Developing a Predictive Framework for Structure Fire through an Activity Theory Lens

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I certify that this work has been reviewed by my supervisor prior to its submission.

Declaration

I hereby submit my thesis for examination and declare that:

1. The thesis is my own composition, all sources have been acknowledged and my contribution is clearly identified in the thesis. Permission has been granted from all co-authors for any work in the thesis that has been co-published, and is specified in the thesis acknowledgments and/or relevant footnotes/endnotes; and
2. This work has not been submitted for a higher degree to any other university or institution.

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Abstract

When a house fire occurs it does not discriminate, it consumes all in its path taking life, injuring, destroying property and damaging the environment which is why firefighters throughout the world are on standby ready to respond.

But what if we could identify where a fire was more likely to occur and do something about it before it happened?

After a review of current literature, I have identified a research gap in this domain and after undertaking an analysis of sample data I am proposing a concept of Dynamic Predictive Analytics where real time inputs into an Information System could model fire risks which can then be used to inform resource deployment decisions.

The direct contribution of this research aims to use predictive analytics to decrease the response time to fire-fighting to reduce its devastating impact on its victims. The indirect contribution is to enable the identification of at risk communities for the delivery of fire safety education through which risks, loss of life and economic costs could be minimised.

Keywords: structure fire, emergency, prediction, demographics, activity theory, action research

Acknowledgements

"To all the brave men and women in the emergency services who dedicate their lives to creating a safer world for us. Hopefully this will make your important jobs a little easier"

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Chapter 1 - Introduction

1. Introduction

Structural fires (house fires) occur rarely and have a devastating impact to those that fall victim to it. With an average of 19,877 house fires occurring every year in Australia at a cost of $3.3 Billion (Productivity Commission 2015) to operate the corresponding response services is there an opportunity to use tools and technology to make improvements in the firefighting industry?

A fundamental principle of firefighting has remained constant throughout the centuries, which is why we have Public Safety Agencies throughout the world, that are on standby ready and waiting to respond to when a structure fire starts. With improvement in technologies, and increase affordability of business intelligence applications, Predictive Analytics is a business information systems tool used in many industries such as the military, police and retailers to forecast likely scenarios. Using analytics enables Managers to make better informed decisions on how to deploy financial and material resources to achieve an organisations mission.

The aim of this thesis is to demonstrate that a framework for an Information System using analytical techniques could be developed to identify communities at risk of structure fires. By using Information Systems to identifying the locations of where there is a higher probability of a structural fire occurring, decision makers could engage and educate those communities on fire safety thus reducing the likelihood of a fire occurring or pre-deploy resources to a location that is closer to the higher risk areas thus enabling a faster response.

First, this thesis reviews the Information Systems and Fire Fighting literature and examines five (5) case studies that are the first steps to utilising the power that analytics could provide emergency managers to make informed decisions on future fire emergency scenarios. This review identifies a gap in Information Systems literature treatment of crises response and management in the context of structure fire-fighting. This is followed by undertaking an analysis of sample data which confirms the factors identified in the literature. This information is used to inform the development of a predictive framework using dynamic information for the identification of at risk communities.

The output of this thesis includes the development of a framework for an information system that uses a combination of static and dynamic data that could be used to predict where structure fires may occur in the future. For practical contribution from this thesis, I propose that Public Safety Agencies have use cases for predictive analytics that could be extended to identify these communities' and areas at risk of structure fire. This information system would enable proactive engagement with communities in these areas, and could improve the management of resources, save lives and reduce costs before a fire even starts.

1.1 Background

Firefighting methods have largely remained unchanged since the Roman bucket brigades were depicted on Egyptian papyrus (200BC) (Kenlon 1913). Industries don't necessarily want to change. Structural fires (house fires) rarely occur in a person's lifetime, but have a devastating impact to those that fall victim to it. When a fire occurs it does not discriminate, it consumes all in its path taking life, injuring, destroying property and damaging the environment. There are 2 main challenges

- A fundamental principle of firefighting has remained constant throughout the centuries, which is why we have Public Safety Agencies throughout the world that are on standby ready to respond to when a structure fire starts.
- It would be a fire fighters dream to <u>forecast a future fire</u> (predictive analytics) and stop it occurring or limit the damage caused to life, property, the environment or economy.

1.1.1 Defining a structure fire

The National Fire Protection Association in their 2015 report on house fires in the United States of America defines a structure fire as:

> "…In general, any fire that occurs in or on a structure is considered a structure fire, even if the fire was limited to contents and the building itself was not damaged…" and includes "…detached dwellings, duplexes, manufactured housing, apartments, tenements, flats, townhouses, row-houses, and other multi-family housing, regardless of ownership…"

The Australian Government Productivity Commission in its 2015 report defines a structures fire as:

> "…A fire event is an incident that is reported to a fire service organisation and requires a response. Fire events include (but are not limited to) structure fires (that is, fires inside a building or structure), regardless of whether there is damage to the structure…"

For the purposes of my research I will define a structure fire as:

> "…a fire that occurs in a dwelling that is used to house people, whether occupied or not, where a fire agency responds to the emergency…"

1.1.2 Response as the paradigm

The Comprehensive Emergency Management Framework (1979) [see section 2.1 and figure 2] is a cyclical process with four distinct stages that is currently used to managing an emergency, these are Prevention/Mitigation, Preparation, Response and Recovery (PPRR). The current approach to dealing with a structure fire is to wait until it starts, which is a classic case of the 'Response' paradigm as noted by Allen (2014). A Public Safety Agency is alerted, usually via phone, they then respond as quickly as possible to the location of the fire under lights and sirens travelling with all due haste.

However, if the Public Safety Agency could forecast the occurrence and location of a future event then an alternative outcome could be achieved - valuable time could be saved in responding to the incident with a greater chance of saving lives and reducing impacts and damage to property, the economy and environment. Moreover, with enough advanced warning, an intervention such as community engagement and education could entirely prevent the forecast event (fire) from occurring in the first place.

The ability to use Information Systems (IS) to forecast a pending event avoids the inevitable delays and communications problems caused by issues relating to interoperability (Frale 2005; NIEM 2007; Chen 2007 & 2009). Governments invest a significant amount of resources in an attempt to reduce delays so Public Safety Agencies can respond to emergencies at the first instance.

During a structural fire, timing is critical. The growth of a fire is exponential and a fire can consume a structure, in 6 minutes (Challands 2010; Host 2015) to such an extent that it cannot be recovered, rebuilt or reconstructed. However, the quicker a Public Safety Agency can respond is likely to significantly reduce the consequences of a fire in terms of the loss of life, level of damages to a property, the economy and environment. The key variable is time, that is how long firefighters have to save lives and a building, and how fast does the fire grow to a point where lives and the building are lost.

There appears that there has been very little literature research done in the domain of emergency and disaster management in the way of rigorous testing of theories, concepts and adopting lessons learnt. This may further explain why public policy failures occur again and again when complex emergencies occur.

1.2 Research Problem

In this section, I will explain the drivers on background and motivation behind this research, this is followed by introducing two research questions.

1.2.1 Background and Motivation

In 2013, devastating bushfires impacted the town of Winmalee in the Blue Mountains of New South Wales, Australia destroying 196 homes (Koperberg 2014). This prompted the then Chief Information Officer of Fire & Rescue NSW, the government department responsible for structural firefighting in New South Wales to question why "…given all the information that is available to us, why we could not have foreseen what was about to happen and taken proactive action to prevent the loss of these homes…" Interviewee A.

The <author>, at the time was a Chief Information Officer of another emergency service organisation and was seconded to Fire & Rescue in 2014/15 to consider the problem for a period of six (6) months.

On commencement, a project was handed over where a large technology company had been engaged to attempt to answer this question as a proof of concept. Local government areas from where the fires had impacted in the Blue Mountains had provided bushfire risk data on the all the properties in their areas. The Bureau of Meteorology had provided 3-minute time slices of all the weather observations that occurred on the 17 October, 2013. The technology company developed a risk model that deliver its results via a web based Geographical Information Systems.

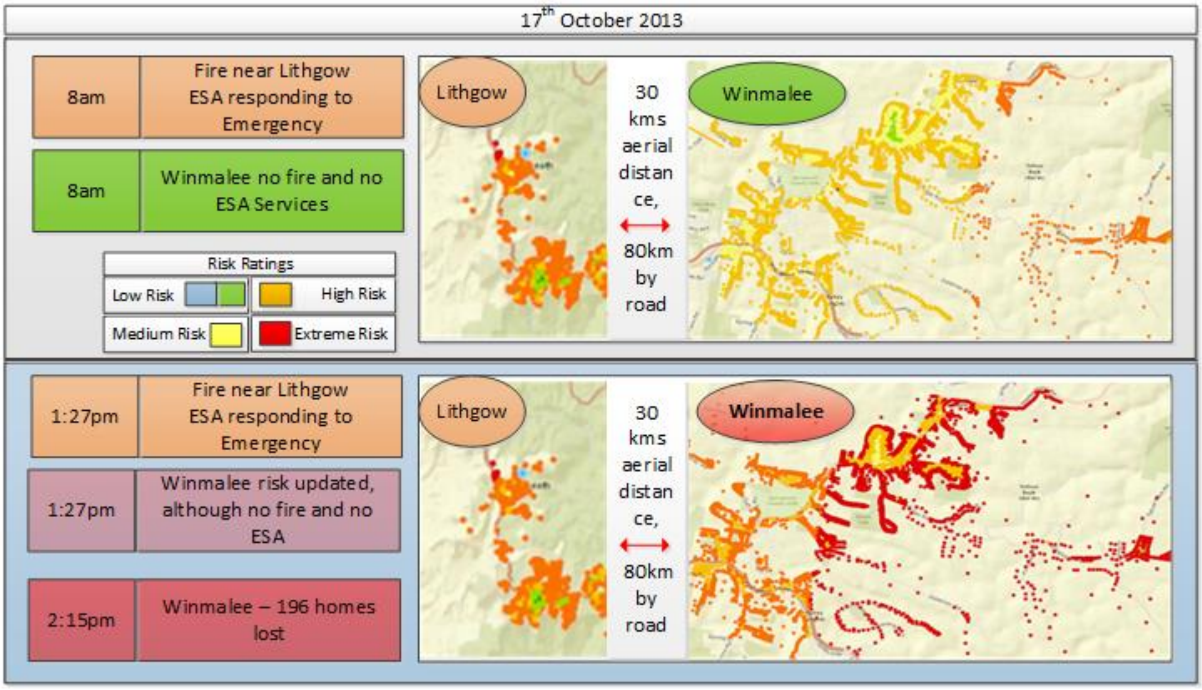


Figure 1 – Output from the proof of concept risk model of the Blue Mountains bushfire – 17 October 2013

The project was a success in modelling, but there were some limitations with outcomes. It was proved that risk to property of a fire could be modelled and displayed visually. Moreover, it showed that risk changed over time with weather being a primary driver of the change in risk, for instance, risk can change from the morning (medium risk) to the afternoon (extreme risk). However, the limitation with the output in Figure 1 was that weather observations were used rather than the weather forecasts. In reality the only data that would have been available in the morning to model the risk in the afternoon would have been the weather forecast, yet this was not used in development of the models. However, an issue that was quickly identified that these homes were primarily destroyed by a bushfire, and Fire & Rescue NSW was not the government's primary agency for bushfire management and response.

Much research has been done in the domain of bushfire (wildfire) modelling and as such it was decided to refocus the project to examine structure (house) firefighting, a domain whose principles remain relatively unchanged for centuries, to identify if predictive frameworks could be developed into an Information System to identify future risks.

1.2.2 Research Question

A gap in the literature has been identified with little to no research work being undertaken in the application of Information Systems using analytics to predict likelihood and location of structure fires. This leads us to my research questions to examine how a radical paradigm shift in the domain of structure firefighting:

1. What relationships and trends can be found in structural fire response data?

2. How can an Information System inform the prediction of structural fire?

1.3 Aims and Objectives

This research will use Participatory Action Research and Activity Theory, coupled with data analytical tools to examine any interrelationships between the predictive tools available to firefighters on the subject of fires.

1.3.1 Expected Outcomes

It is envisaged that there will be relationships between socio-economic indicators, weather patterns such as seasons and temperatures, times of day and locations.

If successful, the answers have the potential to fundamentally transform firefighting and generalisable globally. This research has the further potential to change organisations, structures, resourcing and the operations of Emergency Service Organisations and their management.

1.4 Chapter Summary

This chapter has highlighted that structure firefighting has not changed for a significant period of time (namely centuries) – that is, fire fighters are on standby wait for a fire to start and they then respond with all haste to save lives, property and extinguish the fire.

The motivation for the project was inspired by an idea on how to utilise resources differently by using data and information that is available to improve situational awareness. This in turn would inform decision making so that action could be taken in advance of a structure fire occur to prevent it in the first place through proactive engagement with at risk communities or to respond more quickly through pre-deployment of resources.

A gap in the literature has been identified with little to no research work being undertaken in this domain. Thus, this thesis will address this gap.

Chapter 2 - Literature Review

2. Introduction

A literature review is a toolset used to gather and analyse secondary data It is a means to identify work that has already been undertaken in the domain being studied and to identify gaps in the research. It also enables the identification of the appropriate research frameworks and tools to address the research problem.

The purpose of this chapter is to explore the current literature that exist with the domain of prediction in structure fire-fighting, to examine the current state of the art in the industry and to identify research gaps.

2.1 The Comprehensive Emergency Management Framework

The concept of Comprehensive Emergency Management was first described by the National Governors' Association in the United States (1979). This approach to emergency management is a core component used by many governments, public safety agencies and private companies throughout the world. It is the cyclical process of Prevention/Mitigation, Preparedness, Response and Recovery that accounts for the different phases (see Figure 2) of an emergency or disaster and how to manage these activities:

Prevention/Mitigation activities eliminate or reduce the probability of occurrence of a disaster. Examples include legislation, modifications to built environment, planning

Preparedness activities extend mitigation activities but cannot prevent the occurrence. Examples include warnings, training, stockpiling and pre-deployment of resources

Response activities occur in parallel as the disaster impacts. Examples include first response, medical care, shelter, feeding and search and rescue.

Recovery activities aim to return an impacted area to the same or better circumstances than before the disaster impacted over the short, medium and long term. Examples include accommodation, clean up, loans, planning, and redevelopment.

In addition, I have made two additions to the Comprehensive Emergency Management Framework to highlight that:

- emergency service organisations response after a disaster or emergency occurs; and
- Reconstruction activities occur over an extended period of time to rebuild societal infrastructure.

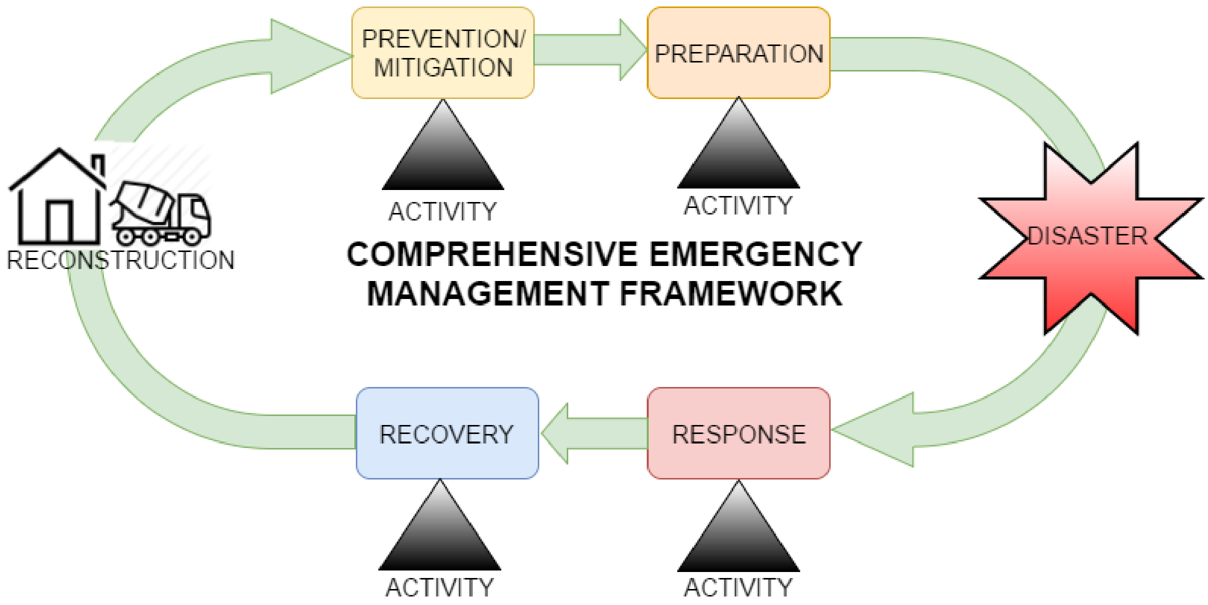


Figure 2 - The Comprehensive Emergency Management framework 1979 (Modified)

The State Governors' Association stresses the importance of co-ordinating activities across these domains to reduce the impact of emergencies and disasters (1979) and incorporating a feedback loop to capture lessons learned (1979).

The Comprehensive Emergency Management approach goes on to describe the command and control arrangements, organisational structures, training and technical expertise required by personnel that operate in these different phases of the disaster management. In addition, by adopting an all hazards, all agencies approach to emergency management the interoperability problems identified by Allen (2014) should be avoided, however this is not the case in practice. It is evident that different personality types would be attracted to different roles, deep thinkers in the prevention/mitigation and recovery phases and hero's during preparedness and response.

In retrospect there is clearly a coordination gap and it was Malone (1990) that defined Coordination Theory as being trans-disciplinary combining management science, phycology, organisational theory, economics and computing science, which is extended to the emergency management domain by Comfort (2004) as being an elusive goal hampered by organisational structures and ineffective information exchange that could by assist by the appropriate application of Information Systems.

Kapucu (2005, 2008) identified the problems with coordinating complex emergency management operations and adds clarity to the theoretic framework. By investing in mitigation and taking on lessons from previous disasters insight can be gained to improve future emergency management activities.

So why isn't this happening? In the domain of structural fire response every day we see fire fighters putting their lives at risk responding to building fires as has been done year after year. Yes, improvements in technology, equipment, communication have made saved lives, but is there a better way.

Cronstedt (2002) asked the question, is the Comprehensive Emergency Management (framework) an outdated concept? And challenged this thinking to highlight that it is not truly comprehensive framework. It assumes sequentially between activities, creates barriers between the four activity elements and is overly focused on action activities (response). He suggests some changes that focus on real world outcomes, economics and accept risk treatments.

Kelly (1999) suggests a software driven approach may assist making Comprehensive Emergency Management more ‘user friendly’. However, Allen (2014) identified that there is a common theme emerging amongst researchers that a technology driven approach is required to improve the complexities that exist involving interoperability and collaboration during major incidents. This approach continues with the action based activities theme identified by Crondstedt (2002)and does not address the need for preventative action to mitigate the likelihood and consequence of a disaster occurring, in fact Allen (2014) suggests that a technology driven approach could be a problem in itself.

Research into Emergency Management occurs mainly at the practitioner level where researchers aid practitioners to study emergency incident in terms of “fire service response times” (Challands 2010). Nearly all the published academic works seek to optimise firefighting or emergency management community warning (Bunker et al. 2009, 2010) and where emergency services should be located (Revelle 1989, 1995; Badri 1998; Gendreau 2001) or despatched (Han et al. 2000). Other research focuses on the emergency response (Chen et al. 2008) and interoperability between Public Safety Agencies (Allen 2014), modelling socio economic (FEMA 1997; Chhetri 2010; Ceyhan 2013), mathematical modelling to show that more fires occur greater the population is greater (Rohde 2010) and neural networks regressions to predict the numbers of fires in a locality (Yang et al. 2006). Risk management is operationally a significant tool for gauging the likelihood and consequences and also used in risk mitigation (prevention) (Rosenberg 2000).

A review of this literature reveals a gap in research into preventing and predicting the time and location of disasters. This gap in literature occurs in academic research and practitioner reports and is a potential failing of the Comprehensive Emergency Management Framework.

Research is this domain to develop a predictive framework for structure fire emergencies is likely to disrupt the current approach used by Public Safety Agencies by shifting focus from action activities (Response) to Prevention activities with an aim to save time, lives and cost by approaching the problem from an alternative real world lens.

2.2 Prediction and Fire Fighting in Information Systems

Firefighting is an industry based on trust and experience. Firefighters trust each other - in the standardised training they have, the operating procedures that are used, the experience of their commanders and their tools, all of which are designed to keep them safe and to allow them to save lives and extinguish fires quickly. A question is why has not Information Systems research examined the domain of firefighting, specifically the use of Information Systems as deployed across the Comprehensive Emergency Management Framework and how they could be used to predict the risks and likelihood of occurrences of structure fire.

In Information System theory development (Gregor 2006) describes prediction as the probability of an outcome given a certain set of condition. The Information System itself can be referred to as a black box in that it explains the "why" not the "how" of what it is predicting.

Shmueli (2011) describes predictive analytics as the use of models, methods and tools to create empirical predictions and the assessment of those predictions. He notes an under representation of predictive analytics in Information Systems literature and presents a schema for the development of predictive models covering goal definition, data collection, data preparation, data exploration, variable, methods, evaluation and use.

Decision Support Systems can be used to guide a user through a myriad of complex information with check points that can inform a user to make a decision (Silver 1991). He notes that the way information is presented and systems designed can influence the decision made by the end user.

Collins (2010) notes that people do not have the cognitive ability to process large volumes of information, and will make decisions based on bias rather than achieving an optimal outcome. He argues that module based Decision Support Systems that leverage internal and external data sources can be used to assist by predicting outcomes based on various scenarios that enable users to make better informed decisions.

Fire & Rescue NSW Computer Aided Dispatch System has 25,000 pre-determined rulesets to assist in the management of a response - Interviewee A

Activity Theory was used by Chen (2013) to develop a data model with core standards across a modified Comprehensive Emergency Management Framework to assist in improving interoperability between first responders.

In a study of the financial industry to developing predictive models for use in Information Systems, where data quality can vary, Bansai (1993) suggests that Neural Networks outperform linear regression particularly where non-linear relationships are present. This is supported by the findings of Churilov (2005) in his data mining study to better understand risk in the health domain.

Spangler (1999) discusses datamining as the search for patterns to make reasoned predictions using statistical methods to link variables. He reviews data mining methods including trees, neural networks and discriminate analysis finding gaps in all the methods across multiple inputs and suggests further research.

In a comparison of datamining methods to build predictive models using neural networks, decision trees and regression, no one method provides a foolproof result and that a combination of tools should be used (Sinha 2015).

Frisk (2015) in her research into the evaluation of technology investments uses a case study of the Swedish Fire Rescue Agency. She argues that Moore's (1995) theory on Public Value is essential but in evaluating benefit but difficult to measure. She goes on to note that a lack of strategy or understanding of the real ongoing costs of technology investment as being an issue.

Brigham (2006) undertook a case study of the implementation of Vehicle Mounted Data Systems in a United Kingdom Fire Service and the disruption it caused. He noted the unintended consequence of a technology implementation designed to replace paper and that technology cannot be controlled according to management theories.

In another case study into technology implementation in a United Kingdom Fire Service Feneley (2008) describes the unintended consequence of technology implementation across three case studies covering mobile computing and how visibility of information enabled seniors officers to over-ride decisions made on the fire ground, the use of global position systems to navigate streets not being as good as local knowledge and firefighters getting bogged down in recommendation made by a mobile computing system for hazardous material response rather than relying on their training. She concludes by noting the unintended consequences of technology and that the intended users or audience may not be those that were first thought.

In a study of Climate Change and Information Systems using Activity Theory, Hasan (2016), describes the output of climate – an increase in disasters, as being complex and the need for information tools to understand these emerging risks.

A review of this research indicates that much research has been one on the use of analytics in Information System Research and on the implementation if Information Systems in firefighting organisations. A gap in the research exists in bring the two disciplines together – predictive analytics in the firefighting domain.

2.3 Prediction in Structure Firefighting

Using the Thompson Routers Incites Journals Report (https://incites.thomsonreuters.com/#/signin), a search was undertaken to identify the top ranking fire related journals using the search term 'fire'.

Of each journal of the seven journals returned, a further search was undertaken using the terms 'fire' and 'prediction'.

The results contained in Table 1, list the Journal Name, the Thompson Routers Incites Journals Report Impact Factor, the results of the search being the number of journal articles returned using the search terms described above and of these the number of journal articles that were manually reviewed and identified as being relevant or not to the subject of the search terms – fire and prediction.

The results demonstrate that there is a fragmented body of knowledge that focuses mainly on the engineering aspects of fire prevention. Very few people have published peer reviewed academic research in the field of fire prediction or the use of analytics within the structural firefighting domain.

Of all the journal articles in Table 1, only two articles identified in the review highlighted the need for theory development concerning resource allocation between preparing for and responding to structural fires (Jennings 1999), and alignment between three different fire propagation models (Rein 2006).

Jennings' (1999) paper provides a significant lead into other research in the domain. He examines the relationships between the incidences of fire and socio economics. Primarily a literature review, he highlights that much of the research within the domain is undertaken in isolation without reference to any other work and identifies that previous studies having been undertaken without using any theoretic basis relying on substandard data. A summary of the factors provide insight into the types of data that will be required in the development of an Information System that can be used to predict structure fire.

In his paper, Jennings (1999) notes much unpublished work within the domain in an effort to use regression analysis to model the demand for fire services in cities. A common theme through the literature review is that fires are "people dependant" and that public education should be provided on the risks. He concludes his work by noting that "…A theory would also be helpful in allocating resources between fire suppression and fire prevention…." and that the use of geospatial systems could assist with further research in this domain.

Table 1: Search results of relevant fire related journals for fire prediction.

Journal Name	2014 Impact Factor	Results Returned	Relevant Articles	Notes
Fire and Materials	1.323	457	Nil	Research is related to prediction of burn rates of differing materials in specific circumstances.
Fire Ecology	1.422	142	Nil	Research focuses on bushfire/wildfire. Predictive models are not relevant to structure fire.
Journal of Fire Sciences	0.857	80	Nil	Research relates to prediction of burn rates of differing materials in specific circumstances.
Fire Safety Journal	0.957	7	Nil	Research relates to prediction of burn rates of differing materials in specific circumstances.
Fire Technology	1.297	13	1	Research primarily relates to structure firefighting and burn rates of materials. One article published in 1999 examined the issue of socio economics and demographics and its relationship to structure fire.
International Journal of Wildland Fire	2.429	343	Nil	Research focuses on bushfire/wildfire. Predictive models are not relevant to structure fire.
Journal of Fire Protection Engineering	0.385	10	1	Research is related to structure fire modelling after ignition. One article published in 2006 may be of interest concerning comparison of models to calculate burn rates. This may be used to identify optimised response times in any model development.

Think again about that romantic evening with your partner – that bottle of wine and a candle puts you at a higher risk of structure fire - Interviewee B

In 2013 Jennings updated his literature review. He specifically excludes public health and medical studies and engineering studies. He focuses his literature review on public policy and prevention activities and again notes the work being done in isolation and that structure fires continue to remain a problem.

Table 2: Summary of factors contributing to structure fire as cited in Jennings (1999)

Factor	Explanation	References (as cited in Jennings 1999)
Overcrowding	Identifies overcrowding in substandard buildings (population density) as a contributing factor to fires and drew an analogy to structure fire being an urban disease	Wallace & Wallace (1984)
Socio economics	A study conducted in greater London found correlations between the instances of fire and property ownership, socio-economic groups and employment status	Chandler (1979)
Smoking	Developed over 1,000 different scenarios in which structure fire could occur. These were consolidated into 14 scenarios in which loss of life was likely to occur. Smoking, that resulted in the ignition of a combustible material was the main factor.	Clarke & Ottoson (1976)
Alcohol	An epidemiological study conducted in Memphis in 1973 found that 80% of the people aged from 16 to 60 who lost their life in a fire had alcohol in their bloodstream. There were also similar findings with instances of smoking being a cause of fires.	Unknown (1973)
Temperature	Found a relationship between the instances of fire and the use of heaters.	Gunther (1982)
Socio economics	Using regression analysis found relationships between children living with parents (aged under 18), income and education level with the instances of fire.	Schaenman et.al (1977)
Socio economics	Continued the work of Schaenman. Used regression analysis at the census level to provide positive results across a range of nine population and five housing characteristics (eg. race, poverty, age, education, children, age of building, number of people in dwelling, vacancy rate). Introduced the measure 'fires per 1,000 population'.	Karter & Donner (1977)
Socio economics	Constructed a structure fire model using income, children, owner occupation, crowding, structural condition, temperature and social tension with findings that temperature, income and owner occupation were the most significant factors.	Muson et.al (1983)
Operating Costs	Examined operating costs of fire departments but was unable to explain any association between costs and loss of buildings.	Goodhart (1982)
Socio economics	Examined population, density, socio economics, firefighter's wages and fire damage to model supply and demand for fire services. The finding was a high population linked to poverty resulted in more fires. A suggested solution was the reduction of poverty could pay long term dividends in reducing fire losses.	Southwick & Butler (1985)

Jennings summaries his work from the 1999 paper and notes the relationships between the many factors identified by the disparate, uncoordinated and unpublished research that relate to structure fire and the limitations in the early work due to funding, computing power, software, the types of studies undertaken, bias and belief.

He points to a recent modest resurgence in interest in the domain coinciding with the use of Geographical Information Systems as an analytical tool. He describes research moving from exploratory to explanatory. Shai (2006) used regression analysis to predict injuries using age of housing, income and English as a second language while Asgary (2010) used a Geographical Information System to visualise his results on incidents by time of day and month of year showing clear patterns of structure fires in space and time.

Corcoran has undertaken many studies (2007, 2007, 2009, 2010 and 2011), particularly in relation to the use of Geographical Information Systems to identify spatial and temporal trends and with Chhertri (2010) they used Australian Bureau of Statistics data to align socio economic indicators, weather, time of year and location with the instances of structure fire and concluded that spatial systems were a good way to demonstrate these relationships and structure fire risk.

Jennings (2013) points out that in the move towards the development of a theory of structure fire, risk can be examined at the individual, building or neighbour level and also in terms of life, injuries and property. He cites his own model using vacant housing, population aged under 16 and over 65, income level and single parent households as providing some success in a number of cities in the United States.

Jennings concludes his paper by identifying the need for further mixed method research, case studies and the identification of variables for using in future quantitative studies. He also suggests population based studies could be advantageous. He notes the need for further funding to develop a credible model and the need to coordinate research. He also highlights success in the United Kingdom and Australia in preventative activates and the need for direct engagement with Fire Services to obtain better data to understand fire risk.

Of specific interest in all this research was that regression modelling was the toolset that was used and alternates did not appear to be considered.

Jennings work has highlighted the different studies and models that have been developed. His work is a cornerstone in the structure fire domain in that it has brought together the disparate work that has been undertaken in this domain.

2.4 National Fire Protection Association Research Foundation

In a discussion after a presentation by Chief Rhoda Mae Kerr of the Austin Fire Department at the 2016 Australasian Fire and Emergency Services Conference (pers conv, 2016), where she presented on the importance of data collection and analytics in the emergency management domain, she referred the <author> to the National Fire Protection Association Research Foundation at http://www.nfpa.org/ for more information. A review of the research presented on the website supports the findings from the Thompson Routers Incites Journals Report, and that is there was no published papers of research forecast in the use of analytics to predict structural fire.

> *New fire fighters are different and need to be developed, not to be clones of the past - Interviewee C*

A single paper (Amon 2016) on economic and environmental impact modelling with a focus on warehouse fires identified a future need for the same models to be developed for house fires.

2.5 Research Gap

There has been very good work done in the Information Systems domain on the use and application of analytical tools such as regression, neural networks and decision trees. There have also been case studies of Information Systems and Information Technology implementations in the firefighting domain. A gap exists on bringing the two together to look at how analytics could be used in the firefighting domain to build Information Systems tools to create safer communities.

> *The military is there not to fight the last war, but the next one. We need to move into this space – forward looking. There is no more money and most mitigation strategies fail so there needs to be another way - Interviewee D*

Work undertaken by Jennings points to the disparate and uncoordinated research in this domain, specifically looking at relationships and trends in response data. Corcoran has developed a model that could be used in the development of in Information System. An emerging development is the use of Geographical Information Systems combined with regression analysis to identify trends and visualise findings.

It has been suggested that fires are a human related problem and that many patterns reside inside the datasets concerning fire response. The human brain is able to assess problems and identify patterns in a non-linear manner. The continued use by researchers of linear analysis tools such as regression analysis provides a gap for non-linear methods such as neural networks to be used.

As much as the research has identified trends and suggested models to identify risk an Information System tool set has not been developed to undertake this task.

2.6 Chapter Summary

In this chapter I have identified the complementary research methodologies of Participatory Action Research that will be used to engage with stakeholders with the results iteratively examined, reflected upon, reassessed and represented whilst being viewed through an Activity Theory lens to understand the motivations of the problem.

The Comprehensive Emergency Management Framework was described as the fundamental basis for managing emergencies and disasters used by First Responders throughout the world. It is important to note the gap in the framework that does not specifically describe prediction as a tool for identification of at risk Communities.

The review of Information Systems Journals reveals case studies in the implementation of technology and Information Systems in Fire Departments and significant work on predictive analytics however there is a gap in the literature on the use of predictive analytics in Fire Departments.

A review of analytics in the fire domain identified a disparate set of informative papers across many years and different research domains eg Geographical Information Systems, Emergency Management etc, making them difficult to locate and posing the question about why haven't any of these findings been acted upon. The research shows a trend of associating the incidences if structure fires with a variety of socio-economic and other indicators, including weather which lead to models that could be developed into Information Systems.

It is important to note that the literature review and cases studies identified little work in the use of analytics to forecast the likelihood of structure (house) fires, much work has been undertaken to create safer communities through changes to the built environment. For example, Sprinkler systems, construction using slow combustible materials, smoke alarms and responding to fires as quickly as possible.

There has been little done in the domain of emergency and disaster management in the way of rigorous testing of theories and concepts. Most research documents the events and looks for patterns to emerge. There is almost rigorous research into fire predictions. There is a research gap considering the global magnitude of domain and the impact on people everywhere.

Chapter 3 - Methodology

3. Introduction

This chapter outlines the research methodology used in this study. It outlines the project, process and data collected to answer the gap identified in the literature review. McGrath (1981) claimed that a single approach to research was a limiting factor, therefore a combination of approaches is likely to provide a more grounded result.

In this chapter, I will provide an overview of Activity Theory and Participatory Action Research as the primary theories selected for research and analysing the problem. Both these theories are complementary and are commonly used by Information Systems Researchers to investigate problems. Action Research is a well understood methodology which has been easy to explain to stakeholders, while Activity Theory has been used as a descriptive tool (the lens) to examine the problem and determine possible solutions to the identified gaps.

3.1 Theoretical Framework

3.1.1 Key Concepts

Epistemology is the study of the acquisition of knowledge, and provides boundaries between justification, validity, belief and opinion. There are many different approaches within Epistemology that were considered as an appropriate methodology for this research, such as historical, empiricalism, idealism, rationalism, constructivism, foundationalism and coherentism to name a few.

It was decided to select constructivism as the key theoretical framework as it brings together the empirical, theoretical and abstract in addressing the problem – it enables people to make meaning from their experiences (Crotty 1998).

The reason for the selection is because:

- The problem is dealing with hundreds of years of learned behaviour in how structure fires are managed and this behaviour will be difficult to address from a change management perspective.
- A data driven logical approach rely on theory and proven tools will attempt to present facts and solutions; and
- Abstract thinking will be required to come up with new and innovative ideas to address the problem.

3.1.2 Operationalisation

A key object of this research is to identify trends in existing data and to see if an Information System could be used to improve the ways that structure fire is managed across the Compressive Emergency Management Framework. Such that, could factors and trends in structure fire data

enable high risk areas of structure fire to be identified and either proactive engagement be undertaken with the communities before or resources pre-deployed to enable a quicker response.
The application of this research will be through the review of previous research, analysis of data, semi structured interviews with stakeholders and the formulation of a framework.

3.2 Activity Theory

Information System researchers would agree with the straight forward claim that "Activity Theory provides a lens to analyse the computer-supported activity of a group or organization and to study the design of artefacts for individuals and organizations" (Chen et al. 2013). Most empirical IS research using Activity Theory applies the Engestrom Framework (Figure 3). While this has merit, Activity Theory has the potential for a more insightful analysis.

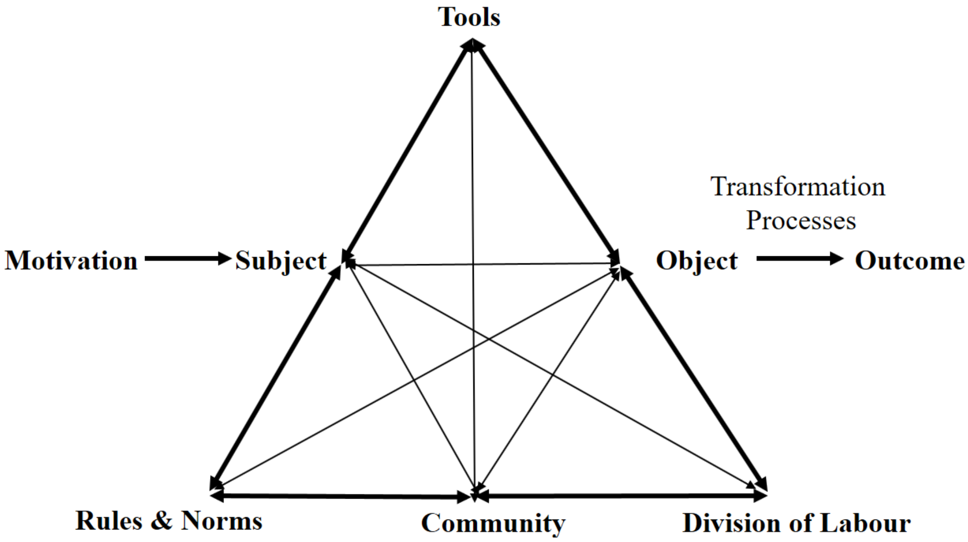


Figure 3 - The Engestrom Activity System (adapted from Allen et al (2013))

Kuutti (1996) notes that Activity Theory has the depth to address the complexities of ubiquitous fragmentation in the Information Systems discipline, which deals with socio-technical systems. Hasan and Crawford (2006) contend that the main reason for the use of Activity Theory in Information Systems research is that it provides a well-developed framework for analysing the complex dynamics settings that typically involve ongoing interactions between human (subject) and technical elements (tools and objects). Moreover, according to Davidson et al. (2012, p.766) "action researchers and their clients use instrumental theories to facilitate specific activities, especially diagnosis, planning and evaluation". In order to provide a holistic explanation for the complex problem of prediction of structure fire, Activity Theory will be used as both the instrumental theory (Davidson et al. 2012) and as a theory for analysing (Gregor 2006).
The activity at the core of Activity Theory is the relationship between subject (doer) and the object (what they are doing and why) as originally described by Vygotski (Allen et al 2013; Hasan & Kazlauskas 2014). The relationship is dialectic in the sense that its subjective and objective natures

are inseparable (Kaptelinen 2005). The object of activity encapsulates its purpose and no human activity is ever objectless (ibid). Human activity is distinguished by the fact that it is mediated by physical and psychological tools (Vygotski 1978). Leontiev (1981) distinguished between, long-term activities, which must be understood in terms of the subject's motive and purpose within a cultural-historical context, are distinguished from short-term goal-oriented actions, which are only meaningful in terms of the motive, purpose and context of the activity of which they are an element (ibid).

The use of Activity Theory as the conceptual framework of analysis is "based on the idea that activity is primary" (Morf & Weber 2000). "Activity Theory is particularly relevant in situations that have a significant historical and cultural context and where the participants, their purposes and their tools are in a process of rapid and constant change" (Hashim 2007).

In this thesis, I adopt the Leontiev interpretation of high-level activity as the unit of analysis. A unit of analysis is the most basic element of a scientific research project (Long 2004). It is the subject (the who) of study, about which an analyst may generalize (Long 2004) or use to build theory (Hasan & Banna 2010). In social science research, typical units of analysis include individuals (most common), groups, social organizations and social artefacts.

Thus the well-known elements of Engestrom's activity system will be used as a framework and language for describing the activity.

Activity Theory allows the development and understanding of the application of the Comprehensive Emergency Management framework in past incidents and to expand it into the complex process of predicting and planning the location of future fire scenarios. In the complex realm of fire prediction, Activity Theory can help make sense of the issues and inform the development of a predictive model. Most significantly it demonstrates that Information Systems expertise can contribute to an understanding of the problem in detailed fire predictions and that practitioners can understand the Activity Theory.

Activity Theory is selected as the primary lens for this study as it is simple enough for practitioners to understand yet robust enough to develop theoretical constructs and frameworks for academics.

3.3 Action Research

Action Research was assessed by to be a valuable research methodology that generates data and interpretations, which are appropriate to a given situation which may be complex. (Dick 1995; Susman 1983).

Action Research develops a solution to a practical problem that is of value to the people with whom the researchers are working, while at the same time developing theoretical knowledge of value to a research community (Kock 1997; Coghlan 2001).

Action Research described action research as a series of iterative cycles that move between action and reflection (Kemmis 1999; Dick 2002).

The dual outcome perspective of action and research means that the research is embedded within a practical context that can be used to explain and be changed to improve practical outcomes and gain new insights that emerge (Chaisson 2008).

As a research method it assists in answering research questions and generating theories, but it also helps potential research participants to improve aspects of their work that are of relevance to them.

Experience and research demonstrates that Activity Theory is compatible with action research as the activities under investigation, and the two activities of research and practice, can be viewed through the lens of Activity Theory.

3.4 Research Method

Action Research is a method where researchers engage with participants to facilitate learning about the problem being examined. It was selected as a method because it is easy to understand and explain and enables open collaboration with participants to explore new ideas.

Activity Theory is a framework where ideas, theories and methods can emerge to explain activity within a human context considering the subject (firefighters), object (fire) and tools (Information Systems) that are currently used or could be developed to address the research questions. See Table 6 and figure 10.

Over the 6-month period of the project, 240 meetings (Table 3) were held across a range of internal, external and technology stakeholders to learn if an Information system could be developed to predict structure fires to assist in understanding Research Question 1 and Develop a Framework to answer Research Question 2.

Table 3: Summary of meetings

	Nov-14	Dec-14	Jan-15	Feb-15	Mar-15	Apr-15	Total
Universities	2	5	3	2	13	10	**35**
Vendors	15	14	11	24	11	5	**80**
Project Team	23	9	16	23	17	10	**98**
Management Team	4	1	2	5	10	5	**27**
Total	**44**	**29**	**32**	**54**	**51**	**30**	**240**

Using the Action Research methodology described by Davidson (2004), Table 4 describes the activities and outcomes of each research cycle. In each cycle unstructured interviews were undertaken with internal and external stakeholders to understand Research Question 1 and Develop a Framework to answer Research Question 2.

Table 4: Typical meeting cycles with vendors

Action Research	Cycle 1	Cycle 2	Cycle 3
(1) Diagnosing	Initial meeting of vendor team (meet and greet) explanation of the imperatives and requirements.	Appraisal of preliminary investigation undertaken by vendor team.	Assessment of selected solution and identification any outstanding of issues.
(2) Action planning	Discussion of possible solution alternatives	Discussion of the steps and follow up actions.	Refinement of selected solution
(3) Intervention (Action taking)	Discussion and definition of the options available, body of work (to be undertaken) and contracts, IP and budgetary considerations.	Scoping of next steps and refinement of work undertaken.	Finalising of steps required to complete and deliver body of work engaged by the vendor team.
(4) Evaluation (Assessment)	Refinement of possible solutions.	Assessment (by the management Team) of presented alternative solutions.	Delivery of work undertaken and review
(5) Reflection (Learning)	Ask the Question - Do the proposed outcomes align with alternative solution approaches?	Selection and recommendation of solution.	Identification of knowledge discovery and future elements and options.

In addition, qualitative analysis using common data analytics tools will be selected to identify patterns and trends in structure firefighting.

3.5 Research Questions

The research questions being examined are:

1. What relationships and trends can be found in structural fire response data?

2. How can an Information System inform the prediction of structural fire?

3.6 Data Collection

A dataset that was made available by Fire & Rescue NSW for the purposes of a data analytics competition was utilised for this research. This dataset contained 7,199 de-identified records of structure (house) fires that occurred over the two calendar years from 2012-2013 taken from its response data collected in its computer aided dispatch Information System.

Using Microsoft Excel, this dataset was modified to align the locations of structure fires to the weather conditions at the time the fire occurred. In addition, the Australian Bureau of Statistics

Socio-economic Indexes for Areas data covering economic disadvantage, access to economic resources and education and employment were aligned to each record by both post code and suburb. In addition, semi structured interviews and discussion were conducted under the guidance of my supervisor with colleagues from the emergency services sector in Australia and other countries to validate ideas and discuss concepts.

3.6.1 Social Media Data

Fire & Rescue NSW publishes some, but not all, fire response data on its twitter feed (@FRNSW). Building on the works of Ehnis & Bunker (2012), the Fire & Rescue NSW twitter feed was monitored. Data was collected only on structure fires with the date, time and location (suburb) which was then aligned to weather data (minimum and maximum temperature) and the Australian Bureau of Statistics Socio-economic Indicators for Area.

This data would be used to test any hypothesis for model development.

3.6.2 Challenges

Access to data is seen as a future challenge. In general, despite legislation existing stating that government agencies are required to put information into the public domain, agencies tend to shy away from this activity as they do not know what data they hold, its implications or what a detailed analysis may identify.

The author, having over 10 years' experience at an executive level within the emergency management domain in Australia may have bias toward certain attitudes, process, concepts or ideas.

3.7 Analytical methods

3.7.1 Correlation and Regression Analysis

Correlation and Regression Analysis is a widely accepted method for determining relationships between variables that can then be used to predict a future outcome based on some inputs (Sirkin 2006). As identified by the work of Jennings (2013), all the research undertaken to analyse structure fire data has used regression analysis to identify trends. A correlation and regression analysis of the Fire & Rescue NSW dataset. It is expected to confirm findings identified in the literature review and confirm Research Question 1 and assist in ascertaining if a model could be developed to answer Research Question 2.

3.7.2 Spatial Analysis and Visualisation

Location based analysis using spatial technologies will be essential to the development of a predictive model for future structure fires. Fotheringham (2009) defines spatial data as having special attributes while Demšar (2012) defines spatial data as containing geographic and attribute information. Jennings (1999) suggested that the emergence of Geographical Information Systems would become a valuable tool in analysis structure fire data. Fire emergencies impact people in places and contain a varying number of attributes that will be used in developing a framework building on the work of Corcoran (2009).

3.7.3 Neural Networks

The human brain is capable of recognising non-linear patterns. Neural Networks are analytical techniques modelled after the cognitive process of the human brain. They emulate the recognition functions of the brain by looking for causal relationships between dependant and non-dependant variables in any given dataset and are capable of identifying non-linear patterns and creating models to represent these functions enabling future predictions (Jain 1997; Neelakanta 1999).

3.7.4 Decision Trees

A decision tree is a linear tool that builds a decision matrix in the form of a tree. It constructs the tree to fit the dataset being examined and then through series of iterations removes those components (branches) of the tree that are identified as having a high error rate. (Sinha 2004)

3.8 Project Planning

The research plan identifies work to be undertaken throughout the period in planning for and development of the thesis. Specifically, weekly meetings with the supervisor will feature as a mechanism to keep the project on track to deliver on time and adequate time for review and changes prior to submission.

Stepped workloads, attendance at classes, support from lecturers, faculty staff and supervisors, combined with regular work review has enabled the project to be delivered in accordance with the research plan. The research plan is at Appendix A Table 1.

3.9 Limitations

One of the criticisms identified noted in Section 1.2.1 Background and Motivation, was the use of retrospective (observed) weather data in the case of the 2013 Blue Mountains Bushfires project instead of forecast weather data. The same use of retrospective data was also used by Corcoran (2009) in the development of his model at Figure 9. This limitation has been accepted with the knowledge that actual observed weather data can be used to inform the development of a model that uses forecast data to anticipate changes in risk.

The Economic data provided by the Australian Productivity Commission includes all fire agencies – Urban and Bushfire. This limitation is accepted and acknowledge, knowing that Bushfire agencies receive a separate funding source for bushfire fighting and bushfire agencies also respond to structure fires in communities where there is no permanent fire brigade.

There a multiple limitations of the Australian Bureau of Meteorology weather data these include the location of weather stations and their alignment to suburbs, and weather forecasts using the Meteye (2015) data being in 5 km^2 blocks.

The data used has been aggregated at the suburb and postcode level, the ability to examine data at a more granular level would be advantageous in the future.

3.10 Chapter Summary

In this chapter I have identified Conceptualism as the Epistemology being used as the key theoretical framework to address the research question as it brings together the empirical, theoretical and abstract concepts.

Both Action Research and Activity Theory have been selected as the research methodologies as they are both complementary and well understood in the Information System domain. Action Research enables the engagement with stakeholders to address and understand problems and share ideas on potential solutions while Activity Theory provides a lens to understand the human interactions within the problem area and develop potential solutions.

I have identified a gap in the literature being a range of disparate research that has examined trends in instances of structure fire and the use of Information Systems to predict future occurrences. The next step in this thesis is examine structure fire data to see if the identified trends exist to validate the existing findings. The findings will be discussed with industry experts and used to inform ideas concepts and solutions.

Chapter 4 - Analysis, Results and Findings

4. Introduction

The purpose of this thesis is to investigate at the relationships between data on structure fires and to examine if an Information System could be used to help predict instances of structure fire. I have used a de-identified dataset that was made available by Fire & Rescue NSW for the purposes of a data analytics competition to undertake this research. Work was done to align additional datasets containing information on weather and socio-economic indicators with each fire record. I used a variety of analytical tools to identify trends and relationships within the data.

Cost is a major driver for change, information published by the Australian Productivity Commission indicates that over the last 10 years that the costs of operating the Fire Services in Australia have increased 31.3% above inflation with the same level of output being maintained.

Discussions with fire fighters provided some initial leads in which to start analysing data – cooler days were busier and there were more responses to the lower socio economic areas. The analysis of the data available reveals complex relationships between people, the instances of fire, the environment (weather and temperature) and socio economic indicators.

I will further discuss the current disaster management framework and a search of the current literature in this domain including five (5) practitioners based case studies that were selected from the United Kingdom, Europe, United States of America and Australia to demonstrate the current and emerging practices within the industry and the opportunities for further research.

4.1 Costs

An analysis of data published annually by the Australian Productivity Commission over the 10 years period 2004–2014 demonstrates increasing costs compared to relatively static levels of responses (see Figure 4).

The data suggests that nationally, Fire Service Organisations are at their peak performance – there is no possible way that a fire appliance (truck) can physically get to a fire and extinguish a fire more quickly than what is occurring now.

Figure 4 demonstrates that the majority of the investment in Public Safety by government is in the having human and material resources on standby to respond. There has been much debate by practitioners and government on shifting investment away from response and into preventative measures such as education, resilience and capacity building and changes to the built environment.

The evidence presented in Figure 4 demonstrates that over the ten-year period from 2004/05 - 2013/14 minor annual fluctuation in responses rates are observed (min 19,175 – max 20,603) while a steady increase in funding ($2.085Bn – $3.328Bn) is required to maintain this level of vigilance.

Adjusted for inflation over the same period at 31.3% (Reserve Bank of Australia) it still represents a real increase in expenditure of $590.3M.

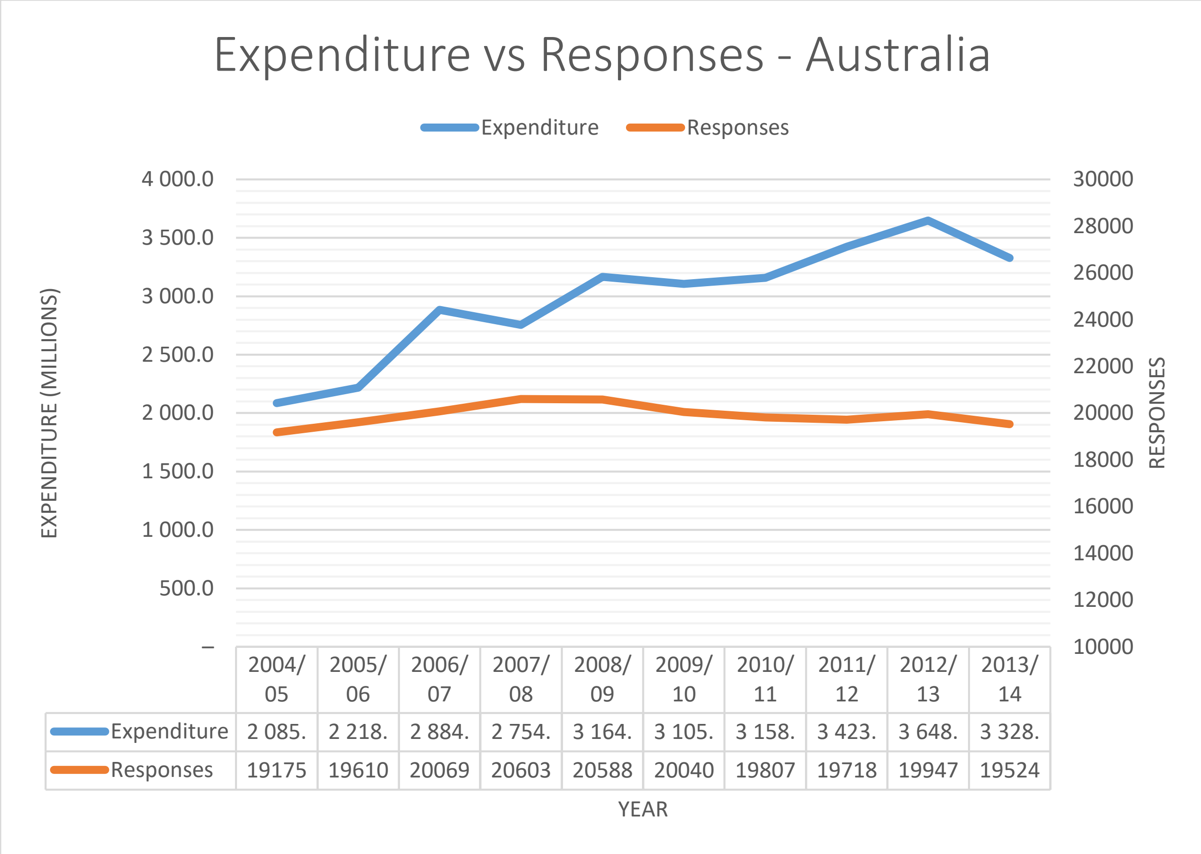


Figure 4: Expenditure vs Responses Fires Service Organisations 2004/05 - 2013/14 – (not adjusted for inflation)

This paradigm appears to represent a classic case in economics if the law of diminishing returns is that more and more funding is being spent in this domain (2004-2013) for the same level of response activity.

During a discussion with the Chief Executive Officer of the Australasian Fire and Emergency Services Authorities Council, a comment was made about the costs of the operating the Emergency Management industry in Australia being approximately $5Bn with costs saved due the intervention of Emergency Service organisations being far less than this amount.

4.2 Environment

4.2.1 Weather (Temperature and Temperature Change)

During the research, discussions were held with fire fighters. As part of these discussions it was not uncommon for the fire fighters to describe the conditions of when they were more likely to have a busy day as opposed to when they wouldn't. It was identified that weather (temperature) was a driving factor.

We know that the weather influences when more fires will occur, like cold snaps coming into winter - Interviewee E

A simple pivot table analysis in Microsoft Excel provides a visual representation from which a trend can clearly be observed that demonstrates more structure fire incidents on days with cold mornings (7C to 17C) coupled with very low increases in temperature (4C to 8C).

These findings are similar to those published by Corcoran (2009) who noted in his research that analysis needs to be undertaken in different locations.

The results are contained in Appendix “A” Table A2.

4.2.2 Season and Time of Day

The results in Appendix “A” Table A2 indicate a seasonal relationship and led to the next analysis which was to examine if there was a relationship between season and the number of fires.

A pivot table analysis in Microsoft Excel was undertaken to examine the number of fires by month.

The results in Appendix “A” Table A3 indicates that the cooler months of late Autumn, Winter and early Spring are when more structure fires occur.

An extension was made to the analysis to consider the time of day of the fire. The results revealed that late afternoon and early evening as being the busiest times which is likely to coincide with the times that people are coming home from work and cooking or heating appliance are being turned on.

These findings align with discussions held with Australian fire fighters, but are contrary to a discussion held with Colonel Jean-Claude Gallet of the Brigade De Sapeurs-Pompiers De Paris (pers conv, 2016). Fire fighters are members of the French Military and trained paramedics providing fire suppression coverage for over 7 million people in an 8oo square kilometre are where they respond to between 15-55 fire incidents a day.

There is no pattern in where and how fires occur - Interviewee F

According to Colonel Gallet the Brigade spends 20% of its time responding to fire emergencies with the balance spent on medical first response. The findings from this analysis support those of Corcoran (2009). However, I suggest that a detailed analysis of their data may not have occurred.

4.3 Human Factors (Socio Economic Indicators)

4.3.1 Correlation Analysis

A discussion with Inspector Matthew McCarthy (pers conv, 2015) from NSW Police provide advice in relation to the use of correlation and regression analysis and how it was applied to high visibility policing and how it may be application to predicting structure (house) fire emergencies.

Inspector McCarthy's general comment was "not to look at anything more complex than socio-economic indicators by area taking into account past instances of structure fire in those areas".

Based on this advice a correlation analysis of the three indicators provided in the Australian Bureau of Statistics Socio-economic Indexes for Areas (ABS 2011) data cube by suburb (economic disadvantage, economic resources and education and population).

The results align to those suggested by Corcoran (2009) and are contained in Appendix "A" Table A4 indicating that:

- a negative correlation between the number of fires and economic resources, that is there are more fires as economic resources go down; and
- a positive correlation between population and number of fires, that is as population goes up so does number of fires.

4.3.2 Regression Analysis

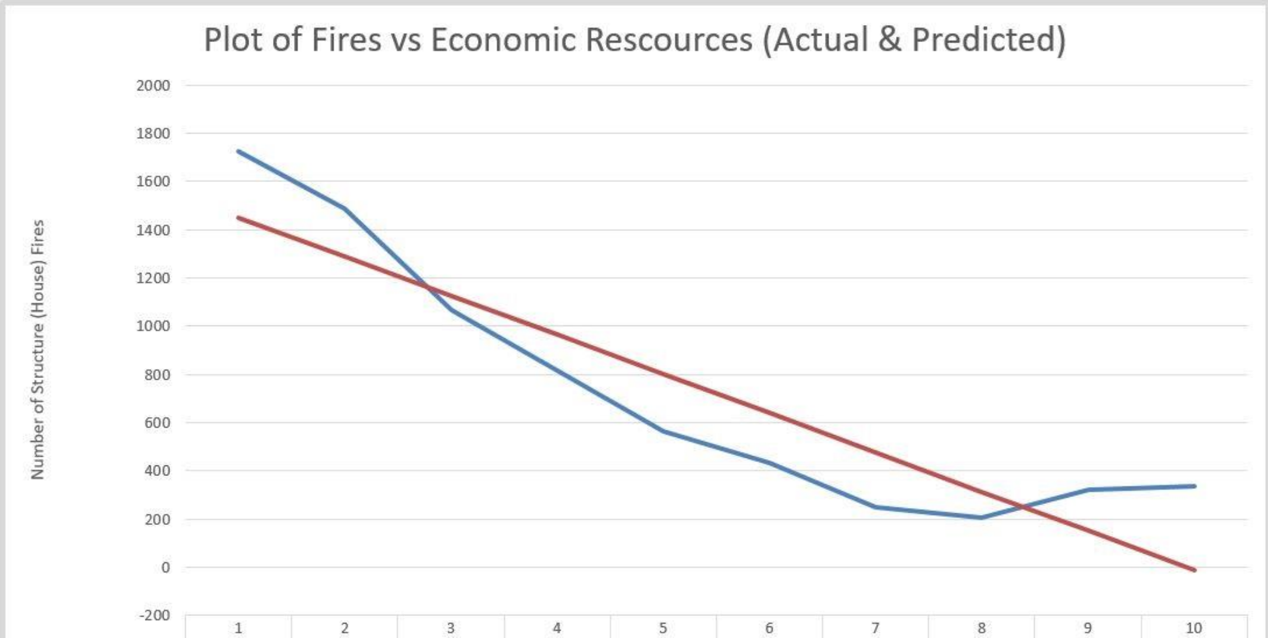
Based on the result identified in Appendix "A" Table A4, a regression analysis was then undertaken comparing the count of fires compared to Economic Resources to develop a trend line to see if structure house fires could be forecast.

The regression statistics listed in Appendix "A" Table A5 show an R Square value of 0.828. This indicates a good alignment of the trend line to the actual data to use as a predictive tool.

The Analysis of Variance (ANOVA) in Appendix "A" Table A6 indicates that the results are significant and within tolerances being confirmed by the F Value (0.000). A result higher than 0.005 indicates a problem with the dataset and invalid result.

The results in Appendix "A" Table A7 of the P Values (0.000 and 0.000) support the F Values and allowing the derivation of a trend line that can be used to assist in the prediction of structure fires:

$$y = \text{Count of Fires} = 1614 - 163 * \text{Index of Economic Resources}$$



	1	2	3	4	5	6	7	8	9	10
Actual Fires	1724	1489	1069	814	562	432	247	207	319	336
Predicted Fires	1451	1289	1126	964	801	639	476	313	151	-12

Figure 5: Plot of Fires vs Economic Resources (Actual and Predicted)

Figure 5 shows the output of the regression analysis, comparing the trend line of predicted fires versus actual fires across the 10 levels of economic advantage, 1 being the lowest and 10 the highest level of economic resources.

This seems to indicate that fires could be readily predicted (but not all fires) for the lower three socio-economic deciles.

This supports the findings of existing research (Jennings (1999, 2013) and Corcoran (2009)) and shows the relationship between the instances of fire and lower socio economic resources.

4.4 Human and Environmental Factors

4.4.1 Economic Indicators and Weather

Appendix "A" Table A4 identifies that more fires are likely on cold days with small temperature differentials. Figure 5 identifies the lower three socio-economic deciles are at higher risk of structure fire.

A pivot table analysis was undertaken using Microsoft Excel to examine any relationship between temperature and socio economic indicators

The output aligns with the findings in both Appendix "A" Table A4 and Figure 5, (and those of Corcoran 2009) that is that the lower three socio-economic deciles are at higher risk of structure fire on lower temperature days.

4.5 Other Analysis Methods

Further multi factor regression analysis was experimented with, but due to the linear nature of this problem solving methodology it did not seem to fit the complex relationships between all the factors.

On advice from a number of researchers I decided to investigate the use of Decision Trees and Neural Networks.

4.5.1 Decision Trees

A decision tree is a tool set that graphically displays an algorithm. It is useful in calculating weights against different factors to assist in determining an outcome. Given the complexities between factors that were noted, I decided to use the Decision Tree toolset in the RapidMiner Studio.

The following attributes were selected - time of day, economic resources, month, temperature minimum and temperature differential with minimum temperature selected as the target. The selection of these attributes was based on discussion with fire fighters that indicated that they were busier on cooler days. The decision tree that was created (Appendix B Figure 1) from the analysis is for too complex and will require further investigation.

4.5.2 Neural Networks

A neural network is a tool that can be used to estimate functions that use a large number of variables and patterns. A neural network analysis using a function in the RapidMiner Studio was undertaken (see figure 6).

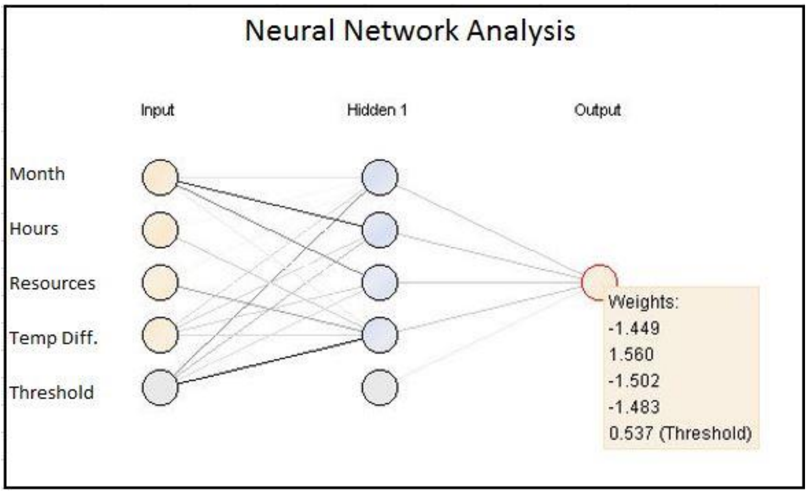


Figure 6: Output of Neural Network Analysis

The following attributes were selected - time of day, economic resources, month, temperature minimum and temperature differential with minimum temperature selected as the target. The selection of these attributes was based on discussion with fire fighters that indicated that they were busier on cooler days. The output is displayed in Figure 6.

4.5.3 Spatial Visualisation

In 1999 Jennings identified that Geographical Information Systems as an emerging technology would become useful in examining the problems associated with structure fire. Corcoran (2009) visually demonstrated relationships between many factors including time of year, temperature and socio-economics in his Queensland case study. Figure 7 shows a visualisation of socioeconomic indicators and a count of fires by suburb (in Sydney). The darker red areas indicates a lower socio-economic status region and correlates with a significantly higher number of fires as compared with other areas. Note – the number of fires is displayed beside the Suburb name.

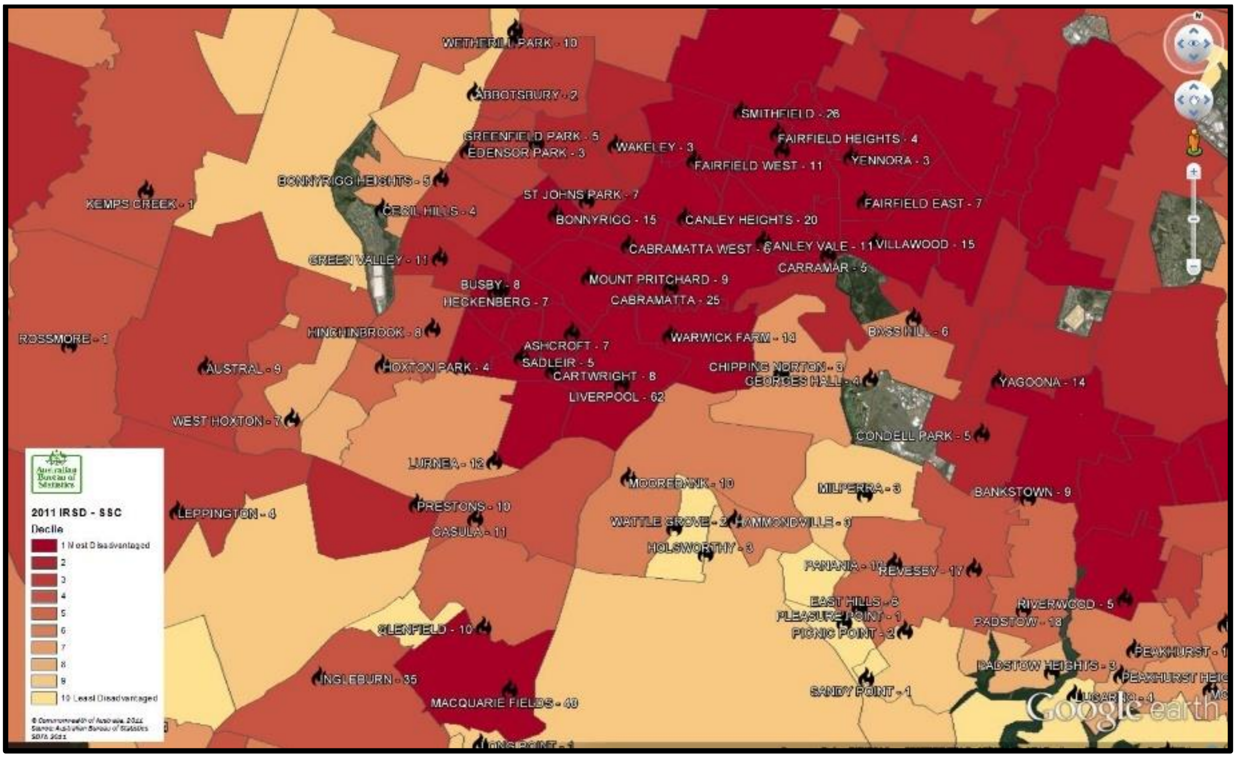


Figure 7: Visualisation of Count of Fires by Suburb and Economic Resources

4.5.4 Twitter Data

Fire & Rescue NSW public twitter feed was also monitored throughout winter 2016 and information on structures fires was collected including suburb, minimum and maximum temperatures and socio economic indicators.

During winter 2016 (June-August) there were 77 fires reported. Although a small dataset, the same trends as data analysed Appendix "A" Table A1 and Table A7, that is the lower three socio economic deciles had a higher portion of structure fires and the fires occurred on days when the temperatures were lower with small changes. The outputs of the analysis are in Appendix "A" Table A8 and A9.

4.6 The Current State of the Art - Five Case Studies

To highlight the disparate research into fire prediction, I have selected, reviewed and summarised five relevant case studies from the academic literature. These five case studies were selected as the best examples of real world outcomes using Information Systems to predict structure fire emergencies. Using Activity Theory, I will highlight the key factor identified in each case that is needed in an Information System to predict structure fire. The case studies reviewed are listed in Table 5.

Table 5: Summary of Case Studies.

Google search engine results	Summary
The Novato Fire District, California	Uses cases for predictive analytics are identified with cultural issues noted as being an inhibitor to change.
The London Fire Brigades, England, United Kingdom	The 2008 Global Financial Crises enabled the London Fire Brigades to redeploy human resources to undertake inspection work of properties that were identified as being high risk through the use of analytics.
South East Queensland, Australia	Analytics are used to determine optimal response times to best service at risk properties.
Fire & Rescue NSW, Australia	Building on the London Fire Brigades experience analytics are used to identify at risk properties to undertake direct education and engagement activities with householders.
Surrey Fire Service, British Columbia, Canada	Data analytics identified 18,473 at risk properties that were visited over a 1-week period by fire fighters that effectively reducing structure fires by 63.9% over a 12-month period.

4.6.1 Case Study 1 – The Novato Fire District, California, United States

In his paper as part of an executive leadership course between 2008-2012, Deputy Fire Chief of the Novato Fire District, Eric Nicol, undertook a detailed analysis of the use of predictive analytics in the military, police, emergency services and the retail sector. In his literature review he identified numerous successes, primarily in the retail, policing and military domains. He cited many interesting examples such as Walmart increasing stock levels of bottled water, non-perishable food and beer in areas where a hurricane impact is predicted, through to Police departments using analytics as their new crime fighting tool to identify crime hot spots and to manage resources to increase presence in these areas with an aim to reduce crime. Nicol's was unable to "…identify failures of predictive analytics in the fire service…" because of a lack of data and research in this area.

Figure 8 provides a summary of the cases examined, noting that there is an equal number of successful outcomes using predictive analytics as to those that failed or had mixed results.

Nicol's makes 19 recommendations focusing on the adoption of a data driven approach using analytics to inform decision making to enable better resource utilising. He identifies an at risk community being people aged over 65 as the first target of the project. He also suggests the establishment of a number forums and groups to address the real issue identified in the paper as being resistance to change due to fundamental long held beliefs by fire fighters about firefighting.

Nicol's paper is well constructed and argues strongly for the use of predictive analytics in a limited way in Novato. His quandary is people management concerning the change, not the technology as he cites proven examples within other domains that indicate a 50% successes rate in outcomes in using analytics to provide insights into how resources can be used more effectively.

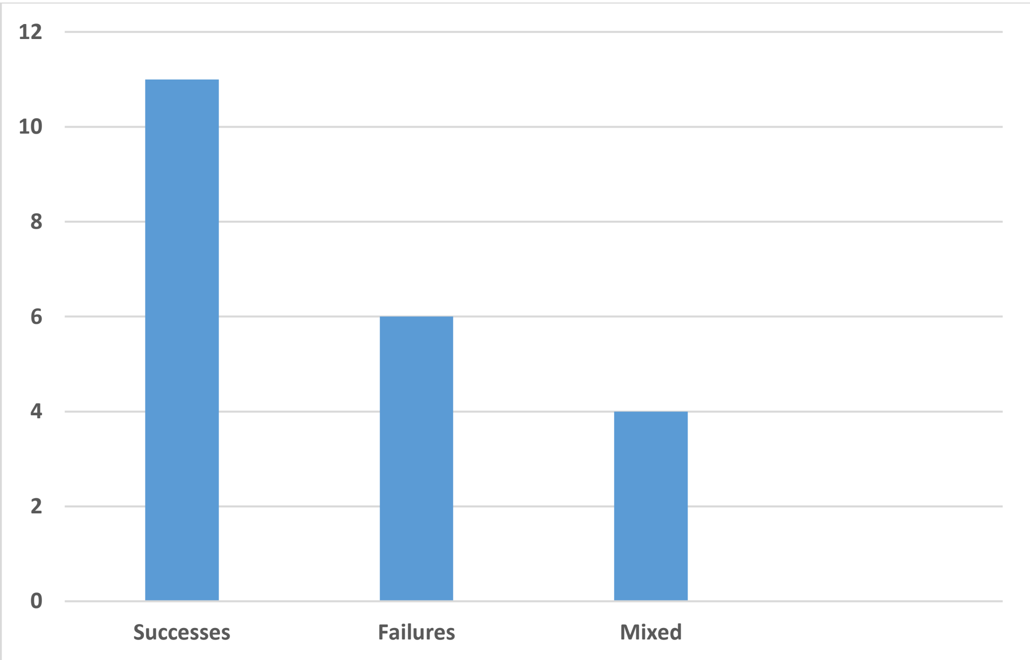


Figure 8: Success and Failures with Agencies using Predictive Analytics (adapted from Nicol)

Using Activity Theory to analyse the work of Nicol, it reveals that the demographic factor of age (subject - elderly) as being more susceptible to structure fire (object) and that analytics (tools) can be used to identify these at risk groups.

4.6.2 Case Study 2 – The London Fire Brigades, England, United Kingdom

A change to the governing legislation of the London Fire Brigades in 2004 presented an opportunity to change the way information was collected on fires along with the modelling that was used to determine optimal response times. Beginning in 2006 surveys of UK based Fire Brigades identified limitations on the current tools used to model response times and how building risk was calculated as to its susceptibility to structure fire.

An analysis identified that it was becoming impossible for fire fighters to undertake all the mandatory inspections that they were required to do as such a risk based approach would be undertaken.

In addition, the Global Financial Crises of 2008 enable a change in working conditions to move fire fighters out from their stations to having them attend and inspect properties that were at a higher risk of structure fire.

To identify the high risk buildings, analytical software provided by SAS was used to undertake regression modelling. A combination of response, census and Mosaic (marketing) data was used to identify the higher risk buildings and then Fire Fighters were directed to undertake inspections of these buildings.

Table 6: Identification of at risk properties using the Mosaic dataset (adapted from London Fire Brigades (2013))

Mosaic Group	Description	Count of Homes	% Home	Count Fires (3yr)	% Fires (3yr)	Count Casualties (3yr)	% Casualties (3yr)
A	Career professionals living in sought after locations	466,617	14	1,871	11	297	9
B	Younger families living in newer homes	83,121	3	299	2	73	2
C	Older families living in suburbia	490,714	15	1,835	11	342	11
D	Close-knit, inner city and manufacturing town communities	497,919	15	2,855	17	509	16
E	Educated, young, single people living in areas of transient populations	919,829	28	4,952	29	872	27
F	People living in social housing with uncertain employment in deprived areas	471,751	14	3,442	20	727	22
G	Low income families living in estate based social housing	23,653	1	124	1	23	1
H	Upwardly mobile families living in homes bought from social landlords	159,562	5	723	4	166	5
I	Older people living in social housing with high care needs	53,774	2	423	2	88	3
J	Independent older people with relatively active lifestyles	105,312	3	586	3	142	4
K	People living in rural areas far from urbanisation	1,319	0	6	0	1	0
Total	**London**	**~3,000,000**	**100**	**17,116**	**100**	**3,240**	**100**

Table 6 provides a summary of the findings published by the London Fire Brigades (2013). The Mosaic dataset segments all household properties into 11 key groups (A-K) which was then geospatially joined to the response data (number of fires and casualties). From this analysis the London Fire Brigades identified Groups F, I and J as the higher risk population groups based on the number of fires and casualties and as such these groups were prioritised for resources for inspections, engagement and education activities.

This activity is innovative in its approach, as it used marketing data to segment the London population. It identified the lower socio-economic and elderly groups as being more at risk of fire. Using Activity Theory to analyse the work of the London Fire Brigades demonstrates that people in lower socio economic groups or an elderly demographic (subject – people) are more susceptible to structure fire (object) and that analytics (tools) can be used to identify these at risk groups. The key factor being the socio economic group.

4.6.3 Case Study 3 – Towards Theory Development - South East Queensland, Australia

In his Australian Case Study, Corocoran (2009) uses weather, socio economic indicators and time of year to explore the instances of structure fires in South East Queensland and proposes a model for fire risk with the hope that the information could be used by fire agencies to reduce risk and better utilise resources to save lives.

Using a large dataset provided by Queensland Fire and Rescue, he aligns fire incidents with weather and Australian Bureau of Statistics Socio-economic Indexes for Areas data to make the following observations:

- Risk is increased in winter because there are more cold days in winter than there is in summer
- Risk increase on school holidays and public holidays
- There is an association between low Socio-economic Indexes for Areas scores and fire risk
- There is no association between rainfall and fire risk
- There is a relationship between low temperature and Socio-economic Indexes for Areas scores and fire risk
- There is an association between risk of fire and extreme temperatures being hot (above 25^{o}C) and cold (below 5^{o}C) days in disadvantaged areas

Building Jennings (1996) unpublished doctoral thesis “Urban residential fires: an empirical analysis of building stock and socioeconomic characteristics for Memphis, Tennessee”, Corcoran proposes a multifaceted model that could be used to predict the instances of fire (Figure 9).

He suggests the model could be used to allocate resources and by used for targeted education programs.

In closing he calls for further research in difference between geographical areas around the world and the understanding of risk such as "…Are all deprived areas during a cold spell on a public holiday affected the same or is there geographical differentiation in fire risk?..." and the utilisation of Geographical Information Systems to visualise the outputs.

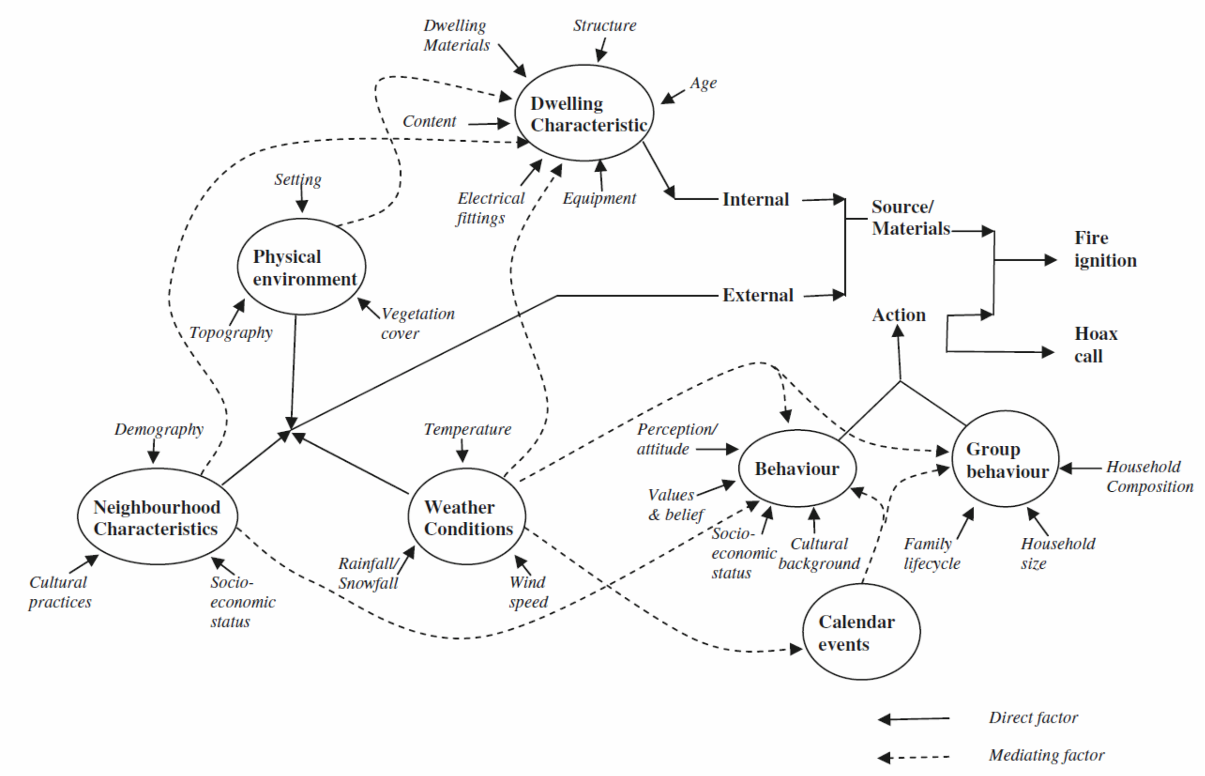


Figure 9: Conceptual model of Fires (Corcoran 2009)

Activity Theory enables the identification of the key factors used in Corcoran model, being a mix of socio economics and demographics (subject – people) and how certain conditions such as weather and the build environment make them more susceptible to structure fire (object) and that his model (tools) can be used to identify these at risk groups. The key factors being the socio economics, demographics and the weather.

4.6.4 Case Study 4 – Fire & Rescue New South Wales, Australia

In 2014 Fire & Rescue NSW implement the Home Fire Safety Check of a pilot program in which an Australian version of the Mosaic dataset (which was used by London Fire Brigades) which grouped households into 1 of 49 different types the Australian Bureau of Statistics census data and other market research datasets.

This dataset was combined with 6 years of in-house response data that identified the lowest socio economic group (K42 in Table 7) as being the highest at risk community from structural fire. Past investigations into structure fires revealed that many of these households did not have working smoke alarms and were not prepared for a house fire.

This project then focused on having fire fighters visit approximately 200 of these households to provide direct community engagement to educate them on fire safety and to provide fire safety devices such as smoke alarms, extinguishers, fire blankets and information sheets.

Tannous et al (2015) in her paper that evaluated the project argues that the project was an overwhelming success as the economic cost of the project would provide an immense benefit when compared to the cost of structure fire in NSW. She identifies that 22% of the housing stock is contained within the top 10 Mosaic (at higher risk) groups.

Table 7: Top 10 Mosaic types by Combined Fire/Injury Index using six (6) years of data (adapted from Tannous et al 2015)

Mosaic Type	Description	No. homes	No. Fires	No. Casualties
K42	Constant Struggle	29,032	517	98
M49	Armchair Blues	50,154	840	173
H32	Multicultural Mix	42,285	374	88
I35	University Diversity	63,358	563	87
H31	Extended Ethnicities	124,991	838	181
M47	Assisted Elders	73,927	595	98
G27	Suburban Backbone	67,902	388	90
H30	Cultural Fusion	48,975	307	64
J37	Aussie Grit	44,263	223	54
G28	Local Focus	76,910	498	95
	Total	**621,797**	**5,143**	**1028**

Furthermore, she argues that savings of between $1.13 and $11.36 could be achieved for every dollar spent on these activities to reduce the $336,409,157 spend on structural house fire response activities each year.

This project is the based on work already undertaken in London and Amsterdam. It is innovative in the Australian context and was recognised as such in 2015 by the Australasian Fire and Emergency Services Authorities Council.

A significant gap not discussed in the paper is that is cost $691,396,000 (NSW Government Budget Estimates 2016-17) to operate the service in totality which includes other services such as rescue, hazardous materials and other (non-house) structural firefighting.

This case study demonstrates through Activity Theory lower socio economics groups (subject – people) are more susceptible to structure fire (object) and that this basic model (tools) was used to identify and engage with at risk groups. The key factor being socio economics.

4.6.5 Case Study 5 – Reducing Structure Fires through risk identification and Engagement, British Columbia, Canada

In 2008, the Surrey Fire Services (British Columbia, Canada) identified, visited and inspected 18,473 dwellings, representing 13.8% of the housing stock in the city of Surrey. Fire fighters visited these homes over a 1-week period and delivered fire safety messages, equipment and inspected the households to provide advice. The activity effectively reduced the instances of structure fire over a 12-month period by 63.9%. (Clare et al. 2012).

Risk dwellings that were visited were selected based on a study of over 20 years of fire data by the University of Fraser Valley. The Fire Chief of Surrey Fire Services instructed all his on duty fire fighters to stop all other activities and conduct the visits over a 1-week period enabling the engagement to occur.

These results are truly outstanding and demonstrate what can be achieved through the use of analytics and engagement do prevent fire disasters, save lives and reduce impacts.

This simple yet powerful case study demonstrates that Activity Theory enables the identification of at risk communities in the lower socio economic groups (subject – people) that are more susceptible to structure fire (object) and that an analysis (tools) followed up by proactive engagement reduced structure fires significantly.

4.6.6 Summary of Case Studies

Using the Engestrom Activity System [Section 3.2 Figure 3] was extended (see Figure 10) to analyse the five (5) case studies with Table 6 providing a summary of each using the Activity Theory Lens.

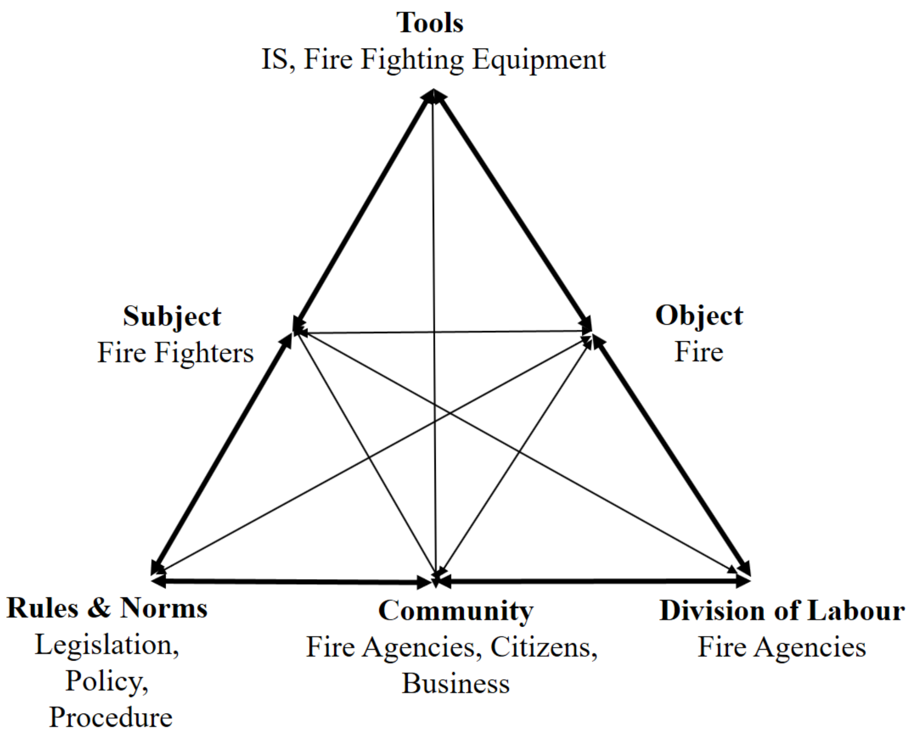


Figure 10 - The Engestrom Activity System of a Fire Prediction Framework

4.7 Review of Case Studies

The analysis of the journals identified in Table 1 reveals that little work has been undertaken in the application of predictive analytics as a tool to reduce the risk of structural fires. Sporadic, disparate work has been undertaken in an ad-hoc manner with little coordination of effort. The few peer reviewed journal papers in the domain of predictive analytics in structure (house) firefighting (see Table 1) demonstrates a gap in the body of knowledge.

The case studies selected (see Table 5) as exemplars of practitioner, industry and academic based use of predictive analytics being considered, piloted or used in fire agencies to identify at risk communities provide grounds for further research.

The literature appears to be published in a variety of journals not necessarily related to the fire domain. For example, Corcoran's (2009) work is published in a Geospatial Journal. The lack of coordination as identified by Jennings in his publications (1999 and 2013) and the volumes of unpublished works cited in the reference s is a cause for concern but demonstrates a clear opportunity for research in the domain of predictive analytics in structure fire emergencies.

Table 8: Review Case Studies Using Activity Theory

Activity Theory Components	Case Study 1 Novato	Case Study 2 London	Case Study 3 Australia	Case Study 4 Australia	Case Study 5 Canada
Tools	Predictive Analytics	Risk Analysis	Risk Analysis	GIS, Risk Analysis	Risk Analysis
Subject	Eric Nicol, Deputy Fire Chief	London Fire Brigades	Fire & Rescue NSW	Queensland fire and rescue	Surrey British Columbia
Object	Identify application of analytics	High risk communitie s	High risk communitie s	High risk communitie s, resource utilisation	High risk communitie s
Outcomes	Reduce fires, 19 recommend ations	Directed inspections of high risk buildings	Engagement with high risk communitie s	Develop a risk model	Reduce structure fires
Rules & Norms	Manage resources to manage demand for fire services	Risks derived from MOSAIC marketing dataset	Risks derived from MOSAIC marketing dataset	Risk derived past data, weather, time, calendar events and socio economic indicators	Risk identified from University study
Community	Citizens of Novato, CA.USA	London Citizens at risk of fire	NSW Citizens at risk of fire	Citizens of South East Queensland	Citizens of Surrey British Columbia
Labours	Public safety, military, and the retail sector	Fire Agencies	Fire Agencies	N/A	Fire Fighters
Research Domain	Emergency Managemen t	Emergency Managemen t Risk Managemen t	Emergency Managemen t Risk Managemen t	Geographic al Information Systems	Emergency Managemen t Risk Managemen t
Journal Name	Not Published	Not Published	Not Published	Journal of Geographic Systems	Journal of Safety Research

In Figure 8 Nicol identified a 50% success versus a 50% failure/mixed result rate in the use of predictive analytics across the military, police, emergency services and the retail sectors. There are two important insights noted by Nicol. The first revealed in the Walmart example, where an analysis of sales data identifies that weather (a hurricane forecast) drives human behaviour to purchase specific types of goods. Now, when a hurricane forecast is issued, Walmart uses the information to stock stores in advance to satisfy the increased demand for these goods (eg canned food, water and beer).The second being that firefighters are unlikely to accept the use of predictive analytics as a tool to inform a risk based approach to structure firefighting due to long held beliefs and an aversion to change.

The London Fire Brigades used a mashup of marketing and response data (see Table 4) to identify its top three as risk communities. Austerity measures implemented by the government enabled the resistance to change identified by Nicol to be overcome and have firefighters engage with the at risk communities.

In the case of Fire & Rescue NSW, the experience of the London Fire Brigades was used to undertake a pilot program that enable the identification of at risk communities (see Table 5). The evaluation of the pilot revealed potential savings, but did not consider the full costs of operating the Services.

In all these cases for structure fire risk the use of dynamic data such as weather information (used by Walmart), social media or resource location were considered. These data in addition to those being used could be used to pre-position appliances, warn communities or match resources to anticipated demand. In other words, in certain types of weather conditions available resources could be prepositioned closer to communities that were at a higher risk. In doing so the time to respond to a structure fire would be reduced which would reduce damage to property, injuries or loss of life.

4.8 Chapter Summary

In this chapter I have analysed a smaller dataset of main structural fire dataset using suburbs and post code information that has been aligned to socio economics and weather data. The resulting trends in data answers Research Question 1 by demonstrating that there are more instances of structure fires:

- In lower socio-economic areas;
- On cold days when there is a small temperature differential (increase);
- During late Autumn, Winter and early spring; and
- In the late afternoon and early evening.

I have also noted (in Section 4.1) the increasing costs of operating fire service over a 10-year period whilst the number of responses remain relatively the same.

The analysis of the data clearly aligns with the Activity Theory Framework described in Figure 10 – firefighters (Subject) could use Information Systems (Tools) to prevent future instances of fires (Object).

It is important to note that, firstly, in relation to Research Question 1, further research into these trends would be significant, specifically using a larger dataset to develop a predictive model.

Secondly, in relation to Research Question 2, it is self-evident that the development of an Information System is required to further study the relationships between the identified factors and which can then be used predict structure fires. Using an Activity Theory lens the output available to emergency managers could to use in making decisions on resource deployments and community engagement activities.

Chapter 5 - Discussion

5.1 Introduction

The literature and five (5) case studies reviews identify a gap in the development of tested concepts and frameworks beyond the current practices of researchers and practitioners. This can help to explain why common failures re-occur again and again within this domain, despite commitments to change with effort being focused on the Response phase of the Comprehensive Emergency Management Framework.

It appears that this domain is worthy of further research. However, there are a number of significant obstacles that will need to be overcome in the structure firefighting domain to progress the use of predictive analytics.

5.1.1 Relationships between factors

The small number of factors examined in this paper that appear to contribute to instances of structure fire demonstrate a complex relationship (Benbya and McKelvey 2006; Simon and Cilliers 2005).

Analysis using typical tools such as correlation and regression provide results however because none of the factors are typically linear further analysis and visualisation was undertaken using decision trees and neural networks. Both of which demonstrated the complexities within the data.

Visually relationship can be observed in the Tables and Figures, however mathematically much further work is required to explain these relationships in order to develop a model that could be used within an Information system to predict future instances of structure fire.

5.1.2 Response as the paradigm

The current approach in dealing with a structure fire is to wait until it starts, then alert a Public Safety Agency, usually via phone, they then respond as quickly as possible to the location of the fire under lights and sirens travelling with all due haste to hopefully extinguish it before there is loss of life, injury or significant damage to property or the environment.

As mentioned before this is no different to the bucket brigades from centuries ago, even the current practice of smoke alarms – still wait for the fire to start than respond.

The issue being that there is an entrenched culture that focuses on response within firefighting organisations (Nicol) and any suggestion of changing the way firefighting may be managed, particularly by using Information Systems is likely to be met with great scepticism.

5.1.3 Engagement

Traditionally fire safety engagement and education activities have tended to focus on communities that were not at the higher risk levels (K42 in Table 5) being the lower socio-economic groups.

It is postulated that Fire Fighters are not trained on how to deal with citizens from this lower socio-economic demographic group and as such less engagement occurs. Thus, this lesser engagement and education may be a factor that contributes to the over representation of fires (see Table 5) in this group.

5.1.4 Cost Benefit Analysis

The actual cost of fire response activities is not well understood or documented. In order for predictive analytics to be embraced researchers need to determine the potential savings a triple bottom line financial model covering people economics and the environment is required.

5.1.5 Proposed Change

A study undertaken by <author> (2012) of emergency services from Australia and around the world on technology adoption identified that acceptance of, and changing to new forms of technology would be at least 4 years behind mainstream adoption. The author identified that this was due to the conservative, risk averse leadership of emergency management organisations.

This coupled with a highly unionised workforce would make changes to new technology difficult. A further study undertaken by <author> (2010) identified ways in which a Public Safety Agency could implement technology change more effectively through proactive engagement of stakeholders and end users has seen few developments in the speed of change in this domain.

This research could be extended to consider modification of the Comprehensive Emergency Management Framework by adding an additional component of Prediction as a new major element of a component embedded within the existing framework.

5.2 Proposed Predictive Framework for Structure Fire

Based on the literature review, case studies and data analysis in Chapter 4, I propose a high level framework shown in Figure 12. This proposed framework includes static information such as socio-economic and demographic information, base geospatial information, plus more dynamic information including marketing data, weather forecasts, social events (public holidays, football Grand Finals), past information on fires and pre incident plans utilising the work undertaken here and by Corcoran in 2009.

Using an Information System based on the Framework described in Figure 12, Public Safety Agencies would be able to place more resources on stand-by where they may be needed, relocated resources to locations to enable a quicker responses and to optimize overall human and material resources to obtain the best economic payback for the community in saving life, property, economic and environmental damage.

Information such as geo-spatial data, socio economic and demographic indicators, consumer purchasing data, marketing data, social media, past history, of fire incidents could be used to create risk profiles that identify areas of higher than average risk.

It would then be possible to combine these static risk profiles with dynamic data such as weather forecasts creating a framework for dynamic predictive analytics. This would enable at least seven days advanced notice on areas that are at a higher level of risk.

The frameworks could then be extended to provide best case, likely case and extremely chaotic (also known as black swan) scenarios with estimates provided for each that considers a triple bottom line encompassing potential loss of life or injury, damage to property, economic and environmental impact. The data suggests that a particular set of conditions (cool days with small temperature increases across the day) act as an initial trigger for structure fire. Combined with factors such as socio economic indicators, historical incident response, planning and build environment data the outputs from such an Information System could be used in multiple ways by providing base line data feeds tailored for different audiences. The proposed framework is at Figure 11.

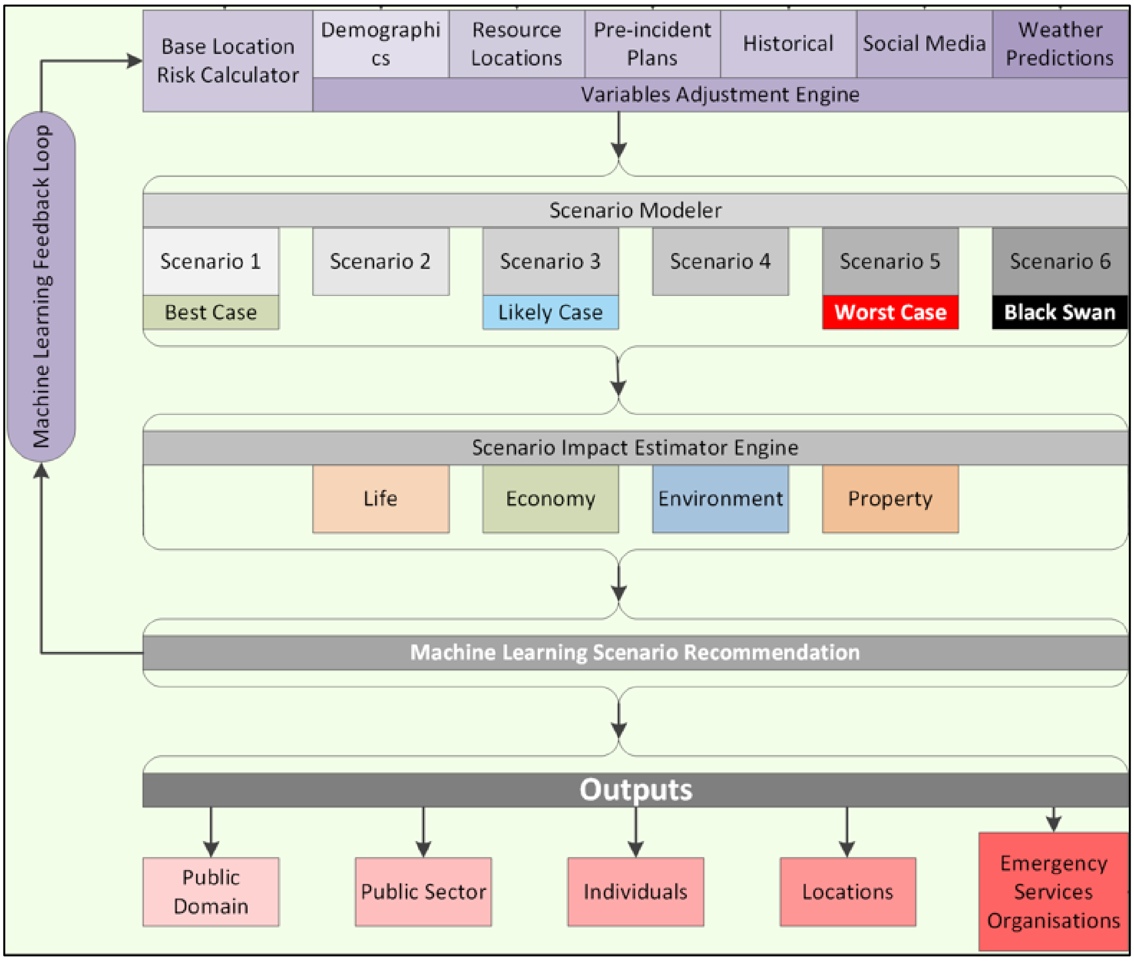


Figure 11: Proposed Information System Framework to Predict Structure Fire Risk

5.2.1 Inputs

Based on the proposed framework the data inputs into the Information System would include a range of dynamic data feeds being primarily weather forecasts. This information would include forecasts for temperature minimum and maximum which is supported by the results in Appendix "A" Table 2. Static spatially enabled data would also inform the Information System including socio-economic indictors and historical events – including past fires and date specific events such as winter which is supported by the results in Appendix "A" Table 3. As the Information System is expanded social media and key resource (human and fire appliances) location based information could be included to provide a user with options around deploying resources. All this static and dynamic information would inform fire fighting management for decision-making.

5.2.2 Scenario Modeller

Analysis of models to predict structure fire was undertaken by Jennings (1999, 2013). It is proposed to use a variety of models in which to forecast best case, worst case and black swan outcomes. Sensitivity analysis within the engine through slight changes in the variables would enable creation of the different scenarios. These six possible scenarios would then be passed to the Scenario Impact Engine (see Figure 11).

5.2.3 Scenario Impact (Estimator Engine)

For each of the six outcome passed from the Scenario Modeller, the Scenario Impact Engine is will consider and calculate outcomes across a triple bottom line including people, planet and profits (or life, economy, environment and property).

The aim is to provide a tangible financial model that could be incorporated into decision making.

The outcomes from each model would then be passed to a machine learning loop to review all proposed models and provide a recommended outcome.

5.2.4 Machine Learning (Recommendation and Loop)

A machine learning loop would encapsulate the entire Information System, initially used to learn how humans are interpreting data outputs and making decisions and once trained it would be used to provide a recommendation.

The machine learning loop would compare its predictions, based on forecast information to what happens in reality (asking itself did the weather forecast provide a valid prediction?) to refine its recommendations and improve the quality of the predictions.

Note - A human would always need to interpret results from the forecast and make decisions on what to do - such as proactive engagement with a community or resource deployment.

5.2.5 Outputs

In addition to the recommendation from the machine learning loop, the six scenarios across best case to black swan (worst case) would be presented. Information could be published not just for the emergency service organisation but also the public sector, individuals and the private sector or not for profit organisation.

It is envisaged that this predictive output could be very similar to a weather forecast that is a weather forecasting organisation will run a variety of weather models using the parameters that are available. The outputs will be interpreted by a human who will make a decision on the most likely outcome and that model will be the published weather forecast. Outputs would primarily be visual in nature to enable ease of interoperation and understanding. Eventually a machine learning algorithm could augment future decision making.

5.3 Chapter Summary

In this chapter I have proposed a framework (see Figure 11) by identifying the existence of trends and relationships between the factors of weather, socio economics, time of day and time of year of instances of structure fire. These relationships are complex and further work is likely to be required.

I have demonstrated that costs have increase above inflation whilst the same level of responses have been maintained (Figure 4), a classic case of the economics law of diminishing returns.

There has been much disparate research proposing models over the recent decades, Figure 9 (Corcoran 2009) being the most recent with little research being taken up within the domain of structure firefighting. A gap in Corcoran's model is the use of weather forecast information to enable proactive real time and advanced (prediction) identification of risk.

A key challenge will be engaging with firefighting organisations and convincing them of the value of Information Systems to inform future risk in the structure firefighting domain so they can take proactive action and prevent the incident from occurring in the first place.

5.3.1 A Case for Dynamic Predictive Analytics

The five (5) case studies identify early use cases for predictive analytics in the firefighting domain. These have mainly been as a result to improve response times or to create efficiencies in engagement activities. A research gap exists in all cases as it was static data was used the studies.

In summary the proposed framework uses of both static and dynamic real time data to continuously assess risk across likely (and unlikely) scenarios taking into consideration cost associated with impacts on life, property, the economy and environment to present options to a senior fire fighter manager that can use the information to make informed decisions about resource deployment.

5.3.2 A proposed Framework

This research supported the notion that an Information Systems, (as detailed in Figure 11) could be used to forecast in circumstance where structure fire is likely to occur which would greatly enhance societies ability to prepare for and respond to these emergencies.

This is a very complex problem that requires far more analysis and research however the potential to save lives, reduce costs and damage is likely to be significant if successful.

It is proposed that any models used in such a system would use pattern recognition systems, and produce outputs much the same as a weather forecast. This information could then be used by governments, the private and third sector and communities to undertake immediate preparatory measures is at a high risk of structure fire and to build resilient communities.

Chapter 6 –Conclusion, Reflection and Future Direction

6.1 Conclusion

Structure fires are a terrible disaster that can impact anyone. I have examined this rare but deadly phenomenon with the aim of answering the two following questions:

1. What relationships and trends can be found in structural fire response data?

2. How can an Information System inform the prediction of structural fire?

In this thesis I have identified that there has been disparate, uncoordinated and unpublished research into identification of trends in data concerning structure firefighting. I have answered Research Questions 1 by the analysis undertaken in Chapter 4, but specifically with the results in Appendix “A” Table A2, Table A3 and Table A8 which show the strongest trends between the instances of structure fire, socio economics, time of year, time of day and weather conditions.

A further examination of five (5) case studies provided practical examples of the use of Information Systems to identify at risk communities. It is a logical extension to conclude that and Information System could be used to predict structure fire. This question will become the focus of further research and a PhD.

The development of an Information System framework as described in Section 5.2 and Figure 11 would be useful in predicting where structure fire is likely to occur in the future and as such has enabled me to answer Research Question 2

6.1.1 Practical Implications

Building on the disparate and uncoordinated work that has previously been undertaken, I have confirmed that there are trends in the collected data that can identify where there is a higher probability of a structure fire occurring. This will most likely occur on days of:

- low (morning) temperatures,
- with small temperature differentials (<10 degrees),
- in lower socio-economic areas,
- during the late autumn, winter and early spring, and
- during late afternoon and early evening.

This information, much of which is intrinsically known by firefighters, once constructed into an Information System could be used to inform decision making to improve community safety through a number of avenues – by using weather forecasts, predictions of at risk communities could be made up to one week in advance. This would enable agencies to proactively engage with and educate at risk communities. Warnings to at risk communities could also be provide to these communities.

This does not mean however that we don't need firefighters ready to response, as a toolset this could be used by firefighters to better use their resources to keep us safe. Further research into these trends using a larger dataset to develop the Information System would be a worthwhile activity.

6.1.2 Potential Ethical Implications

The construction of such an Information System will give rise ethical considerations. Knowing that one area is at higher risk than another and not taking any action could be deemed to be an issue.

Presently all levels of government are in possession of information that identifies at risk communities, properties and individuals across a variety of domain in which it has an option to do something or nothing. This is not solely in the emergency and disaster management domain.

I would argue that this is not the subject of this paper but needs to be acknowledge and could be considered as another avenue of future research – ethical decision making across the comprehensive emergency management framework.

6.2 Reflection

The development of an Information System that enabled the future prediction of structure fire would be a powerful tool that could assist in creating a safer society,

Public Sector

Improved - Response to areas that are identified as being at higher risk as changes in weather conditions occur. This would enable resources to be relocated more closely to where a fire emergency is more likely to occur.

Improved - Prevention by identifying areas which are likely to be a risk and conducting high visibility education campaigns. In addition, targeted warning and safety messages could be provided to specific at risk communities.

Better - Understanding of costs by resourcing what is needed and where. Or geospatial areas that need intervention in the form of economic investment to raise awareness to reduce risk.

Private Sector

Base data feeds could be refined and value added to by commercial enterprises and on sold to clients in much the same way that private weather providers consume data from government weather departments and remodel and sell tailored information to clients e.g., mining industry

Insurance agencies could identify at risk communities outside their client base and contribute to building capacity in these communities that are unable to afford insurance through corporate/community social responsibility programs

Public Domain, Individual and the Third (Not For Profit) Sector

Could subscribe to data feeds and proactively engage with at risk communities in advance of a potential emergency in an attempt to prevent it from occurring in the first place. For instance, faith and community based aid agencies could engage with a community and provide blankets and safe mechanisms of heating households, migrant resource centres could train new immigrants on how to cook in a western house, engage with students at public and private colleges to teach about safe heating and cooking methods.

6.3 Future Direction

Structural fires are rarely occurring phenomenon that have a devastating impact on those impacted by it. Firefighting principles have generally remained unchanged for centuries.

A literature review has identified a significant gap in the use of analytics to inform decision making in this domain. Five practitioners based case studies from the United Kingdom, Europe, United States, Canada and Australia has shown how analytics could be used to identify at risk communities.

Predictive Analytics is a common used tool in many industries that may have application in the disaster and emergency management domain. The current literature has highlighted that there has been little uptake or change in the structure firefighting domain which was identified as a major obstacle in implementing a risk based predictive analytics toolset. This likely due to entrenched cultural beliefs held by fire fighters with a focus on responding to emergencies. Different components of each case study revealed opportunities in the development of a holistic framework that could be used to identify at risk communities.

I am proposing the concept of Dynamic Predictive Analytics that is the use of real time data, such as weather forecasts being used as an input into models that calculate risk across multiple scenarios to enable Public Safety Agencies to make informed decision on future resource deployments and education and engagement activates for those most at risk of structural fire.

Australia wide data of fire emergencies is being made available by the Chief Executive Officer of the Australasian Fire and Emergency Services Authorities Council and Professor Corcoran and Dr Jennings have been contact concerning their theoretical models which will be used as a basis to commence the next step in this project being further research for my PhD which will include the construction of the Information System.

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Appendix A Tables

Table A1: Research Plan

Year	Months	Milestone & Deliverables	Tasks
2016	February	• Research Problem Definition	• Weekly meeting with supervisor • Study of the related papers
	March	• Identification and study of the related papers	• Weekly meeting with supervisor • Study of the related papers • Attend induction and class
	April	Submit: • Literature Review Outline • Research Plan • Research Plan & Methods Presentation • Ethics Approval • Application to access AFAC data	• Weekly meeting with supervisor • Attend class • Study of the related papers • Arrange interviews • Download, install and commence learning SAS • Consider option of using R
	May	• Deliver Presentation on Research Plan & Methods • Outline of Research Frontiers 2 Report • Prediction model development	• Weekly meeting with supervisor • Attend class • Study of the related papers • Work on Literature review • Undertake interviews • Commence data analysis
	June	• Data analysis Submit: • Literature Review • Progress Report	• Weekly meeting with supervisor • Literature review completion • Commence thesis writing • Work on Research Frontiers 2 Report
	July	• Thesis	• Weekly meeting with supervisor • Thesis writing • Work on Research Frontiers 2 Report
	August	• Research Frontiers 2 Report Submission??	• Weekly meeting with supervisor • Complete Research Frontiers 2 Report?? • Thesis writing
	September	• Thesis submission to Supervisor for review	• Weekly meeting with supervisor • Thesis finalisation • Submission to Supervisor for review
	October	• Thesis Submission	• Weekly meeting with supervisor • Update thesis report according to the supervisor's feedback
	November	• Final PhD research Plan	• Weekly meeting with supervisor • Discussion about PhD research plan with the supervisor • PhD research plan submission

Table A2: Number of Fires compared to Daily Minimum Temperature and Temperature Change

Count of Fires - Daily Minimum Temperature vs Temperature Differential

Daily Minimum Temperature (°C)

Daily Temperature Differential (Max - Min °C)	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Total
0									4														5						9
1															3	5	6	9	2	5	3		1		1				35
2														7	2	8			10	7	7	29	7						77
3													4		2	9	1	10	13	17	11	17	13	2	4	2			105
4										4	3	4	19	4	13	11		14	10	33	32	31	31	20	5	1		2	237
5										2	14	29	6	11	15	26	21	28	23	45	30	32	24	12	9		1		328
6										2	40	20	35	19	32	20	23	38	31	26	31	31	32	25	14	3			422
7								1	9	42	23	53	30	37	33	32	47	25	33	50	65	39	46	36	9		1		611
8									12	9	40	29	60	41	52	34	43	40	28	77	60	61	23	11	4	3	2		629
9							6	11	17	39	67	45	66	37	50	48	49	58	54	39	63	25	22	11		3	4		714
10							2	13	14	18	42	45	69	60	49	30	53	39	55	49	33	24	2	2	4	11	3		617
11						1	10	33	30	62	44	65	46	62	30	35	41	22	20	19	22	20	27	13	13				615
12						13	8	42	29	64	73	44	40	17	53	15	25	18	25	21	18	20	16	2	10	3			556
13					1	14	26	22	14	32	15	36	25	30	27	24	37	28	17	8	15	15	3						389
14					4	19	27	22	33	28	18	20	10	34	14	8	40	27	23	20	6	23	8	3	4	1			392
15				4	23	21	25	20	15	29	19	21	16	17	22	21	15	6	13	9	12	7	10	5		3			333
16			1	11	29	19	9	25	13	19	14	9	11	16	7	8	16	19	4	6	8	7	6	1					258
17		5	9	12	15	13	29	9	21	13	13	14	7	22	8	5	15	14	4	12					2				242
18		1	6	3	11	7	21	5	12	10	12	7	6	8	14	6	1	9	2	4	7	8	2	5					167
19		8	1	6	25	6	9	8	8	7	6	4	12	10	5	10		9	6	5			3						148
20		2	9	6	10	4	3	9	7	3	6		1	9	7	1	2	2	2	2	2								87
21		2	3	1	8	4	12	6	1	1	4	6	2	2	1	9	14	2	1				3	1					83
22		1		4		3	3	3	1	3		1	5	3	1	6	3	1	4		3								45
23			1	4				1	2			3	5	5		2					1								24
24				4			1		6	1	4	3	5		4	4		2			2		4						40
25	2						2	2		5			1	2					3	2									19
26					1			1			1	1		1										2					7
27				2				2			3										2		1						10
Total	2	19	30	57	127	124	193	235	248	393	461	459	481	454	444	377	452	420	383	456	433	389	289	151	79	30	11	2	7199

Table A3: Number of Fires – Time of Day by Month

Count of Fires - Time of Day vs Month

Hour of Day

Month	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Total
January	21	22	14	14	5	14	8	12	11	23	25	29	32	21	27	38	32	25	43	41	35	36	32	31	591
February	13	14	6	12	9	9	4	12	12	23	15	21	22	36	21	26	26	35	40	33	26	28	19	21	483
March	16	13	21	12	12	4	14	14	11	22	19	30	33	20	24	28	32	38	35	37	30	25	29	32	551
April	18	21	9	10	14	8	8	10	16	26	33	43	34	37	31	27	33	48	43	27	40	25	19	23	603
May	18	19	12	19	19	14	7	16	19	26	31	31	20	40	32	36	36	61	58	55	45	34	22	23	693
June	21	16	10	10	13	10	10	19	19	20	28	41	35	39	52	23	44	56	51	50	36	26	26	25	680
July	20	19	13	22	8	9	18	18	27	20	26	30	35	31	39	42	36	49	62	51	43	31	22	14	685
August	21	15	12	16	14	13	11	15	29	18	25	34	40	34	33	29	32	59	57	57	39	37	23	29	692
September	22	10	11	11	11	13	10	16	28	18	24	20	23	42	34	34	32	49	48	40	47	42	26	27	638
October	12	11	14	15	6	15	8	12	12	36	28	14	33	24	34	30	34	36	50	43	42	33	22	33	597
November	15	22	11	11	9	7	12	5	18	17	15	18	33	25	28	32	24	27	24	41	25	31	21	8	479
December	17	8	15	9	7	13	8	6	13	19	19	29	39	29	27	30	26	28	38	38	36	13	18	22	507
Total	214	190	148	161	127	129	118	155	215	268	288	340	379	378	382	375	387	511	549	513	444	361	279	288	7199

Table A4: Correlation Analysis – Fires and Socio-economic indicators

	Count of Fires	*Socio-economic Disadvantage*	*Economic Resources*	*Education and Occupation*	*Population*	*Fire per 1000 people*
Count of Fires	1.0000					
Socio-economic Disadvantage	-0.1833	1.0000				
Economic Resources	-0.3287	0.8465	1.0000			
Education and Occupation	-0.0232	0.8342	0.5550	1.0000		
Population	0.4344	0.0157	-0.0529	0.0793	1.0000	
Fire per 1000 people	0.0926	-0.1067	-0.1354	-0.0636	-0.1205	1.0000

Table A5: Regression Statistics

Regression Statistics	
Multiple R	0.9100
R Square	0.8280
Adjusted R Square	0.8065
Standard Error	237.9219
Observations	10.0000

Table A6: Analysis of Variance

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	2180222	2180222	38.515	0.000
Residual	8	452855	56607		
Total	9	2633077			

Table A7: Regression Coefficients

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	1614	162.532	9.930	0.000	1239.201	1988.799	1239.201	1988.799
Index of Resources	-163	26.194	-6.206	0.000	-222.968	-102.159	-222.968	-102.159

Table A8: Count of Fires – Daily Minimum Temperature and Economic Resources

Count of Fires - Daily Minimum Temperature vs Economic resources

Daily Minimum Temperature

Economic Resources

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	**Total**
1		11	15	22	63	81	106	134	146	177	137	136	121	96	115	76	60	57	39	43	27	18	13	8	11	7	2	3	**1724**
2	2	3	15	23	38	82	83	114	143	137	120	127	123	80	75	63	58	57	47	37	17	16	10	5	3	5	2	4	**1489**
3	3	9	11	16	32	42	63	100	80	103	114	99	80	56	53	49	35	38	29	15	7	12	8	6	5	1	1	2	**1069**
4	1	5	10	7	28	39	42	66	64	89	78	72	62	45	55	33	29	21	18	13	9	13	2	3	7	3			**814**
5	1	3	11	10	27	26	43	53	52	53	44	42	44	23	25	30	21	16	10	15	7	1	1		3	1			**562**
6			1	9	10	9	27	46	43	44	37	35	32	32	22	25	19	7	5	8	9	6	4				1	1	**432**
7	1	3	4	5	8	9	9	16	29	26	18	26	22	12	11	15	5	11	6	2	5	2			1	1			**247**
8			4	1	7	13	10	20	14	26	21	22	11	13	7	13	7	6	3	3	1	1	1		3				**207**
9	1	1	3	7	12	14	19	28	29	33	26	25	26	13	12	17	12	13	6	6	2	8	3		1	1	1		**319**
10			3	5	12	13	20	34	29	26	22	31	35	19	17	12	12	16	4	6	3	6	3	2	6				**336**
Total	**9**	**35**	**77**	**105**	**237**	**328**	**422**	**611**	**629**	**714**	**617**	**615**	**556**	**389**	**392**	**333**	**258**	**242**	**167**	**148**	**87**	**83**	**45**	**24**	**40**	**19**	**7**	**10**	**7199**

Table A9: Winter 2016 - Number of Fires compared to Daily Minimum Temperature and Temperature Change

Count of Fires - Daily Minimum Temperature vs Temperature Differential (Twitter Analysis Winter 2016)

Daily Minimum Temperature (^{o}C)

Daily Temperature Differential (Max-Min ^{o}C)	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
2													1		1
3								3							3
4					1	1				1	2		1		6
5											1				1
6				2			2	2		1				1	8
7						1			2	1		1			5
8					2	1	1	1	1						6
9		1			1	1	1	2		3					9
10							1	4	4						9
11			1	1	2	1									5
12		1		3	1			4							9
13		1	1	2	1										5
14		2			1	2									5
15	1	2	1			1									5
Total	**1**	**7**	**3**	**8**	**9**	**8**	**5**	**16**	**7**	**6**	**3**	**1**	**2**	**1**	**77**

Table A10: Winter 2016 - Count of Fires – Daily Minimum Temperature and Economic Resources

Count of Fires - Daily Minimum Temperature vs Economic resources (Twitter Analysis Winter 2016)

Daily Minimum Temperature (^{o}C)

Economic Resources	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
1					2	2	1	2	1	1	1	3			13
2			2	1	1	1	1	2	3	2	3	1		1	18
3	1		1			1	2	2		1	1		1	4	14
4			1		1		1	2	3						8
5		1			1		1		2				1		6
6			1		1					1			1		4
7												1			1
8			1		1						1				3
9		1			1						2				4
10		1				1		1			1		2		6
Total	**1**	**3**	**6**	**1**	**8**	**5**	**6**	**9**	**9**	**5**	**9**	**5**	**5**	**5**	**77**

Appendix B Figures

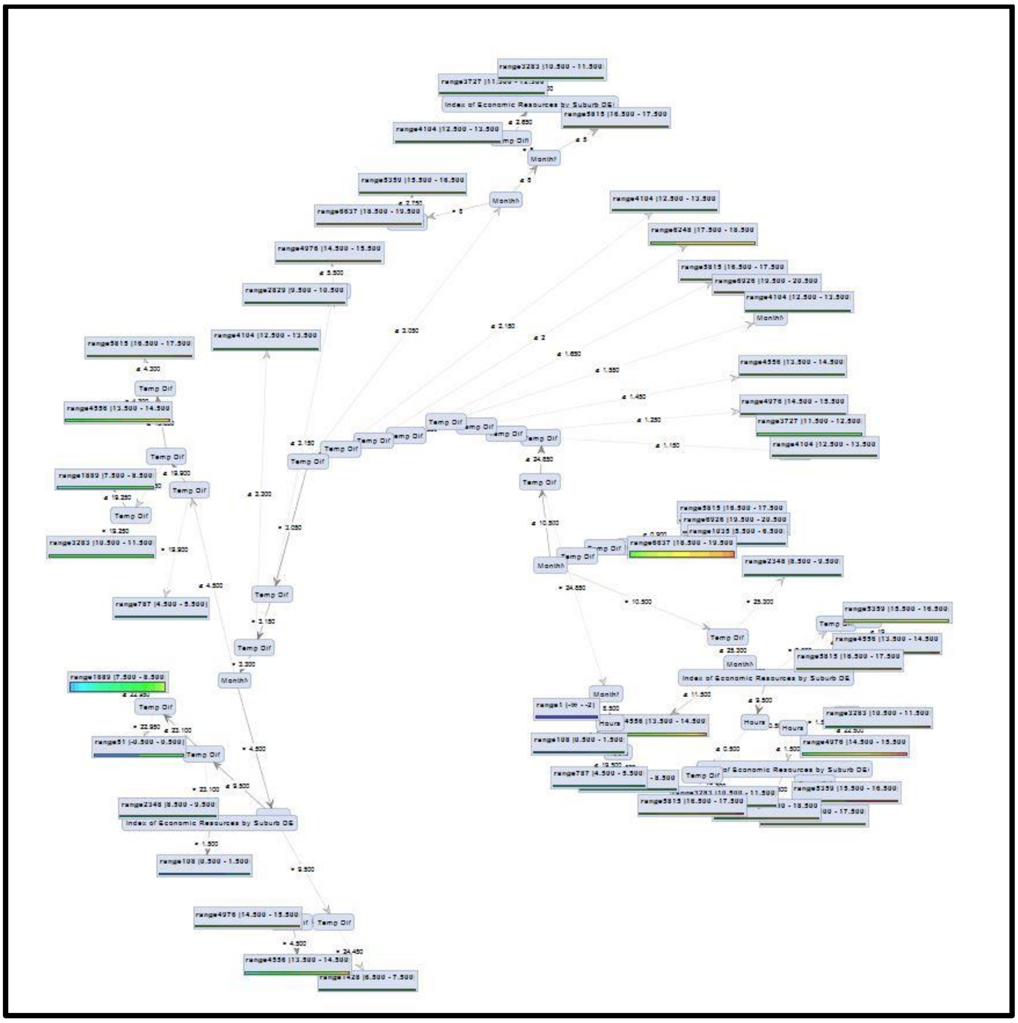

Figure B1: Output of Decision Tree