Prioritization for the Scheduling of Fire Safety Inspections:

Risk-Based and Data-Driven Inspection Framework

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CITY OF SURREY
FIRE SERVICES

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Table of Contents

Executive Summary

This paper explores the administrative systems used to prioritize the annual workload of fire safety inspections. Historically, inspection work has been prescriptively driven with pre-programmed dates for annual or bi-annual inspections. This historical system does not pre-plan for managing higher risk properties which may be challenged with fire code compliance, typically taking several months and multiple inspections to bring into compliance. It also does not recognize the human factor and how owner/operator/visitor behaviour either supports fire safety or is more risk tolerant towards fire safety. These factors and lack of system learning has traditionally led to a backlog of annual workload, which challenges fire prevention staff to complete the important fire safety inspections on all properties due each year. This problem results in some high-risk properties not achieving compliance on an annual basis.

To assess the performance of the fire safety inspection program against actual fire occurrence over time, a system that consistently completes the annual inspection workload is required.

It is important to emphasize that this paper is not intended to suggest that fire safety inspections should not be performed. Instead, it is intended to demonstrate an alternate framework that can be implemented with the goal of maximizing the efforts of fire department resources. This can be achieved by addressing properties with the highest risks first, using prioritized inspection scheduling.

Previous research on the relationship between fire incidents and fire inspections revealed two key findings:

- There was no relationship between an increased duration since the last fire inspection and the frequency and severity of fires.
- Fire incidents occurred following elevated non-compliance at the most recent inspection.

Considering these findings, an opportunity emerged to discuss shifting fire inspection strategy from the existing time-driven approach to a performance-based approach and subsequent research presented the concept of a risk-based and data-driven fire safety inspection framework.

The British Columbia Provincial Government in 2016 created a new act, called the Fire Safety Act, designed to replace and substantially update the current Fire Services Act. At the time of writing this paper, the new act regulations are not yet published or in effect but are expected to promote a system of inspections that is risk-based, which will result in the ability to focus inspection resources where they can have the greatest impact first.

The first step towards a performance-based approach in Surrey was implemented using a basic risk-based inspection prioritization formula, a focus on inspection compliance, improved operational efficiencies and an action plan to manage the cultural change. The results were successful in both improving annual workload completion rates and overall inspection compliance rates. These successes pave the way for further efforts to enhance the performance-based inspection strategy using an expanded risk-based framework.

This paper will further expand on the risk-based framework by incorporating compliance risk factors derived from historical inspection outcomes and building risk factors related to property characteristics to generate total risk scores that can help prioritize inspection scheduling. The total risk score components are:

- The compliance risk score, which is generated from the outcomes of inspections and can therefore change over time. It is the sum of weighted scores which are generated for every unsatisfactory inspected item using a regression model developed to determine the relationship between those items and fire occurrences. Over three inspections, a weighted average compliance risk score is calculated in consideration of whether improvements on outcomes are detected or not.
- Three property characteristics generate the building risk score for every inspectable property. They are the occupancy usage, the fire service incidents at the property, and the by-law violations within a 50-metre proximity radius. Each risk factor receives a weighted score in relation to the occurrences preceding fire incidents. For this purpose, a regression model is developed.
- Inspectable properties will receive an incentive score when there is a complete or partial fire safety system present. The data analysis on structure fires at inspectable properties determined that the presence of a complete or partial fire safety system reduces the fire severity by 59% and 39% which leads to the reduction of fire casualty by 18% and 12%, respectively.

The validation of the risk scores is conducted by performing sensitivity analysis against the scores in different categories of risk and compliance. The sensitivity analysis shows that the risk scores are sensitive enough to discriminate the properties in different categories.

Surrey Fire Prevention Branch experience indicates the basic risk-based model does help with achieving the goal of completing the annual inspection workload without backlogs. Further, the properties with the most fire code challenges are brought into compliance in due time. Nevertheless, future evaluation is deemed necessary to review the enhanced risk scores against actual structure fire incidents and the trend of structure fires at inspectable properties both pre and post implementation.

Purpose of this Research

To explore and evaluate alternative administrative systems for accomplishing annual fire safety inspections. The main goals are to complete required annual inspections and to improve Fire Code compliance by addressing properties with higher risk first.

In British Columbia, the current legislative requirement, the Fire Services Act, states: “A municipal council must provide for a regular system of inspections of hotels and public buildings in the municipality” [1]. To meet this requirement, the Surrey Fire Services has a system of fire safety inspections, where each inspection is assigned either a one-year or two-year frequency.

Fire safety inspections serve to limit the incidence of fire in two ways:

1. By checking for fire code compliance and correcting any situations where the fire safety-related systems have not been tested or are not functioning properly; and
2. Through providing education to occupants on code required operating practices and recommended fire safe behaviors which can reduce the risk of a fire occurring.

The new Fire Safety Act created by the British Columbia Provincial Government and its regulations, are expected to improve fire code compliance monitoring by making the system of inspections risk-based, which will result in the ability to focus inspection resources where they can have the greatest impact. Furthermore, analysis on historical inspections in 2012 [2] showed the interaction among various risk factors which has triggered the discussion of redesigning Surrey Fire Service's time-driven system of inspections. The goal of the redesigned system is to maximize the efforts of fire department resources to address the properties with the highest risks by first using prioritized inspection scheduling. For this purpose, this research will explore and evaluate alternative administrative systems for accomplishing annual fire safety inspections.

Previous research introduced a risk-based and data-driven framework for redesigning fire safety inspection scheduling. This research aims to explore and expand upon that framework by incorporating and further developing the two dynamic risk factors: fire related building risk factors and compliance (behavior related) risk factors.

The resulting framework should inform Surrey Fire Services of the scheduling priority of fire safety inspections for each inspectable property by considering its fire-related risk, which is a result of data analysis on the previously mentioned risk factors. Thus, it should enable Surrey Fire Services to target their efforts at the highest risk properties sooner to have the biggest impact on reducing the risk of fire and ensuring that code violations are brought into compliance while maintaining the overall inspection workload.

Background

In a 2012 study, Garis and Clare's analysis of the relationship between fire incidents and fire inspections found no supportive evidence for maintaining the existing time-driven approach to conducting fire safety inspections. They found that an increase in time between the last fire safety inspection had no significant relationship to the frequency of fire occurrence, the extent of fire spread, or fire-related casualties [2]. The study instead highlighted a broader set of risk factors that align with the 1992 *Interpretive Guide* [3] to determine the frequency of inspections, namely occupancy type, age, condition, maintenance, and degree of cooperation on behalf of the building's responsible person. The study further introduced static and dynamic indicators of risk. The static risk indicators are "…the essentially non-changeable elements of the property that influence fire likelihood, such as construction material, zoning density, geographic location in the city, etc. [2]". Garis and Clare [2] further indicate that the factors of compliance history and building use are two examples of dynamic risk indicators which can change over time as influenced by inspections and improved safety practices.

Garis and Clare [4] determined that there is a relationship between a fire event occurring and elevated non-compliance at the most recent inspection preceding the fire event. Based on these findings, they highlighted the need to make a transition from the existing time-driven approach, that mostly depends on prescriptive fire safety codes, to inspections using performance-based fire safety codes that should consider the performance of the fire itself, the structure, and the occupants of the structure as associated with a fire experience [5,6]. A similar approach has been proven to be successful in reducing community fire-related risks in residential properties [7].

With these findings in mind and looking towards the future of fire safety inspections, Garis and Clare presented the concept of a risk-based and data-driven fire safety inspection framework. This framework would incorporate information about previous inspections performance, the responsible person in charge of the property, the property usage, and the type of structure [5]. The study adopted the 2005 Alberta approach to Service Delivery Standards produced for the Municipal Based Quality Management Plan. It modified the approach to address the multi-dimensional nature of inspections by splitting the characteristics into two measures that operate in parallel: compliance (dynamic factor indicated by the most recent inspection) and building risk (static factor). The measures can be combined to create a compliance-risk framework that separates all inspectable properties into one of four categories:

a. High risk/low compliance
b. High risk/high compliance
c. Low risk/low compliance
d. Low risk/high compliance

By means of this risk-based and data-driven categorization methodology, fire inspection resources can be optimized in which inspection efforts can be targeted to improve inspection compliance. This should result in a reduced number of high-risk/low-compliance and low-risk/low-compliance properties. If adopted, the proposed framework would form the foundation for future inspections that are data-driven and based firmly on risk.

The use of data analytics and machine learning capability to predict fire risk is not a novel concept for data enthusiasts and fire services in North America, although its implementation to inform fire inspection and/or fire prevention campaigns is getting more attention from the practitioners [8],[9],[10]. Despite the outlook of these approaches and the improvement of prediction tools and methodologies, Hinds-Aldrich presented challenges and found a lack of implementation within the respective fire departments [11]. The article highlighted the disconnections between how these prediction tools are developed and made available, and how fire departments and fire inspections often are configured and deployed. The disconnections mostly resulted from differences in the pace of change, departments' resistance to change, and disagreements around the simplicity of assumptions used to predict fire occurrences in a complex environment. Nonetheless, Hinds-Aldrich emphasized the importance in evaluating and utilizing these approaches as decision making tools to support fire inspectors and fire service leaders instead of using them to replace their decision making, experiences and practices. Furthermore, he suggested a hybrid approach to determine fire inspection frequencies, which he refers to as Hierarchical Risk Modeling. The approach is incorporating subject matter expertise and hierarchical frequency matrices as defined in NFPA 1730 [12] in the dynamic risk modeling approach in case certain properties never raise high enough to be prioritized by the prediction models.

Methodology

Implementation of Risk-Based and Data-Driven Approach

Considering the previous studies, this research does not intend to offer any novel concepts on how to determine fire inspection prioritization beyond what has been previously discussed but instead further advance and implement the risk-based and data-driven framework that has been introduced by Garis and Clare [5]. As a first step towards the implementation of a risk-based framework, the existing and long-standing fire prevention culture and workflows needed to be reviewed and changed. To begin, a move towards using a risk-based prioritization system, a basic framework, derived from previous research, was implemented by Surrey Fire Service and workflows were modified to create operational efficiencies.

For that purpose, an action plan was established to anticipate the cultural effects of these types of organizational changes and to prepare not only the fire prevention officers but also external stakeholders (citizens, business owners, occupants, etc.) for the changes [13]. The action plan provided a connection between these changes and the organizational values that the fire prevention officers hold, connected the values to the new processes, and established sustainable processes. The action plan helped to ensure a successful cultural shift towards the new framework.

As a second step, the framework was further enhanced to incorporate dynamic risk factors such as compliance history results from previous inspections, as well as static risk factors that are attached to inspectable properties such as their uses, historical fire incidents, and bylaw violations. Each factor contributes to a risk score that is assigned to an inspectable property and results in a total risk score that will be used to prioritize and assign commercial property inspections.

Step One – Culture Shift Towards Risk Based Prioritization

Existing System

The current British Columbia Fire Services Act, which has been in place since 1979, requires that each local government provide a regular system of fire and life safety inspections. The regular system that the Surrey Fire Services uses is a one- or two-year inspection frequency and is based on occupancy classification.

The methods used to prioritize the completion of inspection work was to ensure that all required annual inspections were completed and follow up compliance inspections could be completed when there was time. This system placed the highest priority on calendar due dates rather than risk. Some compounding factors to the limited available time to complete inspections were operational inefficiencies and work function prioritization of the fire prevention officers. There was a lack of geographical organization of work as well as competing requests for fire prevention officer attendance at other non-essential work such as building occupancy inspections, meetings, etc. which were often time consuming and, based on urgency were placed at the top of the prioritization list.

A combination of due date focus and operational inefficiencies led to reduced time available to complete many follow-up compliance inspections. This led to the follow-up compliance inspections being pushed into the next year, which further reduced the ability to complete the annual and follow-up inspections for that year. This cycle, as repeated year over year, created a compounding effect of overdue or delayed follow-up compliance inspections.

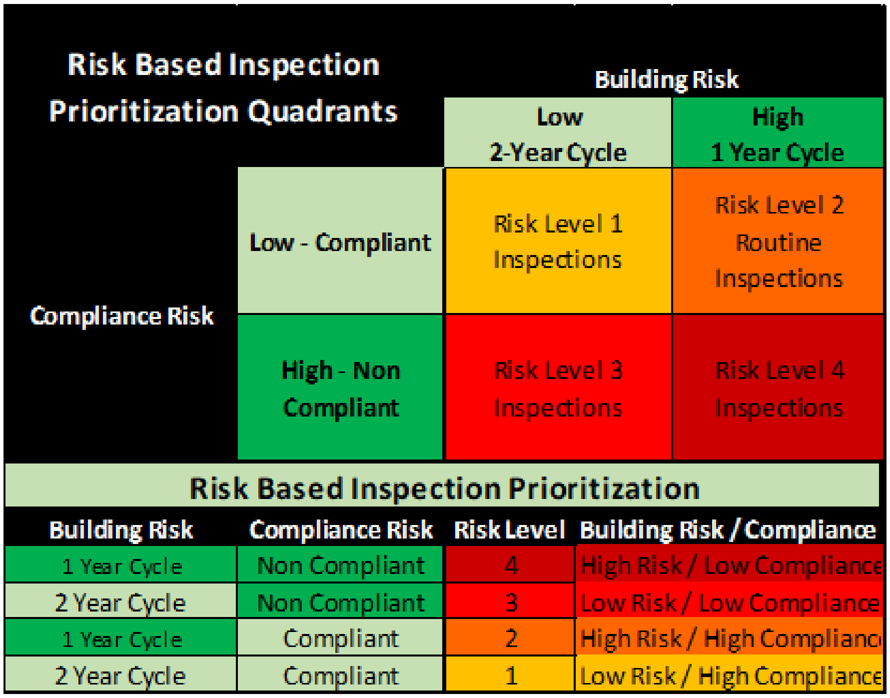
Action Plan

With the challenges posed by the current system and the possibility of moving to a risk-based prioritization system, discussions and planning on how to shift away from the existing system of inspection prioritization model began. During these discussions, fire prevention officers expressed frustration with the lack of time and ability to achieve fire code compliance, in a timely manner, within the existing system. The desire for compliance lined up very well with a risk-based approach to inspection prioritization and therefore became the focus of the system changes.

In reviewing the risk-based framework introduced by Garis and Clare [5] it became clear that there were insufficient required data points available to use that framework right away and that the data would need to be collected over time. To begin with a risk-based prioritization of inspections, a system that could be started right away was developed with the data that was available. One compliance risk data point and one building risk data point were used to build a four-quadrant risk prioritization matrix. Building risk was evaluated based on the frequency of annual inspection (one year or two year) as this has already been built on occupancy classification and worked to provide a broad approach to building risk. A property scheduled on a one-year cycle was considered higher risk than a property scheduled on a two-year cycle. Compliance risk was evaluated using the current inspection status of the last completed inspection. If the last inspection revealed non-compliance, it was considered as higher risk and an inspection with no compliance issues was considered lower risk.

The four-quadrant risk-based inspection prioritization, seen in Figure 1, was populated using the building risk and compliance risk data points, creating a risk ranking quadrant that was assigned to each inspectable property. Those properties with a risk level of four were considered to have the highest risk level and those with a risk level of one having the lowest risk level. Properties with risk levels of three and four were made up of properties with current non-compliance as there were known compliance issues identified on the last inspection.

Figure 1: Risk Based Inspection Prioritization



Risk Based Inspection Prioritization Quadrants		Building Risk	
		Low 2-Year Cycle	High 1 Year Cycle
Compliance Risk	Low - Compliant	Risk Level 1 Inspections	Risk Level 2 Routine Inspections
	High - Non Compliant	Risk Level 3 Inspections	Risk Level 4 Inspections

Risk Based Inspection Prioritization

Building Risk	Compliance Risk	Risk Level	Building Risk / Compliance
1 Year Cycle	Non Compliant	4	High Risk / Low Compliance
2 Year Cycle	Non Compliant	3	Low Risk / Low Compliance
1 Year Cycle	Compliant	2	High Risk / High Complianc
2 Year Cycle	Compliant	1	Low Risk / High Compliance

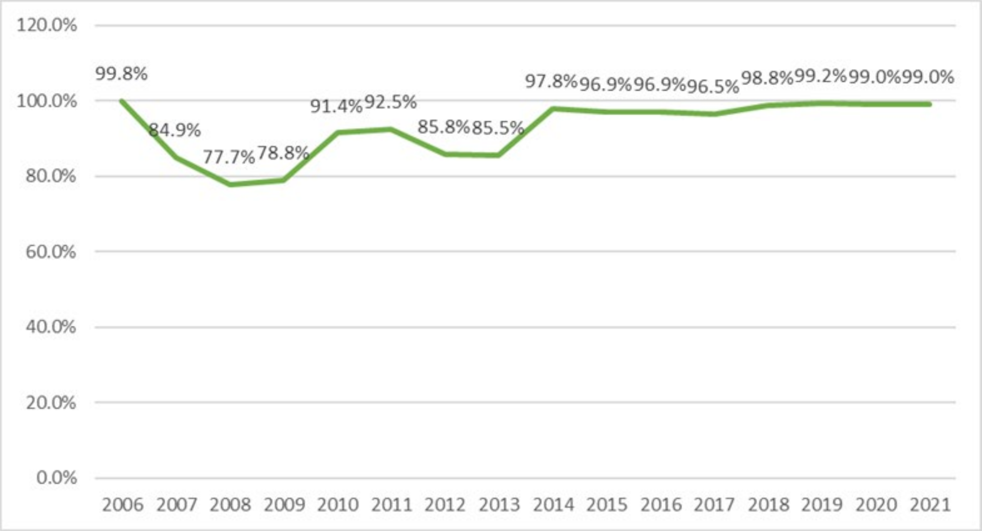
While this was a simple approach to risk ranking, it provided a much-needed starting point for the prioritization of inspection work. The fire prevention officers valued following up on non-compliance, but did not have that specific mandate or focus in previous years.

All fire prevention officer workflows were reviewed, and operational efficiencies were achieved through modifications or reduction in frequency of some of the non-essential work functions. This provided them more time which was used towards compliance inspection follow up. Fire prevention officers were partnered up and given a specific zone within the city where they were responsible for working together to complete inspections using the risk-based prioritization approach. Geographic inspection sorting was used to determine if there were any other inspections near to the high-risk ones that they were attending. This created further efficiencies by reducing driving time and providing alternate inspection options when a scheduling change occurred. Having consistent fire prevention officers assigned to the zones was designed to provide an opportunity to build relationships with business owners, create consistency and develop area familiarization. These partnerships provided the inspection teams with the ability to support each other with their challenges and celebrate their successes.

Results

The change to focus on compliance inspections became the new normal for the fire prevention officers with the priority firmly rooted in the risk ranking prioritization system. There was some potential risk that by shifting the workload to focus on compliance that there could have been more incomplete annual inspections at the end of the year than seen previously. However, Graph 1 shows that the opposite occurred, and the annual inspection completion rate increased in 2018 to 98.8% and has increased further to 99% in recent years.

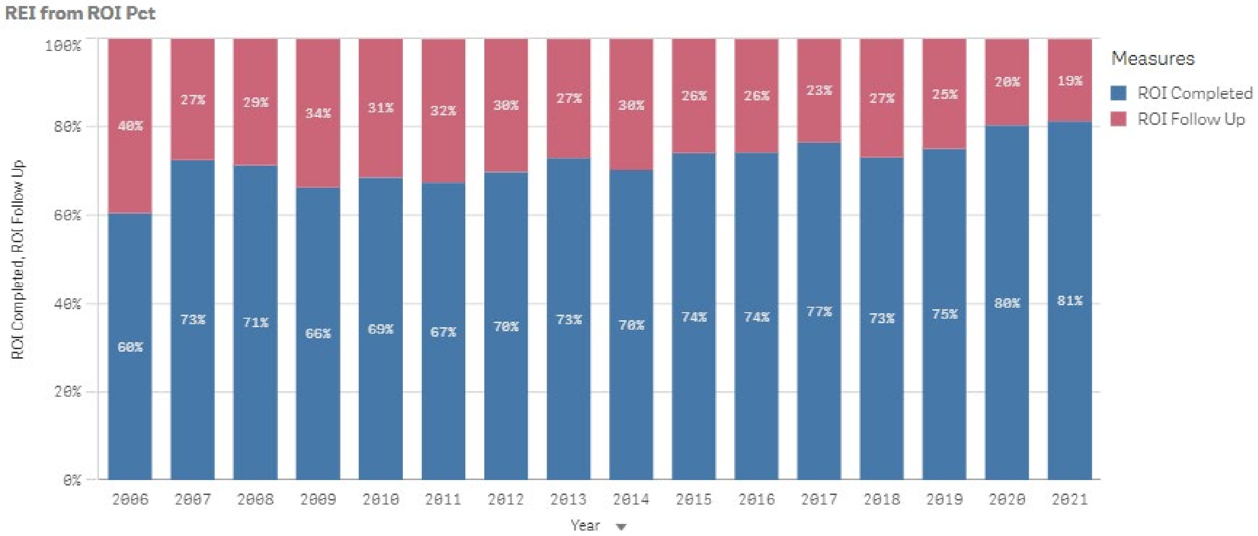
Graph 1: Percentage of Routine Of Inspections (ROI) Completions at the Same Year (2006-2021)



The goal of focusing on risk to improve compliance was two-fold. Firstly, that by working to bring properties into compliance and addressing the riskiest ones early in the year would provide an improved level of fire code compliance and improve fire and life safety sooner. Secondly, by ensuring that any non-compliant items are dealt with, the next inspection, at the same location, should not find the same or as many violations resulting in a much quicker inspection while maintaining a lower level of risk.

The expectation was that it would take approximately two years to begin to see an improvement in overall compliance rates, as after two years an inspection of every business would have been completed at least once. The compliance rate was evaluated in two ways; the first measure, in Graph 2, shows the compliance rate of annual inspections. This is the rate of which the regular annual inspections are compliant during their initial annual inspection. The second measure, in Graph 3, shows the compliance rate when following up on a previously non-compliant inspection. You can see in both graphs that starting in 2017 there has been a steady increase in compliance rates.

Graph 2: Compliance Rate of Routine Annual Inspections (ROI)



Graph 3: Compliance Rate of Re-inspections (REI)

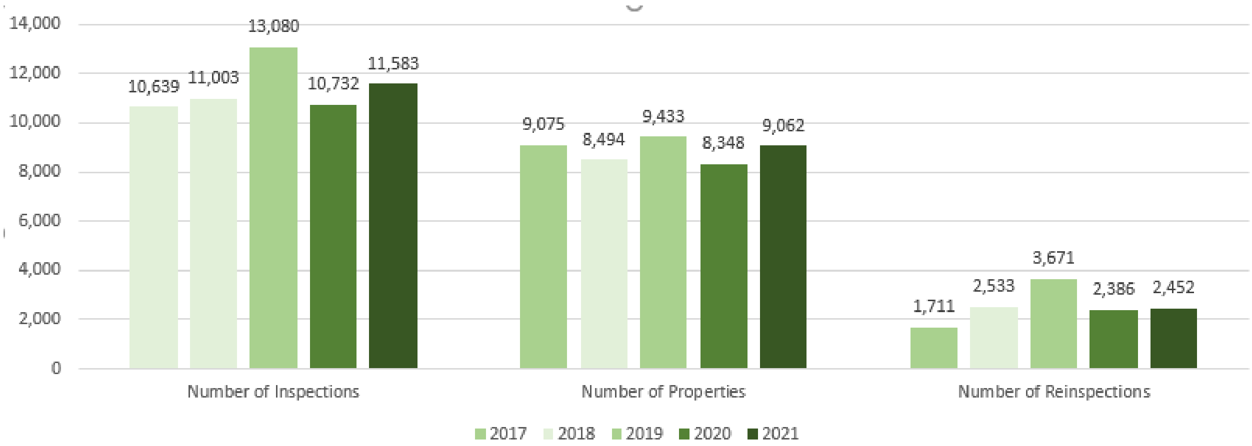
The culture change towards a focus on compliance by using basic risk-based prioritization and workflow efficiencies has shown improvements in both the annual workload completion rate and the overall inspection compliance rate. This shows that further enhancements to the risk-based framework would more accurately predict risk and allow for more accurate inspection prioritization. The next sections of this paper will focus on some of those potential enhancements.

Step Two – Risk Based Framework Enhancement

Inspection Compliance Data

Surrey Fire Service's inspection data has been used to inform a history of compliance at each inspectable property. To generate initial risk scores from inspection compliance results, the authors have selected the inspection data from 2017 to 2021 as it is more recent and reliable. There are over 57,000 fire inspections completed for more than 18,000 distinct properties within the five years (average of over 11,000 inspections per year). Out of those inspections, nearly 23% are re-inspections, which is where the business owners have failed to comply at a previous inspection and need to be re-inspected to rectify over 58,000 unsatisfactory inspection items.

Graph 4: Number of Inspections/Inspectable Properties/Re-inspections over 2017-2021



Structure Fire Incident Data

Another important dataset used to generate risk scores is structure fire incident data which includes all incidents with an actual incident type of structure fires (including stovetop fires) that occurred succeeding fire inspections of those inspectable properties. This dataset should display the relationship between structure fire incidents and results from failed inspections as discussed in the previous study [4]. Structure fire incident data from 2017 to 2021 was collected to achieve this purpose. During these five years, there were over 1,800 structure fire incidents, including stovetop fires, out of which 33% occurred at inspectable properties (see Appendix C for a map of those properties).

Other Data Used

Further datasets have been used to generate scores for the following risk factors: property uses, historical incidents, and bylaw violations. Firstly, the Surrey Fire Services have collected occupancy usage data for all inspectable properties to classify them into different risk categories according to their use as found in the *Interpretive Guide to the British Columbia Fire Services Act* [3]. These uses range from structures with assembly uses such as performance arts and arenas to those involving industrial uses such as power plants. Secondly, for historical incident data, incident types related to alarms, burning complaints, explosion, hazmat, smoke, selected medical incidents: burns, assaults, overdoses, alcohol poisoning, stabbing, and other types of fire incidents apart from structure fire incidents are used as they provide a relationship with the inspectable property or occupant behaviours. Several fire incident types are excluded as they do not provide a relationship with inspectable properties or occupant behaviours. These include fire hydro pole fires, urban interface fires, miscellaneous fires, and brush fires. Further medical incidents are also excluded as they do not relate to any fire-related incidents. These include abdominal pains, allergies, back pain, breathing problems, cardiac issues, choking, chest pain, convulsions, diabetic, drowning, eye injuries, falls, headache, heat/cold exposure, hemorrhage, pregnancy, psychiatric, sick person, stroke, traumatic injury, unconscious, and lift assist. Finally, for bylaw violations, the authors have decided to collect the data of bylaw violations within a 50-meter proximity radius of the inspectable property. All offences related to abandoned property, operating contrary to regulation, graffiti, controlled substances, multiple suite removal, noise, property maintenance, property use, suite identification, recovery home, and parking lot inspection are selected. The rationale of using these offences is to assess the neighbourhood risks of these inspectable properties.

The selection of these incident types and bylaw offences has not been conclusively studied in terms of their relationships with the outcomes. However, the experience of fire officers as subject matter experts plays a significant role in building the risk-based model and therefore aids in the selection of these incident and bylaw violation types as defined in NFPA 1730 [12].

Data Not Used

The study of age-related data did not reveal a strong relationship between the age of the properties and the frequency of fire incidents. The study found similar fire rates between newer and older commercial properties. The study has also determined that the higher number of and increased density of commercial properties in recent years increases the probabilities of fire occurrences among those properties.

Another external factor, crime data, was considered for its relationship to the potential risk of fires based on crimes that occurred within the proximity of the inspectable properties. However, no location-specific crime data is available to Surrey Fire Services and therefore is not able to be used in generating a meaningful risk model.

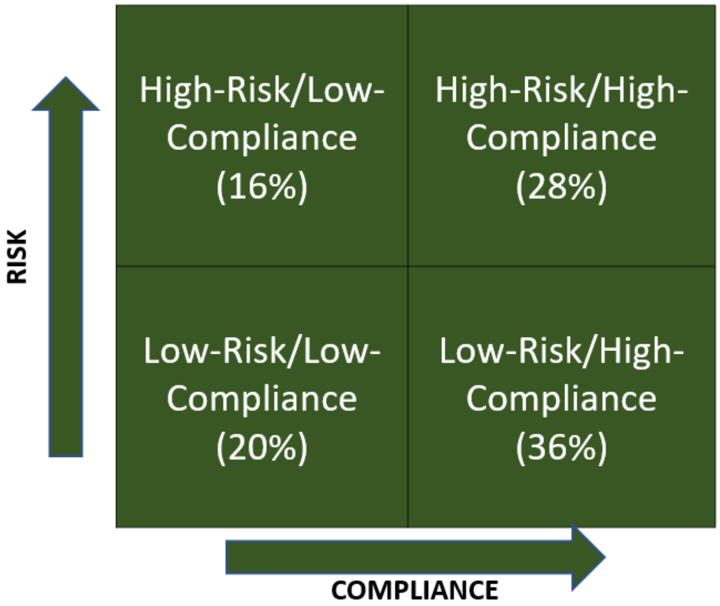
Risk Based Models

These risk factors will be used to generate risk-based models by means of a machine learning tool and methodology that results in risk scores for inspectable properties. Several models have been tested in terms of their performance (see Appendix A and B for the schema of the machine learning process and the risk factors). Based on their model fitness to the actual dataset, a logistic regression model shows the best performance among other models and has therefore been selected. Nonetheless, the model test and selection need to be performed on a regular basis every time a new dataset has been generated. The model generates a risk score for each contributing factor which will later be aggregated as both total compliance risk and total building risk scores. Both aggregated risk scores will result in a total risk score for a respective inspectable property. The total risk scores show the risk of inspectable properties based on the occupants' behaviour and the physical properties of the buildings. As the risk scores will drive frequencies of inspections, the inspections should focus on correcting occupants' behaviours and the physical components of the buildings which would limit the increased risk of future fire occurrences. In addition, the model also applies an incentive score with the purpose of reducing risk scores of inspectable properties when they have functional fire and life safety systems such as sprinkler and fire alarm systems.

As a final step in the methodology, a sensitivity analysis has been performed on the risk scores. The risk scores derived from the risk-based model will be validated against the segmentation of properties in each compliance/risk quadrant from the existing framework. As seen in Figure 2, the quadrant separates 2017-2021 inspectable properties into four categories: High building risk/Low-compliance (16%); High building risk/High-compliance (27.7%); Low building risk/Low-compliance (20%); Low building risk/High-compliance (36%). The risk scores generated by the model should be sensitive enough to separate inspectable properties into a distinct quadrant.

Furthermore, the implementation of an enhanced risk-based and data-driven framework will create further organizational changes within the Surrey Fire Services and lead not only to technology changes but also changes for human resources and external stakeholders. To anticipate the effects of these changes, further action planning is needed to manage the shift towards the new framework successfully. The action plan should bridge any disconnections between how the framework is developed and the existing configuration and deployment of fire inspections, as Hinds-Aldrich indicated this was a hindrance to implementation [11]. Despite the importance, the detailed action planning is outside the scope of this research but is discussed in a different report by Cairney [13].

Figure 2: The Four Quadrants of Risk/Compliance on inspectable Properties between 2017-2021



Dynamic Risk Factor: Compliance

The dynamic risk factor is strongly influenced by the behaviours of properties' occupants in ensuring properties are free of fire risks. Furthermore, fire inspections should be used to modify the behaviours of properties' occupants by enforcing the remedy of any violations found during the inspection and therefore working to mitigate any increased risk of fire. For this purpose, the risk-based model generates risk scores that are derived from the level of compliance resulted from historical outcomes of fire inspections. As such, the dynamic risk factor score will change over time as these behaviours are reflected in the outcomes of the fire inspections.

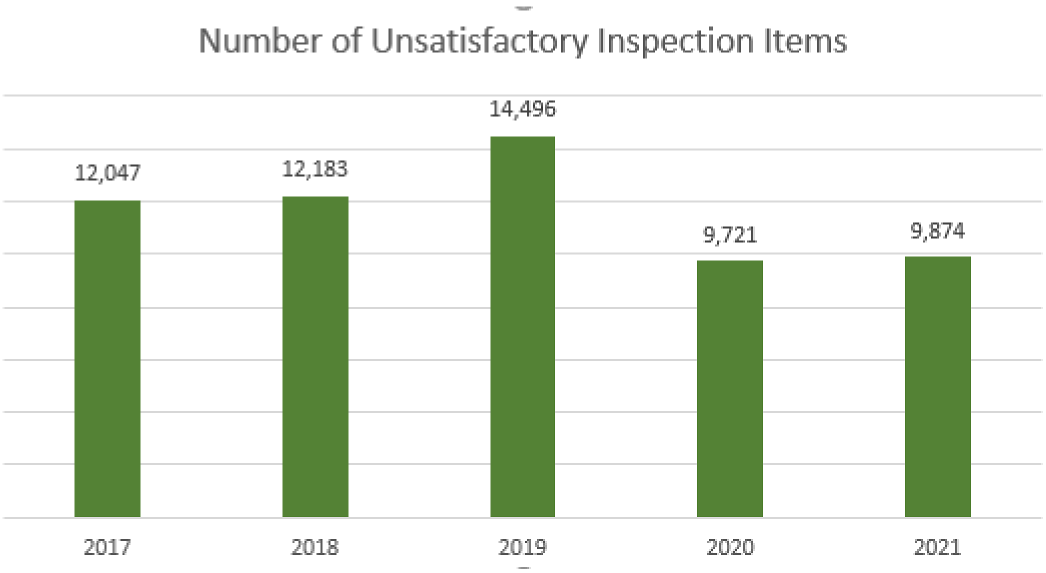
Types of Inspections

Within the Surrey Fire Services inspection system, there are three distinct statuses of a fire inspection: completed, follow-up, and pending. Firstly, a completed inspection is where the business owner has satisfied all requirements to pass the inspection and no corrective actions are needed. Secondly, a follow-up inspection (re-inspection) is where the business owner is not able to pass an inspection due to unsatisfactory inspection items and therefore corrective actions are needed before the next re-inspection. Within the current system, a re-inspection can be prevented if the violations occurred only for any of the following items: Exit Signs and Lights, Emergency Lights Servicing, Portable Extinguishers, Servicing Extinguishers, Fire Safety Plans-updated, Hydrant Servicing, and Electrical Panel Minor as these are considered low-risk violations. This has helped to optimize inspection workloads while minimizing the risk level. Follow up for these items can consist of the business owner or occupant reporting to Surrey Fire Services Inspectors that corrections have been made and providing any required documentation. This practice will be amended after the implementation of the risk-based framework to ensure that risk is evaluated using the risk-based framework. Finally, a pending inspection is an initial or follow-up inspection with a pending date as it is scheduled to be completed in the future.

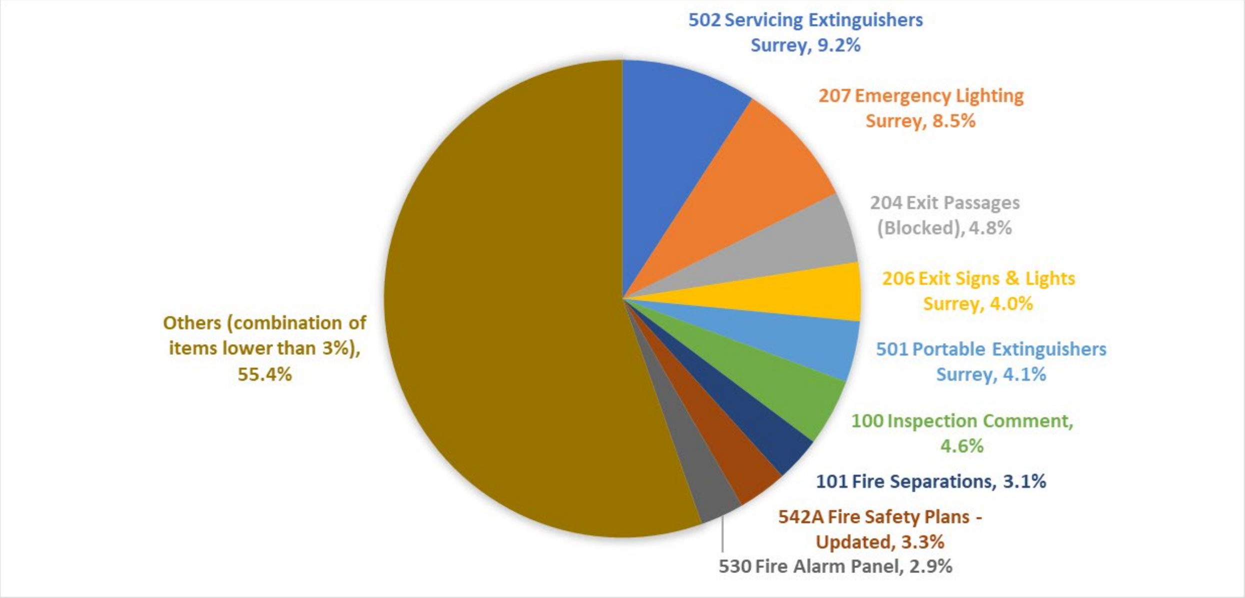
Historical Inspection Compliance

Within the five-years (2017 – 2021), over 57,000 inspections were completed with a nearly 23% re-inspection rate. About 13,000 re-inspections were conducted at approximately 5,500 distinct properties (see Appendix D for the map of those properties) resulting in nearly 59,000 unsatisfactory inspection items (Graph 5). Graph 6 shows the 9 out of 173 unique inspection items that contributed to nearly 45% of unsatisfactory inspection items at these inspections: Servicing Extinguishers, Emergency Lighting, Exit Passages (Blocked), Exit Signs & Lights, Portable Extinguishers, Inspection Comment, Fire Separations, Fire Safety Plans, and Fire Alarm Panel. Nevertheless, the unsatisfactory inspection items do not have equal risk levels as related to fire occurrences and the extent of damage and casualties.

Graph 5: Number of Unsatisfactory Inspection Items



Graph 6: Percentage of Unsatisfactory Inspection Items (2017 – 2021)



Compliance Risk Model

A statistical model has been built to determine the risk weighting for each unsatisfactory inspection item that contributed to the occurrences of structure fire incidents. Fire inspections that occurred preceding structure fire incidents should inform as to which inspection items and which behaviours of business owners/occupants contribute to fire occurrences. The unsatisfactory inspection items would not only inform the magnitude of risks of those properties but also determine the risk levels of those items that contributed to fire occurrences and the extent of damages and casualties.

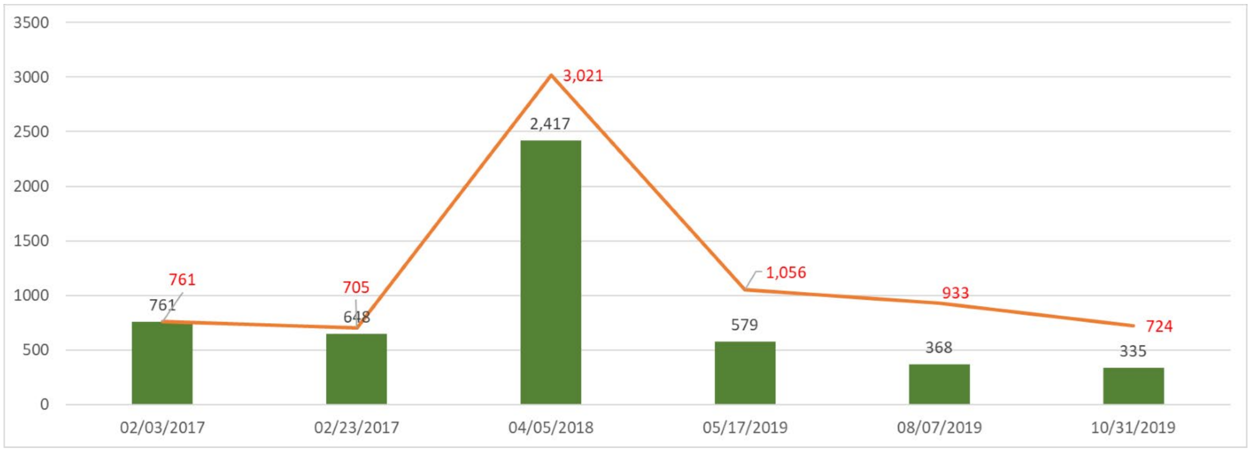
The total compliance risk score that a property receives for each inspection is the sum of risk weights of each unsatisfactory inspection item. In case of a re-inspection, a compliance risk score is added to the property as a result of the outcome of that re-inspection. In this way, a property will receive total compliance risk scores as resulted from the outcomes of every inspection/re-inspection. Every risk score will be kept as historical scores for that property and a 3-period weighted moving average will be calculated to produce an average score over time. This will be applied as follows:

1. if a declining trend of scores is detected, the biggest weight of 50% will be given to the period with the minimum score; or
2. if an increasing or constant trend is detected, a multiplication factor of 25% will be added to the weight of the maximum score.

These weightings will penalize re-offenders but allow businesses who are compliant or working towards compliance to improve their scores over time. The average compliance risk score will be combined with the building risk score and used as a basis to determine future inspection priorities.

Graph 7 shows an example of an inspectable property with six compliance risk scores (displayed in the black fonts) as results from the six previous inspections. The weighted average score can be seen in the red fonts over the orange line graph. The graph shows an increasing trend of non-compliance over the first three inspections in 2017 & 2018, which triggers a higher weighted average score on the third inspection (3,021) as the 25% multiplication factor is applied on the third inspection score (2,417). This moves the compliance risk score of the non-compliant business upwards indicating that there is a greater risk of fire. As the business works towards compliance in 2019, improved inspection outcomes result in a downward trend where the biggest weight of 50% is applied to the minimum score (579) making the overall score much lower at 1,056. This allows the business to reduce its compliance risk score and show its improvements.

Graph 7: A history of compliance risk scores of an inspectable property



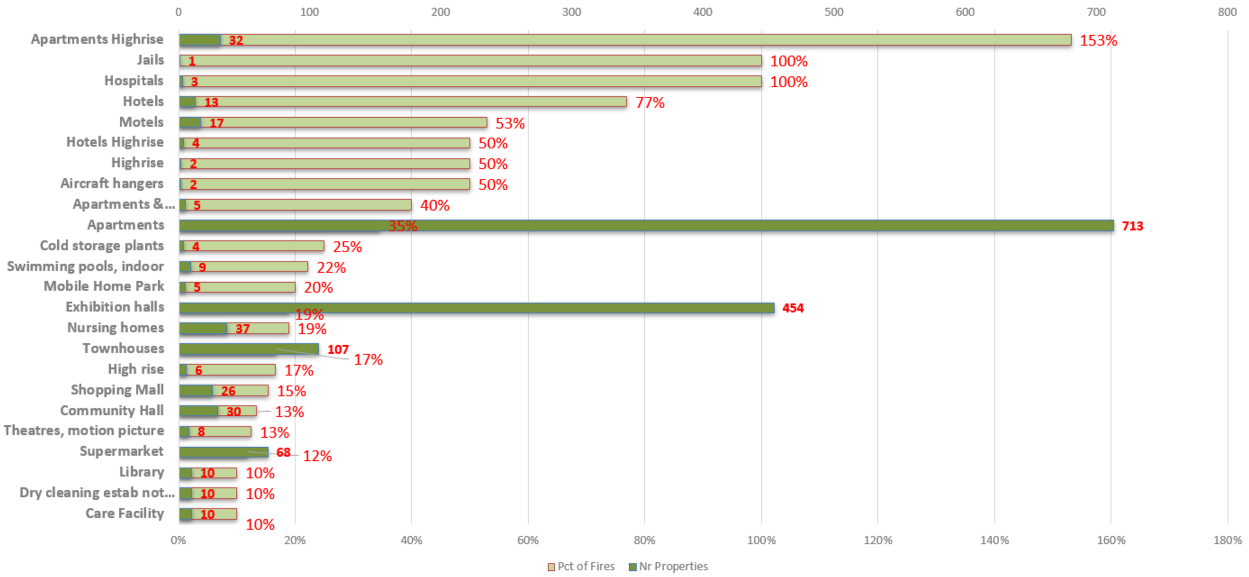
Static Risk Factor: Building Risk

The static risk factor pertains to certain factors which are attributed to the property directly; therefore, unlike the dynamic risk factor, the static risk factor is not likely to change significantly over time. This factor includes an evaluation of occupancy usage, fire service incidents at the property, and by-law violations within a 50-metre proximity radius of the property.

Occupancy Usage

Besides the risk categories derived from the *Interpretive Guide to the British Columbia Fire Services Act* [3], this study has found that certain types of occupancy usages are more likely to precede structure fires and cause more casualties (injuries and fatalities) than others in the event of a fire; therefore, their relative fire risks need to be included in the building risk scores. Graph 8 shows occupancy usage types and their relative percentage of fires of 10% or over in the period between 2017 and 2021. The percentage of fires per occupancy usage represents the rate of structure fires in 100 structures for that occupancy usage type.

Graph 8: Percentage of Fires among Occupancy Usages



The highest rate of fire is found in the Apartments Highrise occupancy usage with over 100%. However, the denominator used for the calculation only counts the number of buildings and does not count the number of units. The number of units is supposed to reflect the true number of denominators for apartments. Thus, the fire rate in the Apartments Highrise is over estimated.

Subsequently, jails, hospitals, hotels, motels, and hotel high-rise have shown 100%, 100%, 77%, 53%, and 50% of fires with 1, 3, 13, 17, and 4 structures recorded respectively. Apartments, exhibition halls, and townhouses are the occupancy usages with the largest number of structures and 35%, 19%, 17% of the fires respectively. The fire rate influences the weighting of the assigned risk score for each occupancy usage.

Further, each occupancy usage also poses a potential risk of casualties (fatalities and injuries combined) in the event of a fire occurring. To increase the accuracy, the analysis of potential risk is performed at the occupancy class level. Each occupancy usage is grouped into an occupancy class (see Table 1).

Table 1: Occupancy Class

Abbreviation	Occupancy Class
A	Assembly Use
B	Institutional Use
C	Residential Use
D	Business Use
E	Commercial/Mercantile Use
F	Industrial Use

Table 2 shows the relationship between the occupancy class and fire severity which is measured by comparing the percentage of fires that stay within or extend beyond the room of origin. The analysis has been performed on the reportable structure fire data for inspectable properties between 2010 and 2021.

Table 2: Relationship between Occupancy Class and Fire Severity

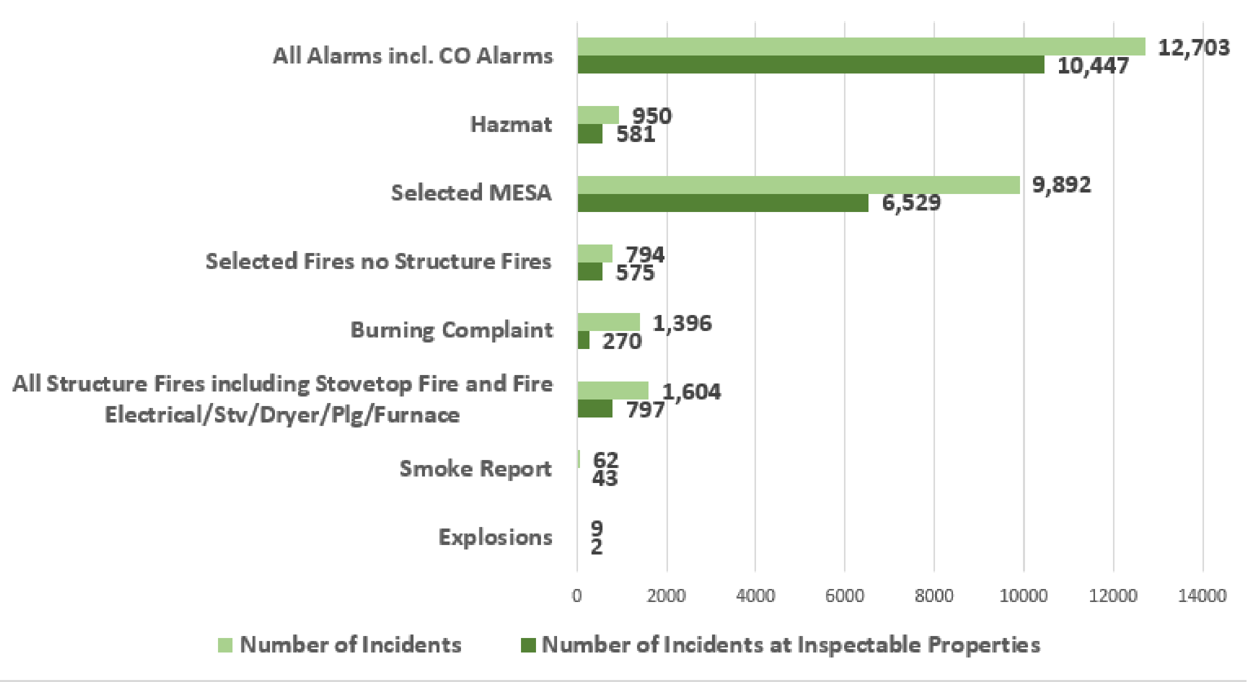
Occupancy Class	Percentage of Fires within Room of Origin	Percentage of Fires beyond Room of Origin
A	60%	40%
B	87.5%	12.5%
C	52%	48%
D	71%	29%
E	62%	38%
F	60%	40%

The analysis on the relationship between fire severity and fire casualties (fatalities and injuries combined) determined that fires remaining within the room of origin were 24% less likely to result in a fire casualty whereas fires spreading beyond the room of origin were inversely 31% more likely to result in a fire casualty (see Table 4). A risk score for each occupancy class is resulted by applying the percentage increase in fire casualties to the percentage of fires extending beyond room of origin for each occupancy class. For example, Occupancy Class A with 40% of fires beyond room of origin will receive 31% of 40% = 12% score. Thus, all properties within the Class A will receive 12% risk score in addition to the risk score derived from fire rates to result in a total weighted risk score for each occupancy usage.

Fire Service Incidents

For fire service incidents, certain incident types have been selected for what are considered incidents at inspectable properties that relate to fire occurrences. The criteria include the following fire service incident types: alarms, burning complaints, explosion, hazmat, selected medical incidents, smoke report, and other types of fire incidents, but excludes hydro pole fires, urban interface fires, brush fires, miscellaneous fires, and all medical incidents that are unrelated to fire occurrences. Graph 9 shows both the total number of related fire service incidents compared with the same incidents at inspectable properties over the period.

Graph 9: Number of related Fire Service Incidents from the Inspectable Properties (2017 – 2021)



In relation to the fire occurrences, each fire service incident type will be assigned a risk weight score based on the structure fires that occurred following these specific fire service incidents. Certain incident types preceded structure fires more often than the other types and will therefore be assigned larger weight scores. The risk weight scores for fire service incidents will be aggregated for each property based on its total number of related incidents.

Bylaw Violations

There are over 40,000 by-law violations recorded between September 2018 and December 2021 of which 29 % are within the 50-metre proximity radius of the inspectable properties. Not all by-law violations have an equal risk of fire occurrence; therefore, they need to be selected based on their likelihood of preceding fires. Table 3 below shows the number of violations found around inspectable properties by selected violation types.

Table 3: Number of By-law Violations by Selected Job Types (September 2018 – December 2021)

Bylaw Job Types	Number of Violations
Abandoned Property	38
Operating Contrary to Regulations	18
Operating Without License	133
Graffiti Complaint	277
Suite Identification	127
Recovery Home	81
Parking Lot Inspection	183
Displacement/Camps/Loitering	985
Dumping	279
Parking By-law	227
Multiple Suite Removal	11
Property Maintenance	1365
Property Use	436

Similar to fire service incidents, a model will be built to depict the relationship between fire occurrences and by-law violations. The model will assign a risk weight score for each violation type based on the violations that happened preceding structure fires. The risk weight scores for by-law violations will be aggregated for each property depending upon the number of violations that occurred within its 50-metre proximity radius.

Building Risk Model

In total, each property will be assigned three risk weight scores based on their occupancy usage, the number of fire service incidents it had, and the number of by-law violations within its 50 metres proximity radius. The risk weight scores will be aggregated to result in a single building risk score. These scores are expected to remain constant regardless of the outcomes of each inspection/re-inspection but will be updated every year as new datasets for structure fires, fire service incidents, and by-law violations become available.

Fire Safety System

The intent of fire safety systems, such as fire alarm and/or sprinklers, is to provide early alerting and early fire suppression respectively. Previous studies [12], [13], [14] have shown that the presence of fire safety systems improve fire severity, damage, and the rate of fire injuries and death. To better understand the positive impact of these systems, an analysis has been performed on the reportable structure fire data for inspectable properties between 2006 and 2021. The focus was placed on the relationship between fire injuries and deaths (fire casualties) and fire severity (beyond the room of origin and within the room of origin). Table 4 shows the results which revealed that fires remaining within the room of origin were 24% less likely to result in a fire casualty.

Table 4: A relationship between Fire Severity and Casualty

FIRE SEVERITY	TOTAL CASUALTY	NUMBER OF INCIDENTS	CASUALTY RATE PER 100 FIRES	PCT REDUCTION
Beyond Room of Origin	35	332	10.5	
Within Room of Origin	41	507	8	24%

Furthermore, the analysis of the relationship between fire severity and the presence of fire safety systems (Table 5) shows that the combined presence of both fire alarm and sprinkler system reduce fire severity by approximately 59%, which is measured by the ratio of the likelihood of having fires beyond and within the room of origin (29%/71% - 1 = 59%). The presence of partial systems (where only one of the systems is present) reduces fire severity by 39% (38%/62% - 1 = 39%) whereas when no fire safety systems are present there is a negative impact on fire severity with an increase in fire severity by 44% (59%/41% - 1 = 44%).

Table 5: A relationship between Fire Safety System and Fire Severity

SPRINKLER PROTECTION	NR FIRES OF BEYOND ROOM OF ORIGIN	NR FIRES OF WITHIN ROOM OF ORIGIN	TOTAL FIRES	PCT OF OCCURRENCES TO BEYOND	PCT OF OCCURRENCES TO WITHIN
BOTH FIRE ALARM & SPRINKLER SYSTEMS PRESENT	112	271	383	29%	71%
PARTIAL (ONE SYSTEM NOT PRESENT)	87	145	232	38%	62%
NO SYSTEMS PRESENT	135	94	229	59%	41%

With these findings, further analysis was conducted to determine the incentive scores for an inspectable property with a functioning fire safety system. A property with both presence of fire alarm and sprinkler protection system receives the following incentive score: (71%/41%-1)*24% = 18%. For a property with the partial presence of fire protection system, the incentive score is (62%/41%-1)*24%=12% and no incentive scores are assigned for properties without fire protection systems.

Model Validation

Prior to validation, total risk scores are generated for each inspectable property and are made up of the average of their compliance risk score and their building risk score which is adjusted through the application of any incentive score derived from the presence of fire safety systems.

Next, a validation step is conducted against the total risk scores by performing a sensitivity analysis against the existing four quadrants of risk and compliance. The purpose of the sensitivity analysis is to determine that the total risk scores are sensitive enough to discriminate the inspectable properties among the four quadrants. The percentiles of risk scores of all inspectable properties within the four quadrants are calculated and observed to determine adequate gaps to discriminate those properties. Table 6 shows that the risk scores are sensitive enough to discriminate the inspectable properties among the four quadrants.

Mann-Whitney-Wilcoxon statistical test has been used to compare two groups of high building risk (high compliance vs low compliance), low building risk (high compliance vs low compliance), high compliance (high building risk vs low risk), and low compliance (high building risk vs low risk). The test is selected as two groups are independent and do not affect each other, and no assumptions are made on the population distributions. The null hypothesis for the test is that two groups are identical whereas the alternative hypothesis for the test is that two groups are not identical. The test produces a sum of the ranks of each group (W-value) which will later be used to generate a probability value (p-value) of accepting or rejecting the null hypothesis. If the p-value is less than 0.05 than the null hypothesis is rejected meaning the two groups are not identical.

Table 6. A Sensitivity Analysis on Risk Scores against Four Quadrants

High Building Risk / Low Compliance 95th percentile = 259 Median = 123 5th percentile = 62	**High Building Risk / High Compliance** 95th percentile = 179 Median = 88 5th percentile = 51
Low Building Risk / Low Compliance 95th percentile = 229 Median = 98 5th percentile = 44	**Low Building Risk / High Compliance** 95th percentile = 127 Median = 62 5th percentile = 34

High Building Risk Property Comparison

The statistical test shows that a significant difference can be seen in the high building risk properties between high compliance and those with low compliance (W=52879000, p-value < 2.2e-16). High compliance properties showed scores only as high as 179 points 95% of the time, whereas those with low compliance showed higher scores (95% percentile) at 259 points.

Low Building Risk Property Comparison

The same significant differences can also be seen in the comparison of low building risk properties between those with low compliance and those with high compliance (W=39191000, p-value<2.2e-16). Those with low compliance showed scores as high as 229 points 95% of the time, whereas those with high compliance only showed scores as high as 127 points,95% of the time.

Low Compliance Property Comparison

The statistical test conducted on the properties with the low compliance continue to show the same significant differences between those in the high building risk and those in the low building risk categories (W=64975000, p-value<2.2e-16). The lowest score (5% percentile) for the high building risk properties is 62 points which is higher than for the low building risk properties which is 44 points.

High Compliance Property Comparison

The statistical comparison of high compliance properties with both low and high building risk shows the significant difference between both property types (W=64975000, p-value<2.2e-16). The lowest score on those properties with low building risk is 34 points which is lower than the lowest score of properties with high building risk (51 points).

The overall validation showed that there were adequate gaps to discriminate the properties amongst the four quadrants. It further showed that the impact of compliance risk was more significant than the impact of building risk on the total risk scores as can be seen in the comparison of the range of possible scores.

Next Steps

For the risk-based and data-driven framework to become part of a usable inspection framework, the risk score and its calculation methodology need to be implemented in a useable way. The risk calculations will need to be available in real-time and as such should be applied within the inspection and property modules of the records management system.

The current total risk score, for a property, should be continually changing when new data is inputted. These scores should be displayed on each inspectable property while the historical scores, that existed at the time of an inspection, should be maintained on the inspection record for future reference and comparison. The compliance score factors should be calculated automatically using the results found at each completed inspection and will be reflected within the current total risk scores of the property moving forward. As the factors affecting the building risk score are not likely to change significantly from month to month, this score is calculated annually when data is available.

In the end, future inspection due dates should be adjusted according to the newly calculated total risk scores. This integrated scoring mechanism will be rolled out to fire prevention officers for future use and be part of their inspection duties as improved decision-making tools for the prioritization of inspections.

After the implementation, an evaluation should be conducted reviewing the current scores of the inspectable properties comparing them with their history of compliance and their historical incidents of structure fires. Overall, in the long run, an evaluation of this approach should be performed against the trend of commercial structure fires by comparing them between pre and post implementation.

Conclusion

The previous studies around fire inspections on commercial properties in the City of Surrey, BC determined no relationship existed between the increased duration since last inspection and the fire frequency and severity. Nonetheless, the studies also revealed a link between the occurrence of fire incidents and elevated non-compliance at the most recent inspection prior to the fire [2], [4]. Both findings highlighted an opportunity to shift the inspection strategy from the time driven approach, that mostly depends on prescriptive fire safety codes, to a performance-based approach that relies firmly on risk assessments based on compliance.

To move towards a performance-based approach, an initial step was taken to build a basic inspection prioritization formula that was risk-based. This basic formula was developed consisting of three areas of focus: improved inspection compliance, an action plan to manage cultural change and improving operational efficiencies. This initial step proved successful as overall inspection compliance rates and annual workload completion rates both improved. These results led to a further enhancement of the performance-based inspection strategy using a more defined risk-based framework.

The enhanced performance-based inspection strategy should be driven by inspection data that will be used to generate risk scores for every inspectable property. The risk scores will highlight the performance of every property and drive the future inspection frequencies. With this strategy, the Surrey Fire Services should target their efforts at the highest risk properties for more frequent inspections while maintaining the overall inspection workload to maximize its return on investment. The same risk-based strategy has been implemented at residential properties through the HomeSafe program [7]. Within this program, the fire crews and community volunteers have visited targeted properties based on risk scores from various risk factors that are generated from Statistics Canada census data. HomeSafe has shown success through improving specific outcome measures such as: the reduction of residential fire rates and fire-related casualties as well as the increase of percentage of working smoke alarms at residential structures.

Each inspectable property has its risk score generated from the combination of two factors. Firstly, its compliance outcome following inspections (compliance risk factor), and secondly, from its building characteristics (building risk factor). The former should change over time depending upon the outcomes of its inspection/re-inspection compliance (dynamic factor) whereas the latter depends more on its use, fire service incidents (at the property), and the by-law violations within its proximity (static factor). Each risk factor receives a weighted score in relation to its occurrences preceding fire incidents. The higher the frequency of occurrences preceding fire incidents, the higher the weight that will be assigned to that risk factor. To generate weighted scores for every risk factor, a machine learning model and methodology has been used, and the logistic regression model is selected based on its model performances.

The study also determines the benefit of having fire safety systems in relation to fire severity and fire casualties. An inspectable property with complete and partial fire safety systems will reduce 59% and 39%, respectively, of its likelihood of having high fire severity which consequently reduces its likelihood of having a fire casualty by 18% and 12%, respectively. This reduction of fire severity and fire casualty due to the presence of fire safety systems will apply an incentive score for every inspectable property with complete and/or partial fire safety system.

As the final step, the risk scores are validated by performing sensitivity analysis against the percentiles of risk scores of every inspectable property in various risk and compliance categories. The validation result shows that the risk scores are sensitive enough to discriminate those properties into different categories.

Future steps would incorporate the risk scores into the property and inspection modules of a records management system. The expanded risk-based approach would form part of the Surrey Fire Service's inspection strategy in which the Fire Prevention Officers use as a part of their decision-making process for inspection prioritization. Furthermore, an evaluation is deemed necessary to review the calculated historical scores and compare them against commercial structure fire incidents along with monitoring the trend of commercial fire incidents before and after the implementation.

References

[1] "Fire Services Act", *Bclaws.gov.bc.ca*, 2021. [Online]. Available: https://www.bclaws.gov.bc.ca/civix/document/id/complete/statreg/96144_01. [Accessed: 23-Oct- 2021]

[2] Garis, L and Clare, J. *Examining "Regular" Fire Safety Inspections: The Missing Relationship between Timing of Inspection and Fire Outcome.* March 2012. University of the Fraser Valley School of Criminology and Criminal Justice.

[3] Office of the Fire Commissioner. *Interpretive guide: criteria for determining frequency of inspections, Subject Fire Services Act – Sections 26 (1) & 38 (3).* 1992. Ministry of Municipal Affairs, Recreation and Housing, Province of British Columbia.

[4] Garis, L and Clare, J. *The Non-Random Nature of Fire Safety Inspection Compliance: A Platform for Predicting Fire Risk.* June 2013. University of the Fraser Valley School of Criminology and Criminal Justice.

[5] Garis, L and Clare, J. *A Dynamic Risk-Based Framework for Redesigning the Scheduling of Fire Safety Inspections.* August 2014. University of the Fraser Valley School of Criminology and Criminal Justice.

[6] R.M. Tavares*, An analysis of the fire safety codes in Fire Safety Journal, 2009.* ***44****: p. 749-755.*

[7] Thomas, L. Garis, L. Morris, S. and Biantoro, C. *Journey of HomeSafe: Community Risk Reduction in Surrey*. October 2020. University of the Fraser Valley School of Criminology and Criminal Justice.

[8] Roman, J. *In Pursuit of Smart.* November/December 2014. NFPA Journal. Official Magazine of the National Fire Protection Association.

[9] Heaton, B. *New York City Fights Fire with Data.* May 2015. Emergency Management. https://www.govtech.com/em/safety/New-York-City-Fights-Fire-Data.html

[10] Roman, J. Embracing Analytics. May/June 2016. NFPA Journal. The magazine of the National Fire Protection Association. https://www.nfpa.org/News-and-Research/Publications-and-media/NFPA-Journal/2016/May-June-2016/Features/Embracing-Analytics

[11] Hinds-Aldrich, M. Pre-Fire: The promise and problems of fire risk prediction. March 2020. https://medium.com/@dr._matt/pre-fire-the-promise-and-problems-of-fire-risk-prediction-e84986dca131

[12] National Fire Protection Association. NFPA 1730 Standard on Organization and Deployment of Fire Prevention Inspection and Code Enforcement, Plan Review, Investigation, and Public Education Operations. 2019.

[13] Cairney, J. Organizational Change towards Risk-Based Inspections. May 2019. Study Paper.

[14] Garis L, Clare, J and Biantoro C. Structure Fires in British Columbia: Exploring Variations in Outcomes as a Function of Building Height and Life Safety System. May 2019. University of the Fraser Valley School of Criminology and Criminal Justice.

[15] Garis, L., Singh, A., and Plecas, D. Fire Protection System (s) Performance in the Residential Building Environment: Examining the Relationship between Civilian and Firefighter Injuries: A Retrospective Evaluation of Residential and Residential Apartment Fires, 2005 to 2015. November 2017. University of the Fraser Valley School of Criminology and Criminal Justice.

[16] Garis, L., Singh, A., Clare, J., Hughan, S. and Tyakoff, A. Sprinkler Systems and Residential Structure Fires-Revisited: Exploring the Impact of Sprinklers for Life Safety and Fire Spread. October 2017. University of the Fraser Valley School of Criminology and Criminal Justice.

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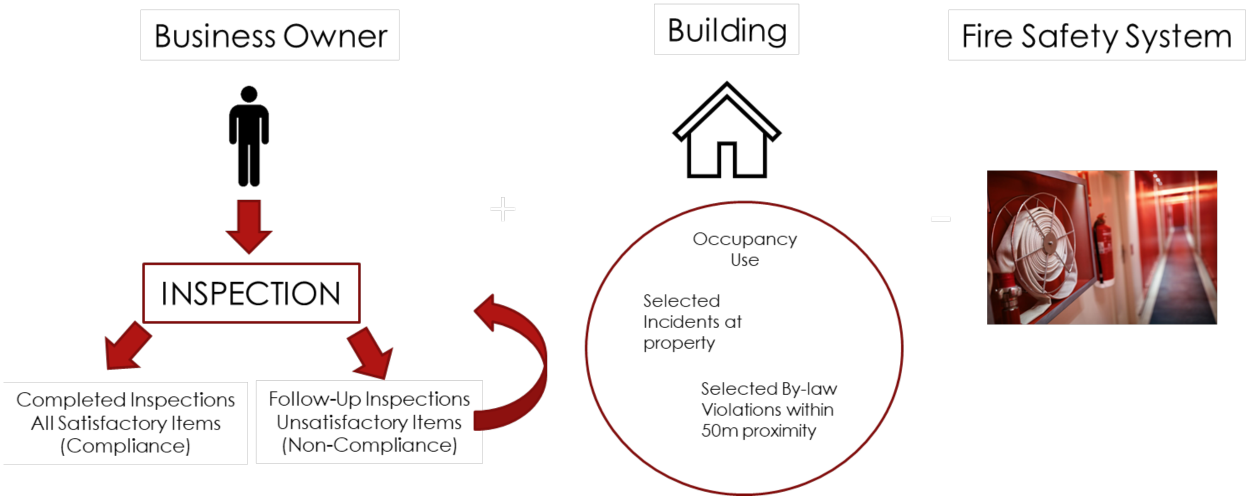
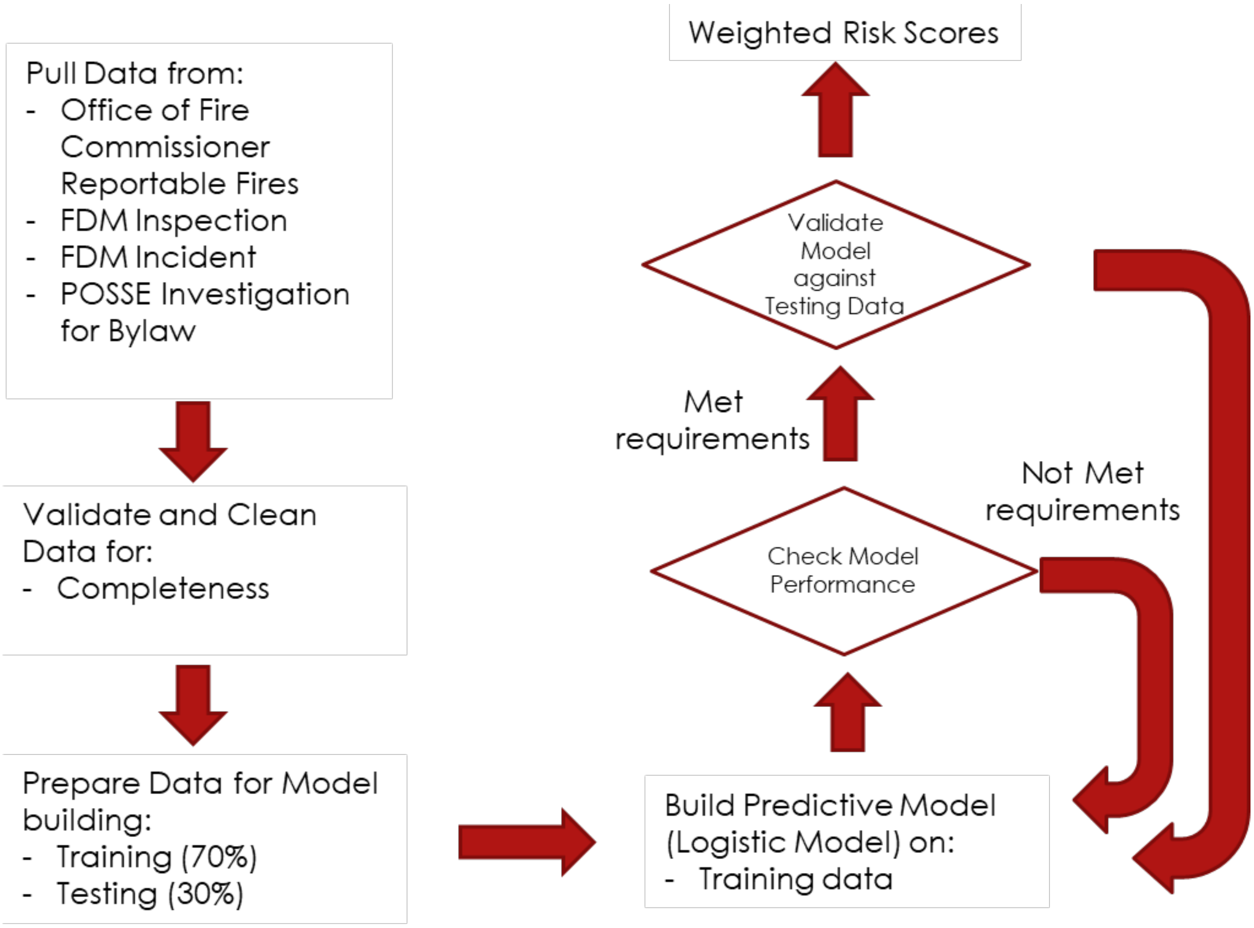
Appendix A

FIGURE 3: THE SCHEMA OF RISK-BASED INSPECTION FACTORS



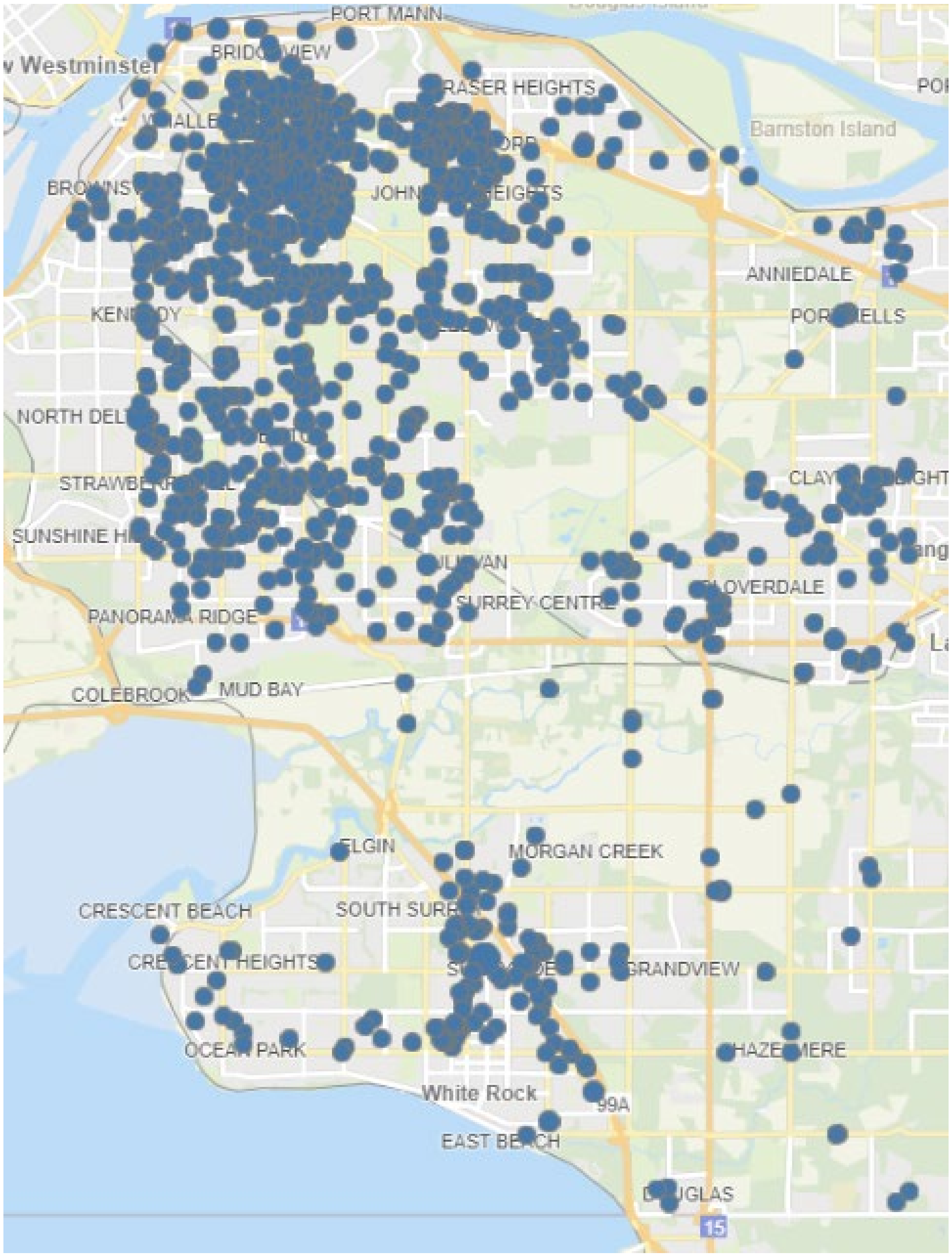
Appendix B

FIGURE 4: A PROCESS OF GENERATING WEIGHTED RISK SCORES BY MEANS OF MACHINE LEARNING MODEL



Appendix C

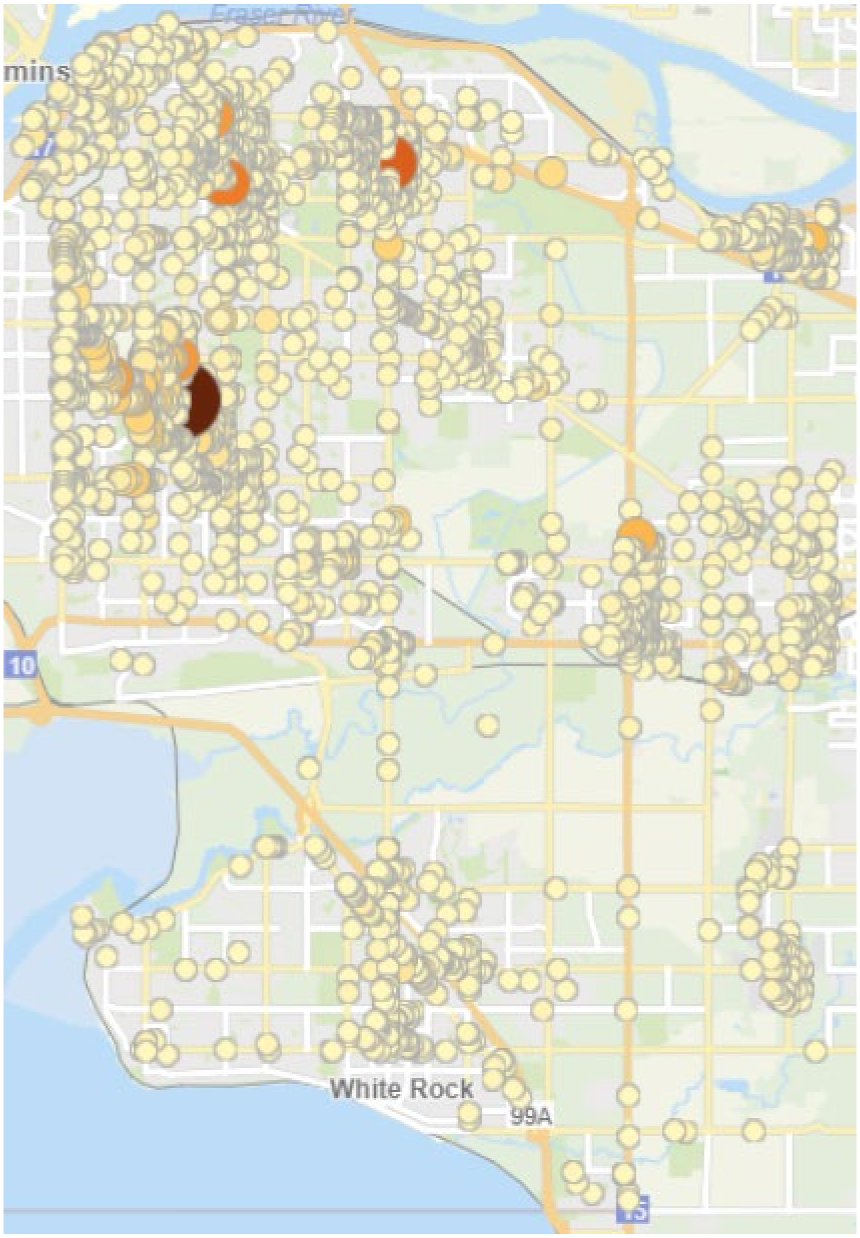
FIGURE 5: MAP OF INSPECTABLE PROPERTIES WITH STRUCTURE FIRE INCIDENTS IN CITY OF SURREY (2017-2021)



Note:
Every dot represents a structure fire incident occurred at an inspectable property.
The dot size represents the number of structure fire incidents.

Appendix D

FIGURE 6: MAP OF INSPECTABLE PROPERTIES WITH RE-INSPECTION IN CITY OF SURREY (2017-2021)



Note:
Every dot represents an inspectable property with re-inspection history.
The dot size represents the number of re-inspections performed in that inspectable property.

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