Assessing Fire Response Efficiency and the Crucial Role of Protection Systems in Reducing Damage*

Insights from Toronto's Fire Incidents

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September 23, 2024

This paper analyzes fire incidents in Toronto between 2013 and 2023, focusing on the response times of the Toronto Fire Service (TFS) and the impact of fire protection systems. The study finds that TFS usually responds within 5 to 10 minutes, but the correlation between response time and economic losses is weak, and other factors like fire protection equipment play a larger role in mitigating damage. Fire alarms and sprinkler systems in present and operational reduce losses significantly. This research the importance of maintaining fire protection systems and improving fire service efficiency to enhance urban fire safety.

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*Code and data are available at: https://github.com/yulexun/toronto-fire.

1 Introduction

The urban fire hazard is one of the most pressing issues in this context, especially in Canada where cities are dealing with such issues like climate, facilities, or population density. As of July 1, 2023, the population in urban area in Canada reached 33,812,133 (Statistics Canada 2024). Not only do fires in highly populated regions result in heavy losses in terms of property, but also, in the context of people and the environment, the consequences are enormous. Also, urban fires are resource-dependent and require attention from city services and emergency services, thus indicating the need for prevention, action and planning based on risk assessment. With such issues in mind, the knowledge of urban fire hazards in Canadian cities is needed for creating policies that address public safety and increase urban resilience.

In Canada, articles about fire incidents have a focus on wildfire. For instance, Goemans and Ballamingie (2012) discuss the fire mitigation plan during the 2003 wildfire at Kelowna, British Columbia, while Mamuji and Rozdilsky (2018) talk about the evacuation during the Fort McMurray wildfire in Alberta. Research conducted about urban fire incidents is done in other parts of the world such as East Asia. Masood Rafi, Wasiuddin, and Hameed Siddiqui (2012) research the nature and level of this threat. They conclude that the lack of training in fire department, shortage of facilities and infrastructure the key issues in Pakistan. The research by Hari Murti et al. (2023) in Semarang City also emphasizes the importance of community understanding and the installation of fire protection facilities. This article uses the data provided by opendatatoronto library (Gelfand 2022) to analyze fire occurrences in the city of Toronto, which is an important research gap in the study of fire incidents in America. This study seeks to provide a deeper understanding of fire patterns to improve fire prevention and emergency response strategies.

In this paper we visualize Toronto's Fire Incidents data. The remainder of the paper is structured as follows. Section 2 discusses the raw and cleaned data, as well as the summary statistic. Then in Section 2.2 and Section 2.3, we discuss the trend and distribution of TFS response time and fire protection equipment presence. In Section 3, we provide analysis of the trend and correlation in Section 2, as well as the limitations and future directions in resolving urban fire incidents.

2 Data

2.1 Overview

The data used in this paper is obtained from the opendatatoronto library (Gelfand 2022). The dataset used is Fire Incidents. According to Gelfand (2022), it includes fire incidents as defined by the Ontario Fire Marshal (OFM) up to December 31, 2023. The data gathering and analysis is done in R (R Core Team 2024) with the following packages: opendatatoronto (Gelfand 2022), knitr (Xie 2014), tidyverse (Wickham et al. 2019), ggplot2 (Wickham 2016), dplyr (Wickham et al. 2023), and lubridate (Grolemund and Wickham 2011).

The cleaned data are divided into two groups in accordance with the two most crucial factors in urban fire incidents: responsiveness of fire department and fire protection equipment, as indicated by Hari Murti et al. (2023) and Masood Rafi, Wasiuddin, and Hameed Siddiqui (2012). The first group focuses on the fire services' response time, extent of fire and the loss of money, and the second group focuses on the loss of money, reason of fire incidents and the presence or operation of fire protection equipment. All other data features are ignored during the data cleaning process.

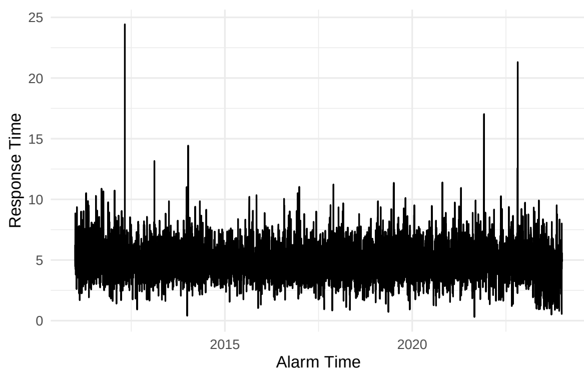
2.2 Toronto Fire Service Responsiveness

The first group of data shows the responsiveness of Toronto Fire Services. An example of this dataset is presented in Table 1. "Alarm Time" is the time when TFS are notified of the incident. "TFS Arrival time" is the timestamp of the first arriving unit. The difference in minute is calculated at the data cleaning step as "TFS Response Time". "Estimated Loss in Dollars" is the estimated loss measured in dollars. "Extent of Fire" is a categorical indicator from "1" to "11" according to the seriousness of the incident.

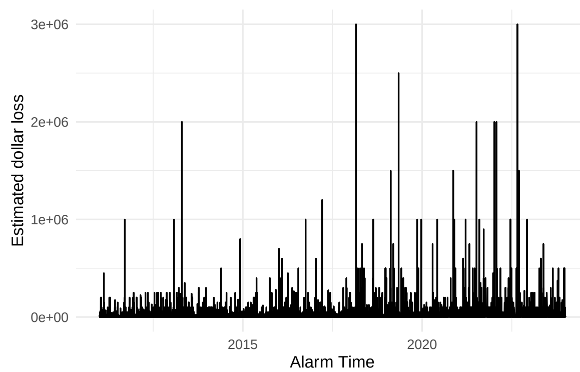
Table 1: Top rows of cleaned Toronto Fire Service response time and loss data

Alarm Time	TFS Arrival Time	TFS Response Time	Estimated Loss in Dollars	Extent of Fire
2018-02-25 15:48:34	2018-02-25 15:52:04	3.500000	5000	1
2018-02-26 18:11:59	2018-02-26 18:15:50	3.850000	500	1
2018-03-03 09:49:14	2018-03-03 09:53:09	3.916667	0	1
2018-03-03 17:54:38	2018-03-03 17:59:42	5.066667	15000	2
2018-03-03 18:34:35	2018-03-03 18:40:47	6.200000	0	1

Figure 1a shows the line plot of Toronto Fire Service's response time over the period between 2013 to 2023. The response time fluctuated around a consistent level, typically between 5 and 10 minutes, with occasional spikes where the response time increased significantly above the usual range, particularly around 2014 and 2019. Figure 1b shows the line plot of estimated dollar loss of the fire incidents. Most of the incidents resulted in low dollar losses, but there are several spikes that represent incidents where the loss was significantly higher. Some of the most notable spikes occurred between 2015 and 2019, with losses exceeding 2 million dollars.



(a) TFS response time over time



(b) Estimated dollar loss over time

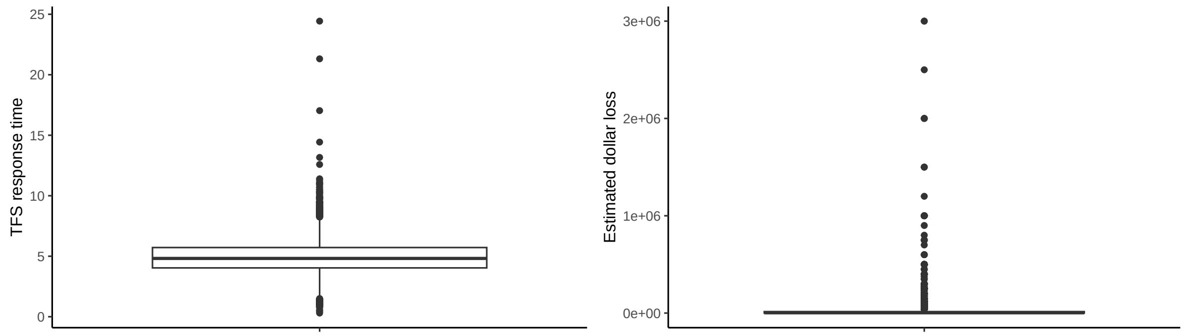
Figure 1: TFS response time and estimated dollar loss over time

Table 2a indicates the summary statistic and Figure 2a graphs the boxplot of TFS's response time. The value ranges from 4.03 minutes to 5.7 minutes as shown in Table 2a, with a mean value of 4.911868 minutes. Notably, in Figure 2a, several outliers are indicated by dots above the upper whisker, suggesting occasional instances of significantly higher response times.

Table 2b indicates the summary statistic and Figure 2b depicts the distribution of economic losses in boxplot. In Table 2b, values span from 0 dollar to over 3000000 dollars, with median value of 3000 dollars, mean value of 24551.64 dollars and standard deviation of 93520.08 dollars, indicating a skewed distribution. Figure 2b reveals numerous outliers above the upper whisker, highlighting instances of exceptionally high economic losses.

Figure 3 illustrates that most of the observed fires are relatively small. The x-axis depicts the extent of the fire, while the y-axis shows the frequency of observations. A notably tall bar at the start signifies a high occurrence of smaller fires. As fire size increases along the x-axis, the number of observations drops sharply, indicating that larger fires are far less frequent.

Figure 4 shows a line of best fit, which indicates a weak correlation between TFS response time and estimated dollar loss. There is a wide range of TFS response times for lower dollar losses.



(a) Boxplot of TFS response time (b) Boxplot of estimated dollar loss

Figure 2: Boxplot of TFS response time data and estimated dollar loss

Table 2: Summary Statistic of TFS response time data and estimated dollar loss

(a) Summary of TFS response time

Statistic	Value
Min.	0.300000
1st Qu.	4.033333
Median	4.816667
Mean	4.911166
3rd Qu.	5.716667
Max.	24.433333
SD	1.399413

(b) Summary of estimated dollar loss

Statistic	Value
Min.	0.00
1st Qu.	500.00
Median	3000.00
Mean	26584.26
3rd Qu.	15000.00
Max.	3000000.00
SD	104422.21

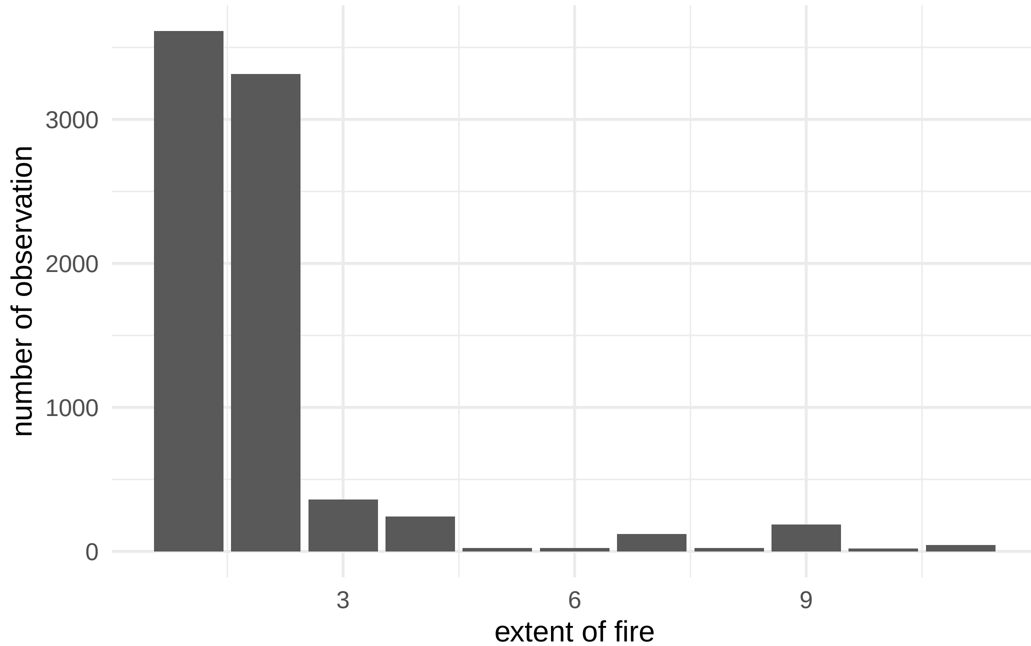


Figure 3: Distribution of extent of fire

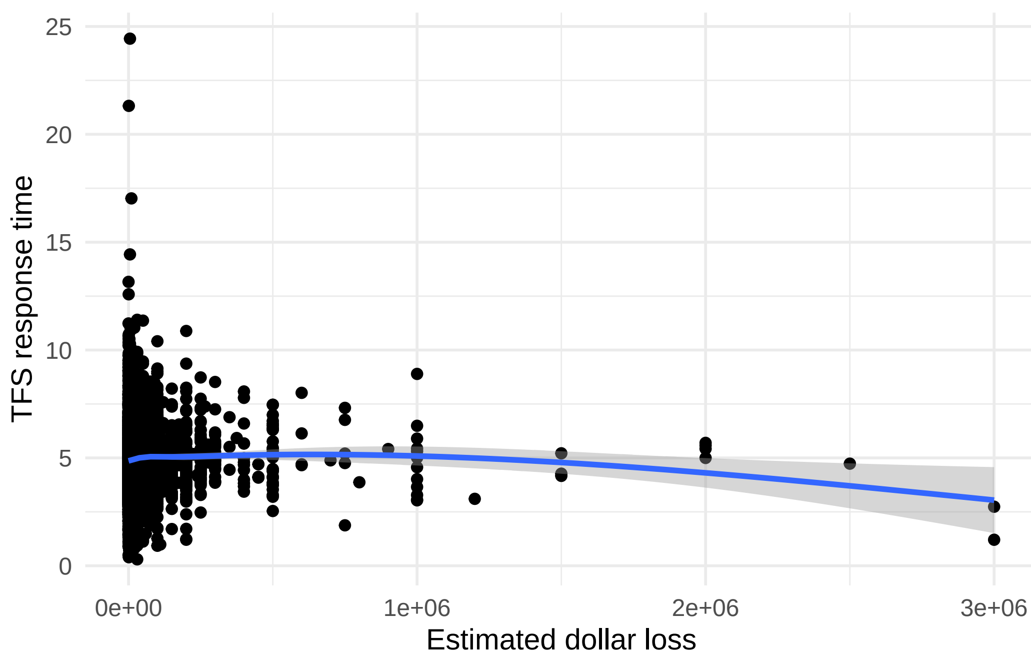


Figure 4: Line of best fit between TFS response time and dollar loss

2.3 Fire Protection Equipments

The second group of data shows the money loss, cause of fire and the presence of fire prevention equipment. Table 3 shows the first five rows of the second group of data. "Estimated Loss in Dollars" is the estimated loss measured in dollars. "Area of origin" indicates the area fire originates. "Ignition Source" shows the object causing fire. "Fire Alarm Status", "Smoke Alarm Status" and "Sprinkler System Status" indicate the presence and operation of fire protection equipment. In the second group of data, 'PO' = System present, 'N' = System not present, and 'P' = System present but not operated.

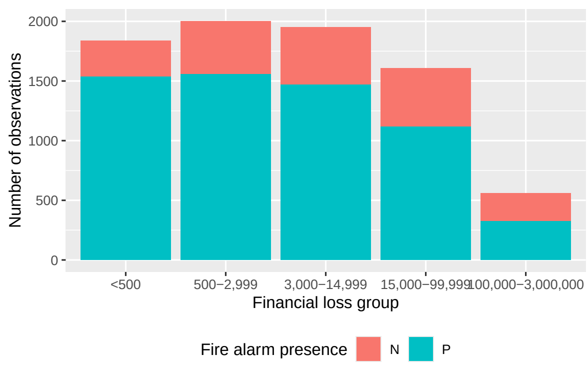
Table 3: Top rows of cleaned data showing Area of Origin, Ignition source and Fire, Smoke, Sprnkler System Presence.

Estimated Loss in Dollars	Area of Origin	Ignition Source	Fire Alarm Status	Smoke Alarm Status	Sprinkler System Status
5000	28	41	P	PO	P
500	24	11	P	PO	N
0	24	11	N	PO	P
15000	25	24	N	N	N
0	24	11	P	PO	P

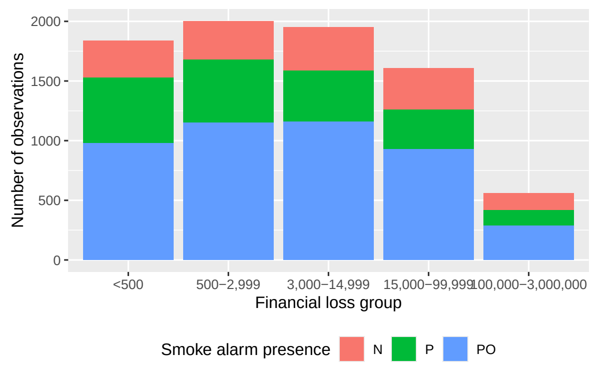
Figure 6 in Appendix A.1 illustrates the distribution of the fire incidents' area of origin. It consists of 71 unique categories. The most common area of origin is category 24, which is cooking area or kitchen. Other common areas include category 64: Porch or Balcony, 22: Sleeping Area or Bedroom, 21: Living Area, and 27: Laundry Area. However, fires in these locations occur significantly less often compared to those in kitchens.

Figure 7 in Appendix A.2 shows the distribution of ignition source in fire incidents. It contains 73 unique categories. The most common ignition source is 11: Stove, Range-top burner and 71: Smoker's Articles. Other common ignition sources include 55: Candle, 43: Clothes Dryer, and 12: Oven.

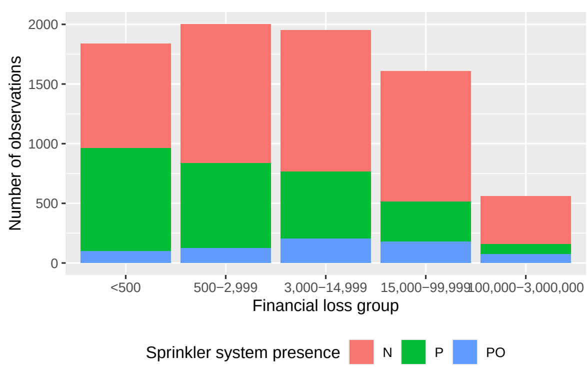
Figure 5 shows the distribution of grouped economic loss and the presence of fire prevention system. In Figure 5a, the graph shows that incidents with no fire alarm system (red bars) are less than incidents with fire alarm system (blue bars). Among the incidents with higher economic loss, there are more cases without a fire alarm system. In Figure 5b, Most of the incidents happen with the smoke alarm present. Among the incidents with lower economic loss, more smoke alarms are present but not operated compared to higher economic loss cases. In Figure 5c, we can tell that a substantial proportion of incidents does not have a sprinkler system installed. Among those incidents with sprinkler system present, most of them are not operated.



(a) Distribution of economic loss group, and fire alarm presence



(b) Distribution of economic loss group, and smoke alarm presence



(c) Distribution of economic loss group, and sprinkler system presence

Figure 5: Distribution of economic loss group, and fire prevention system presence

3 Discussion

The analysis of Toronto's fire incident data reveals critical insights into both the responsiveness of the Toronto Fire Service (TFS) and the role of fire protection systems in mitigating economic losses.

3.1 Toronto Fire Service Responsiveness

The Toronto Fire Service (TFS) has efficient response times, averaging about 4.9 minutes, as noted in the summary statistics Table 2a. Over the period from 2013 to 2023, response times varied between 5 and 10 minutes, with some notable outliers, according to Figure 1a. This indicates that while TFS usually responds quickly, there can be occasional delays due to outside factors. Importantly, these response times do not lead to significant economic losses, because the relationship between response time and economical impact is weak, as indicated by Figure 4. This implies that for the TFS, rapid response to fire incidents is not the most critical factor. Other elements, such as the severity of the fire and existing fire protection measures, are more decisive in determining the financial consequences of fire events.

Financial losses from fire incidents vary, with most cases resulting in low losses, as illustrated in Figure 1b. However, certain outliers, especially from 2015 to 2024, have reported losses exceeding $2 million. This indicates that larger fires occur occasionally, leading to considerable property damage.

3.2 Impact of Fire Protection Equipment

The presence and operation of fire protection equipment, particularly alarms and sprinklers, had a noticeable effect on economic losses. According to Figure 5, incidents where fire alarms were absent or failed to operate resulted in higher economic losses. This is consistent with previous research carried out including the one conducted by Hari Murti et al. (2023) which further corroborates the studies that the absence of effective fire prevention systems makes the aftermath of fire destruction more damaging. Additionally, the data reveals that while smoke alarms were present in most cases, sprinklers were often absent or not operational. This underlines the importance of incorporating sprinkler systems particularly in these areas where most fire outbreaks are recorded such as kitchens in accordance with statistics.

The results also indicate that there are other factors such as the location of the fire's ignition and its sources that are critical in determining the outcome. According to Figure 6 and Figure 7, kitchens and living rooms are the most common areas where fires start with most cases arising from stovetops and smokers' articles being the most common. Such information makes it evident that fire outbreaks should be prevented by targeting those measures in these severe areas. For instance, fire incidents would be reduced considerably alongside its severity by making people understand the dangers of kitchen fires and the need to manage sprinkler and smoke alarm systems so that they do not malfunction.

3.3 Future Directions and Limitations

This assessment is important in the context of fire prevention and emergency response plans in Toronto. First, the response times from TFS, apart from being fairly constant, also fluctuate at times, justifying the strategy that more improvements in the fire service will be in order in particular areas where there are delays. Furthermore, the data emphasize the importance of fire protection systems in decreases in losses and the necessity of not only having fire protection systems in place but having them in working order as well.

There are a few limitations to this research. First, there are other factors affecting TFS response time, such as extreme local weather or traffic. The response time data may not show the full picture of TFS's responsiveness. Second, the presence of fire protection equipment is oversimplified in the dataset. It is grouped into only three main categories. The state of fire alarm, smoke alarm and sprinkler system have to be analyzed more thoughtfully during the data collection process for a more useful analysis.

Overall, this analysis contributes to a deeper understanding of fire risks in urban environments and supports the development of targeted interventions aimed at minimizing fire-related damage.

A Appendix

A.1 Graph of areas of origin of fire incidents by number of occurrences

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Index of 'Area of Origin':

11 - Lobby, Entranceway
12 - Hallway, Corridor
13 - Stairway, Escalator
18 - Covered Court, Atrium, mall concourse
19 - Other Means of Egress
21 - Living Area (e.g. living, TV, recreation, etc)
22 - Sleeping Area or Bedroom (inc. patients room, dormitory, etc)
23 - Dining or Beverage Area (inc mess, canteen, lunchroom, cafeteria
24 - Cooking Area or Kitchen
25 - Washroom or Bathroom (toilet,restroom/locker room)
26 - Sauna
27 - Laundry Area
28 - Office
29 - Electronic Equipment
30 - Sales, Showroom Area
31 - Process Manufacturing (inc manf, prod assembly, repair)
32 - Assembly Area (inc school room,spectator area, church, etc)
33 - Laboratory
34 - Operating Room, Treatment or Examination Area
35 - Performance Area (inc stage, rink, boxing ring, gym floor, altar
36 - Backstage, dressing room
39 - Other Functional Area
41 - Closet (eg. clothes, broom, linen closet, etc.)
42 - Garage
43 - Locker (apartment storage)
44 - Trash, Rubbish Storage (inc garbage chute room, garbage/industri
45 - Supply Storage Room (inc maintenance/office/document storage, et
46 - Product Storage (inc products or materials awaiting manuf, assembly)
47 - Shipping/Receiving/Loading Platform
48 - Records storage area (inc vaults)
49 - Other Storage Area
50 - Basement/cellar (not partitioned)
51 - Elevator (includes shaft)
52 - HVAC Equipment Room (furnace room, water heater closet, boiler)
53 - Chimney/Flue Pipe
54 - Incinerator Room
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55 - Mechanical/Electrical Services Room
56 - Conveyor Shaft or Chute (inc dumbwaiter, laundry chute, garbage
57 - Ducting - Heating, Air Conditioning
58 - Ducting - Exhaust (inc cooking, fumes, etc.)
59 - Utility Shaft (eg. electrical wiring/phone, etc.)
60 - Other Building Services/Support Facilities
61 - Exterior Wall
62 - Roof
63 - Awning or Canopy
64 - Porch or Balcony
65 - Crawl Space (includes sub-structure)
66 - Concealed Ceiling Area
67 - Concealed Floor Area
68 - Concealed Wall Area
69 - Attic Area
70 - Other Structural Area
71 - Open Area (inc lawn, field, farmyard, park, playing field, pier,
72 - Court, Patio, Terrace
73 - Parking Area, Parking Lot
74 - Storage Area (outside)
75 - Trash, rubbish area (outside)
76 - Fuel Dispensing Area (outside)
78 - Attached Deck
79 - Other Outside Area
81 - Engine Area
82 - Running Gear (inc wheels and braking systems, transmission syste
83 - Electrical Systems
84 - Fuel Systems (eg. fuel tank, etc.)
85 - Operator/Control Area
86 - Passenger Area
87 - Trunk/Cargo Area
89 - Other Vehicle Area
91 - Multiple Areas of Origin
92 - Residential/Business: Restaurant area
93 - Residential/Business: Other busines area

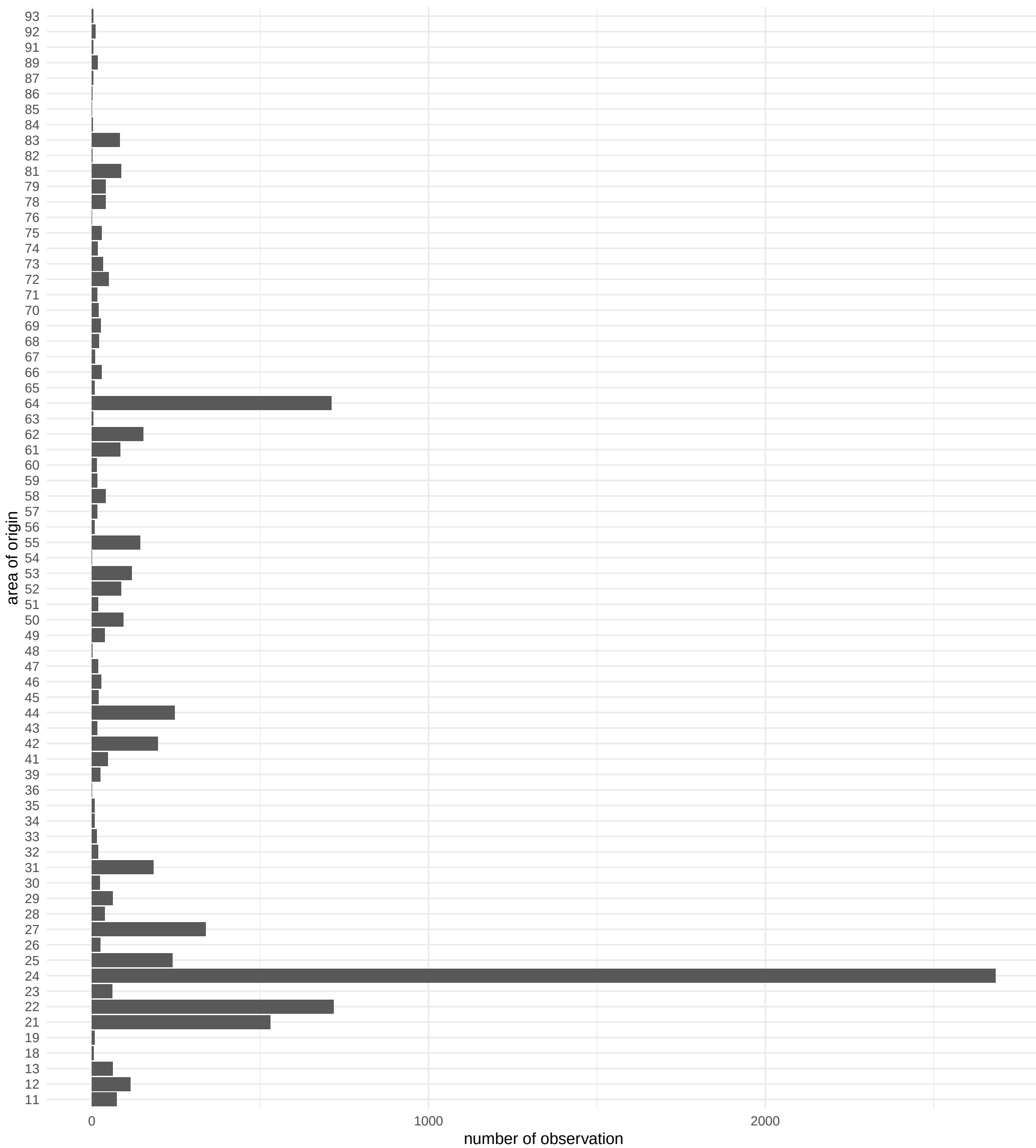

Figure 6: Areas of origin of fire incidents by number of occurrences

A.2 Graph of ignition source of fire incidents by number of occurrences

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Index of 'Ignition Source':

100 - Outdoor fireplace/heater
101 - Exposure, source structure detached
102 - Exposure, source structure semi-detached or attached
103 - Exposure, source outside storage container, tank
104 - Exposure, source open fire (inc campfire, rubbish fire)
106 - Exposure, source grass, shrubs, trees
107 - Exposure, source vehicle (outside structure)
108 - Exposure, source other
11 - Stove, Range-top burner
12 - Oven
13 - Microwave
14 - Open Fired Barbeque - Fixed or Portable
15 - Range Hood
16 - Deep Fat Fryer
17 - Wood burning stove
19 - Other Cooking Items (eg Toaster, Kettle, elec frying pan)
20 - Service/Utility Lines (includes power/hydro transmission lines)
21 - Transformer
22 - Meter
23 - Distribution Equipment (includes panel boards, fuses, circuit br
24 - Circuit Wiring - Copper
25 - Circuit Wiring - Aluminum
26 - Terminations-Copper (incl receptacles, switches, lights)
27 - Terminations-Aluminum (incl receptables, switches, lights)
28 - Cord, Cable for Appliance, Electrical Articles
29 - Extension Cord, Temporary Wiring
30 - Other Electrical Distribution Item
31 - Central Heating/Cooling Unit
32 - Water Heater
33 - Space Heater - Fixed
34 - Space Heater - Portable
35 - Fireplace - Factory Built
36 - Fireplace - Masonry
37 - Fireplace Insert
38 - Chimney - Factory Built
39 - Chimney - Masonry
40 - Flue Pipe
41 - Other Heating Equipment
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42 - Television, Radio, Stereo, Tape Recorder, etc.
43 - Clothes Dryer
44 - Iron, Pressing Machine
45 - Washing Machine
46 - Electric Blanket, Heating Pad
47 - Refrigerator, Freezer (includes vending machine)
48 - Air Conditioner - Window or Room Unit
49 - Other Appliances
51 - Incandescent Lamp - Light Bulb, Spotlight
52 - Florescent Lamp (includes ballast)
53 - Christmas Lights, Decorative Lighting
54 - Lamp (eg. coal, oil, naphtha, etc.)
55 - Candle
56 - Halogen Lamp or light
59 - Other Lighting Equipment
61 - Incinerator
62 - Heat Treatment Equipment (eg. furnace, oven, kiln, quench tanks,
63 - Painting Equipment
64 - Chemical Processing Equipment (eg. reactors, distilling units, e
69 - Other Processing Equipment
71 - Smoker's Articles (eg. cigarettes, cigars, pipes already ignited
72 - Cutting/Welding Equipment
73 - Blow Torch, Bunsen Burner
74 - Salamander
75 - Matches (open flame)
76 - Lighters (open flame)
77 - Matches or Lighters (unable to distinguish)
79 - Other Open Flame Tools/Smokers' Articles
80 - Portable generator
81 - Vehicle - Electrical
82 - Vehicle - Mechanical
83 - Other Electrical
84 - Other Mechanical
85 - Vehicle collision
88 - Multiple Ignition Source or Igniting Equipment (suspected arson)
91 - Fireworks
92 - Open Fire (eg. camp fire, rubbish fire, etc.)
93 - Hot Ashes, Embers, Spark
94 - Static Electricity (spark)
95 - Lightning
96 - Chemical Reaction (eg. spontaneous combustion, etc.)
97 - Rekindle

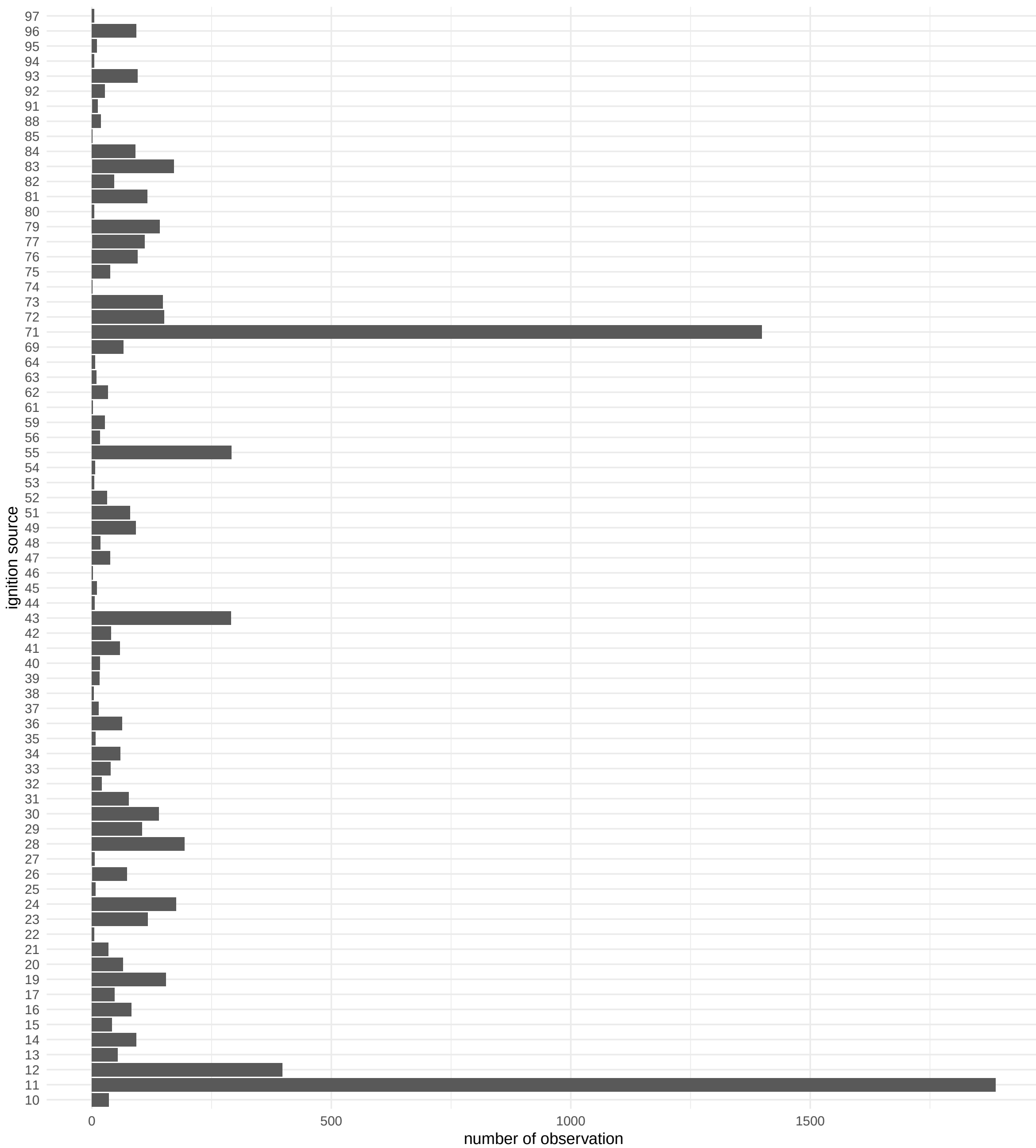

Figure 7: Ignition Source of fire incidents by number of occurrences

A.3 Attribution Statement

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