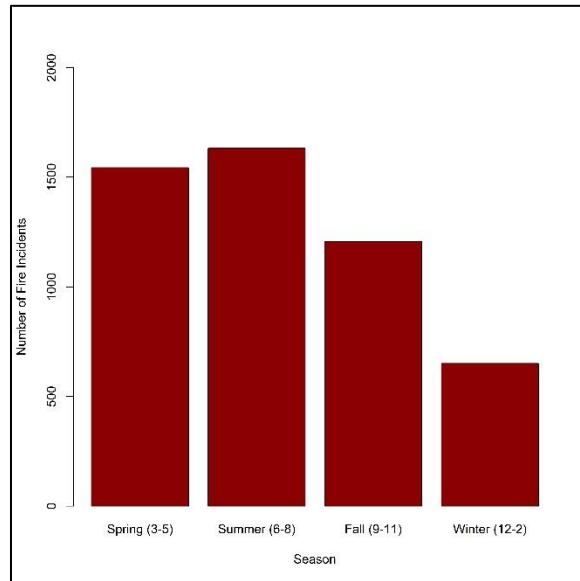
**Figure B-2. Incidents Responses with Ladder Equipment (a) Month and (b) Day of Week**



**Figure B-3. Incidents Responses with Ladder Equipment by Hour of Day**

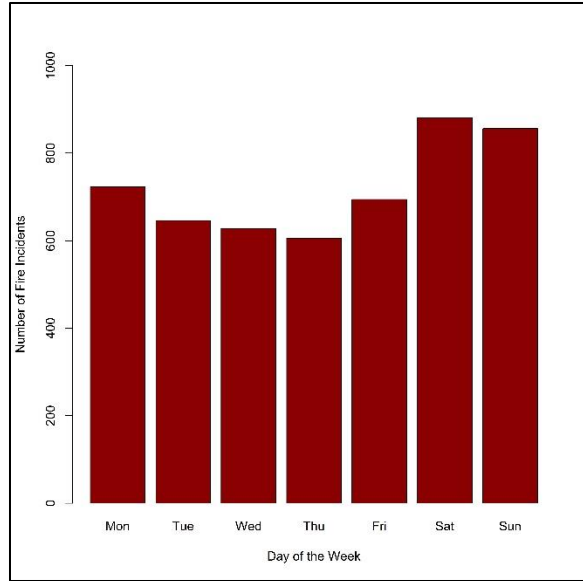
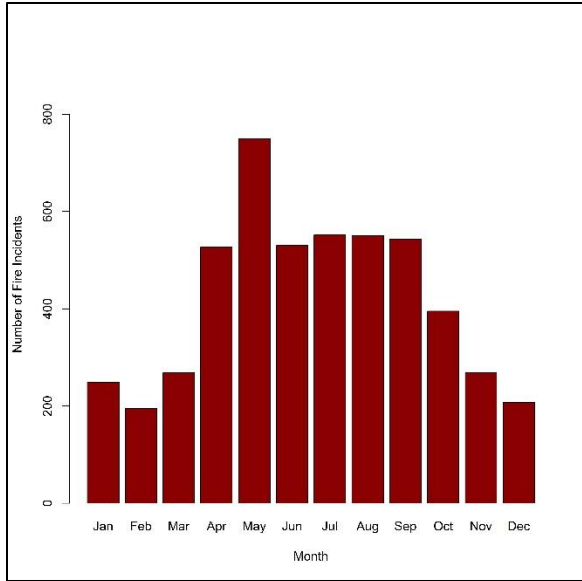


(a)



(b)

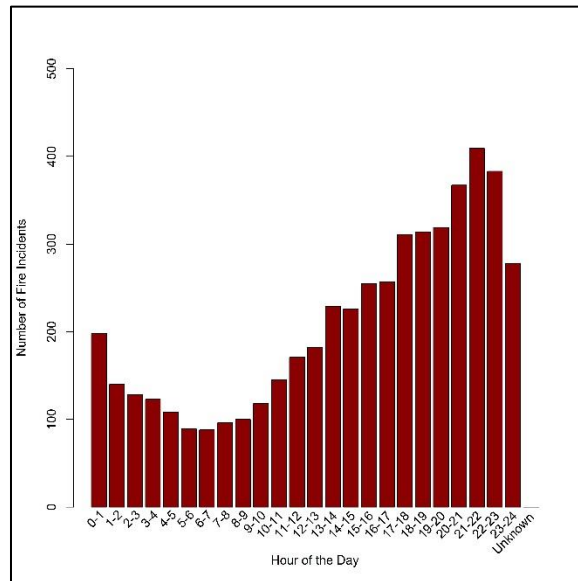
**Figure B-4. Incidents Responses with Tanker Equipment (a) Year and (b) Season**



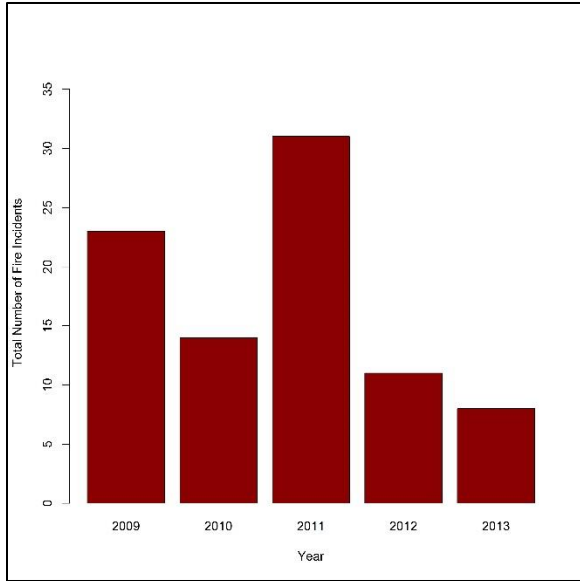
(a)

(b)

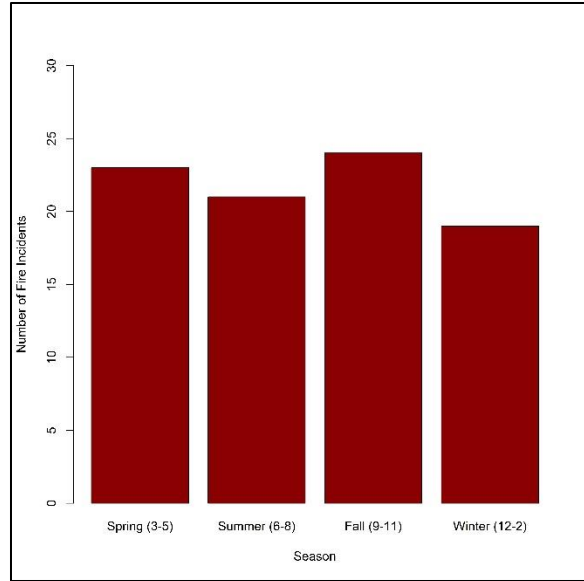
**Figure B-5. Incidents Responses with Tanker Equipment (a) Month and (b) Day of Week**



**Figure B-6. Incidents Responses with Tanker Equipment by Hour of Day**

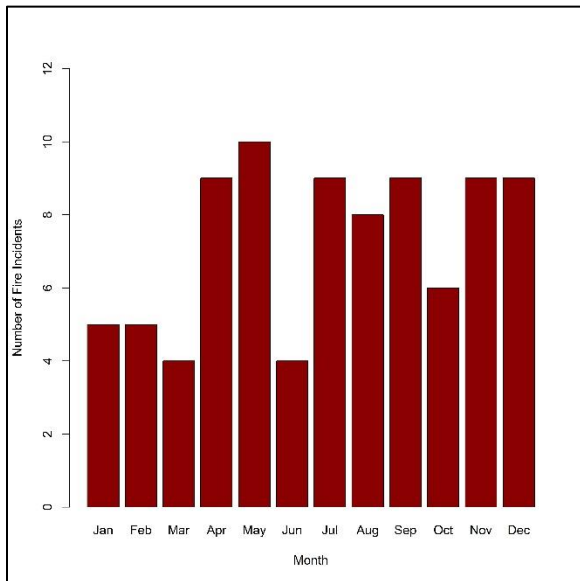


(a)

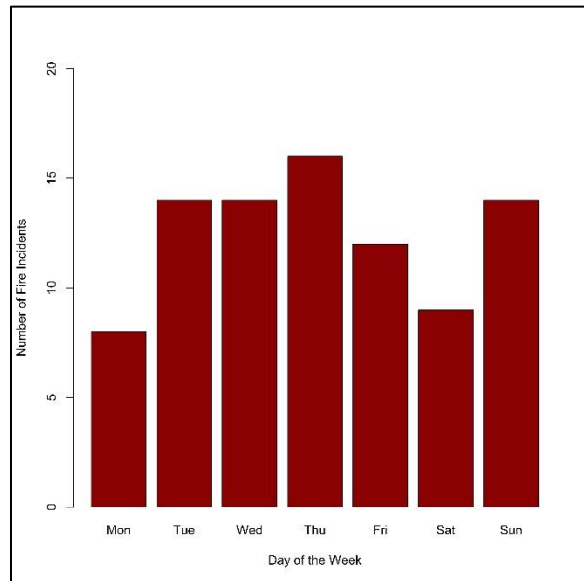


(b)

**Figure B-7. Incidents Responses with Decontamination Equipment (a) Year and (b) Season**

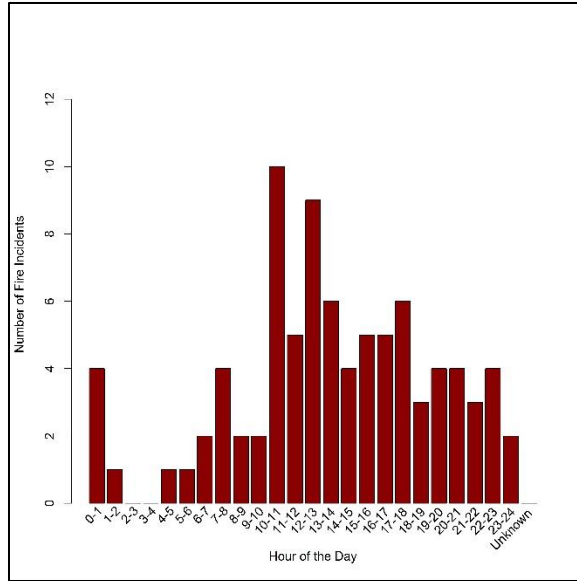


(a)

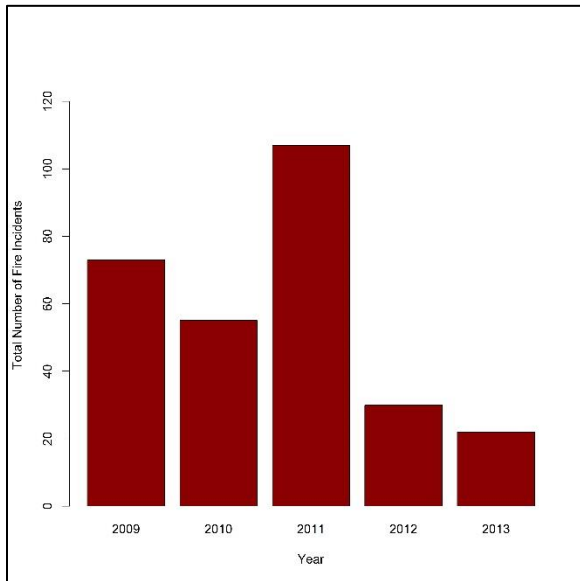


(b)

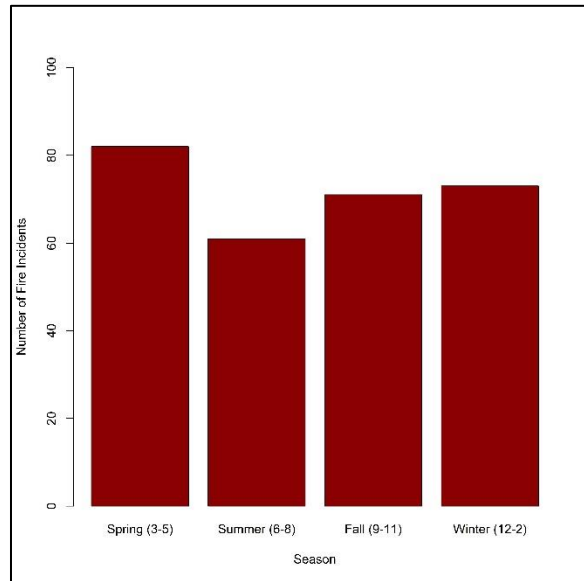
**Figure B-8. Incidents Responses with Decontamination Equipment (a) Month and (b) Day of Week**



**Figure B-9. Incidents Responses with Decontamination Equipment by Hour of Day**

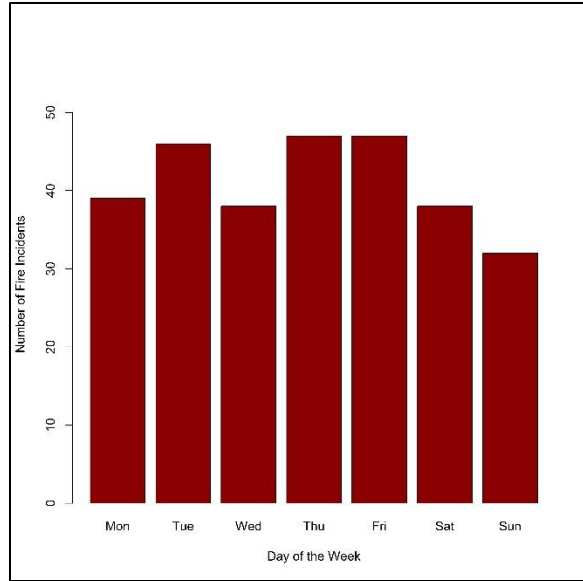
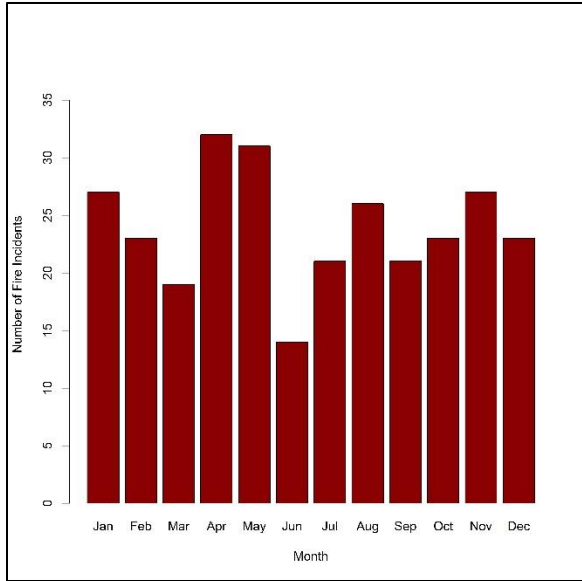


(a)



(b)

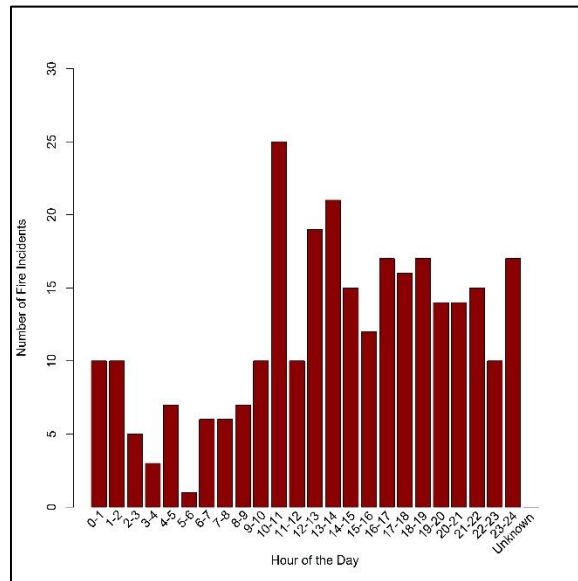
**Figure B-10. Incidents Responses with Hazmat Equipment (a) Year and (b) Season**



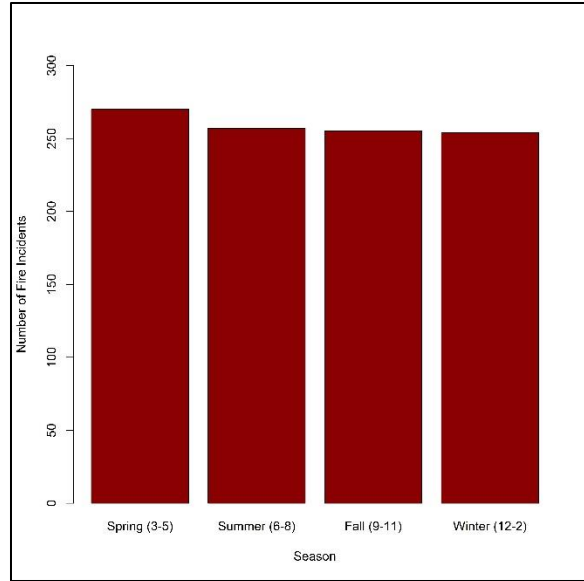
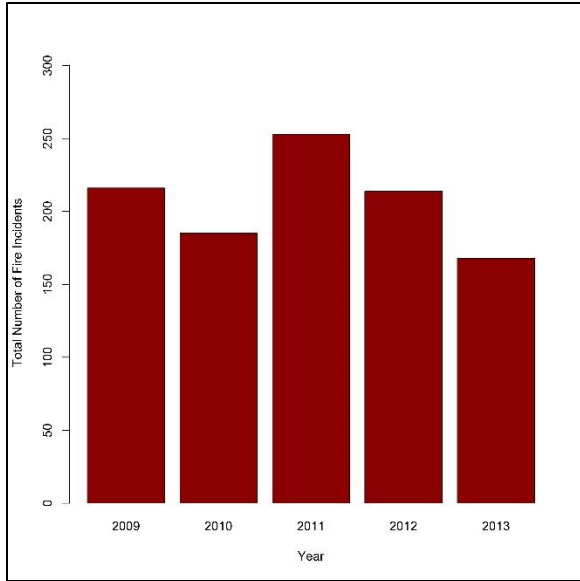
(a)

(b)

**Figure B-11. Incidents Responses with Hazmat Equipment (a) Month and (b) Day of Week**



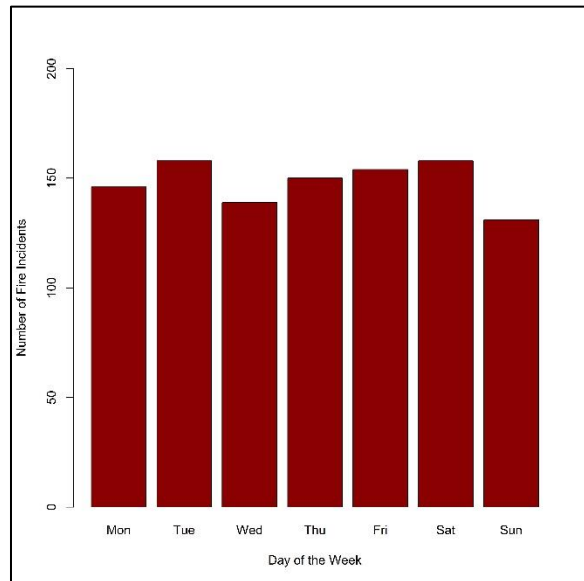
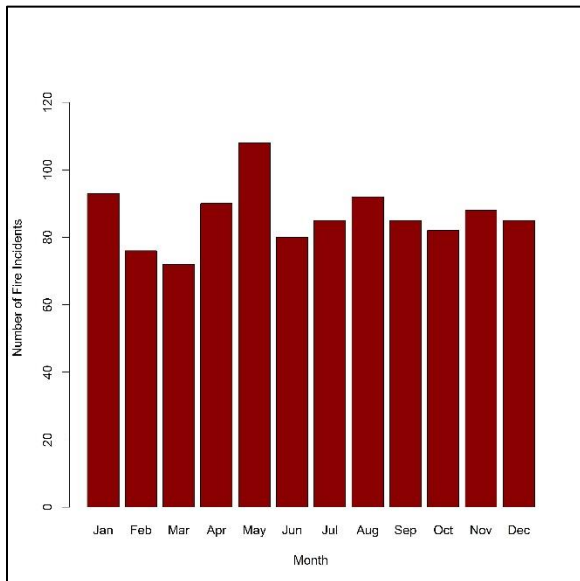
**Figure B-12. Incidents Responses with Hazmat Equipment by Hour of Day**



(a)

(b)

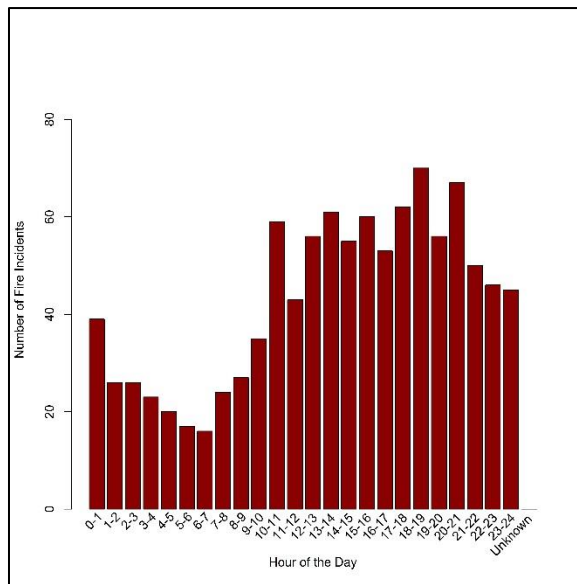
**Figure B-13. Incidents Responses with Trailer Equipment (a) Year and (b) Season**



(a)

(b)

**Figure B-14. Incidents Responses with Trailer Equipment (a) Month and (b) Day of Week**



**Figure B-15. Incidents Responses with Trailer Equipment by Hour of Day**

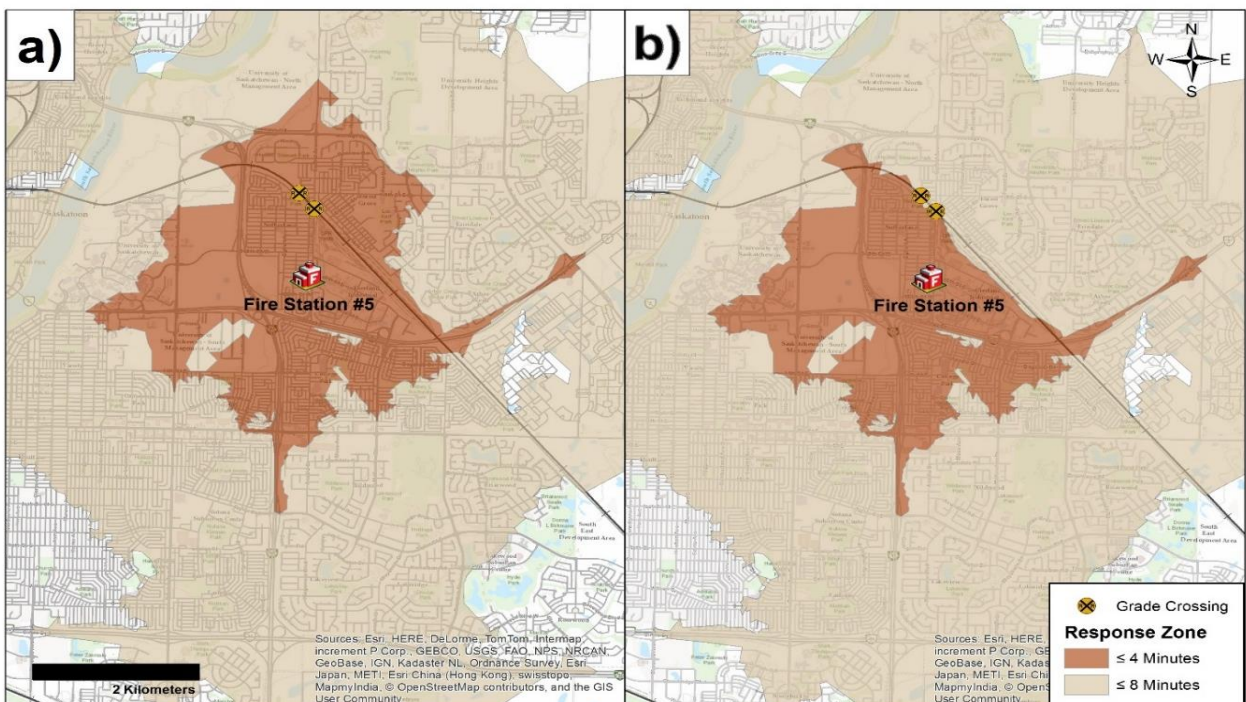


## APPENDIX C

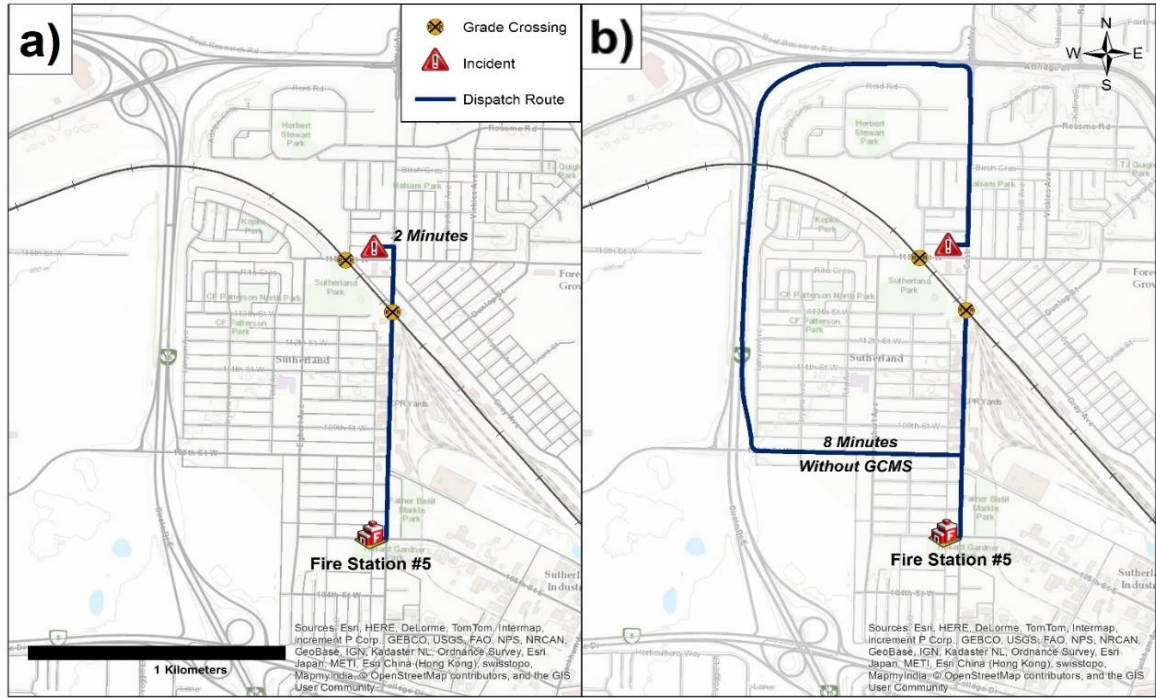
### RESPONSE TIME ANALYSIS FOR SLOW MOVING TRAIN

The SA analysis in **Figure C-1a** shows the estimated service area for FS#5 when there is no blockage. A service area of 11.32km<sup>2</sup> can be reached within four minutes (chocolate). Assuming there is blockage, **Figure C-1b** shows the estimated SA of 8.54km<sup>2</sup> that can be reached within the four minutes target response time. This shows that an estimated SA of 2.784km<sup>2</sup> (26%) cannot be reached within four minutes due to train blockage.

The network analysis in **Figure C-2a** shows the route to an incident when there is no grade crossing blockage and without GCMS. It takes a dispatched fire engine 2 minutes (blue line) to reach an incident from FS# 5. When there is a grade crossing blockage and no GCMS, **Figure C-2b** shows the dispatch route from FS# 5 to an incident. The dispatched engine gets to the grade crossing and a train on the level crossing and has to take a detour which takes 8 minutes. **Figure C-3** shows the change in route with a real-time information indicating that there is train on the grade crossing. It takes FS#5 7 minutes to reach an incident, saving 1 minutes. With GCMS, the fire department can call on FS#9 to respond to the incident which takes 3 minutes (dotted red line), saving 5 minutes.



**Figure C-1. Fire Station #5's Varying Service Area Due to Slow Moving Train**



**Figure C-2. Fire Engine Dispatch Routes to an Incident with/without Grade Crossing Blockage and without GCMS**



**Figure C-3. Fire Engine Dispatch Routes to an Incident with/without Grade Crossing Blockage and with GCMS**