NEW ZEALAND FIRE SERVICE COMMISSION
Whakaratonga Iwi

Fire Research Report

Scenario Tool for Allocating Resources (STAR)

Navigatus Consulting

July 2015

For this research project, Navigatus Consulting developed and piloted a Scenario Tool for Allocating Resources (STAR). The purpose of STAR is to enable Rural Fire Authority decision-makers to make more informed and strategic decisions on the allocation of firefighting equipment within their district and reduce the time taken for adequate initial response to arrive to vegetation fire events.

Navigatus developed the initial version of STAR to be piloted in the Marlborough/Kaikoura Rural Fire District and consulted extensively with the Marlborough/Kaikoura Rural Fire Authority while building and modifying the tool.

STAR works by using a Monte Carlo based simulation to model a distribution of fires across the district and record expected outcomes. The tool uses historical fire data to simulate fires, generates resources required for the initial response, and then calls resources based on proximity and availability. STAR uses the generated response time to provide decision-makers with a clear understanding of service gaps and limitations.

Feedback from the pilot trial indicated STAR is proving useful for strategic and tactical planning at the rural fire district level. The development of STAR has shown that a resource allocation tool can be developed and be successful in simulating the complexities of rural firefighting resource deployment. Consequently, STAR would be a relevant and useful tool for rural fire managers to support decisions on the optimal deployment of resources. STAR could be developed further by piloting it across other rural fire districts to expand its functionality before rolling it out nationally.

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Prepared by Navigatus Consulting
July 2015

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Photo Credit: Navigatus Consulting

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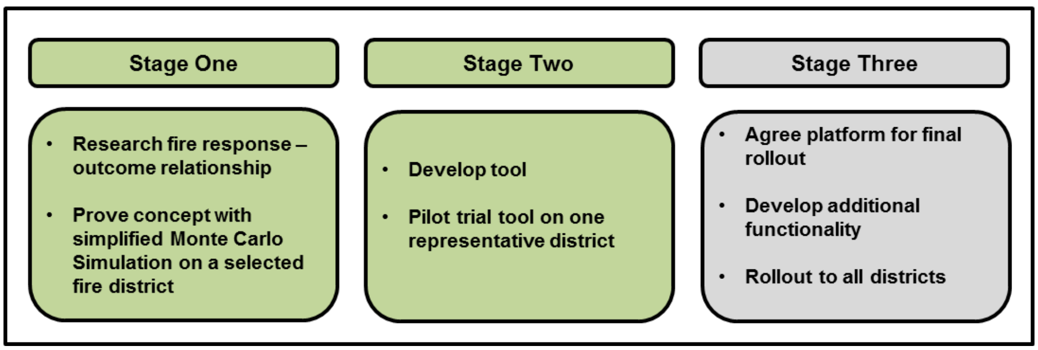
1 Introduction

As part of the Contestable Research Fund, the New Zealand Fire Service Commission (NZFSC), through the National Rural Fire Authority (NRFA), engaged Navigatus Consulting to undertake initial research and development that would support the eventual rollout of a tool for risk based resource allocation within each of New Zealand's rural fire districts. The research brief is attached in Appendix A.

This report covers the work undertaken so far on this project (Stages One and Two), as outlined in the diagram below. Stages One and Two covered the development of a Scenario Tool for Allocating Resources (STAR), and the pilot of this tool in the Marlborough/Kaikoura Rural Fire District (MKRFD). The final stage of work is dependent on the outcomes of this pilot and securement of further funding.

Figure 1 Project steps for development of a risk based resource allocation tool



STAR would enable Rural Fire Authority (RFA) decision-makers to make more informed and strategic decisions on the allocation of firefighting equipment within their district and reduce the time taken for adequate initial response to arrive to vegetation fire events.

This ability aligns with a strategic goal of the NRFA to reduce the number and consequence of wild fires by ensuring that Rural Fire Authorities deliver effective fire control measures on forest and rural lands (National Rural Fire Authority 2009).

1.1 Project Context

Navigatus undertook the project with regard to the wider context of the NRFA and the New Zealand Fire Service (NZFS). The main factors of contextual importance are detailed in the following subsections.

Urban risk resource models

In the urban context, the NZFS has developed a National Risk Resource Model (NRRM) (McGill & Waring 2013). The NRRM approach focuses on timeliness of response, as this is the metric that the public associate most strongly with level of service and is critical to how NZFS performance is viewed. Navigatus has designed STAR so that it would complement the NRRM. STAR has been developed to present on a standalone basis, or to run on the NRRM platform if the NRFA chooses that option in Stage Three.

Enlargement of rural fire district

In the past, a large and diverse group of stakeholders provided forest and rural fire management in New Zealand, including Territorial Authorities, the Department of Conservation (DoC), the New Zealand Defence Force, and forest owners. Stakeholders were generally aware that they could achieve better results through the pooling of resources.

This awareness is resulting in the enlargement of rural fire districts, with the aim of improving the efficiency and effectiveness of the forest and rural fire sectors through greater professionalism and better resource management by rural fire authorities (National Rural Fire Authority 2010). Enlargement of rural fire districts also provides the opportunity to re-optimise resource deployment.

Integrated Response

A strategic objective of the NZFSC is to increase integration of urban and rural service delivery (New Zealand Fire Service Commission 2012). Navigatus has kept this future direction in mind during development of STAR.

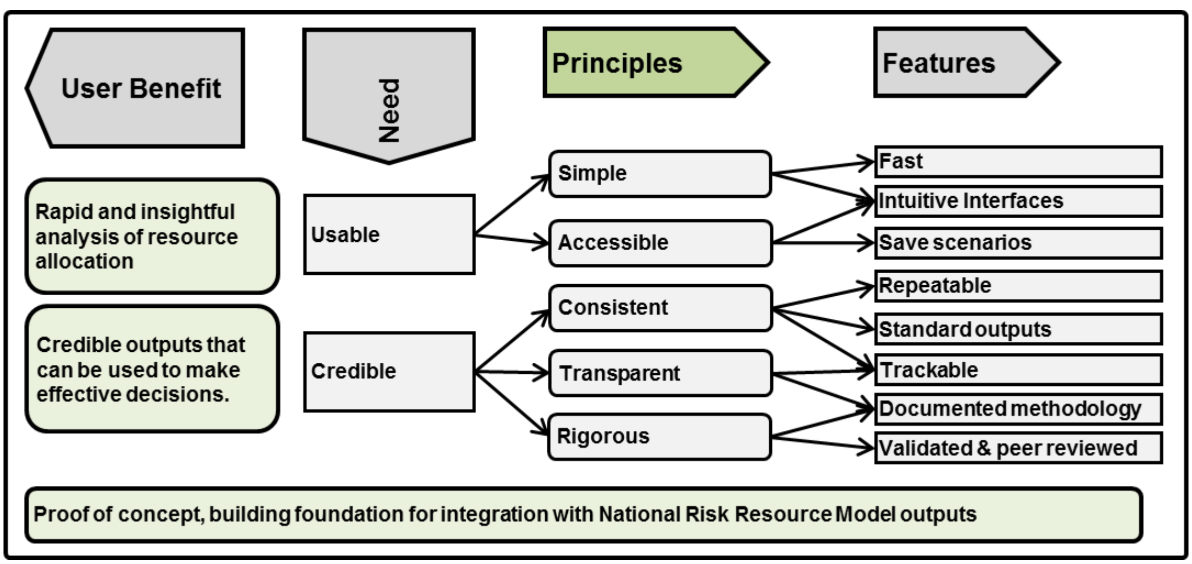
1.2 Project Objectives

The main objectives of Stages One and Two of the project were to develop a tool that:

- Provides tangible benefits;
- Is easy to use, understand, and explain; and
- Is a stepping-stone to the third stage of the project.

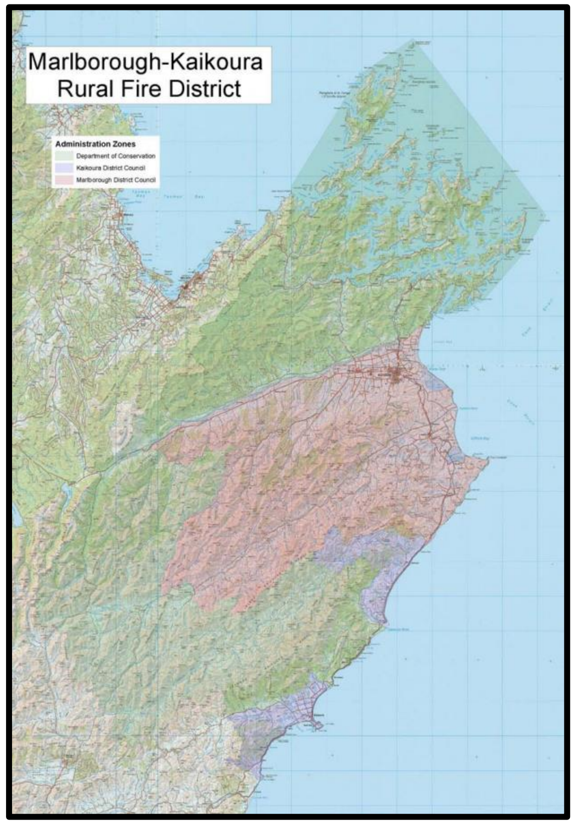
Figure 2 below identifies other key principles and features of the tool. Navigatus has focused on developing a tool that the average user can run and understand, rather than a model with a complex and confusing interface.

Figure 2 Logic map of key principles and features



2 Project Methodology

Navigatus designed the project methodology to be in line with the principles of the Risk Management Standard ISO31000. This meant an emphasis on providing work that was based on best available information, delivered in a timely manner, and that was iterative (repeating the process until the desired product was delivered). The main project steps are outlined in the following subsections.



2.1 Pilot District Selection

Navigatus developed criteria to help the NZFSC choose a rural fire district for the pilot of the tool. The criteria were that the area should contain:

- A typical range of major vegetation types and resources *(e.g. DoC estate, plantation forest, helicopter operators, contractor personnel and equipment, DoC and forest owner resources, and RFA resources);*
- A relatively simple geographical layout to allow research to focus on firefighting aspects *(e.g. relatively few roads);* and
- A fire officer that could engage actively with Navigatus staff during development of the tool.

The NZFSC chose to use the MKRFD for the pilot trial.

The MKRFD has most of the typical range of vegetation types, but did have some complexity in its geographical layout.

2.2 Initial Research

Navigatus visited the MKRFD on 9 and 10 October 2014 as an initial research step and held interviews with:

- Principal Rural Fire Officer (Richard McNamara)
- Deputy Principal Rural Fire Officer (John Foley)
- DoC Rural Fire Officer (Brian Paton)

Navigatus also interviewed Ken Rodley (Fire Depot Manager, DoC) and other contractors. The interviews assisted Navigatus in understanding the MKRFD and how fire response is managed.

A key conclusion from the initial research was that there are social complexities around the ownership and allocation of resources, including factors such as community fundraising and engagement. Accordingly, the plan to provide a decision input tool that allowed managers to trial scenarios of their choosing was critical.

2.3 Literature Review

Rural fire planning can be seen as involving two stages: a strategic stage where resources are allocated to stations; and an operational stage where resources are dispatched to fire locations (McCarthy et al. 2012). While the principle aim of STAR is to assist in the strategic stage, a robust understanding of the operational stage is also required. Navigatus undertook a literature review to provide general context and address specific questions relating to both the strategic and operational stages. The aim was to:

- Develop awareness and understanding of similar work in the rural environment;
- Explore characteristics of fire occurrence, growth and natural fire extent to inform the best approach for STAR; and
- Determine to what extent resource 'suppression effectiveness' is modelled by others to inform the best approach for STAR if no usable Response-Outcome relationship is found in New Zealand.

Background and Similar Studies

In 1980 New Zealand adopted the Fire Weather Index (FWI) system module of the Canadian Forest Fire Danger Rating System for rating fire danger in exotic pine plantations (Fogarty et al. 1998; Stocks et al. 1989). A key lesson from this experience was the need to adapt the system to the New Zealand environment to get the most value from it (Fogarty & Pearce 1998). More recent work, such as the Wildfire Threat Analysis, has improved the understanding of rural fire danger in New Zealand (e.g. Hansford 2011; SCION 2011). The Marlborough Kaikoura Rural Fire Authority (MKRFA) considers this information in setting risk ratings.

The fundamental question of how to allocate resources for best outcomes has received significant attention in the rural fire environment. However, much of this research is overlapping, with many papers presenting variations on the same fundamental analysis. Selected examples of approaches to the problem are shown in Table 1.

Table 1 Selected examples of similar studies

Type	Metric	Author(s)
Optimisation - perimeter containment	Cost plus Net Value Change.[1]	(Donovan & Rideout 2003)
Stochastic simulation / "what if" – perimeter containment	Percent contained by size, percent fires by response time, area burned of contained fires cost.	(Fried et al. 2006)
Optimisation - standard response / perimeter containment	Number of uncontained fires and cost.	(Ntaimo et al. 2012)
Optimisation – standard response / perimeter containment	Expected number of fires that do not receive a standard response.	(Lee et al. 2013)

[1] *Note: An overview of C+NVC can be found in* (BERL 2009).

Donovan & Rideout (2003) developed an optimisation model with the capability to automatically adjust variables such as stationing of fire-fighting resources, pre-suppression budgets, and dispatch rules, with the aim to minimise simulated costs and damages for a given geographic area. Fried et al. (2006) developed a similar model, although based on the 'what-if' concept, whereby the user adjusts variables to create potential scenarios, which can then be tested against a base scenario. The model is known as the California Fire Economic Simulator version 2 (CFES2). A possible disadvantage of this approach, compared to Donovan & Rideout (2003), is that the optimal solution may not be identified by the user. On the other hand, a fully automated model is likely to give solutions that may be unfeasible in the real world.

Navigatus' early discussions with the MKRFA revealed that the reality of rural environments is considerably complex, with many dynamic constraints relating to specific locations, stations or even, potentially, crews or individuals. Given this, it was considered preferable to develop a stochastic 'what-if' tool that would allow rural fire managers to test scenarios they knew to be feasible.

Ntaimo et al. (2012) brings focus to the concept of a 'standard response', i.e. a known required response to a fire of a given size or intensity. Lee et al. (2013) also uses the concept of a standard response, further developing the CFES2 model by incorporating an optimisation module to minimise the expected number of fires that do not receive a standard response (an addition not seen as relevant for the New Zealand environment).

A key feature of these models is the use of a 'perimeter containment' concept for determining when a fire has received sufficient response to say that it is contained. This concept involves assigning fireline productivity rates to different resource types and matching this against fire perimeter growth estimates. This concept was not deemed appropriate for the New Zealand environment.

Another feature of many models is the attempt to provide an estimate of area burned. There are many complications with such estimates which are discussed by Lee et al. (2013). In most cases these value estimates are arbitrary and do not give an accurate reflection of the real world. Area estimation was not included in the initial scope of the STAR pilot trial.

Other research has provided valuable context on the capabilities and limitations of fire and fire-response modelling, helping to inform the development of STAR to include those features that are robust and relevant to the New Zealand rural environment (Butry 2007; Plucinski et al. 2012; McAlpine & Wotton 1993; Benoit et al. 2013; NWCG 2004; NWCG 2014; Gosai et al. 2004; Lee 2012; Greulich 2003; Donovan & Rideout 2003; Richard et al. 1990; Fried & Fried 1996; McCarthy et al. 2012; Stocks et al. 1989).

Performance Metrics

A model that aims to improve the allocation of resources needs to define improvement based on some output metric, such as:

- Number of fires that do not receive a defined response, based on the combined risk of the fire location and the fire weather on that day.
- Number of fires that are not contained before they exceed simulation size or time limits (e.g. 3 hectares, 2 hours) – requires modelling fire growth and suppression.
- Sum of area burned for fires that are contained within simulation limits. A value can be assigned to this area, e.g. $100 per hectare – requires modelling fire growth and suppression.
- Sum of area burned for all fires including both contained and uncontained – requires modelling fire growth, suppression and natural fire extents (i.e. where the fire would burn itself out).

Most research uses metrics based on exceedance of simulation limits, rather than statistics such as total area burned that are potentially more useful. This is because no simulation model yet devised is capable of accurately predicting the size of fires that exceed initial attack, and these fires almost always account for nearly all of the area burned (Lee et al. 2013).

Measures of Resource Effectiveness

Arienti et al. (2006) examined variables relating to two types of suppression failures. Suppression failures occur when fire size exceeds a target before the response arrives (a response failure) or if fire cannot be contained below the target (containment failure). The frequencies of containment (7%) and response failures (10%) were similar, but the latter accounted for 85% of the area burned. Response failure probability was greater for fires caused by lightening than those caused by humans and increased with longer response times, containment failure probability was related to size at initial attack and fire weather conditions (Arienti et al. 2006).

As detailed in Section 3, the statistical analysis of New Zealand fire events did not reveal a statistically reliable Response-Outcome relationship. The potential for this outcome was anticipated and an alternative approach was identified in the research proposal. However, before moving to this approach, further research was undertaken in an attempt to identify other ways of modelling the effectiveness of response, specifically by looking at the individual resource types, e.g. fire crews, helicopters, etc.

Navigatus explored three potential options:

1. **Production Line Concept:** Use the production line concept, whereby each resource generates firebreak at a certain rate, if found to be appropriate.

2. **Fire Growth Simulation Models:** Use inbuilt relationships from fire growth simulation models, e.g. Prometheus, if found that they are appropriate.

3. **Other Models:** Use other types of response-outcome relationships identified in the literature.

Production Line Concept

In Donovan & Rideout (2003), each fire-fighting resource was defined as having four parameters: fixed rental cost, variable cost, arrival time, and rate of line production. The rate of line production determines how effective a resource is at supressing a wildfire once on site. The fire is contained once the aggregate rate of production from all resources on site reaches a critical point relative to the growth characteristics of the fire perimeter. This concept is common throughout the literature and estimation of line production rates has been the subject of several papers.

Hirsch & Podur (2004) presented results of a structured expert-judgement elicitation exercise to develop probability distributions for fireline production rates. Holmes & Calkin (2013) tackled the same problem using operational data collected for large rural fires to estimate the parameters of economic production functions that relate the rate of fireline construction of different resources. Plucinski & McCarthy (2012) explored the effect of aerial suppression on the containment time of Australian wildfires (as estimated by fire management personnel) from the production line perspective.

Although the production line view of resource effectiveness is useful from a modelling perspective, early consultation with the MKRFA revealed that the concept does not align well with the reality of fire fighting in New Zealand. This simplistic view of resource effectiveness does not account for typical tactics, such as attacking the flank of a fire, nor does it address the interdependencies between resources, for example helicopters and land-based crews working in concert to suppress and extinguish fires. For this reason, Navigatus did not pursue this concept further in the development of STAR.

Fire Growth Simulation Models

Navigatus reviewed fire growth simulation models to identify a model that already included in-built relationships regarding response times, suppression efforts, and fire outcome. The relationships could potentially be used in STAR if an appropriate model could be found and validated against actual New Zealand fires.

For this to work, the model would need to be cognisant of New Zealand’s fire environment. This was the key challenge as the models have international origins and do not account well for New Zealand factors. New Zealand topography is complex, fuel types are diverse, and weather is changeable. These variables are constraints on fire expansion – for example, wild fires often burn to the top of a ridge and then stop, patches of damper native vegetation on south-facing slopes might slow or stop a fire, and weather conditions such as precipitation or a change in wind direction may also contribute to a fire burning itself out.

Opperman et al. (2006) evaluated several spatial wildfire spread and growth simulation models for use in New Zealand, noting that most simulators are designed to handle specific areas and requirements. The simulation models included Prometheus, FARSITE, the Portable Fire Growth Model, Bushfire CRC, Networked Fire Chief, and Minimum Travel Time.

This research found FARSITE and Prometheus to be potentially relevant for New Zealand. However, a disadvantage of both simulators was that each was built around one set of fire spread equations.

Prometheus is a deterministic fire growth simulation model. Simulation scenarios for a specified time period are executed by loading the appropriate fuel, topography, and weather data for the landscape extent and simulation period and then defining an ignition event or events (Tymstra et al. 2010).

Prometheus was designed to use Canadian-based fuel types, and modifications were made to incorporate the custom New Zealand fuel types that are based on the Canadian models. Though some simulation inputs were easily manipulated, neither Prometheus nor FARSITE supported the entry of fully customized fire spread equations with varying parameters.

Discussions with users of Prometheus showed that this model is limited in its ability to model the effect of suppression. In some cases, the user was able to add a linear ‘fire break’, however, this was not considered an adequate proxy for suppression resources such as fire crews and helicopters. As with other models, Prometheus appears limited in its ability to determine when the fire will ‘naturally stop’, i.e. it does not adequately account for ‘natural burn-out’ of uncontained fires, with users typically running scenarios for a fixed amount of time.

Other Measures

Some of the challenges of assessing individual resource effectiveness in a quantitative way are outlined by Plucinski (2013), with reference to aerial suppression:

“Fires that involve aerial suppression are likely to be more difficult to contain on average than those that do not involve aerial suppression because aircraft tend to be deployed to fires that occur during elevated fire danger conditions. Fires involving aerial suppression will therefore have lower probabilities of initial attack success and higher probabilities of burning large areas or for longer durations, than those that do not.”

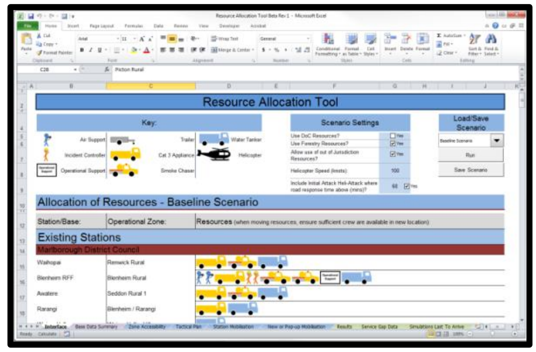
Summary

The literature review found:

- No statistical relationship between fire response and outcomes.
- Fire growth simulation models, such as Prometheus, require that the user determine the end-point. They are useful for post hoc XYZ but not for prediction of fire extent.
- Perimeter models do not take account of the helicopter/land crew interaction that is more common in New Zealand.
- Uncontained fires represent the greatest threat and are most likely to be attacked by land and helicopter.
- Due in part to the above limitations, optimisation of fire resource allocation tends to focus on optimising response times to minimise the number of uncontained fires.

2.4 Fire Analysis and Development of Tool

Navigatus analysed incident data received from the NZFS to assess the relationship (if any) between fire response and fire outcome in terms of area burnt. The method and results of this analysis are discussed in further detail in Section 3.



Navigatus developed the tool in Microsoft Excel 2010 using Visual Basic Macros. The tool uses a Monte Carlo based simulation to model a distribution of fires across the district and record expected outcomes.

Navigatus initially set the baseline scenario and settings in the tool to represent MKRFD current operations with reference to the fire plan and other resources (Marlborough Rural Fire Authority 2012; Hurunui District Council 2009).[2] These settings were refined following the workshops from feedback received. Development of the tool is covered in detail in Section 4.

2.5 Preliminary Workshops and Revision of Tool

Following the initial development of STAR, Navigatus held workshops with John Foley and Richard McNamara at the MKRFD Optimisation Centre in Blenheim on 23 and 27 March 2015.

Navigatus demonstrated the tool, its features and limitations, and outlined the methodological decisions made in developing the tool.

Following each workshop, Navigatus refined and further developed STAR to take on board the suggestions received. These refinements and developments included:

- Addition of the probability a crew is able to roll out (i.e. that they are not short crewed)
- Addition of Blenheim as a cover resource in certain operational zones, rather than next closest resource
- Inclusion of heli-attack as an alternative first response where the road response time is longer than a specified amount
- Addition of simulation of inaccessible fires which receive response according to Heli-attack Tactical Plan
- Addition of simulation of fires that occur outside of daylight hours, plus addition of Night Tactical Plan to model the associated tactical response
- Creation and export of “Gap Map” to Google Earth enabling view of operational zones where performance is missed
- Addition of ability to view more rows in the list of ‘seldom used’ resource in the results section
- Removal of Foam as a separate resource, as Tankers and Appliances have foam on them
- Adjustment of resources and response times to best fit the current scenario in the MKRFD

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[2] Personal communication with John Foley and Ian Reade.

2.6 Formal Workshop

After revising the tool, Navigatus held a formal workshop on 19 April 2015 in Blenheim. This workshop demonstrated the beta version of STAR, having integrated the suggested developments from the preliminary pilot trial. Navigatus provided workshop attendees with a user guide for the tool (see Appendix B).

This workshop was attended by:

- Richard McNamara (MKRFA);
- John Foley (MKRFA);
- Brian Paton (DoC);
- Ken Rodley (DoC); and
- Ian Reade (Waimea Rural Fire Authority).

Following this workshop, Navigatus also demonstrated the tool to Gary Lockyer, National Manager Operations (NRFA project sponsor), on 30 April 2015.

Following comments received at these workshops, Navigatus added the following functions:

- The ability to cut the results page for specified zones
- The ability to make a 'pop-up' station only respond during certain seasons

2.7 Pilot Trial

The pilot trial was an opportunity for the MKRFD to use STAR independently. The pilot trial finished on 31 May 2015. Feedback from users has been positive (e.g. validates gut feeling) so far and has not necessitated any further changes to STAR. Further information from the pilot trial is provided in Section 5.3 (Examples of Use).

3 Fire Analysis Methodology and Results

Navigatus analysed NZFS and DoC fire datasets to assess the relationship between fire response and fire outcome (area burnt). A report on the analysis and findings is provided in Appendix C (NZFS data) and Appendix D (DoC data).

Navigatus undertook this analysis because a moderate to strong relationship between fire response and fire outcome would allow STAR to model loss under different resource allocation scenarios.

The datasets analysed were:

- **NZFS Station Management System (SMS) incident data**
  Vegetation fires between 1 September 2000 and 14 January 2015 (extracted by filtering by relevant incident types, e.g. crop fire, exotic forest fire, tussock fire etc.)
- **DoC Historic Fire Inventory**
  Historic Fire Inventory data that could be mapped to NZFS data (to get time taken to arrive).

The NZFS (rural) database records all fire incidents and responses. The DoC Historic Fires Dataset is the outcome of a DoC project aimed at recording all major vegetation fires in New Zealand.

Navigatus processed and cleansed the data to ensure the best chance of identifying a relationship between the variables. An initial exploratory analysis explored if there was any indication of a relationship between variables. For both datasets, there were no clear or strong trends identified, only a possible weak increasing trend for area burnt with time for the first rural unit to arrive.

Navigatus then investigated which variables to use in the statistical model (logistic regression), as only significant variables should be included.

For the NZFS data, Navigatus then ran the model using all significant explanatory variables and then only arrival time and incident type, checking the predictive power of the model. For the DoC data, Navigatus did not run the model due to the poor fit of the logistic regression.

In summary, although there appeared to be a relationship between time taken for the first rural unit to arrive and the resultant size of the fire, there was too much variation in the data to build an accurate predictive model from the dataset. A surprising outcome of the modelling was the poorer regression fit to the DoC data, as that dataset had been more carefully assembled. Results are set out in greater detail in Appendix C and Appendix D.

Consequently, a statistical relationship to the area burnt was unable to be incorporated into the simulations and meant that this pilot version of STAR would not be able to directly model loss. Instead, STAR uses response time vs target time only. The limitations of this result are discussed in Section 5.1.

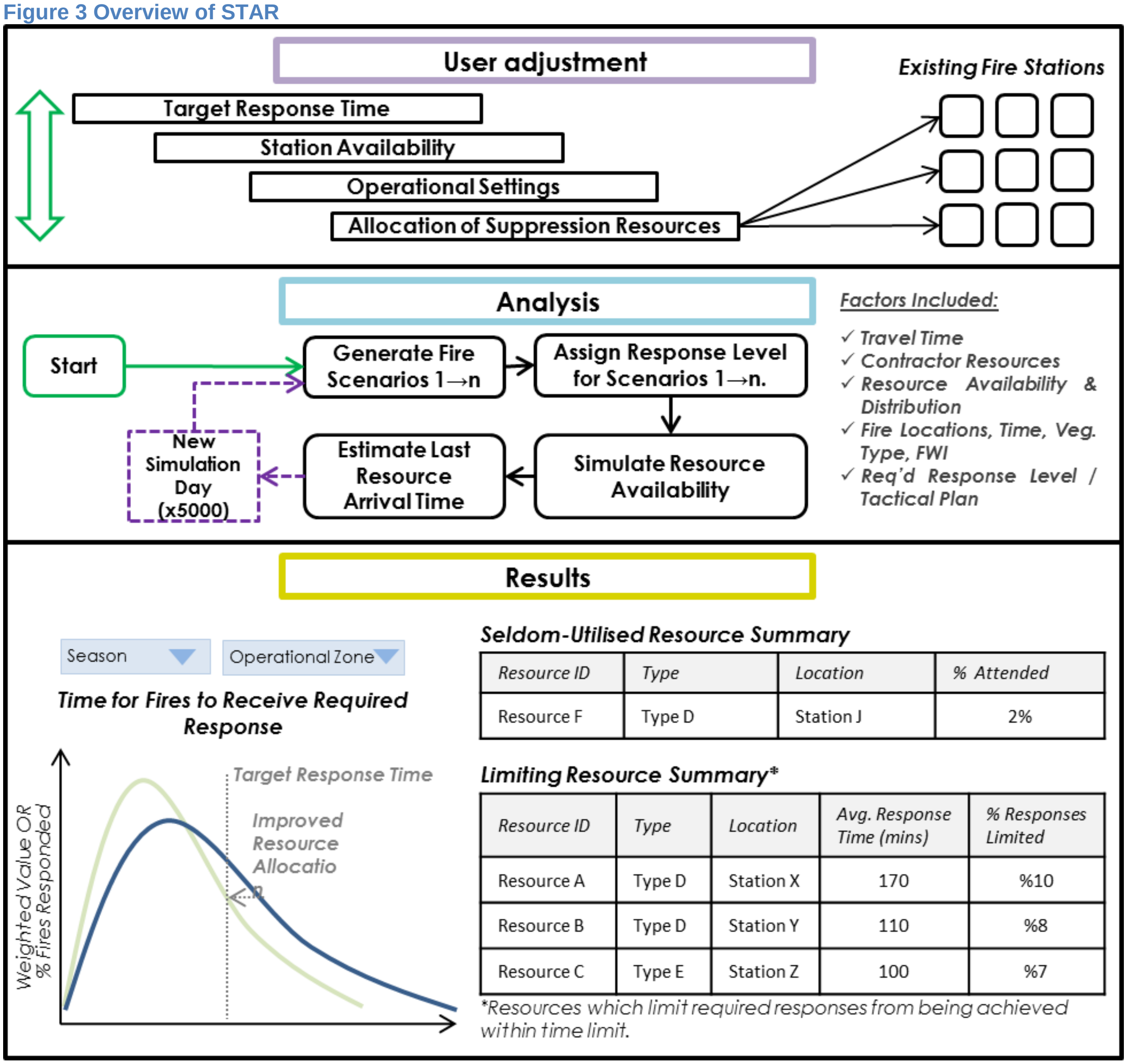
4 STAR Development and Outputs

4.1 Tool Overview

Navigatus developed STAR as a Monte Carlo based simulation in Microsoft Excel 2010 using Visual Basic Macros. Outputs from STAR can also be mapped in GIS.

STAR has three main components: inputs (user adjustments), the analysis engine, and the outputs. Figure 3 gives an overview of these three components.

Figure 3 Overview of STAR



The user gets full control of the scenarios in STAR through the user adjustments they can make. This lets the user take into account relevant factors when making decisions on where to move resources (e.g. the ownership of different resources). A user guide for STAR is provided in Appendix B.

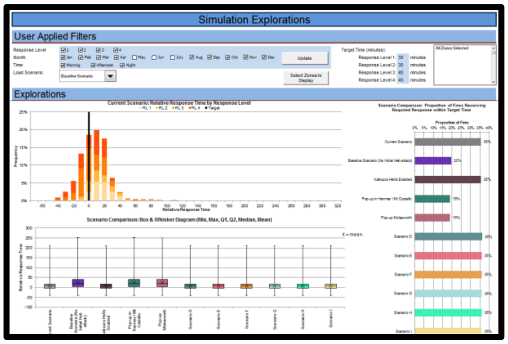
STAR uses historical fire data to generate the operational zone, month, fire weather index, accessibility, time of day and the response level required (which considers the fire weather index and operational zone) for each simulated fire. STAR generates 5,000 simulated fires (approximately 90 years of fires in MKRFD) (MKRFA 2015) and uses the same set of simulated fires each time the tool runs.

For each simulated fire, STAR then generates the resources required for initial response (based on the response level and tactical plan). Lastly, STAR calls the resources in order of proximity (assessed by a travel matrix developed using an application which draws on Google's API) (Van Kuijk 2015) and assesses whether they are available to attend the fire. STAR repeats this step until it meets the initial response requirement.

4.2 Type of Outputs Produced

STAR produces the following results:

- **Graphical results**, including scenario comparison, limiting resources, utilisation, and station workload
- **Service gap data** (for producing Gap Maps – example results shown on the following page)
- **Summary of the simulations** including last to arrive



4.3 Example Results

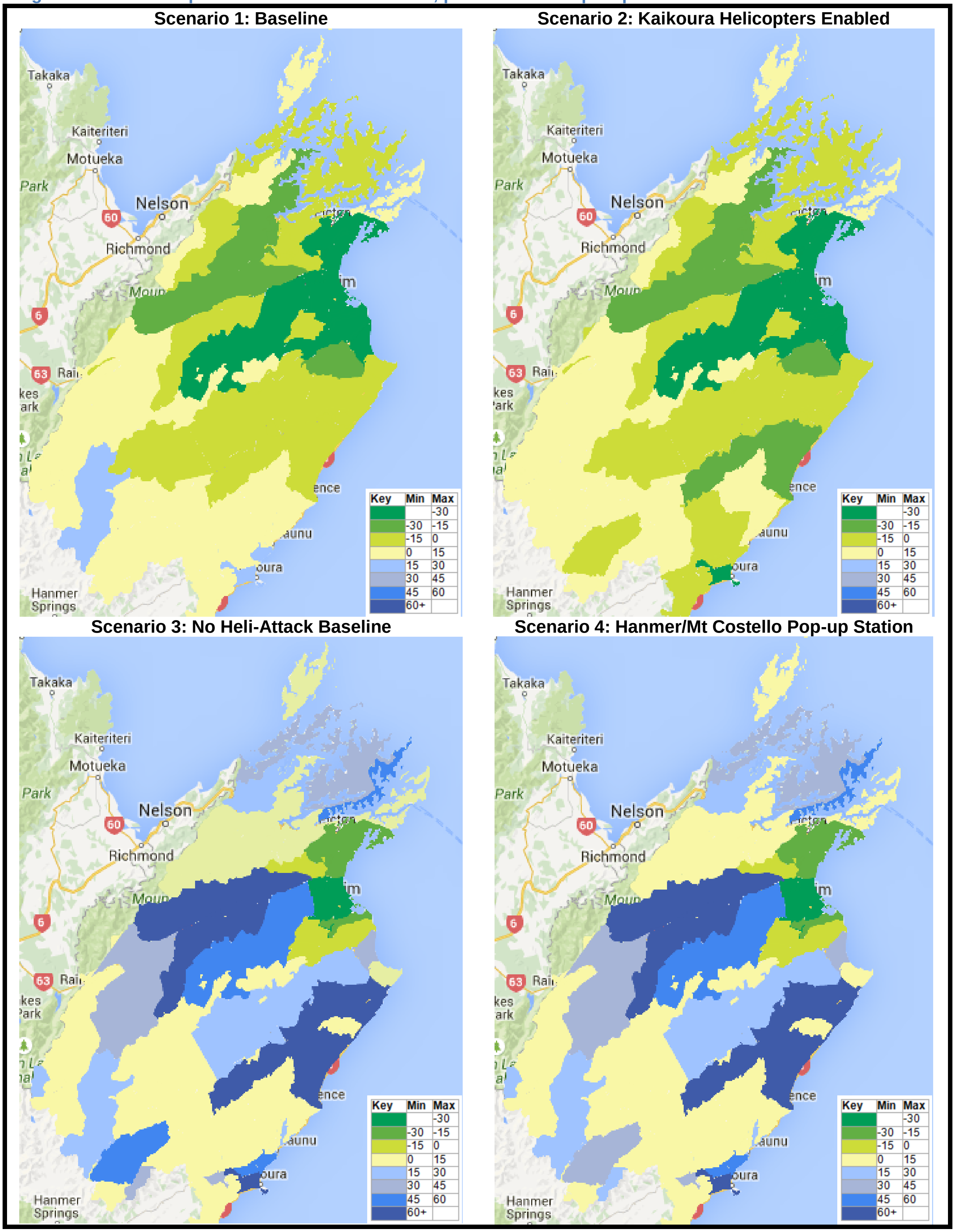
Once STAR was completed, Navigatus ran four different scenarios to ensure the tool was producing sensible outputs and to test the usefulness of the tool. The Gap Maps for these scenarios are provided on the following page.

The maps use a colour key to show the service level provided to each zone under the given scenario, illustrating gaps in service levels.

The results from the scenarios were as expected:

- **Scenario 1: Baseline** - 'automatic' heli-attack for distant areas where road response time for all resources to arrive is over an hour. There was generally good performance for this scenario, except around Kaikoura.
- **Scenario 2: Kaikoura Helicopters Enabled** – baseline with addition of reliable helicopter capability in Kaikoura. This scenario was beneficial compared to baseline, with the area around Kaikoura improving.
- **Scenario 3: No Heli-Attack Baseline** – present deployment of resources with no 'automatic' heli-attack for distant areas. The results showed a different response is being modelled for distant zones.
- **Scenario 4: Hanmer/Mt Costello Pop-up Station** – Scenario 3 with addition of pop-up station in Hanmer/Mt Costello. The scenario showed a small improvement to Hanmer/Mt Costello compared to Scenario 3, but improvement was limited by the low number of fires in the locality and long travel times due to the sparse roading network.

Figure 4 STAR example results for four scenarios, presented as Gap Maps



5 Discussion

This discussion section covers limitations of the tool, a comparison of the tool to the NRRM (urban tool) (McGill & Waring 2013), examples of use of the tool, lessons learned, and insights.

5.1 Limitations

The main limitation of the tool is that it is based on response time, rather than outcome (area burnt). This was necessary because the fire analysis could not find a moderate or strong relationship between area burnt and any other variables.

This means that the STAR, in its current form, does not model loss from different scenarios. Despite this limitation, STAR still provides useful information to assist fire managers to make better strategic decisions. STAR uses response time, which is commonly used in other fire resource allocation models, and provides a clear understanding of service gaps and limitations.

The user guide (Appendix B) covers limitations of the model at a more detailed level.

5.2 Comparison of STAR to Urban Tool

STAR was developed to complement the urban resource tool, the NRRM. In this section, some of the differences and similarities between the two tools are discussed, as well as the context in which they are used by fire staff.

Context

In the rural context, costs and benefits are more clearly recognised and are more powerful directors of action than in the urban context. The difference in these drivers in rural and urban settings leads to different solutions and requires some differences in culture to support the effective implementation of those solutions.

Rural firefighting requires a more complex array of resources to be deployed and assembled. The resources required are also more context dependent than in an urban setting. RFA volunteer personnel and some other resources are not waiting in depots, but are dispersed over the landscape doing their usual jobs. Any method seeking to advise on the optimal deployment of RFA resources must recognise these core differences from the NRRM approach.

Model approach and outputs

The NRRM is a strategic tool that considers resources and cost. STAR is a tactical model that considers where it is best to deploy currently available resources, or to consider other tactical options. Navigatus views the two tools as complementary.

STAR takes into account the need to manage the arrival of a variety of resource types. These resource types vary based on the fire type, the suite of resources available at the time, and the weather conditions. On the other hand, the NRRM considers the arrival times of the first pump. Due to the differences between the rural and urban setting, STAR is necessarily a more complex and dynamic tool.

The NRRM operates on a GIS platform. At the pilot stage of STAR, it has been developed in Microsoft Excel 2010 (with Visual Basic Macros). Scenario outputs from STAR have also been visualised as Gap Maps displayed on Google Maps (Google 2015) to help identify likely gaps in service levels.

Integration

If STAR is further developed, it can be moved to a GIS platform and either be integrated with the NRRM or kept separate.

5.3 Examples of Use

Navigatus has received feedback that STAR is proving useful for strategic and tactical planning at the rural fire district level. Results are reported to validate “gut feeling”. For instance, of the scenarios considered, the scenario with heli-attack enabled had the highest proportion of fires responded to within the required target time.

5.4 Lessons Learned

Lessons learned from this pilot trial are important for further development of the tool for all rural fire districts, if the final stage of the project proceeds. Lessons learned have also been used to inform recommendations that Navigatus has proposed for consideration by the NRFA (see Section 6).

The pilot district had good records on equipment and its availability and location. However, when Navigatus began working with the data it became clear there were still some significant gaps. This experience has underscored the need to validate the results with the managers concerned.

There was some uncertainty from rural fire staff regarding whether a model could replicate their management responses accurately enough. This sentiment emphasised the importance of making sure that variables could be user-defined so that user experience could be incorporated into the model and resulting outputs. It also emphasised the importance of understanding operational limitations, such as command chains and rules around how resources are called out.

5.5 Insights

The example scenarios Navigatus ran in STAR showed the significant difference that having heli-attack makes to outcomes in the MKRFD and how heli-attack covers what would otherwise be deficiencies in a purely land-based response.

6 Conclusions and Recommendations

STAR has demonstrated that a resource allocation tool can be developed and be successful in simulating the complexities of rural firefighting resource deployment. Consequently, STAR would be a relevant and useful tool for rural fire managers to support decisions on the optimal deployment of resources.

STAR is able to assist fire managers to make better decisions and provides a clear understanding of service gaps and limitations. STAR provides insights that can be combined with practical on-the-ground experience of fire managers to enable more informed decision-making.

Historical incident information in the SMS at the detailed level is known to have had quality issue (Glazier Systems 1999; MartinJenkins 2009). The statistical analysis on data for this research reinforces that view in regard to area burnt. Navigatus recommends that the NZFSC data entry units for recording incidents in the NZFS SMS be clarified. For instance, area of vegetation burnt should be entered in either ha or m^2, rather than both. A single unit would help ensure that entered is reliable and accurate.

6.1 Further Development of STAR

Given the outcomes of the initial development of STAR, Navigatus recommends further work should be undertaken (refer back to Stage Three in Figure 1).

The recommended steps below set out the work needed to move STAR from proof of concept to an effective tool that can be rolled out nationally.

Navigatus suggests a key principle of this further development should be making the tool customisable so each fire district can model its own management and operational approaches.

1. Pilot STAR in rural fire districts that have different firefighting approaches and constraints than the MKRFD. This will assist in expanding the functionality of the tool to cater for a wider range of resource types and management approaches.

2. Investigate the best software for the final development and delivery of STAR based on:
    - Ease of use
    - High level of user customisation
    - Availability to required personnel (with and without access to current NZFS GIS system)
    - Ability to interface with existing NZFS data and systems (to extent feasible)
    - Ability to automatically view GIS results

3. More direct interface with Fire Service GIS:
    - Simulation Base Data to be extracted directly from Fire Service database (and updated)
    - Possibility to initially assign and compare mobilisation times to historic records at station level

4. Further possible developments to STAR:
    - Develop metric for area burnt and value of lost vegetation;
    - Ability to view all resources that have been called (including those that were unavailable);
    - Possibility to include NZFS urban firefighting resources into response;
    - Target times dependent on location, shorter target time at urban fringe (to take into account different service level expectations), possibly related to target times from NRRM;
    - Ability to set mobilisation time and probability of mustering a full crew for each resource (currently set at station level); and
    - Expansion of risk and response levels to cater for a wider range of tactical plans.

7 Acknowledgements

Navigatus would like to thank the National Rural Fire Authority as the project sponsors, the Marlborough/Kaikoura Rural Fire Authority, and the Department of Conservation for their engagement on this research project and for providing data, assistance, and their time.

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Appendix A – Research Brief

Risk-based resource allocation across rural fire districts

Introduction

The National Rural Fire Authority needs to ensure that it understands what level of resourcing is required for fighting rural fires to distribute them in a way that maximises their efficient and effective use. We would like a model that uses landscape elements of vegetation loadings and weather and is consistent with the National Resource Allocation Model (NRAM) to identify rural fire risk profiles and establish optimal location of various equipment to mitigate this risk.

Project Purpose

The aim is to provide an evidence base for making decisions about the optimal allocation of fire fighting equipment across rural fire districts, using a risk based approach consistent with NRAM.

Specific Areas of Focus

The project will include, but is not limited to, the following deliverables:

- the development of a modelling tool for the supply of water and other resources to fire events in rural areas, in sufficient volumes and number to meet the firefighting requirements for extended fire incidents. Resources which are involved include static water supplies, tankers, aircraft, trained firefighters, earthmoving machinery, etc.
- a sound risk management process will be part of the solution

Fire weather and fire spread modelling in the different fuel types and fuel loading will be available to researchers to assist in identifying the level of exposure to risk, required to develop the modelling tool.

Project Team

Project Sponsor: Murray Dudfield - National Rural Fire Officer, National Rural Fire Authority.

Project Leader and Technical Advisor: the researchers will propose a suitably qualified individual.

Project Team Members: the researchers will propose a project team with an appropriate mix of skills to meet the project objectives.

Timelines

The project is to commence in May 2014.

Previous Research

Researchers are strongly reminded to visit the NZFS website to familiarise themselves with previous research reports as a foundation for future work www.fire.org.nz

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Appendix B – User Guide for Marlborough/Kaikoura Rural Fire District

Scenario Tool for Allocating Resources

User Guide for Marlborough/Kaikoura Rural Fire District

Prepared by Navigatus Consulting

July 2015

Scenario Tool for Allocating Resources

User Guide

Prepared for:

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Rev 1	5 May 2015	Kevin Oldham	
Rev 1.3	13 July 2015	Kevin Oldham	

Contents

1 Introduction

A strategic goal of the National Rural Fire Authority (NRFA) is *to reduce the number and consequence of wild fires by ensuring that Rural Fire Authorities deliver effective fire control measures on forest and rural lands* (National Rural Fire Authority Strategic Plan 2009-2014).

The Scenario Tool for Allocating Resources (STAR) is aimed at enabling Rural Fire Authority (RFA) decision-makers to make better strategic decisions on the allocation of firefighting equipment within their district, reducing the time taken for adequate initial response to arrive to vegetation fire events. The tool also enables assessment of the benefit of operational practices such as the use of heli-attack as an initial response.

This tool has been pilot-trialled in the Marlborough/Kaikoura Rural Fire Authority (MKRFA). This guide is intended to inform users on how to use the tool as configured for MKRFA.

This beta version of the tool is designed as simply a proof of concept. If the results of this proof of concept version are found useful then the tool may be developed into a more integrated version for wider deployment.

Ultimately, the tool is intended to be developed for use within the NZFS, supplementing the urban risk-based resource allocation tools GIS. This tool might also be able to run as a stand-alone tool, as it currently does.

2 Overview of Model Concept

STAR gives full control of the scenarios to the user, so the user can drag and drop resources to the desired location. This allows the user to take into account relevant factors when making decisions on where to move resources, for example, social factors such as ownership of the resource.

STAR simulates 5,000 fires (approximately 90 years of fires in MKRFA) based on historic fire data for the area, assigning response level (one to four), time of day (morning, afternoon, night) and whether the zone is sufficiently far away to require an initial heli-attack. Further information on how the fires are simulated is contained in 0. These factors are then used to determine the resources required to meet the initial response from the tactical plan. The closest resources which are able to respond are then dispatched according to availability (Appendix B3), resulting in a response time for the simulated event.

The tool then presents the results of the scenario, comparing overall performance with other saved scenarios. Drill down enables the user to assess where the most improvement is needed, which resources are less utilised, and which take the longest to respond. A graphical representation of the scenario or, Gap Map is also able to be produced. The Gap Map shows colours by operational zone for the weighted value (proportion of fires within the zone x the number of minutes ahead or behind target the response x by 100). This helps identify likely gaps in service levels so resource deployment can be adjusted to remedy them.

The tool also introduces the concept of pop-up stations. This is intended to be a station that is in a more remote location and does not have any personnel. The pop-up station is staffed by Blenheim crew who fly from Omaka Aerodrome to the pop-up station before driving to the fire. A pop-up station would be an ideal location for older equipment to become semi-retired. Ideally, someone local will check the equipment from time to time to ensure it is operational.

3 Accessing the System

The pilot version of STAR has been developed using Microsoft Excel 2010 and implements Visual Basic Macros. The file is named Scenario Tool for Allocating Resources Rev 1 and will be provided on a memory stick.

If the tool is developed further it is possible that it will be implemented in GIS to interface directly with the NZFS GIS system.

4 Base Settings

The tool was developed with a number of operational parameters able to be adjusted and updated. Before using the tool for the first time these settings should be checked to ensure they best represent current operating procedures in the applicable district.

In the tool, the tabs corresponding to the base settings are coloured blue. It is important to note, any changes made to these parameters are only applied to scenarios run after the change was made. For comparison, saved scenarios should be re-run (including the baseline scenario).

4.1 Zones

Ideally, the operational zones of the fire district will be configured to only have one station per zone. This will improve the travel time and call-out accuracy, as with more than one station in a zone they are all assumed to be located at the zone centre.

The tool will also be more accurate where the operational zones are not too large. This is due to travel times being calculated to and from the centre of the zone. In the pilot trial of the tool for MKRFA, the Seddon Rural zone has been split into four due to its large size. This has enabled the Awatere station to be located closer to its true location (at the centre of the smaller split zone).

4.2 Zone Accessibility

The *zone accessibility* tab sets out the baseline zone risk (risk when the fire weather index (FWI) is high) and the proportion of fires in the zone that are accessible. These factors are used to determine the response level and which tactical plan is used respectively, and thereby the resources required for initial response (0).

4.3 Tactical Plans

The *tactical plan* tab of the tool outlines how many of each resource would be deployed at each response level. There are three different tactical plans. The selection of tactical plan applying to each ignition event is undertaken automatically depending on the simulated situation:

- Night Tactical Plan
    - This tactical plan is applied where the simulated fire occurs at night (between 6pm and 6am). Fires occurring between these times would be monitored until the following day. Once sufficient resources to monitor the fire have arrived at the fire location, the model determines the initial response has been met.
- Initial Response Heli-attack Tactical Plan

- This tactical plan is applied to fires where either the simulation location is not accessible (Section 4.2) or, if initial attack heli-attack is enabled, for distant fires, where response to the fire for the closest resources would take longer than the time specified on the interface. (Default level 60 minutes – user adjustable)
- Base Tactical Plan
    - This tactical plan is applied where simulated fires occurred between 6am and 6pm and Initial Response Heli-attack is not called.

4.4 Station Mobilisation

The *station mobilisation* tab sets out the operational parameters relating to a station, the mobilisation times and an indication of the proportion of time the station can muster a full crew.

The mobilisation time is used in conjunction with travel time to determine the time taken for a resource to arrive at a fire.

The proportion of time a station can muster a full crew is used to set the likelihood the station is able to muster enough crew to turn out the resource called up in the simulation. If the resource cannot be turned out, the simulation calls out the next closest available resource in that class. Proximity is measured in travel time. This process continues until sufficient resources have been mobilised.

The tool introduces the ability to simulate the effects of adding additional stations or creating a pop-up station (Section 2).

For new or pop-up stations, the probability of turnout and the mobilisation time are read in from the *New or Pop-up Mobilisation* tab for the operational zone. This means the times and probabilities for these stations do not have to be set every time and are saved for future scenarios.

For new stations, the availability and mobilisation time for each zone can be adjusted on the *New or Pop-up Mobilisation* tab.

For pop-up stations, the crew is mobilised from Blenheim therefore the availability is equal to that of Blenheim Rural Fire Force. The mobilisation time is determined by the mobilisation time of Marlborough Helicopters Ltd plus the time taken to fly to the centre of the operational zone of the pop-up station.

5 Use of the Tool

Once the base settings satisfy the operating conditions, scenarios can be created and run on the interface to assess the benefit or detriment of moving resources or changing operational parameters.

5.1 Scenario Settings

Each scenario has a number of operational decisions (*scenario settings* on the *interface* tab of the tool) specific to the scenario:

- Enabling/Disabling use of DoC resources
- Enabling/Disabling use of forestry resources
- Enabling/Disabling use of out-of-jurisdiction resources (e.g. from adjoining districts)

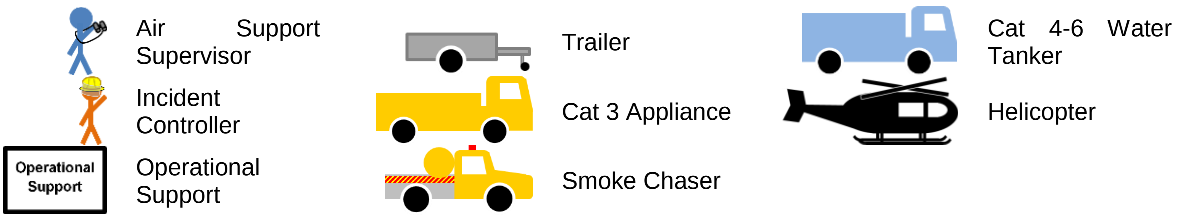
- Adjusting the average speed of helicopters
- Inclusion of initial attack heli-attack for distant fires, where the road travel time for the required number of the closest resources[1] to arrive is greater than the time specified.

These settings apply to the current scenario only and do not affect previous or future scenarios.

5.2 Allocation of Resources

Once the settings are determined and set, the resources can be reallocated. This is done by dragging the images to the desired station. The resource will be allocated to the station corresponding to the row that the top of the image is located in. After the scenario is run, the resource image will align with the other resources so the allocation can be checked.

There are 8 types of resources modelled in the tool:



Land-based resources should not be moved to helicopter bases and vice-versa as this will result in the wrong travel times applied to the resources. Air support Supervisors and Incident Controllers may be allocated to either land stations or helicopter bases and depending on which they are allocated to this will affect their travel time (as it affects whether they travel by air or land).

5.2.1 Use of Pop-up Stations

Pop-up stations have the ability to select the months during which they are operational. For any unselected month, the pop-up station and associated resources are assumed unavailable. These settings are saved and reloaded with scenarios.

5.3 Save Scenario

After a scenario has been created (resources have been moved, or settings adjusted), the scenario needs to be run using the button on the top right of the interface. The scenario can then be assessed using the results section and, if desired, saved.

The tool has the ability to save up to 10 scenarios. Scenarios may be overwritten or renamed. Saved scenarios can be re-loaded (and consequently modified or adjusted and re-saved) they can also be compared to subsequent scenarios in the results section.

5.4 Load Scenario

Any saved scenarios can be loaded from the drop down menu. Selecting a loaded scenario will re-allocate the resources on the interface as well as reselecting the scenario settings and updating the results. Note that loading a scenario will mean the current scenario (if not saved) will be lost.

[1] Does not occur where closest resources could respond in time, but due to availability more distant resources attend the fire.

6 Outputs

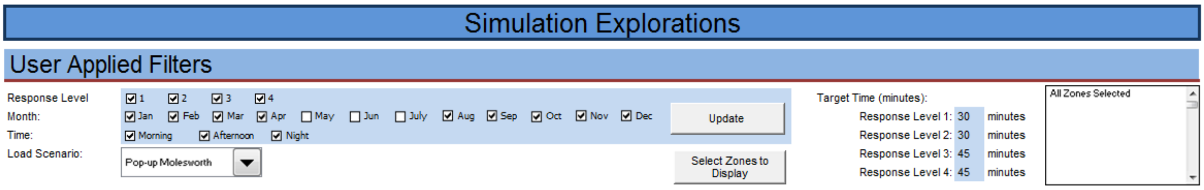
There are three results tabs included in the tool, a graphical results section, service gap data, and a summary of the simulations.

6.1 Graphical Results

The results tab contains a number of graphical outputs based on the scenario created. Graphs with the title *Scenario Comparison* indicate where saved scenarios are plotted against the current scenario (active scenario on the Interface tab). Where the title of the graph is *Current Scenario* this refers to the active scenario on the Interface tab.

The following pages are taken directly from the tool and outline the graphs and tables presented in the results tab.

Filters and Target Times



Using this section of the results tab, filters can be applied to most graphs on the tab and to the base data for the Gap Map. This allows drill-down to specific scenarios to assess the performance of the scenario. Drill-down also includes the ability to select the results for selected operational zones, with multiple zones able to be selected filtering the graphs.

Saved Scenarios are also able to be loaded from this tab; however, using this will overwrite any unsaved changes on the interface tab.

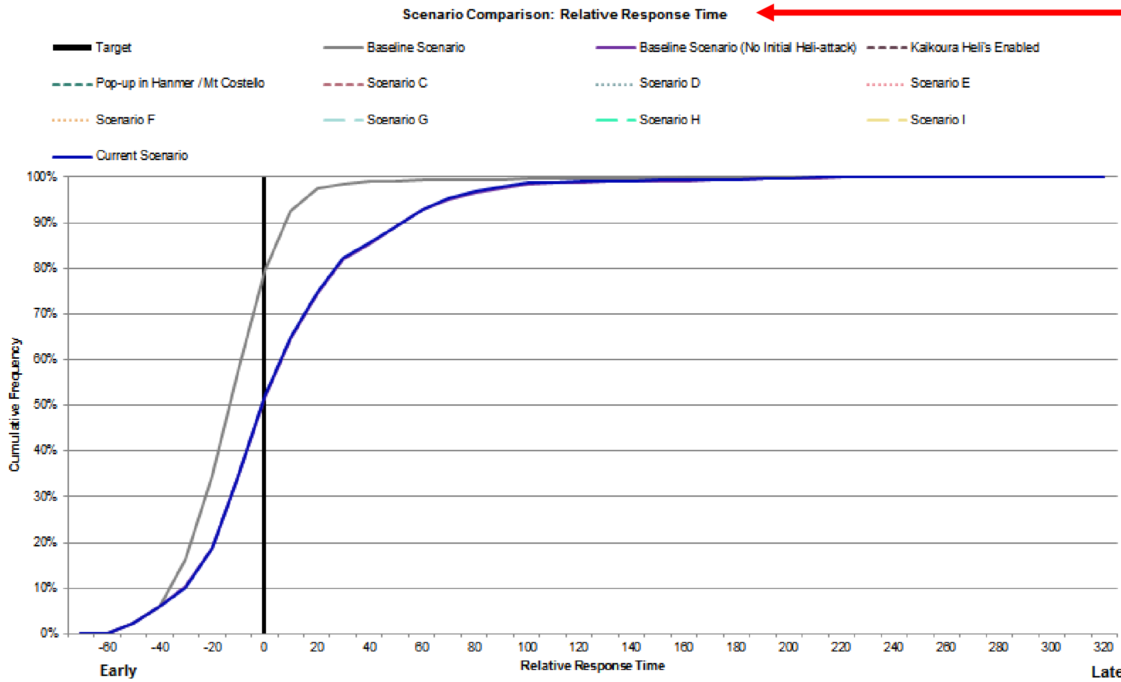
This is also where the target times are set, the target times are split by response level to enable comparison of performance between the different response levels using the time taken to respond relative to the target time (relative response time).

Comparison of Scenarios

This dashboard provides an overview of scenarios generated by the user, so that the user can track and manage the scenario development process.

Explorations

Scenario:	Helicopter Speed (knots)	Initial Attack Heli-Attack where road response time above (mins)?	Out of Jurisdiction Resources Respond?	DoC Resources Respond?	Forestry Resources Respond?	Display Scenario on Graph?	Average Response Time Relative to Target (mins)	Proportion of Fires Receiving Required Response within Target Time
Current Scenario	100	No	Yes	No	Yes	☑	10	45%
Baseline Scenario	100	60	Yes	No	Yes	☑	-8	70%
Baseline Scenario (No Initial Heli-attack)	100	No	Yes	No	Yes	☑	11	44%
Kaikoura Heli's Enabled	100	60	Yes	No	Yes	☐	-10	76%
Pop-up in Hanmer / Mt Costello	100	No	Yes	No	Yes	☐	10	44%
Scenario C	100	60	Yes	No	Yes	☐	-8	70%
Scenario D	100	60	Yes	No	Yes	☐	-8	70%
Scenario E	100	No	Yes	No	Yes	☐	-8	70%
Scenario F	100	No	Yes	No	Yes	☐	-8	70%
Scenario G	100	No	Yes	No	Yes	☐	-8	70%
Scenario H	100	No	Yes	No	Yes	☐	-8	70%
Scenario I	100	No	Yes	No	Yes	☐	-8	70%



Click to display scenario on graph to right.

This shows the saved scenarios, indicates performance and outlines the parameters surrounding the scenario to enable comparison and identification of the differences between the scenarios.

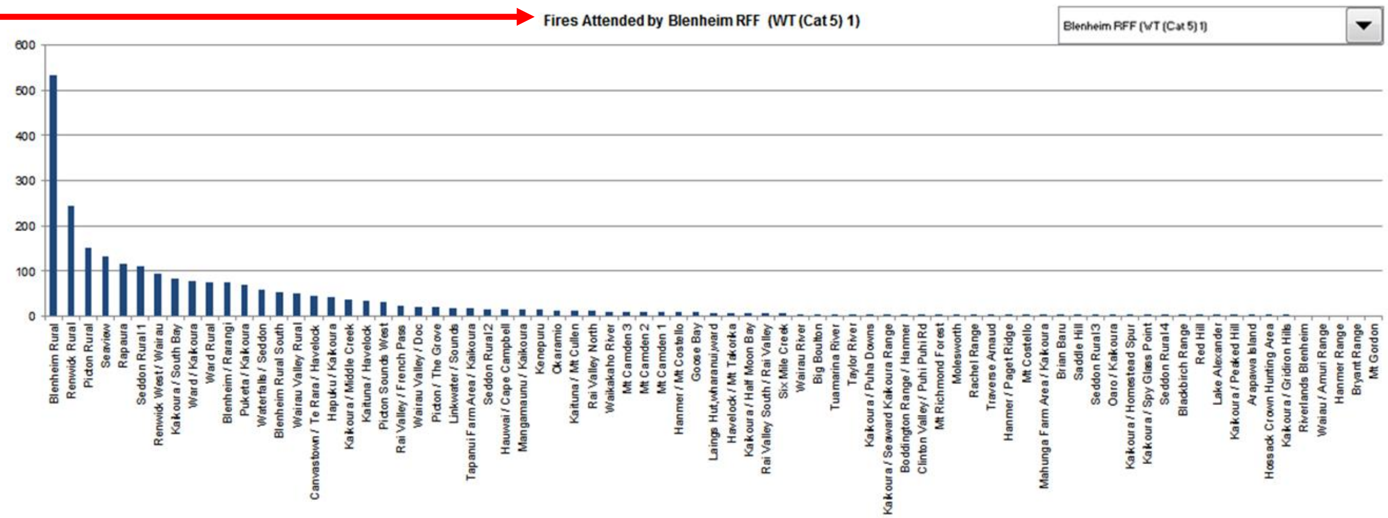
This graph shows the proportion of simulated fires that have received the required initial response at each relative response time. Lines plotting higher on the y-axis are the better performing scenarios. Times less than zero mean that on average the response arrived earlier than the target.

Limiting Resources, Utilization and Station Workload

This panel provides resource-based view of the fire response, showing which resources are called out most and least often.

Limiting Resource Summary - Current Scenario			
Limiting Resource Rank Rank 1 to 5	Resource ID Water Tanker	Avg Response Time	% Responses After Target Time
1	Pop-up Station 1 (New WT 3)	137	100%
2	Hanmer (WT (Cat)1)	112	93%
3	Nelson Forests (Kaituna) (WT (Cat 4) 5)	89	90%
4	Flaxbourne (WT (Cat 4) 3)	86	72%
5	Canvastown VFF (WT (Cat 4) 2)	74	61%

Seldom Utilised Resource Summary - Current Scenario		
Seldom Utilised Rank Rank 1 to 5	Resource ID Water Tanker	% of Fires Attended
1	Okiwi Bay (WT (Cat 5) 4)	0%
2	Pop-up Station 1 (New WT 3)	1%
3	Hanmer (WT (Cat)1)	3%
4	Canvastown VFF (WT (Cat 4) 2)	4%
5	Nelson Forests (Kaituna) (WT (Cat 4) 5)	4%



This graph shows the count of simulated fires that a resource attends in each zone. It can be used before moving a resource to identify the zones that may be affected.

Limiting Resource Summary, this shows the average response time and the proportion of responses that arrive after the target time. The display shows resources that respond to at least one fire.

Click the drop down menu to select the resource for the graph to display.

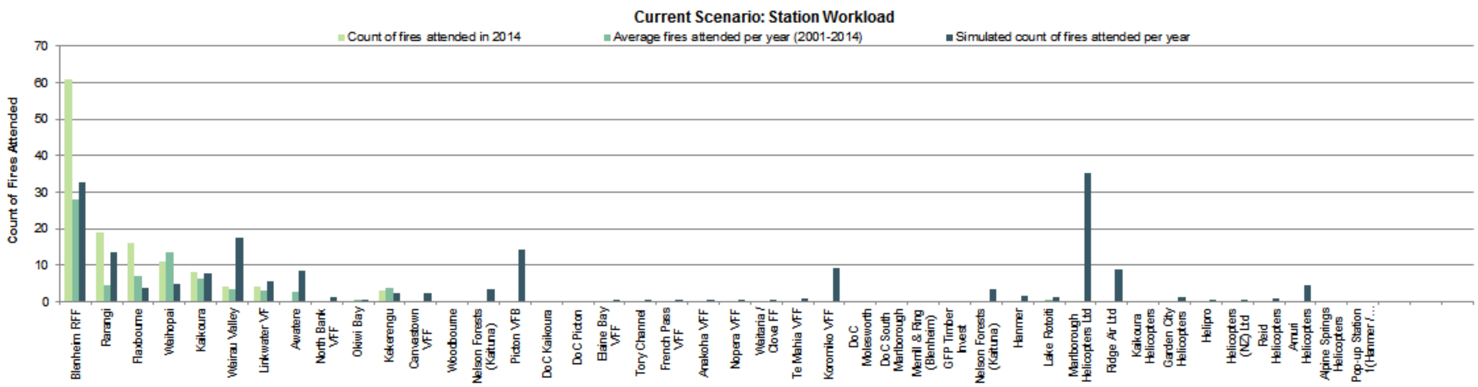
Click to view table for other resource types.

Seldom Utilized Resource Summary, this shows the proportion of simulated fires which resources responded to as initial response, arranged by order of frequency of callout.

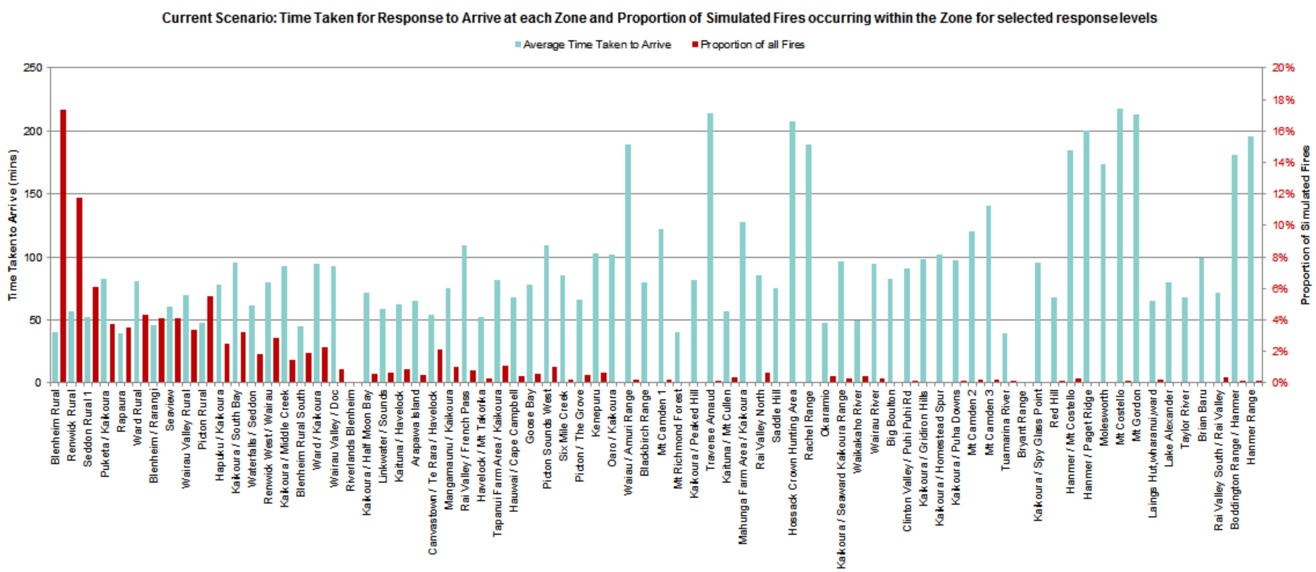
Click to select higher ranked resources.

Station Workload and Response Times to Zones

This graph illustrates the simulated average number of fires each station would attend during a one-year period. This is plotted against the count of fires attended in 2014 and the average count of fires attended per year.

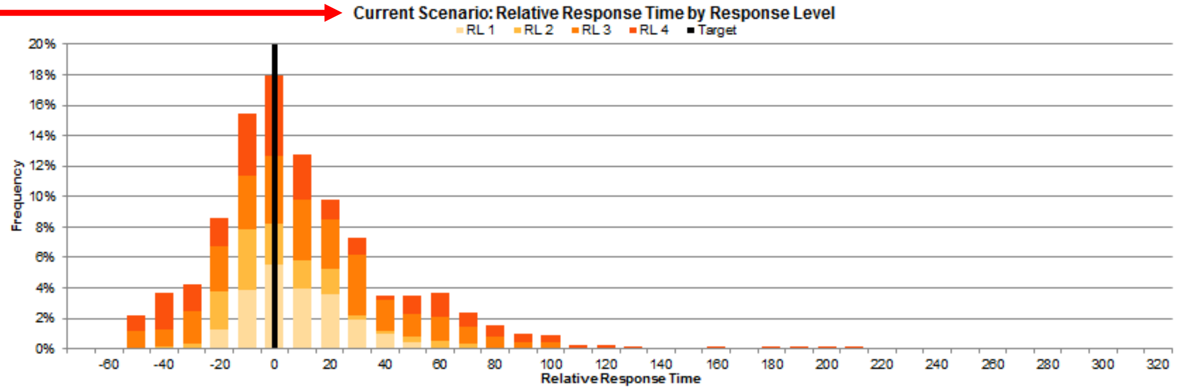


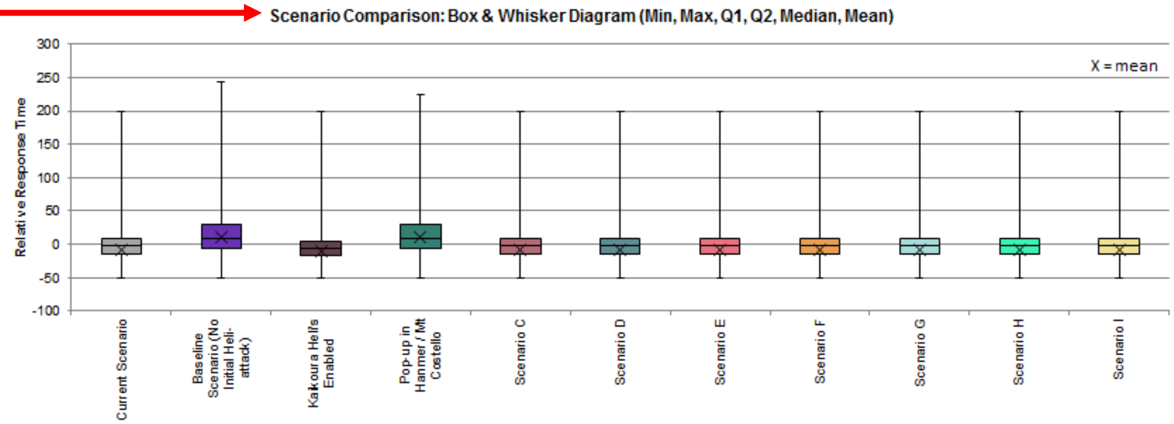
This graph identifies the average time taken to arrive to the simulated fires in each zone and the proportion of simulated fires that occur in the zone. Areas where the proportion of fires is high and the time taken is also high should be focused on for maximum improvement. These areas are identified geographically in the Gap Map (Section 6.2).

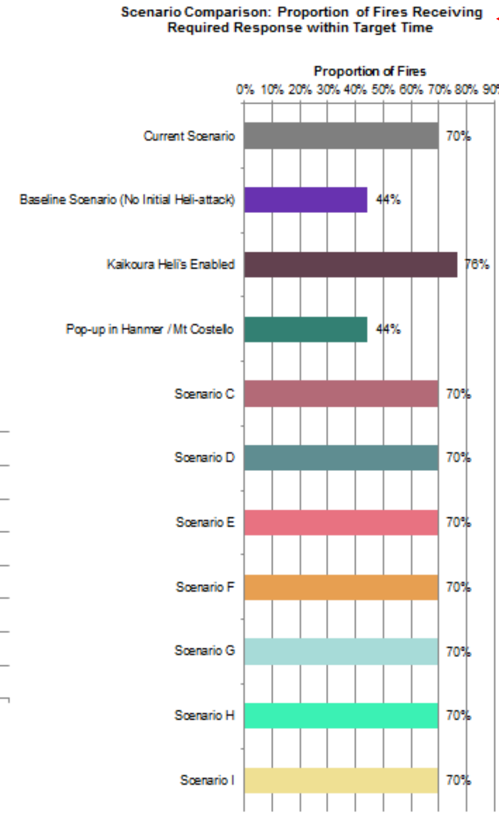


Relative Response Time, Scenario Comparisons

This graph illustrates further statistics on the scenarios performance as well as comparison with other scenarios.







This graph compares the current scenario with the saved scenarios, showing the shortest, longest, median and mean relative response times.

This graph shows the frequency that the relative response time falls within the response time bracket by response level.

This shows a comparison of the proportion of fires that are responded to before the target time for the current and saved scenarios.

6.2 Service Gap Data (Gap Map)

This tab contains a table with information relating to the service level each operational zone receives. The table identifies the response level at which initial heli-attack kicks in (if at all), the average time taken for the required resources to arrive in relation to the target and the proportion of simulated fires that occur within the zone. From this, a measure of the service level is calculated from the simulations (proportion of fires within the zone x the number of minutes ahead or behind target the response multiplied by 100), and the service level then categorized into groups.

6.2.1 Creating a Gap Map

From the service map data, a csv can be created and this joined to a shape file containing the boundaries of the operational zones. From here, the merged shape file can be uploaded on Google Maps and styles applied to the weighted value categories. The description field can be used to describe the main parameters of the scenario.

The map can then be made accessible to collaborators who can view/edit/save or invite others to view (depending on their access rights). Once invited, the map will become accessible to the user from the following link and appear in the *Shared with me* tab as per Figure 6.1. https://www.google.com/maps/d/

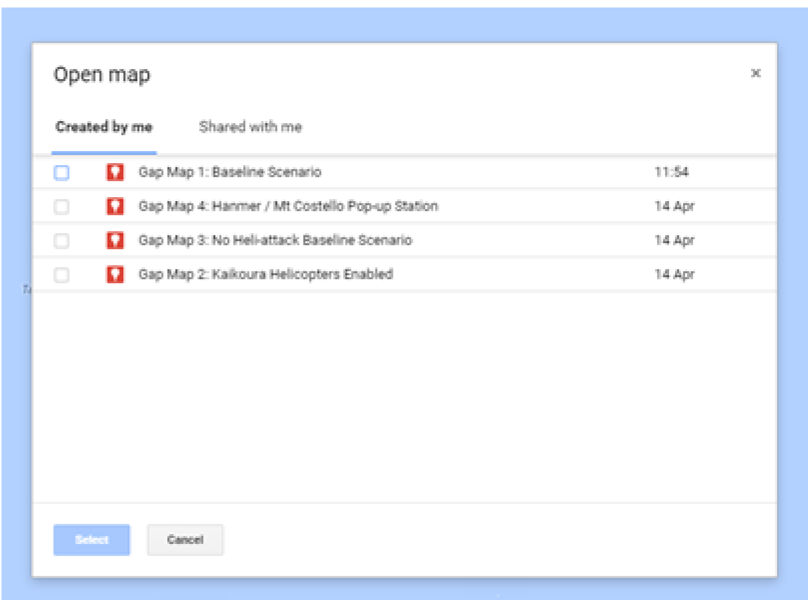


Figure 6.1 Google Maps, maps available to view

6.2.2 Viewing a Gap Map

Gap Maps that have been shared with you are available by accessing the following link https://www.google.com/maps/d/

The maps will appear in the *Shared with me* tab as per Figure 6.1.

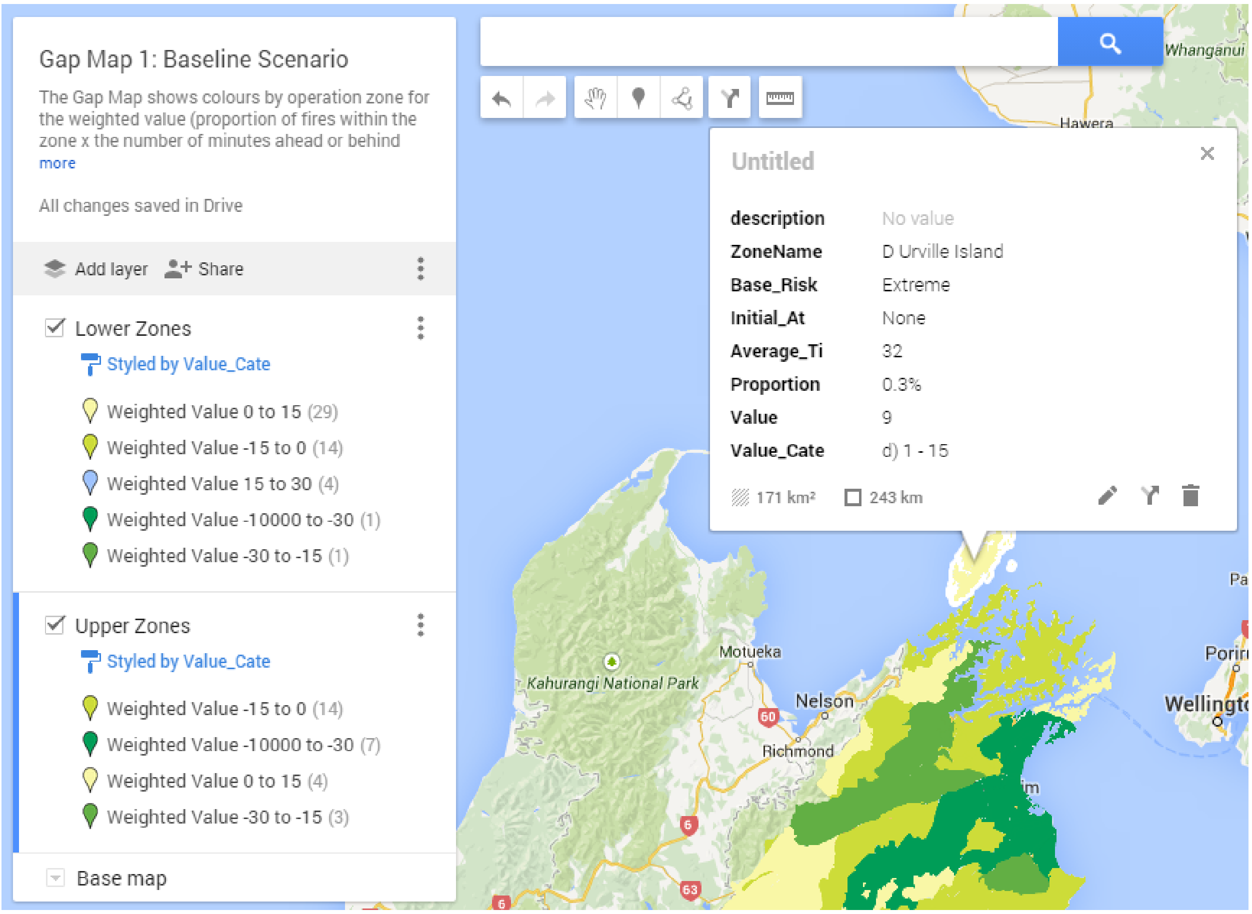


Figure 6.2 Gap Map for the Baseline Scenario

Figure 6.2 shows the Gap Map for the Baseline Scenario. A brief explanation of the scenario is contained on the top left. Also included on the lower left is the key. Due to the size of the file, the lower zones and upper zones have been uploaded separately.

Clicking on a zone also offers other information for the operational zone specific to the scenario, including the average time taken in relation to the target and the proportion of simulated fires within the zone. You can also view the area the zone covers, or edit the description.

Other functions of Google Maps are also able to be used, for example search, measure distance and find directions. Additionally, markers are able to be added to the map with editable descriptions.

6.3 Simulations Last to Arrive

This tab contains for every simulation, the zone, time of day, base zone risk, whether the fire was accessible, whether heli-attack was deployed, the fire weather index, response level, target time, relative response time and finally the resource(s) that were the last to arrive. This enables drill down to specific situations, to identify how to improve the scenario.

7 Assumptions and Limitations

The following assumptions and limitations of the tool should be borne in mind by users:

- If an Operational Support vehicle is unable to attend, the next closest Operational Support is called.
- Incident Controllers and Air Support supervisors are available 100% of the time.
- Medium Appliances, Smoke Chasers and Trailers are treated as equal as a response vehicle in terms of the tactical plan.
- The turnout order of 4x4 type resources from a single station is Medium Appliance, Smoke Chaser, and then Trailer.
- If a resource is located at a helicopter base it travels by air otherwise by land. Therefore it is important to ensure resources are allocated to the correct type of station.
- The tool assumes stations are located at the centre of the zone.
- The tool randomizes travel times by ±10 minutes in part to account for fire locations away from the centre of the zone or weather conditions.
- Where an aircraft was used as a taxi only (e.g. to transport incident controller and/or air support supervisor) this was not counted as part of the initial response.
- The results by station and/or resource do not count responses where Blenheim attended as a cover resource, but where there were available resources closer to the fire.

8 Tool Tips

In practice, for optimisation, a two-stage approach is recommended. Firstly, optimise the resources with Heli-attack turned off, as this allows underlying performance of land based resources to be assessed. Following this, turn the Heli-attack switch on to assess the overall performance of the optimised resource deployment. This approach will minimise the call on more expensive helicopter resources and should lead to a more optimal allocation of resources.

The simulations last to arrive tab of the results can be used in conjunction with the Gap Map, using the map to identify zones that require improvement to the service level and filtering the last to arrive table for the corresponding zone. The limiting resource column may identify a particular resource or type of resource that is limiting the response; this then provides a start point for further adjustments to the scenario.

9 Conclusion

STAR development and successful pilot trial in MKRFA demonstrates the feasibility of simulating the complexities of rural fire-fighting resource deployment. STAR assists managers to make better strategic decisions on the allocation of firefighting equipment within a district. The tool supports managers, putting control in their hands, and providing them with a clear understanding of service gaps and limitations.

The tool runs 5,000 simulations, modelling many decades of fires, which provides insights that may not be apparent from shorter-term experience. The best outcomes will be achieved by combining the insights from such long-run modelling with the practical on-the-ground experience of fire managers.

10 Appendices

The following data lists ignition data abstracted from the NZFS database for the calendars years 2000-2014. The NZFS data were used only for time, date, FWI and place of ignition.

Appendix B1 Base Data

B1.1 Zone

The table below identifies the historical record of ignition locations (fire location if ignition not separately identified) by zone from the NZFS record for the 15-year period 1 Jan 2000 to 31 Dec 2014. The first column is a switch indicating whether the zone is one which the Blenheim RFF turns out for as the default backup, and substitutes for any nearer resource which is unable to turn out for a particular fire simulation.

Operational Zone:	**Blenheim Turn-out? (1=Yes)**	**Count of Historic Fires**
Blenheim Rural	1	148
Renwick Rural	1	102
Picton Rural	0	53
Seddon Rural 1	1	49
Seaview	1	34
Ward Rural	1	33
Puketa / Kaikoura	0	32
Blenheim / Rarangi	0	31
Wairau Valley Rural	1	29
Rapaura	1	28
Kaikoura / South Bay	0	26
Hapuku / Kaikoura	0	21
Renwick West / Wairau	1	20
Canvastown / Te Rara / Havelock	0	18
Kaikoura / Middle Creek	0	15
Waterfalls / Seddon	1	15
Blenheim Rural South	1	14
Ward / Kaikoura	0	14
Mangamaunu / Kaikoura	0	8
Tapanui Farm Area / Kaikoura	0	7
Wairau Valley / Doc	0	7
Rai Valley / French Pass	0	7
Kaituna / Havelock	0	7
Picton Sounds West	0	6
Linkwater / Sounds	0	5
Kaikoura / Half Moon Bay	0	4
Goose Bay	0	4
Picton / The Grove	0	4
Rai Valley North	0	4
Seddon Rural 2	1	3
Hauwai / Cape Campbell	1	3

Kenepuru	0	3
Arapawa Island	0	3
Havelock / Mt Takorika	0	2
Okaramio	0	2
Waikakaho River	0	2
Rai Valley South / Rai Valley	0	2
Mt Camden 1	0	1
Mt Camden 2	0	1
Mt Camden 3	0	1
Kaikoura / Seaward Kaikoura Range	0	1
Laings Hut,wharanui,ward	0	1
Oaro / Kaikoura	0	1
Six Mile Creek	0	1
Wairau River	0	1
D Urville Island	0	1
Kaituna / Mt Cullen	0	1
Seddon Rural 3	1	0
Seddon Rural 4	1	0
Big Boulton	1	0
Blackbirch Range	1	0
Clinton Valley / Puhi Puhi Rd	0	0
Kaikoura / Gridiron Hills	0	0
Kaikoura / Homestead Spur	0	0
Kaikoura / Puha Downs	0	0
Lake Alexander	1	0
Mt Richmond Forest	0	0
Taylor River	1	0
Tuamarina River	0	0
Brian Baru	0	0
Bryant Range	0	0
Kaikoura / Peaked Hill	0	0
Kaikoura / Spy Glass Point	0	0
Mahunga Farm Area / Kaikoura	0	0
Red Hill	0	0
Saddle Hill	1	0
Boddington Range / Hanmer	0	0
Hanmer / Mt Costello	0	0
Hanmer / Paget Ridge	0	0
Hanmer Range	0	0
Hossack Crown Hunting Area	0	0
Molesworth	0	0
Mt Costello	0	0
Mt Gordon	0	0
Rachel Range	0	0
Traverse Arnaud	0	0
Waiau / Amuri Range	0	0
Riverlands Blenheim	1	-
Rai Valley / Whangamoa	0	-

Blenheim Township	0	-
Havelock Township	0	-
Kaikoura Township	0	-
Picton Township	0	-
Rai Valley Township	0	-
Renwick Township	0	-
RNZAF Woodbourne	0	-
Roselands Blenheim	0	-
Seddon Township	0	-
Wairau Valley Village	0	-
Ward Township	0	-
Hamner Springs	0	-
St Arnaud	0	-

B1.2 Month

	Fire Weather Index			
	0-4	**5-15**	**16-30**	**30+**
Month	**Low**	**Moderate**	**Very High**	**Extreme**
January	4	21	24	24
February	0	12	25	15
March	2	13	24	21
April	6	19	8	0
May	7	11	5	1
June	4	12	2	0
July	7	8	2	1
August	8	20	4	0
September	6	24	9	2
October	9	25	13	6
November	13	18	21	32
December	7	37	24	23

B1.3 Time of Day

Time:	**Count of Historic Fires**
Morning	117
Afternoon	359
Night	217

B1.4 Fire Weather Index

Month	**Count of Historic Fires**
January	107
February	70
March	76
April	36

May	26
June	21
July	19
August	34
September	43
October	58
November	95
December	108

B1.5 Response Level

		Risk Level (from Operational Zone)			
		RL 1	**RL 2**	**RL 3**	**RL 4**
		Low	**Moderate**	**Very High**	**Extreme**
FWI Level	Extreme	two	three	four	four
	Very High	two	three	four	four
	High	one	two	three	four
	Moderate	one	one	two	three
	Low	one	one	two	two

Appendix B2 Fire Event Simulation

Each simulation has factors assigned, these factors help determine the resources that are needed to meet the initial response. The factors are based on historic fire data, user defined values and the fire plan.

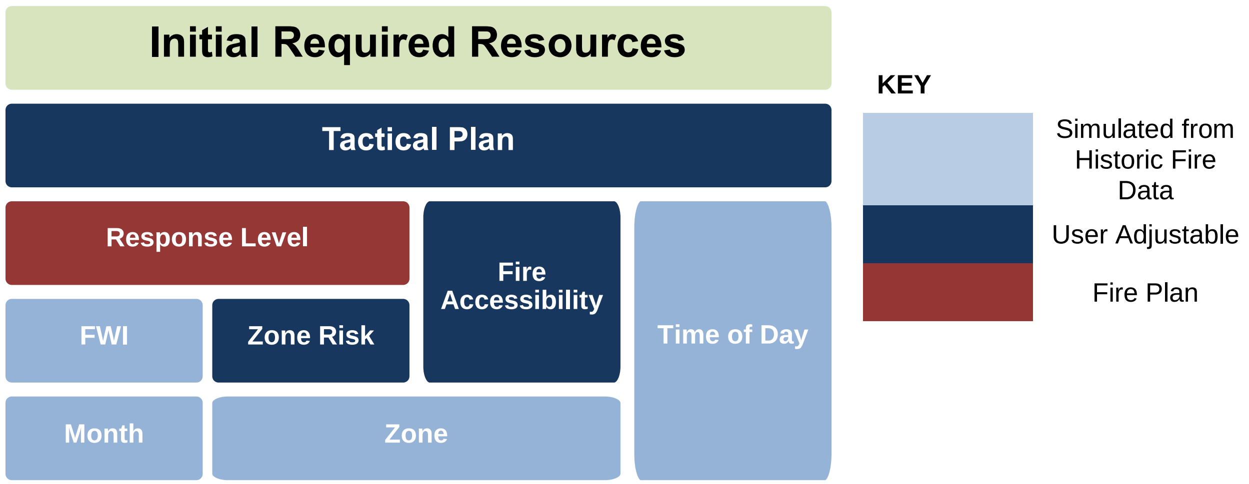


Figure 10.1 Simulation factors

B2.1 Month

The month for each simulated fire is randomly generated from the historic fire data according to the proportion of fires that occurred during each month. The fire weather index (FWI) is assigned based on the historical distribution of FWI for that month.

B2.2 Zone

Fires are populated to operational zones according to the proportion of fires in the historic dataset (2000 – 2014). This factor is used to simulate the accessibility and base risk of the fire.

The operational zones were taken from a shape file provided by the Fire Service, with Seddon Rural split into four zones due to its large size.

To allow for zones where no historic fires were recorded, the data was transformed by adding one dummy fire to every zone. This results in a low probability (but possibility) of a fire occurring in every zone.

B2.3 Time of Day

Simulated fires are assigned a time of day to determine the type of response (which tactical plan is used). Fires are allocated as either occurring in the morning, afternoon or night, according to the proportion of fires in each category from the historic fire dataset. If the simulated fire occurs at night, the night tactical plan is used to determine the resources, otherwise the base tactical plan is assumed.

B2.4 Fire Weather Index (FWI)

A category based on the FWI is assigned to the simulation according to the month the fire was determined to occur during. This is based on the historic fire dataset and the average proportion of fires each month that had a FWI corresponding to each level (low, moderate, very high, extreme). This is used in conjunction with the base zone risk to determine the response level of the fire from the *response level / fire weather index correction matrix* in the *MKRFA Rural Fire Plan*.

B2.5 Zone Risk

This is a field able to be redefined by the user; the values represent the risk rating and are based on the MKRFA's *Risk Ratings Key*. The key modifies the risk level for FWI. This is used in conjunction with the FWI to determine the response level.

B2.6 Fire Accessibility

This factor refers to whether the fire is accessible by land. This is controlled by the user through the probability entered on the *zone accessibility* tab (refer Section 4.2). If the fire is not accessible, the Heli-attack tactical plan is used as the required response (regardless of whether the Heli-attack interface switch is on, Section 5.1).

B2.7 Response Level

Response Level is determined from the assigned FWI and zone risk assigned to the simulation. It is assigned by the tool according the *Response Level / Fire Weather Index Correction Matrix* from the MKRFA Rural Fire Plan. This response level determines the number of resources required for initial response from the tactical plan.

B2.8 Tactical Plan

There are three tactical plans used by the tool, one for night responses, another for simulations where initial Heli-attack is deployed and one for all other simulations. Each of these is able to be adjusted by the user. The accessibility and time of day determine which tactical plan is used and the response level determines which part of the plan is modelled. This results in the initial required number of resources of each type for every simulation.

B2.9 Initial Required Resources

If the initial heli-attack switch is turned on (*interface* tab), the shortest time taken for the closest land based resources to arrive (assuming all turn-out) at the simulated location is calculated. This is compared with the minutes after which heli-attack would be deployed input on the interface (Section 5.1) and determines whether initial heli-attack is implemented, thereby adjusting the required resources (if heli-attack is determined to be deployed).

Appendix B3 Determining Response Time

With the simulation factors determined, and the resources required for initial response identified, the responding resources can be modelled. Figure 10.2 shows an overview of the process undertaken by the tool to determine the resources that respond to the simulated fire and thereby the time taken for all the required resources to arrive.

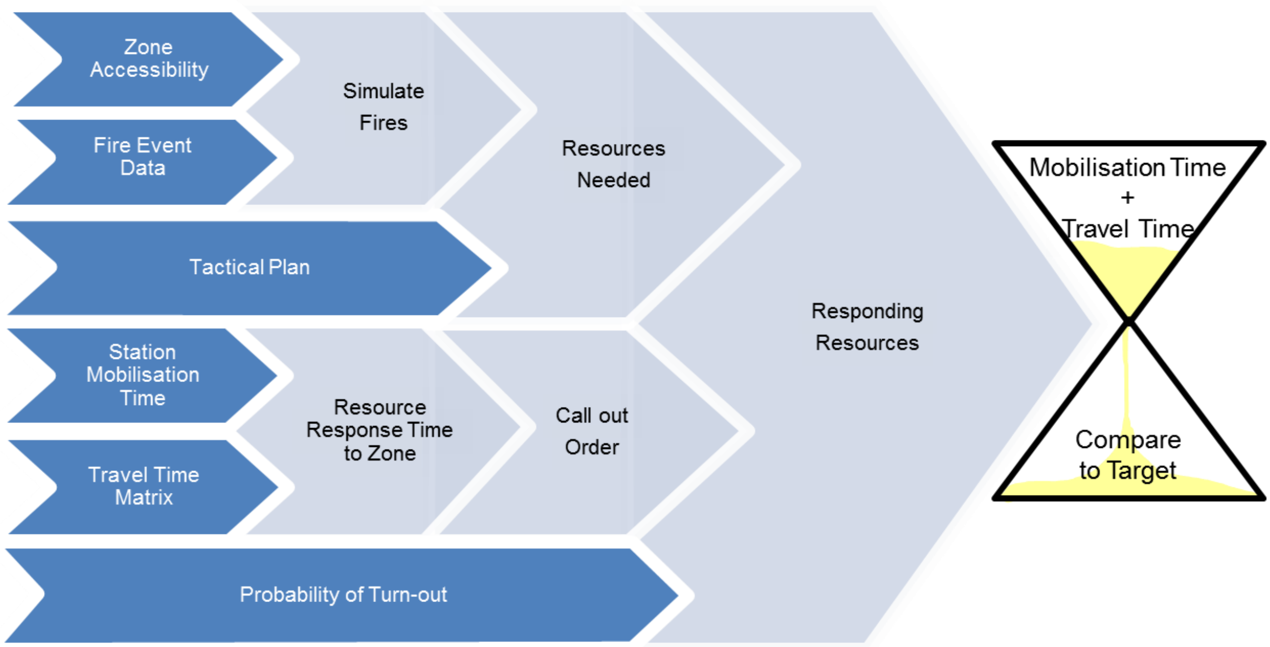


Figure 10.2 Overview of process undertaken to find the response times to simulated events

The response time to the centre of all operational zones is calculated for all resources. This is taken as the mobilisation time of the station (user defined, Section 4.4) plus the travel time from the operational zone of the resource to the operational zone. From these times, the call out order of resources for each zone is calculated. The tool then looks up the simulation zone and calls the resources out in order (determining whether they are able to attend according to the probability of mobilisation, Section 4.4) until the response is met.

In practice, in MKRFA the Blenheim station provides a higher proportion of backup than would occur if resources were called strictly in order of proximity to the fire. This is because Blenheim has more capability and capacity. In the model, this preference for Blenheim backup is simulated for operational zones in the vicinity of Blenheim (Figure 10.3). In these zones, where resources are unable to attend and Blenheim has additional resources, Blenheim is turned out as cover rather than the next closest resource. If all Blenheim resources are already attending the fire, or the operational zone is outside the Blenheim cover area defined below, the next closest resource is called until the response is met.

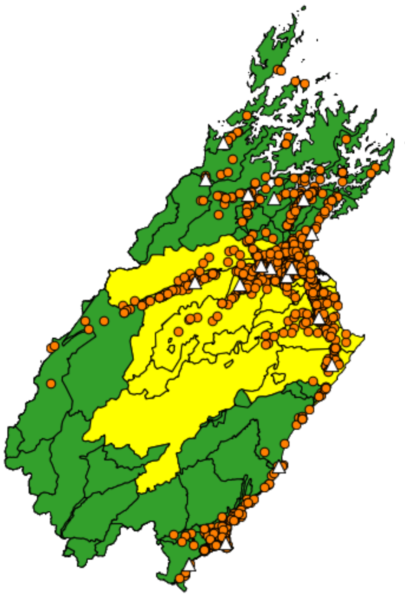


Figure 10.3 Operational zones where Blenheim is called as cover for a non-attending resource (yellow zones).

Appendix B4 Validation

1. Data Validation

One form of validation was to compare data supplied by NZFS against the Marlborough Kaikoura Rural Fire District cleaned record for the 2014 calendar year. This is shown in Table 10.1.

Table 10.1 Validation of station turnout records against MKRFD cleaned record.

Station	NZFSC Data	MKRFD Summary
Blenheim	17	23
Kaikoura	12	7
Linkwater	1	1
Nelson	1	1
Picton	2	2
Rai Valley	1	1
Renwick	7	6
Seddon	5	6
Wairau Valley	2	2
Ward	2	2
Rarangi	0	6
Total	**50**	**57**

The comparison finds that the distribution of responding stations is generally similar. Differences are likely due to reclassification of fire events.

It is not essential that fire counts are identical, provided that the distribution of fire events is representative.

2. Trial Run of Scenarios

Following the completion of the tool, several tests were run to assure the tool was producing sensible output.

Four Gap Maps (Section 6.2) were produced for different situations. The Gap Map shows colours by operation zone for the weighted value (proportion of fires within the zone x the number of minutes ahead or behind target the response is, multiplied by 100). This helps illustrate where gaps in the service levels are. These all performed as expected.

B4.1 Key

Colour	Min	Max
		-30
	-30	-15
	-15	0
	0	15
	15	30
	30	45
	45	60
	60+	

B4.2 Gap Map 1: Baseline Scenario

This shows performance of the present deployment of resources, with "automatic" Heli-attack for distant areas where the road response time for all resources to arrive is above 1 hour. The response time is compared against the default target response times set for each alarm level. The baseline shows generally good performance, except around Kaikoura.

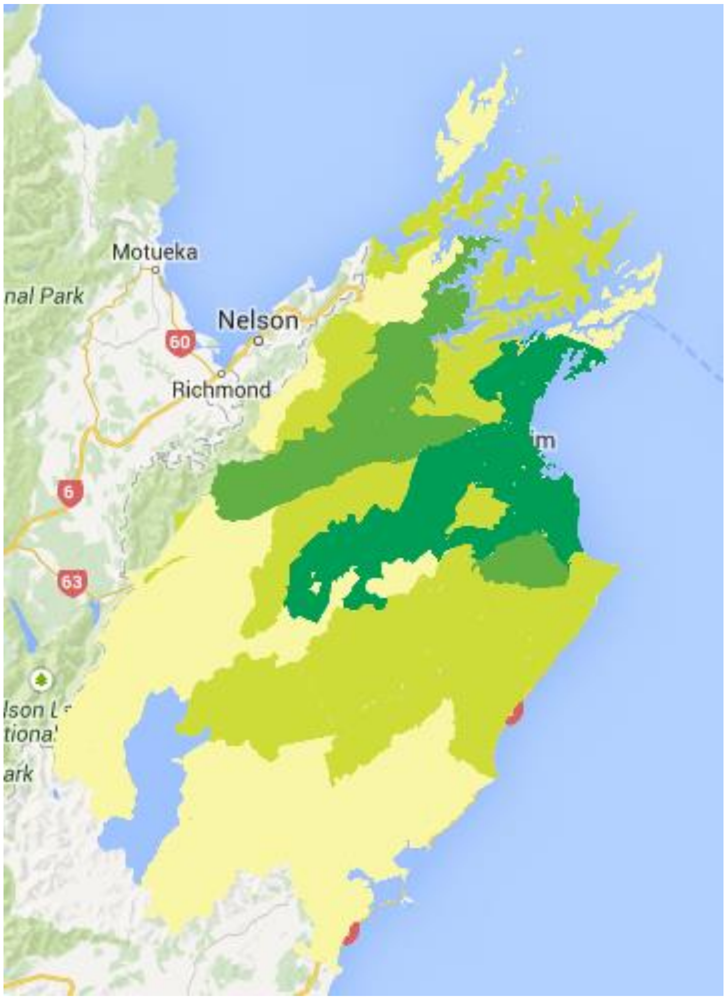


Figure 10.4 Gap Map 1

B4.3 Gap Map 2: Kaikoura Helicopters Enabled

Kaikoura Helicopters Enabled: This shows performance of the present deployment of resources (with initial Heli-attack), for the default target response times set for each alarm level. In addition, this scenario develops reliable helicopter capability in Kaikoura (both operator and the MKRFA staff to direct such operations, an Incident Controller and an Air Support Supervisor). Comparing to the baseline, it shows the benefit if such capability can be developed/deployed. In this scenario, the area around Kaikoura has been improved and the simulations show Kaikoura Helicopters responding as expected.

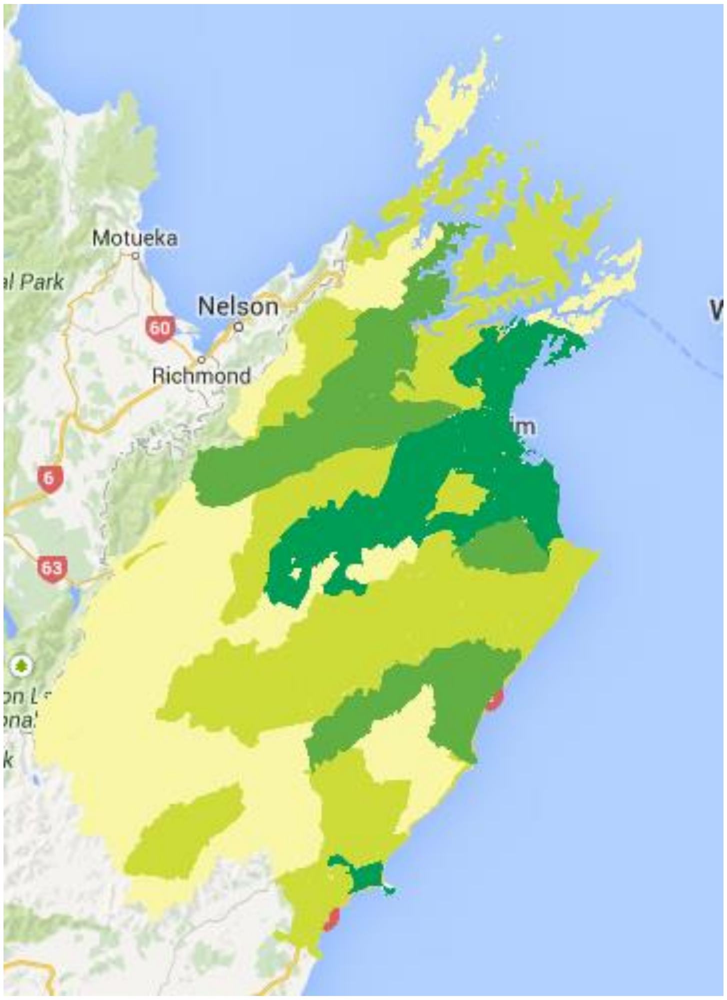


Figure 10.5 Gap Map 2

B4.4 Gap Map 3: No Heli-attack Baseline Scenario

No Heli-attack Baseline Scenario: This shows performance of the present deployment of resources (with no initial Heli-attack), for the default target response times set for each alarm level. This shows the effect if there was no "automatic" Heli-attack for distant areas. Comparing to the baseline, it confirms the positive difference that Heli-attack makes for outlying areas. This confirms that the Heli-attack switch is working and that a different response is being modelled for distant zones.

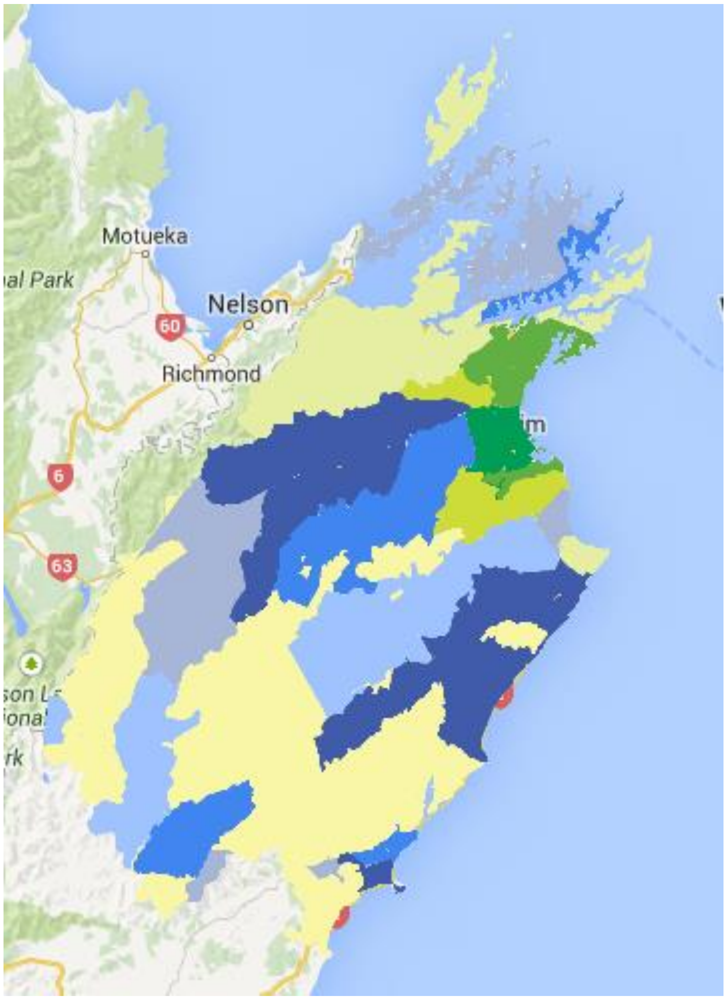


Figure 10.6 Gap Map 3

B4.5 Gap Map 4: Hanmer / Mt Costello Pop-up Station

Hanmer / Mt Costello Pop-up Station: This shows performance of the deployment of resources (with no initial Heli-attack), for the default target response times set for each alarm level. In addition to the current deployment of resources, a "pop-up" station is placed in Hanmer / Mt Costello. This pop-up station has an additional medium appliance and water tanker and would require a helipad. Crews are mobilised from Blenheim by Helicopter. Comparing to the baseline with no Heli-attack (Gap Map 3), it shows a small improvement local to the area. The benefit is limited by the low number of fires in the locality and by the long travel times due to the sparse roading network. Due to the low utilisation, this would be an ideal place for older equipment to be semi-retired.

This example illustrates that simulation of the pop-up station concept works in the model.

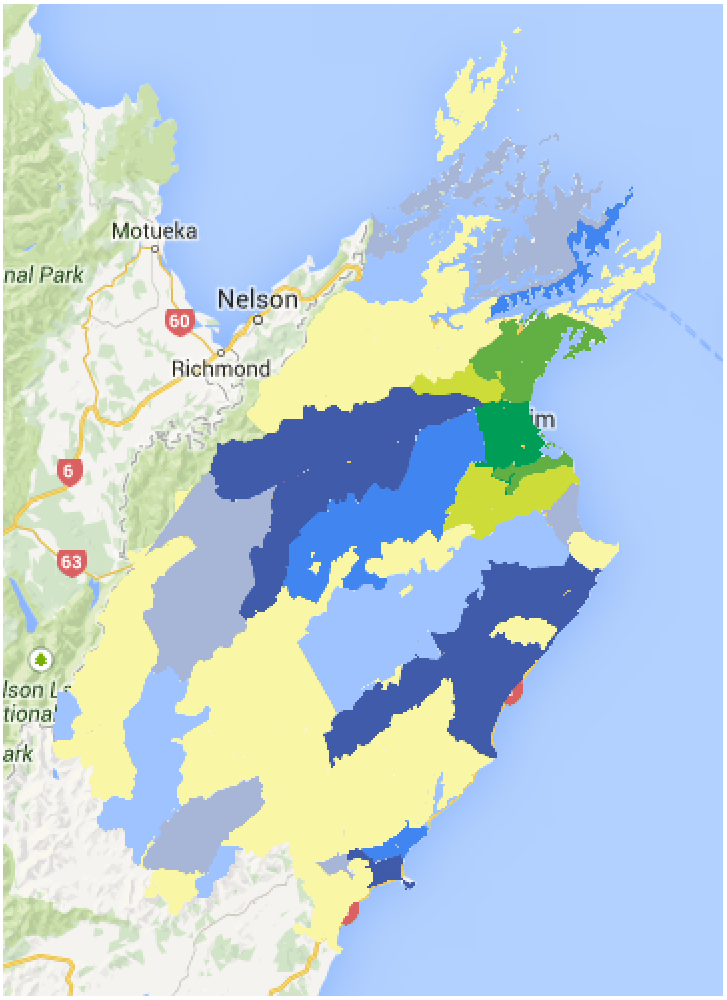


Figure 10.7 Gap Map 4

Appendix B5 Amendment Log

Version	Amendment
Rev 0	Finalised from Draft
Rev 1	Updates resulting from: • addition of zone filter for model results • addition of month specification for pop-up stations Adjustment of gap map legend.
Rev 1.3	Final editing

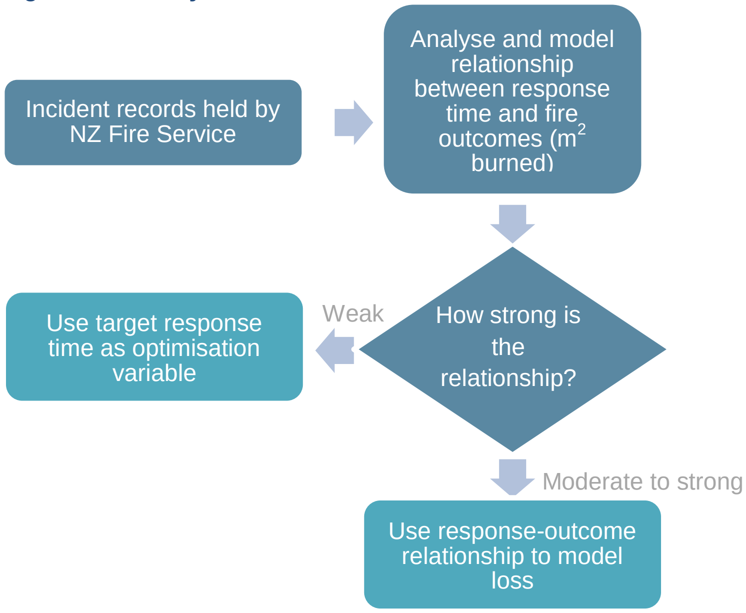
Appendix C – Statistical Analysis of Fire Size by Response Time

1 Introduction

Navigatus undertook analysis of the fire data received from the New Zealand Fire Service (NZFS) to assess the relationship (if any) between fire response and fire outcome in terms of area burnt, as outlined in Figure 1.1.

If a moderate to strong relationship were to exist between these variables, this would inform the Scenario Tool for Allocating Resource (STAR) through modelling the loss under different resource allocation scenarios.

Figure 1.1 - Analysis of Effect of Response Time



2 Dataset

Data from the NZFS database was used to assess the relationship between variables and the outcome (fire size).

The final data feed was received on 15 January 2015 following a site visit by Navigatus to the NZFS headquarters to review the available data and to discuss data limitations. This helped to gain an understanding of the data contents, structure and the caveats surrounding the data fields.

A preliminary data dictionary assisted with identifying the data contents ("Incident Data Dictionary subset," n.d.), in conjunction with advice from the NZFS data intelligence team[1].

[1] Personal communication with Kelvan McEwen and Stuart Waring, 2015.

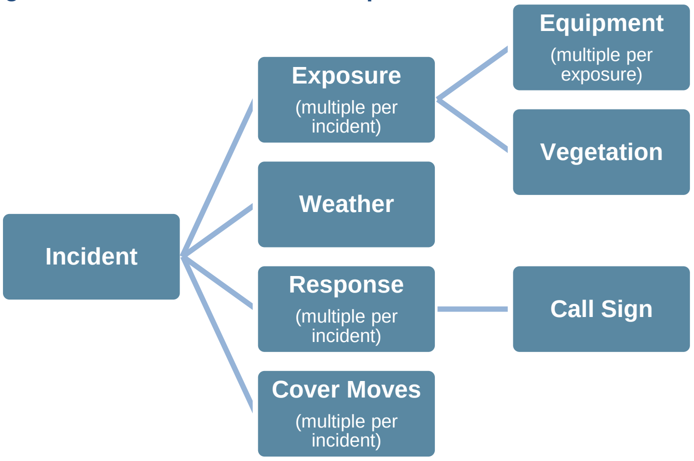
The nine tables of received data covered vegetation fires between 1 September 2000 and 14 January 2015 across the whole of New Zealand and are outlined in Table 2.1. Vegetation fires were extracted by the NZFS by filtering for the following types of incidents:

- Crop fire
- Exotic forest fire
- Gorse fire
- Grass fire
- Hedge, Shelterbelt fire
- Native forest fire
- Scrub fire (excluding gorse)
- Single tree fire
- Tussock fire
- Vegetation fire - not classified above
- Vegetation Fire (less than 20 sq. m)
- Vegetation Fire (specify Area of Vegetation burnt)
- Wetland fire

Table 2.1 – Outline of data tables

Table Name	Description
Incident	Particulars of the incident including the start and stop date and time, incident type, location and alarm level.
Vegetation	The total area of vegetation that was burnt by the fire, split into the area of gorse, grassland, indigenous forest, plantation forest, scrub, tussock, wetland and crop burnt. Data quality was cautioned by NZFS data intelligence team.
Responses	This is a table of the response to the fire, it contains an ID field, the call sign of the vehicle, unit type, time the station was alerted, left the station, arrived and departed.
Weather	Weather at the time of the fire, including humidity, temperature, rainfall, wind speed, wind direction, distance travelled etc.
Exposure	Relates to the exposure, usually there is only one exposure per incident. Occasionally a fire spreads to multiple locations generating more than one exposure. The table includes ID fields, incident type, and location.
Call Sign	Allocates the call sign of responses to Station ID and the type of Station (Rural, Volunteer etc.)
Equipment	The incidental equipment used to fight the fire including hose reels, building facilities, foam etc.
Notifications	Log of parties notified.
Message Log	Free text record of information relevant to response.
Fire	This table not used. None of the incidents matched the other tables. This was likely to be due to people filling out details for a different type of fire then changing the event type.

Figure 2.1 – Data table relationships



3 Data Processing

Processing was undertaken to combine and cleanse the data to ensure the best chance of identifying a relationship between the variables, as shown in Figure 3.1.

Figure 3.1 – Outline of Data Processing

The datasets listed in Table 2.1 were assessed, to identify factors thought to likely contribute to the size of the fire (as measured by total area burnt). These factors were mapped together as outlined in Table 3.1 and Figure 2.1 for all incidents identified in the incident table. The Exposure, Cover Moves and Equipment tables did not appear to contain data that would affect the size of a fire, so were not considered further.

Table 3.1 – Variables identified to possibly have an effect on fire size

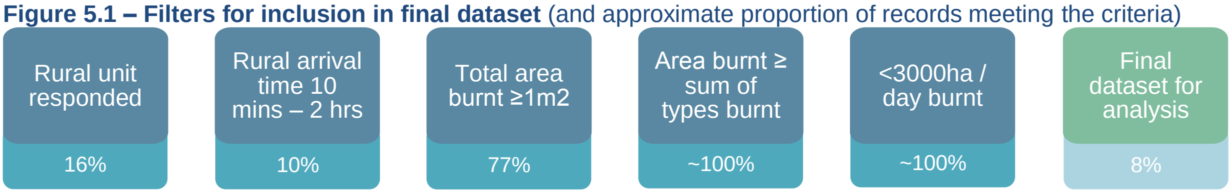
Variable	Comment
Incident Type	Directly mapped from incident table.
Area of Vegetation Burnt	Duplicates removed (identified by identical exposure ID), Exposure ID mapped to Incident ID (per Exposure table), area summed by Incident ID.
Main Type of Vegetation Burnt	Followed process outlined in area of vegetation burnt, vegetation type with largest area burnt assigned.
Alarm Level	Directly mapped from incident table.
Drought Code	Rating of the average moisture content of deep, compact organic layers. Directly mapped from weather table.
Fine Fuel Moisture Content (FFMC)	Rating of the moisture content of litter and other fine fuels. Directly mapped from weather table.
Fire Weather Index	Directly mapped from weather table.
Rainfall	Snapshot from weather station at the time of the fire. Directly mapped from weather table.
Humidity	Snapshot from weather station at the time of the fire. Directly mapped from weather table.
Temperature	Snapshot from weather station at the time of the fire. Directly mapped from weather table.
Vegetation Wind Speed	Snapshot from weather station at the time of the fire. Directly mapped from weather table.
Vegetation Wind Direction	Snapshot from weather station at the time of the fire. Directly mapped from weather table.
Fire Season Status	Open, Restricted, Prohibited fire season. Directly mapped from weather table.
Initial Spread Index	Rating of the expected rate of fire spread. Combines wind and FFMC on rate of spread. Directly mapped from weather table.
Burning Time	Time taken as the difference between the fire start time and the fire stop time.
Time Until Arrival of First Rural Unit	Station Type mapped from call sign table to response table. The time was taken as the difference between the time the fire started and the arrival time of the first unit from a rural station.

5 Data Cleansing

The data was checked for inconsistencies and the following cleansing operations were undertaken.

- Duplicates with identical exposure IDs were removed.
- Incidents with no exposures in the vegetation table were removed.
- Fires where rural stations did not respond to the fire were excluded, as the purpose of this research is aimed at the distribution of rural resources.
- The time lapse between the fire start time and the arrival of the first rural unit was occasionally zero minutes, which suggested that timing errors were sometimes present. Incidents where the time taken for the first rural unit to arrive was less than ten minutes were excluded. Ten minutes was considered likely to represent shortest feasible time between fire start and arrival of a rural unit.
- The time lapse between the fire start time and the arrival of the first rural unit also ranged to over two days. This could be due to the time or date being recorded incorrectly, or the fire may have been intentionally lit, but become out of control and required response days later. As the reason for this delay is unlikely due to resource allocation, a filter for the maximum time to arrive was applied, removing records where the time lapse was longer than 2 hours.
- Fires with a recorded area burnt of less than $1m^2$ were excluded. These particularly small fires were considered less likely to have accurate information and may have been constrained via a method other than the response of a fire crew.
- The sum of the area burnt of individual vegetation types was not always equal to the total area burnt column. The total area burnt was considered an easier variable to measure and was more likely to be accurate in most circumstances. If the sum of the vegetation types was smaller than the total this was considered to be due to absence of measured areas for some vegetation types. In this case the total vegetation burnt was taken as correct and accepted. If the sum of vegetation types was larger than the total vegetation burnt then the record was treated as unreliable and excluded from the dataset. If effort was undertaken to measure the individual vegetation types, this was considered more accurate.
- Records for some fires that burnt for a short period of time exhibited a large area burnt. This seemed unlikely, suggesting an error in either timing or area. Any fires burning at a rate of more than 3,000 hectares per day were therefore excluded. This was assumed to be an upper bound on the burn rate of large fires.
- The weather data also contained some negative rainfall and humidity records, however these were excluded upon applying the other filters.

Figure 5.1 – Filters for inclusion in final dataset (and approximate proportion of records meeting the criteria)



Prior to data cleansing there were 71,300 incidents in the dataset, of which 70,739 had unique incident IDs. After applying the filters, 5,725 incidents remained for analysis (8% of the original count).

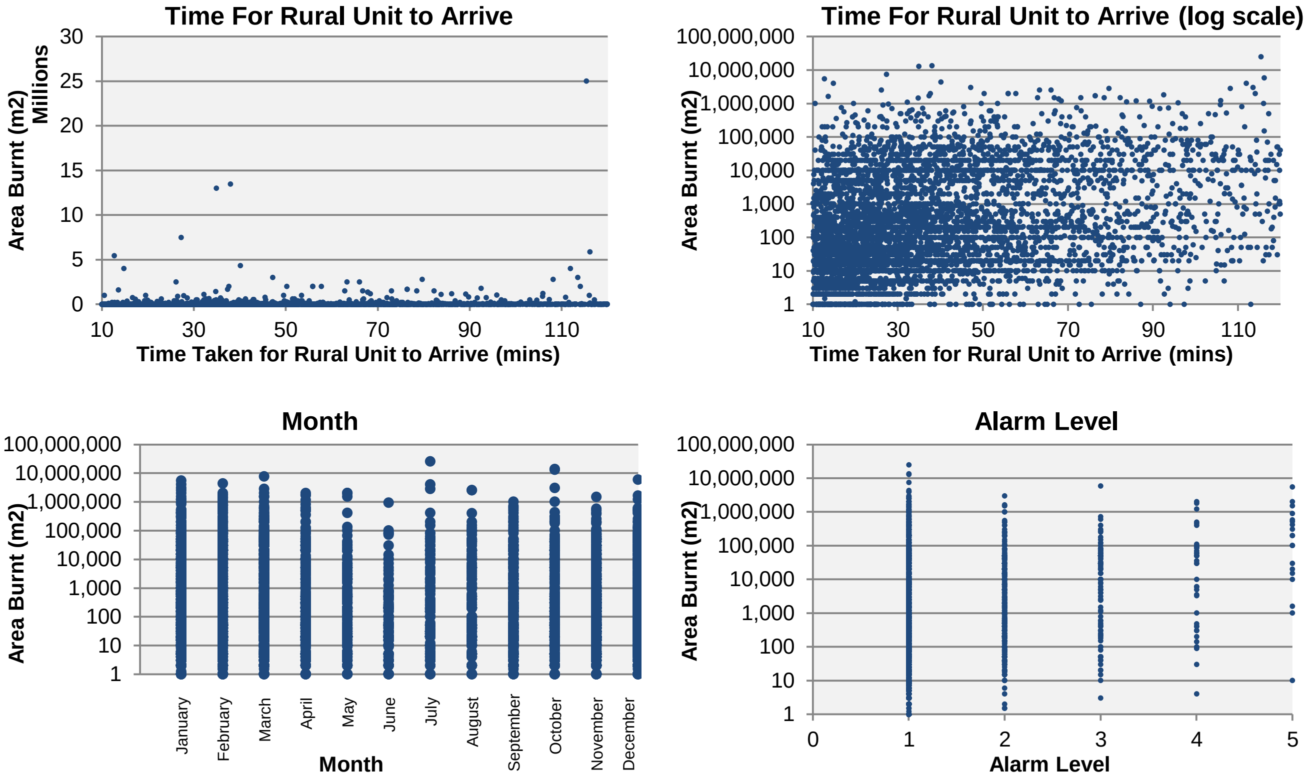
As shown in Figure 5.1, a large proportion of incidents were filtered out due to no rural units responding to the fire. The arrival time and total area burnt falling outside of reasonable ranges were the other main contributing factors to reducing the dataset. These two filters combined resulted in the elimination of approximately half of the otherwise eligible incident records where rural units responded. This is of concern for the subsequent analysis as it suggests that the data quality for these two critical variables may be of lower reliability.

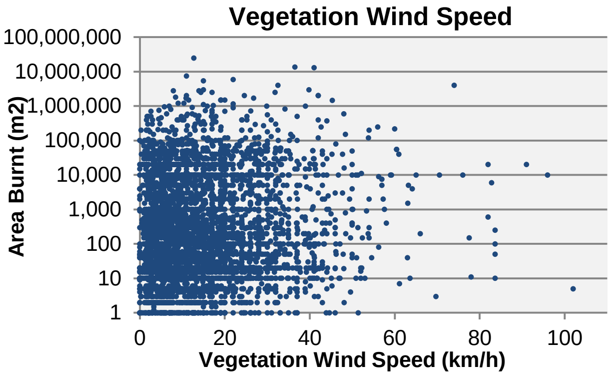
6 Exploratory Analysis

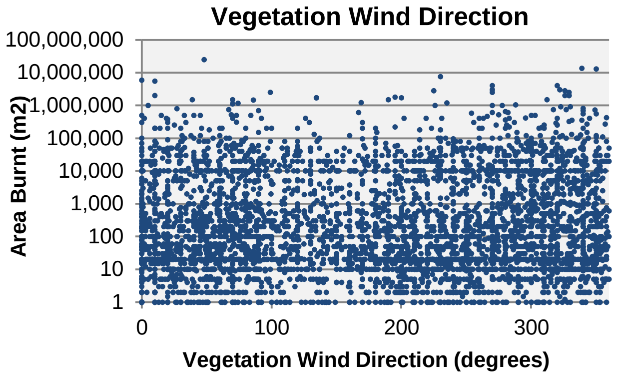
Following data cleansing, initial explorations were undertaken to assess the relationship (if any) between the variables listed in Table 3.1 and the area burnt. Not all incidents in the dataset are complete for all variables, where the variable on the x-axis is not specified it is not plotted; this is why some of the larger fires are noticeably missing from some plots.

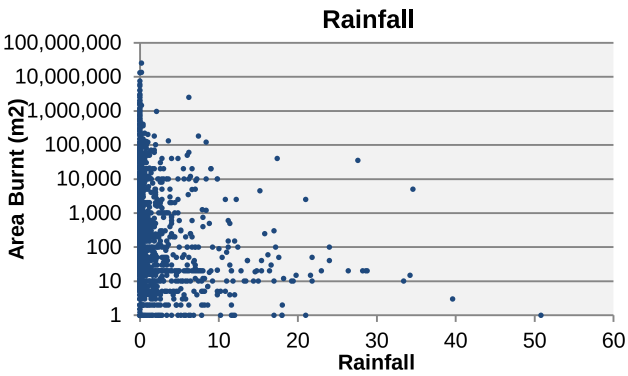
In some of the graphs the area burnt is presented on a log scale due to the large range of fire sizes.

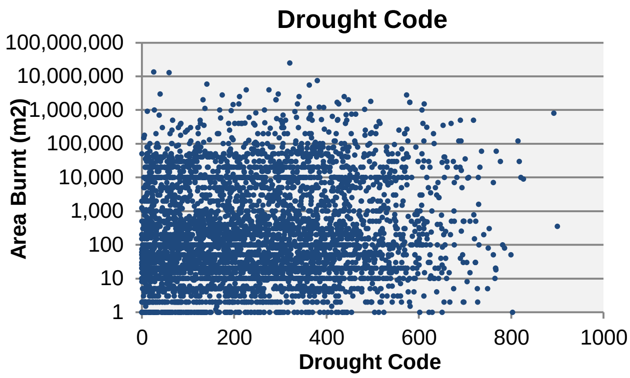
Figure 6.1 – Exploratory analysis of the effects of the variables on fire size

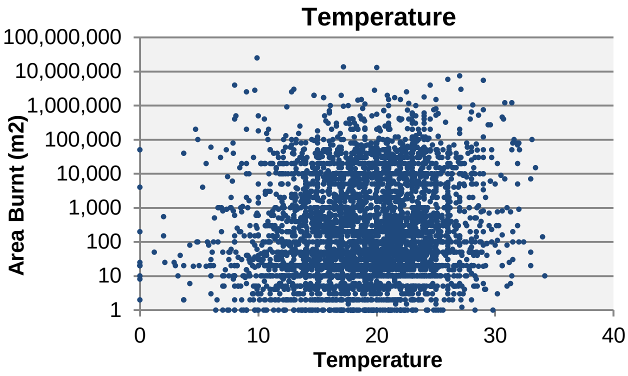


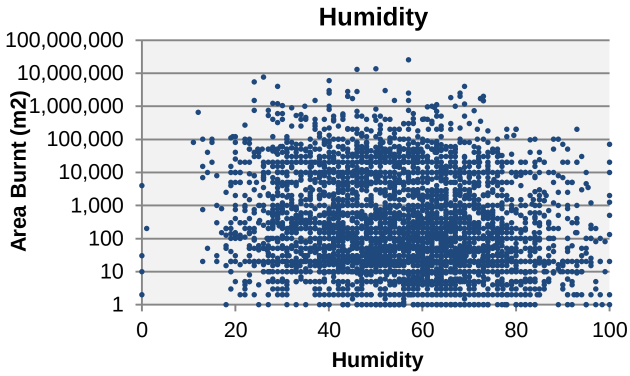

Vegetation Wind Speed
Area Burnt (m2)
100,000,000
10,000,000
1,000,000
100,000
10,000
1,000
100
10
1
0
20
40
60
80
100
Vegetation Wind Speed (km/h)

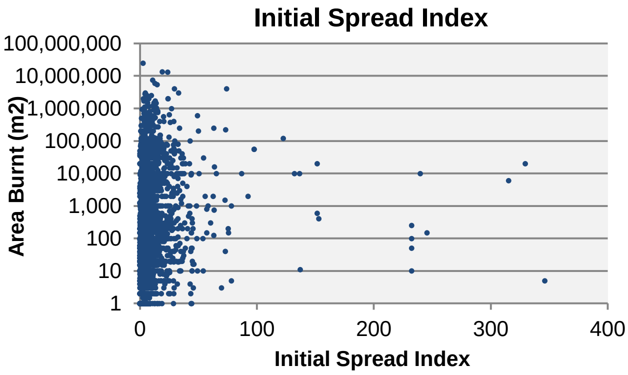

Vegetation Wind Direction
Area Burnt (m2)
100,000,000
10,000,000
1,000,000
100,000
10,000
1,000
100
10
1
0
100
200
300
Vegetation Wind Direction (degrees)

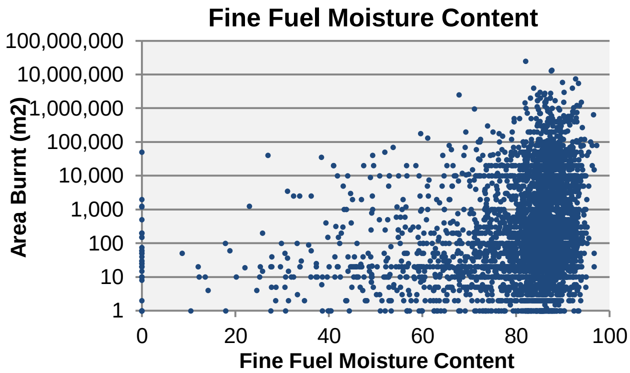

Rainfall
Area Burnt (m2)
100,000,000
10,000,000
1,000,000
100,000
10,000
1,000
100
10
1
0
10
20
30
40
50
60
Rainfall

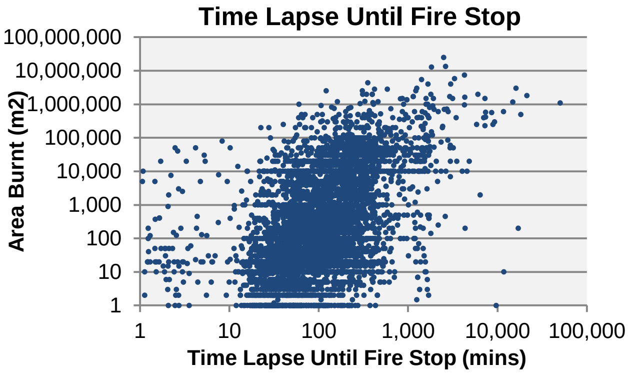

Drought Code
Area Burnt (m2)
100,000,000
10,000,000
1,000,000
100,000
10,000
1,000
100
10
1
0
200
400
600
800
1000
Drought Code

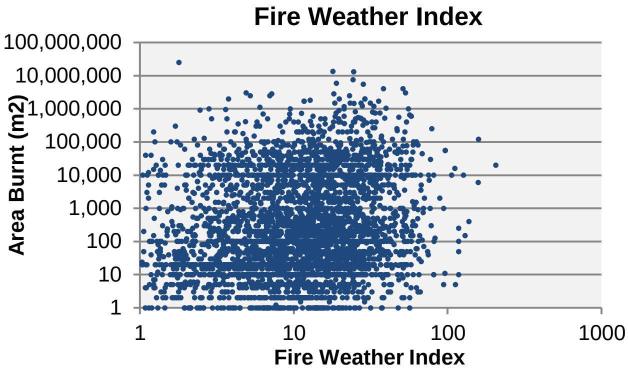

Temperature
Area Burnt (m2)
100,000,000
10,000,000
1,000,000
100,000
10,000
1,000
100
10
1
0
10
20
30
40
Temperature

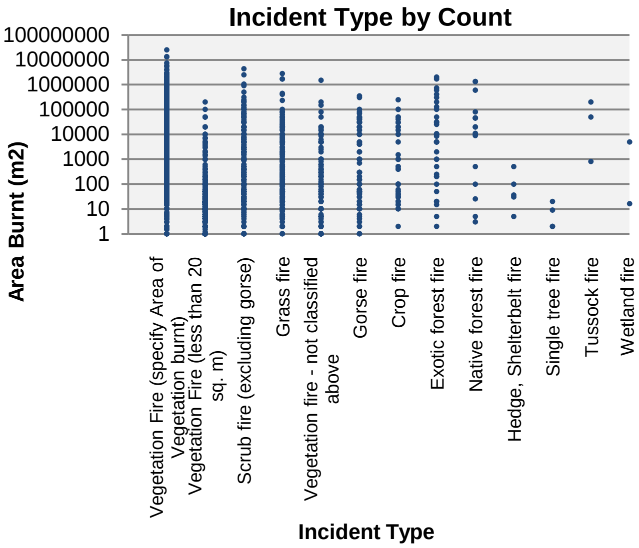

Humidity
Area Burnt (m2)
100,000,000
10,000,000
1,000,000
100,000
10,000
1,000
100
10
1
0
20
40
60
80
100
Humidity

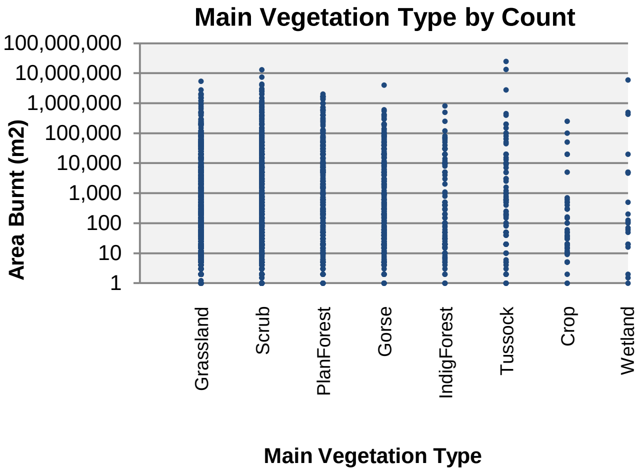

Initial Spread Index
Area Burnt (m2)
100,000,000
10,000,000
1,000,000
100,000
10,000
1,000
100
10
1
0
100
200
300
400
Initial Spread Index

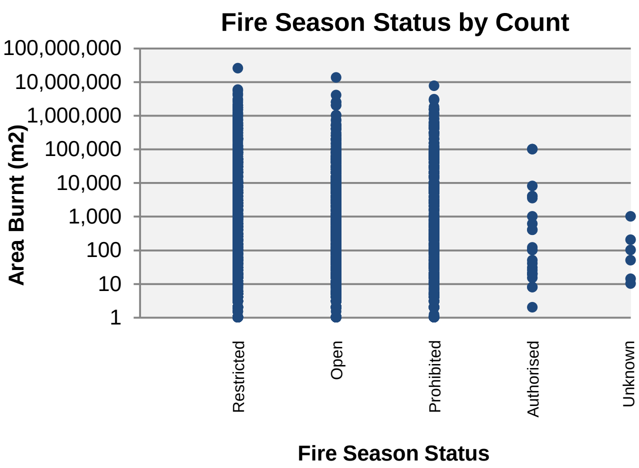

Fine Fuel Moisture Content
Area Burnt (m2)
100,000,000
10,000,000
1,000,000
100,000
10,000
1,000
100
10
1
0
20
40
60
80
100
Fine Fuel Moisture Content

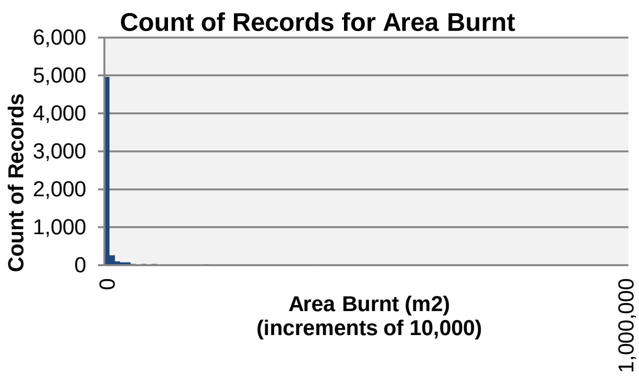












As exhibited in the count of records for area burnt graph, fire size appears to follow a power law relationship. This is where one quantity (count of fires of a certain size) varies as a power of another (fire size). O'Donnell, Boer, McCaw, & Grierson, (2014) clarify that fire size and frequency tend to be negatively correlated i.e., small fires are more common than large fires. This is shown by the high proportion of smaller fires in the dataset, specifying almost 5,000 fires had a recorded area burnt of less than 10,000m^2, with less than 300 in the next bracket (10,000m^2 - 20,000m^2), and further decreases from there. The inclusion of a higher proportion of smaller fires in the dataset may mean the analysis is influenced by the large number of smaller fires.

The graphs shown in Figure 6.1 do not exhibit any clear or strong trends between the variables and the area burnt. In particular, vegetation wind speed and wind direction, drought code, temperature, humidity, initial spread index, and fire weather index all do not appear to have any consistent relationship with the area burnt.

There seems to be a weak but slightly increasing trend for area burnt with the time for the first rural unit to arrive. Additionally, a higher rainfall is associated with smaller area burnt. The graph of the alarm level shows higher alarm levels corresponding to larger fires. This is also to be expected as only larger fires would be escalated to a level five response.

With the possible exception of fewer big fires in June, the month in which the fire started does not appear to have any obvious relationship to fire size. The largest fire occurred during July, in the middle of winter.

In addition, the largest three fires in the dataset have an alarm level of one, this is also counterintuitive as it is expected a large and long burning fire would have the alarm level escalated to a higher level. This may be due to only the initial alarm level being recorded in the dataset.

A counterintuitive finding from the exploratory analysis is that the larger fires are associated with higher fire fuel moisture content, though not all fires with high fire fuel moisture content have a large area burnt. A possible explanation is that larger fires release sufficient thermal energy to sustain ignition across a wide range of fuel types, resulting in a higher average moisture content as the fire size increases.

7 Statistical Modelling

7.1 Model Development

The model was built in the statistical programme R using a logistic regression model (Hosmer & Lemeshow, 2004; Menard, 2002). A logistic model was chosen due to the large range in the magnitude of the area burnt (Benoit, 2011). The model code was developed with reference to the general online R documentation (R Core Team, 2015) and also the package specific documentation (A. A. Balemi et al., 2015). In a regression model it is important to include not only the variables that are being tested (in this case response time) but also any other variables that affect the response and failure to do this may lead to biased results. It is also important not to include too many variables as this may lead to less precise estimates.

To select the appropriate variables for inclusion, an initial model was built, which contains all variables from the dataset. Backwards stepwise regression (Backwards Elimination) (Karim, 2004; Kleinbaum, Kupper, Nizam, & Rosenberg, 2013) (Karim, 2004; Kleinbaum et al., 2013) was then used, systematically removing the variable with the highest p-value until all remaining variables were significant at the chosen confidence interval (in this case 95%, e.g. p-values all less than 0.05).

The variables removed from the model are those presented below with a strikethrough. Table 7.1 shows the p-values of the remaining variables obtained through the summary output (for continuous variables) and ANOVA (Laerd Statistics, 2015) (for categorical variables).

log(area burnt) = Time for Rural Unit to Arrivex_1 + Main Vegetation Type*x_2 + Incident Type*x_3 + Alarm Level*x_4 + Fire Season Status*x_5 + Month*x_6 + ~~Drought Code*x_7~~ + Fire Fuel Moisture Content*x_9 + Fire Weather Index*x_{10} + ~~Rainfall*x_{11}~~ + Humidity*x_{12} + ~~Temperature*x_{13}~~ + ~~Vegetation Wind Speed*x_{14}~~ + ~~Vegetation Wind Direction*x_{15}~~ + ~~Initial Spread Index*x_{16}~~*

Table 7.1 – Significance of remaining variables

Variable	Significance[2]
Arrival Time	< 2e-16
Incident Type	< 2.2e-16
Alarm Level	< 2.2e-16
Humidity	1.20E-04
Main Vegetation Type	8.77E-04
Fire Weather Index	1.23E-03
Fire Fuel Moisture Content	4.45E-03
Month	8.89E-03
Fire Season Status	3.88E-02

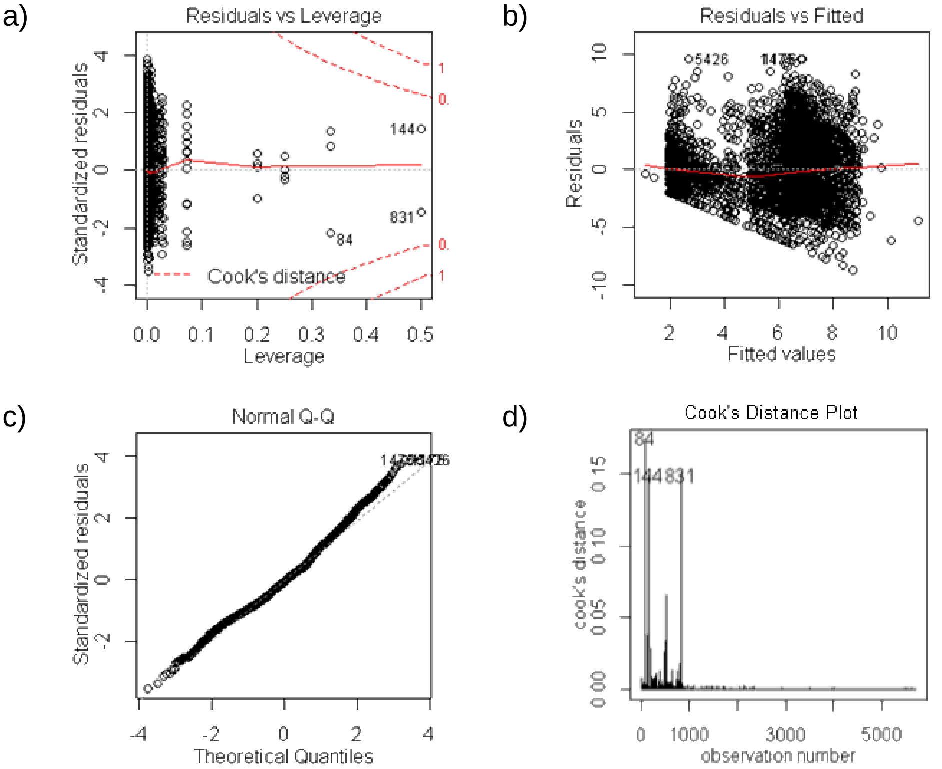
Table 7.1 is for a model including nine variables. However, with the idea in mind that simpler models are generally preferable, the number of variables in the model was reduced. This was done by removing variables one at a time and assessing the change in the adjusted R^2 value[3]. Although all the above variables were determined to be significant, removal of some of the variables made little difference to the adjusted R^2 value. These were consequently left out of the model. This resulted in a very simple model including only two explanatory variables: arrival time and incident type. This simplified model had an adjusted R^2 of 0.843, compared to 0.855 where all 9 variables identified as significant were included.

The reduced model was then checked against the assumptions of a (logistic) linear regression in R using a downloaded package (A. Balemi et al., 2015). The checks ensure that the errors are independent, identically distributed, follow a normal distribution and are centred at zero (Menard, 2002). The plots shown in Figure 7.1 enable assessment of the validity of these assumptions for this model.

[2] Pr(>F) for categorical variables, value taken from ANOVA.

[3] R^2 measures the proportion of the variability explained by the model, adjusted R^2 is a similar measure that accounts for the different number of predictors in a model. This allows models to be directly compared to find the most suitable model.

Figure 7.1 – Model Assumption Checks



It was assumed the recorded fires are independent events, thus satisfying the assumption of independence of the errors.

The plot of residuals vs fitted values (b) above indicates slight heteroscedasticity, or non-constant variance in the data, likely due to the large difference in the size of the observations. This may cause bias in the model predictions. The normal Q-Q plot (c) also shows slight right-skew meaning the positive errors may tend to be larger than the negative errors.

Cook's distance is a measure of the effect of deleting a given observation (D. R. Cook, 1977). The graphs (a and d) identify some observations with higher Cook's distances than others, however they are all within the guideline range[4] indicated on the graph (a) and are not likely to be highly influential points.

Though some of the assumptions are marginally violated, and the predictions and confidence intervals may be slightly biased, it was judged that the analysis could proceed, provided that caution was exercised in interpreting the results.

7.2 Predictive Value of Model

The reduced model was used to predict the estimated fire size using the observed values for arrival time and incident type obtained from the dataset. This was then compared against the observed fire size (Figure 7.2). The model was found to be a poor predictor of fire size, with a correlation coefficient of only 9% (where 100% would be a perfect predictor). As an example, the largest prediction from the model is for 17,000m^2 burnt, whereas there are a number of fires larger than this.

[4] $D_i > 1$ (R. D. Cook & Weisberg, 1982) as shown in the graph.

For comparison, a prediction was then made using a model including all significant variables identified in Table 7.1. The resulting predictions from this model were similarly poor as shown in Figure 7.3. The expanded model also had a correlation coefficient of only 8%.

Figure 7.2 – Model estimate of fire size vs observed fire size including only arrival time and incident type (all fires)

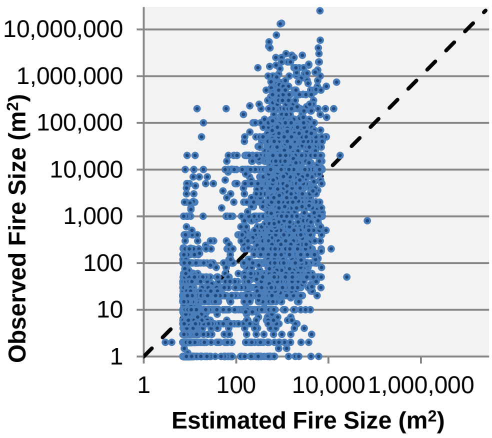
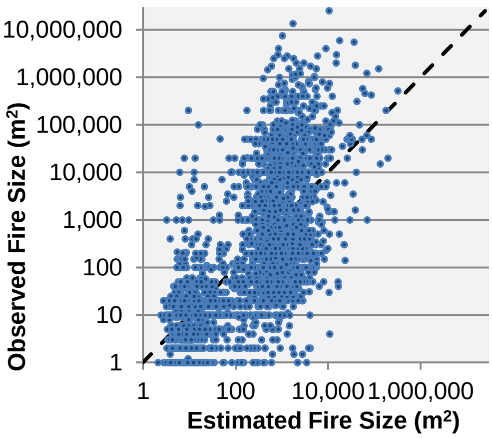


Figure 7.3 – Model estimate of fire size vs observed fire size from dataset including all significant variables (all fires)



7.3 Larger Fires

Both of these models appear to show a better fit with smaller fire sizes. This is likely due to the large number of such fires influencing the derivation of model parameters. However, as the most costly fires tend to be larger, these are more important for the purpose of this analysis. For this reason, an additional analysis was undertaken by filtering the data to select just the larger fires for analysis (being those with an area burnt ≥ 10,000m^2). This includes 1,085 of the previous 5,725 fires from the filtered dataset.

Using this subset of data, the analysis was repeated using the method described above. The resulting model included arrival time and main vegetation type as the explanatory variables. This model had an R^2 value of 98%, and a correlation of 22%. Figure 7.4 shows the graph of the predictions from this model, compared to the observed values. For comparison, including all significant variables resulted in a model with arrival time, main vegetation type, alarm level, fire season status and humidity. This model also had an R^2 of 98%, but a correlation of 23%. Both of these models are an improvement from those obtained without filtering for larger fires (in terms of the correlation), but are still poor predictors.

The residuals for the larger fire models appeared to have non-constant variance, with the predictions for larger fire sizes tending to have larger errors. In addition, the residuals were also somewhat right skewed, meaning the positive errors tended to be larger than the negative errors. This is shown in Figure 7.4, where the distance of observations above the dotted line (which represents 100% accurate prediction) is greater than that for those below the line.

Figure 7.4 – Two parameter model estimate of fire size vs observed fire size for large fires.

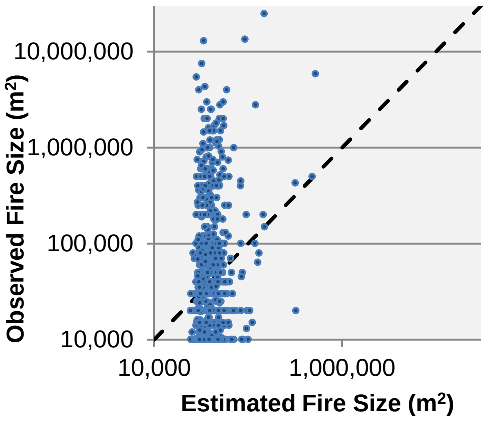
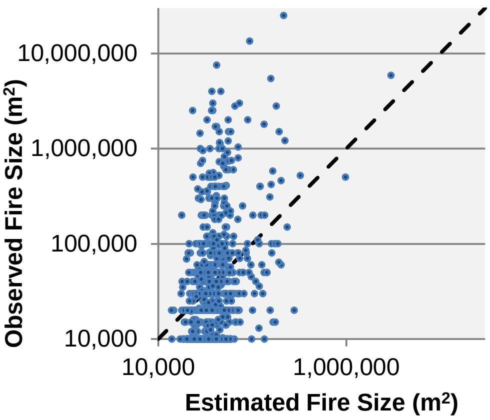


Figure 7.5 – Five parameter model estimate of fire size vs observed fire size for large fires.



8 Summary

Although there appears to be a relationship between time taken for the first rural unit to arrive and the resultant size of the fire, there is too much variation in the data to build an accurate predictive model from the dataset.

This may be due to data quality or due to the influence of other factors influencing fire size. For example, geographical factors may promote or naturally constrain fire size. Additionally weather conditions may also change during the course of the fire to become more or less favourable. These factors, and possibly others are all likely to affect the fire size and are not accounted for in the model.

9 Bibliography

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Appendix D – Supplementary Statistical Analysis of Fire Size by Response Time (DoC Historic Fire Inventory)

1 Introduction

Analysis of the fire data received from the New Zealand Fire Service (NZFS) was undertaken to assess the relationship (if any) between fire response and fire outcome in terms of area burnt, as outlined in Appendix C. Although there appeared to be a relationship between time taken for the first rural unit to arrive and the resultant size of the fire, there was too much variation in the data to build an accurate predictive model from the NZFS data. A potential cause of this lack of relationship could be the data quality.

In 2008 to 2009 (and maintained since), the Department of Conservation (DoC) built an historic fire inventory, consisting of attribute and spatial data, including ignition point and burnt area (mapped where records exist). In building this dataset, the data was checked against all records held, to ensure accuracy and consistency. An example of the checks undertaken in this process is the National Rural Fire Authority (NRFA) spatial extents, which were checked against their map, site photos and site description from the claim record, where available (Henson et al., n.d.; Hunt, 2012).

A statistical analysis was undertaken on this dataset to determine if it was possible to overcome data quality issues (in relation to the area burnt) from the NZFS data used in the previous analysis. Though this dataset is assumed to contain more accurate records, it is not a comprehensive list of all fires. For the purpose of this analysis, the DoC data is assumed to be a representative (non-biased) sample of larger fires.

This supplementary analysis is undertaken by Navigatus on its own account. If a relationship is found, this could form the basis for modelling of loss occurring from the response times modelled in future versions of STAR.

2 Dataset

The Historic Fire Inventory was obtained from DoC. This consists of rural fires dating between 1803 and 2011, sourced from NRFA claim records, the Department of Conservation (DoC) fire occurrence database, New Zealand Forest Service records of fires, other recently published reports or journal articles and archived or published historical data. This dataset was extensively checked upon collation and the best effort made to ensure the data entered represents the parameters of the fire (Henson et al., n.d.; Hunt, 2012).

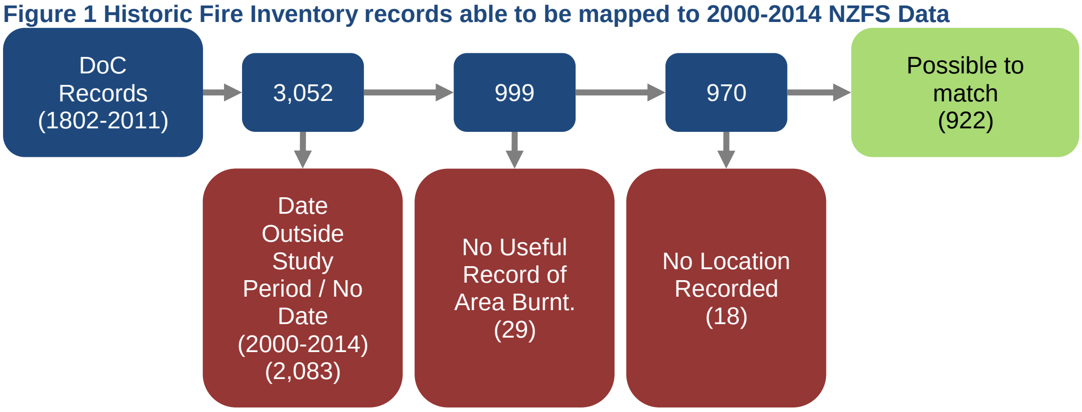
As mentioned above, the DoC Historic Fire Inventory does not contain a comprehensive list of all fires attended by NRFA as it is based of claim records, where claims are only made if the fire incurs a significant cost.

3 Data Processing

Unfortunately, the Historic Fire Inventory does not record original NZFS identifier. As the relationship between time taken to arrive and fire extent was the target of this analysis, (and the time taken to arrive only available via the NZFS records) the DoC dataset and the NZFS dataset needed to be mapped together.

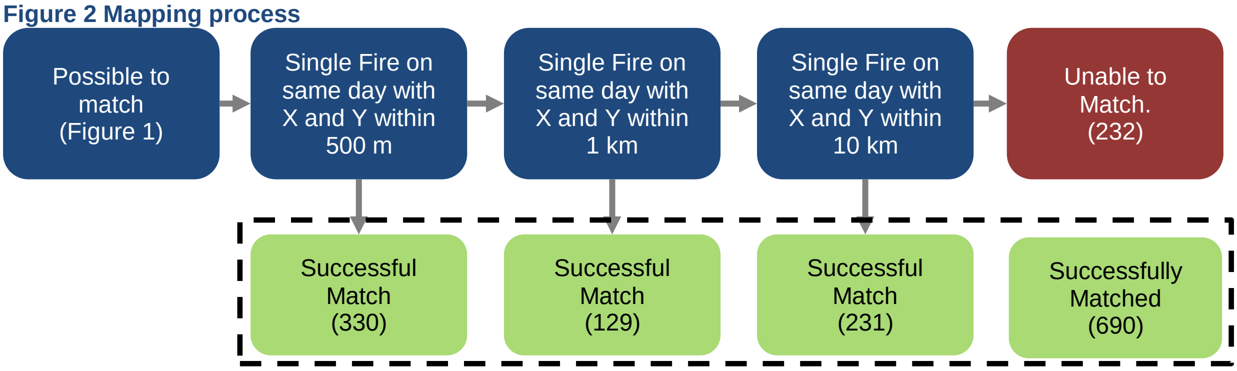
Due to the different date parameters of the datasets, few of the records overlapped in time (999), of those, 690 were able to be mapped together. Figure 1 shows the process for exclusion of records from the dataset.

Figure 1 Historic Fire Inventory records able to be mapped to 2000-2014 NZFS Data



The mapping process was undertaken using a staged approach to maximize the likelihood of accurate matches. Fires from the NZFS dataset occurring on the same day as a Historic Fire Inventory fire were matched; firstly where X and Y co-ordinates were each within 500m of the DoC dataset; then those within 1km; and finally within 10km (Figure 2). Further expansion of the X and Y tolerance was examined, however the increase in the count of fires mapped was marginal and it was considered that the potential for introduction of error through implementing a larger tolerance would outweigh the benefits of including the additional records.

Figure 2 Mapping process

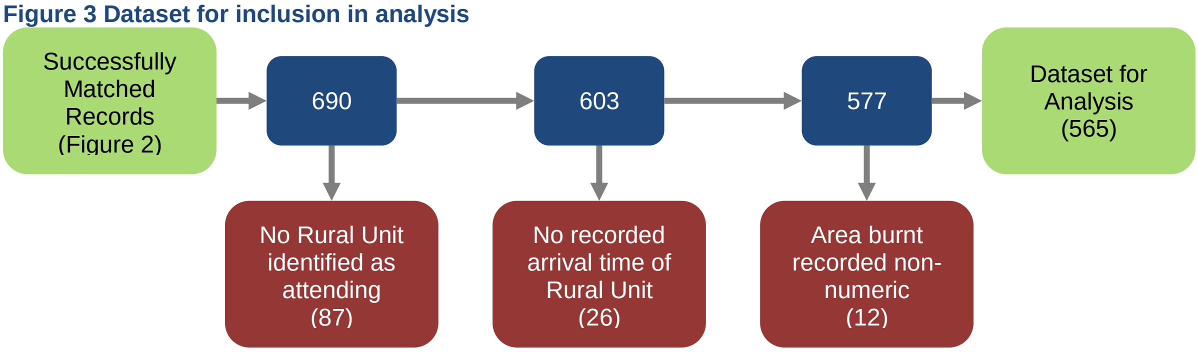


Following this, the 690 matched records were checked to ensure at least one rural unit attended the fire. These were determined as either RFO, RP, RTH, RTU, RU, RWT, SC, WT, or WTFT unit types in the NZFS dataset. These were the codes most commonly associated with rural stations. The *Rural* from the station type field was not used to filter as some rural stations were recorded as *Volunteer*. In all but 87 of the matched records a rural unit was determined to have attended. The 87 records with no rural unit in attendance were excluded from the dataset as this may have been due to incorrect mapping between the datasets.

A further 26 records had *NULL* recorded for the arrival time and therefore the time taken to arrive could not be determined.

Finally, 12 records were excluded due to the area burnt being recorded as non-numeric (e.g. <1). It was assumed excluding these records would not introduce bias as there were many other records with areas burnt smaller than 1 which were recorded more precisely.

Figure 3 Dataset for inclusion in analysis



Following the mapping of the datasets together, Table 1 shows the data variables included for analysis and their origin.

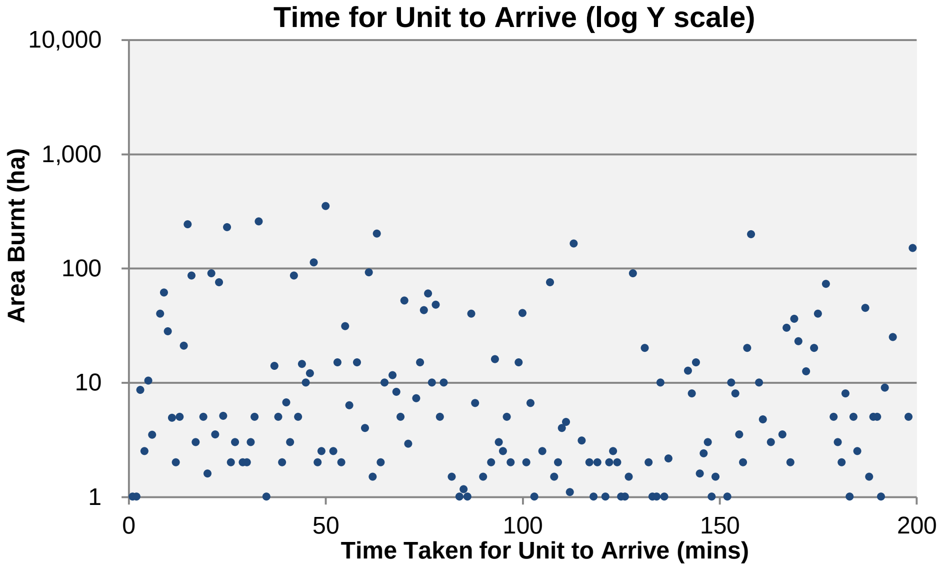
Table 1 Variables initially included in analysis

Variable	Comment
Month	Month Fire occurred during.
Incident Type	Mapped from NZFS data.
Area of Vegetation Burnt	Doc Record.
Main Type of Vegetation Burnt	Vegetation type with largest area burnt assigned from NZFS record (process as per Appendix C).
Alarm Level	Mapped from NZFS data.
Drought Code	Rating of the average moisture content of deep, compact organic layers. DoC.
Fine Fuel Moisture Content (FFMC)	Rating of the moisture content of litter and other fine fuels. DoC.
Fire Weather Index	Snapshot from weather station at the time of the fire. DoC.
Rainfall	Snapshot from weather station at the time of the fire. DoC.
Humidity	Snapshot from weather station at the time of the fire. DoC.
Temperature	Snapshot from weather station at the time of the fire. DoC.
Vegetation Wind Speed	Snapshot from weather station at the time of the fire. DoC.
Vegetation Wind Direction	Snapshot from weather station at the time of the fire. DoC.
Fire Season Status	Open, Restricted, Prohibited fire season. Mapped from NZFS data.
Initial Spread Index	Rating of the expected rate of fire spread. Combines wind and FFMC on rate of spread. DoC.
Burning Time	Time taken as the difference between the fire start time and the fire stop time. Mapped from NZFS data.

4 Exploratory Analysis

An initial exploration, Figure 4, shows the area burnt versus the time taken to arrive for the matched records. It shows no clear or strong trend between the variables and appears similar to the exploration undertaken on the NZFS data in Appendix C.

Figure 4 Time Taken for Unit to Arrive



5 Statistical Modelling

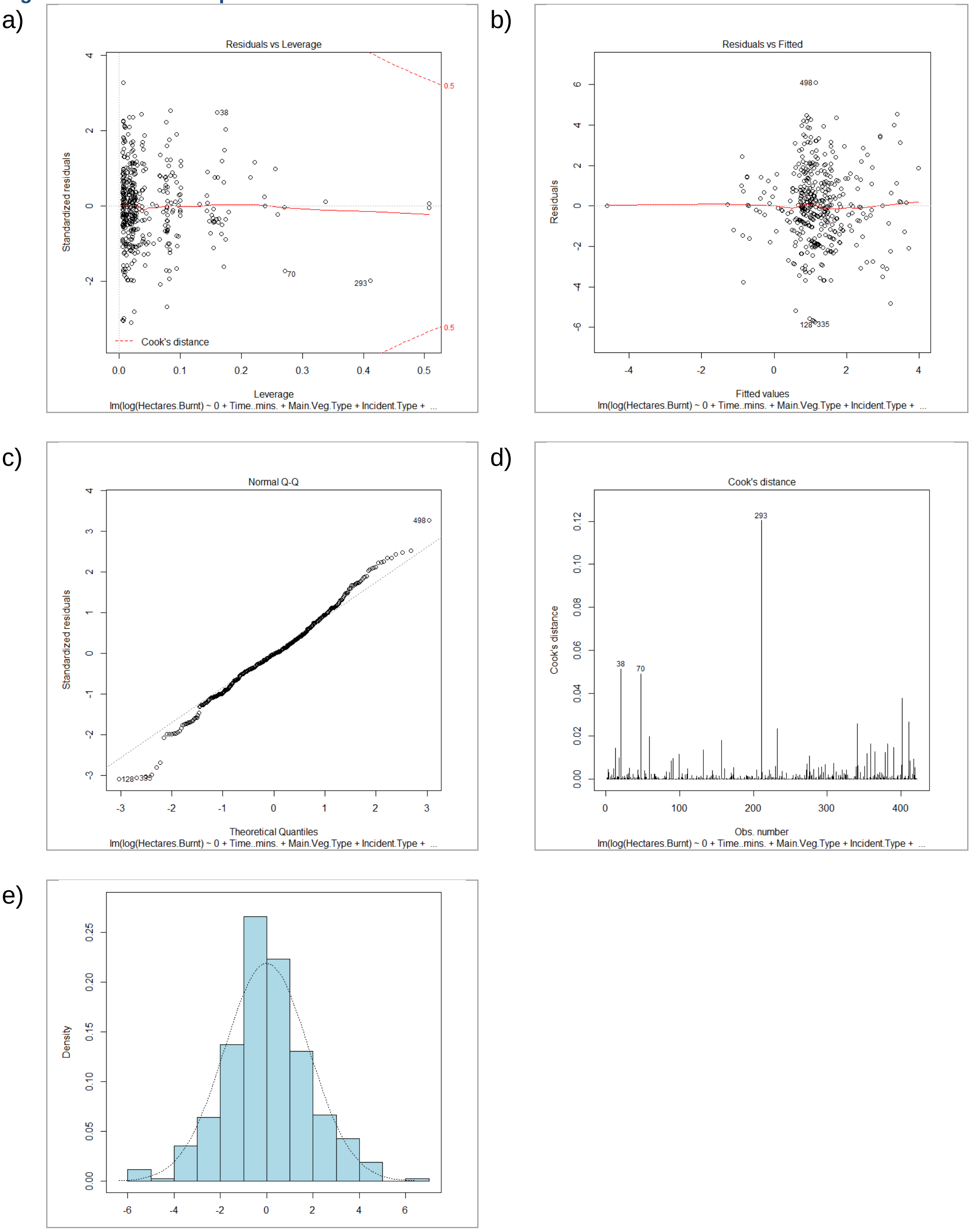
The model was developed using the same methodology and initial model as in Appendix C. The resulting model contained the variables presented in Table 2, a subset of those found as significant in the previous analysis. This model has an R^2 value of 0.3501[1], indicating it models the data very poorly.

Table 2 Significance of remaining variables

Variable	Pr (>F)
Time taken to arrive	0.31
Main Vegetation Type	< 2.2e-16
Incident Type	0.0004
Fire Weather Index	0.004

[1] One data point was removed due to being high leverage.

Figure 5 Model Assumption Check



The plots above show reasonably constant and symmetric variance, with slightly larger tails than would be expected (Plot C). This means more of the data points have a large variance than would be expected under the normality assumption. However overall, there are no clear violations of the assumptions.

Due to the low R^2 value, the predictive value of the model was not tested as the R^2 value has already determined that the model poorly explains the data variance.

6 Summary

The model is a poor fit for the data and only explains 35% (R^2) of the variance in hectares burnt.

Overall, a model estimating the hectares burnt was unable to be built from the data fields at hand. This is likely due to the influence of other factors on fire size as identified in Appendix C.

7 Bibliography

Henson, S., Beautrais, J., Burlace, D., Kappers, B., Gover, I., & Mann, C. (n.d.). Historic Fire Inventory Report.

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