A Systems Engineering Analysis of Early-Response Aerial Detection of Bushfires in Australia

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Abstract

Bushfires in Australia cause wide-scale devastation on the environment, economy, and communities. The existing systems in place for early bushfire detection for lightning-fires can be improved through adoption of autonomous Unmanned Aerial Systems (UAS). Such systems will reduce the risk to fire-fighter pilots that would otherwise be required to perform aerial surveillance tasks during bushfire seasons. Moving towards autonomous systems would also bypass current limitations to human-piloted aircraft, and provide a more effective and integrated system for detection of early-stage bushfires. A significant advantage is the ability for the UAS to operate at night and in adverse conditions; situations a human pilot would be unable to safely fly in. Establishing an eleven year action plan for the development, testing, and ultimate integration of a UAS program is recommended. This consists of a preliminary and ongoing study phase, a contract and policy phase, and a pilot-implementation and system-wide implementation phase.

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1 Bushfires in Australia

1.1 Background

Since the 1970's, Australia has seen an increase in extreme fire conditions and longer fire seasons across large parts of the country (Bureau of Meteorology and CSIRO, 2014). The events of the Ash Wednesday bushfires in 1983 and the Black Saturday fires in 2009, the two deadliest bushfires in Australia's recorded history, demonstrate the danger that bushfires pose to the Australian people. The state of Victoria feels the damage of bushfires more than anywhere else in Australia, due to the environmental conditions that make bushfires a regular occurrence there. The Black Saturday bushfires alone are estimated to have cost a total of $2.94 billion ($942 million net cost to the state of Victoria), and the economic and social ramifications are still ongoing (Stephenson et al., 2012). 178 people died, and thousands of homes were destroyed, during the Black Saturday fires (Victorian Country Fire Authority, 2012).

The events of 2009 are not a one-off incident. More severe weather conditions combined with a growing population makes the risk an escalating one. It is therefore critical that ongoing research and development is invested in furthering the capabilities of the fire-fighting forces in Australia. Utilising future technology to improve early detection of fires will play a significant role in this effort. In particular, the use of existing systems and aerial surveillance systems to detect bushfires in their early stages is a critical area that will be the focus for this portfolio. This portfolio seeks to understand the question: how can future technology be used to improve the current early detection system of bushfires in Australia?

1.2 Cultural Perspectives

Prior to British settlement in the 18th century, the indigenous people of Australian had nearly 60,000 years to learn how to harness fire to control and shape the environment (WA Parks and Wildlife, 2013). Grasslands were artificially created using controlled fire to provide a habitat for game, a process that occurred over many generations of Aboriginal people and was given the name 'fire-stick farming' by Rhys Jones, an ANU Archaeologist, in 1969 (Petty, 2012). This is only one example of the many ways the Aboriginal people used fire as a fundamental tool to shape the landscape and improve their way of life. Bushfires were, and remain, an integral part of the Australian environment and the traditional custodians of this land have extensive and learned knowledge of the use of fire management. While the remainder of this portfolio will explore the engineering and technical aspects of fire-management, the significance of this should not go unnoticed. Consultation with local Aboriginal elders in each region of concern should occur in the future to provide a traditional perspective on methods to control fire in the environment, and to harness the extensive knowledge base that has been cultivated over tens of thousands of years. Building on this knowledge and utilising the techniques that have been refined over the millennia will enable more effective fire-fighting efforts, as well as environmental management; the importance of this is discussed further in the *Positive Feedback Cycle* section.

1.3 Positive Feedback Cycle

Building on this understanding that the fire-management techniques of the Aboriginal people were an integral part of the Australian environment, it must be understood what implications arise when these bushfires are suppressed entirely. Bushfires that can pass through a region regularly will remove old fuel and debris, thereby reducing the impact of the next bushfire

(Hughes and Fenwick, 2015). This behaves as a negative feedback cycle, and ultimately reaches a stable point from which the severity of bushfires is balanced by their frequency. Conversely, by preventing large-scale bushfires from occurring, the significant quantities of fuel will grow to critical levels. Since no system at present can prevent all bushfires from occurring, the severity of these fewer fires will continue to increase. The primary method to combat this is pro-active management of the environment, through techniques such as a preliminary burnings. Since this portfolio is concerned specifically with detection methods, this will not be explored here. However it is a critical area of fire-fighting that will require ongoing research and collaboration, both internationally and with the local Aboriginal people of various regions to build on the vast knowledge base that exists.

2 Bushfire Statistics

2.1 Quantitative Analysis

Establishing an understanding of the processes that lead to bushfires in Australia will enable the scope of this project to be narrowed, which is especially important as it will allow the systems analysis to focus on the most impactful area of interest. In Victoria between 1976-77 to 1995-96, the two largest causes of bushfires was lightning, responsible for 26% of fires, and deliberate human action, responsible for 25%. Importantly, bushfires that result from lightning strikes are disproportionately larger and responsible for 46% of the land that is burnt, compared to only 14% for deliberately lit fires (Australian Bureau of Statistics, 2004). The breakdown of these causes, measured by area burnt, is shown in Figure 1. One possible explanation for the significant area burnt by lightning-caused fires is that lightning-strikes often occur in remote locations, where rugged terrain makes it difficult for ground-crews to reach the site in time to establish control early on (Ahrens, 2013). What can be concluded from this is that addressing the issue of lightning-caused fires would result in the largest reduction of damage. Therefore this portfolio will focus on bushfires that are initiated by a lightning strike (denoted *lightning-fires*).

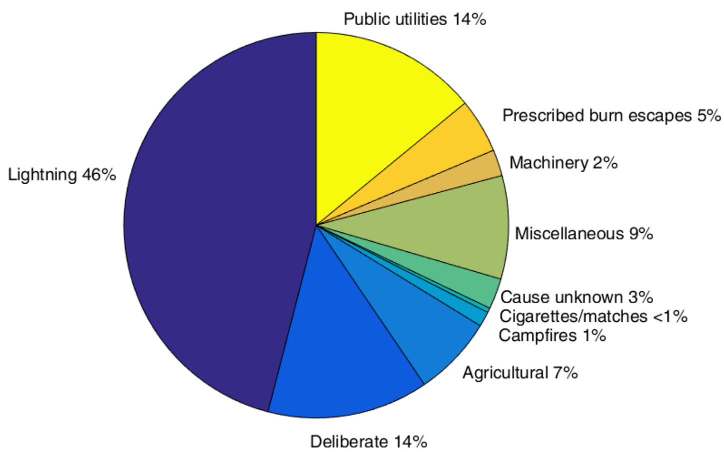

Figure 1: Breakdown of Area Burnt (in ha/yr) of Bushfires in Australia between 1976-77 to 1995-96 in Victoria, adapted from Australian Bureau of Statistics (2004)

2.2 Smoulder Period Regression

Lightning-fires can be particularly problematic to detect and predict because of a phenomenon known as 'smouldering'. When lightning hits a tree, the tree often will not spontaneously combust. Due to the high water content of a tree and the strong circumferential force from the structure of the tree, a lightning strike can superheat the internals (Caroline et al., 1996). This results in a high-pressure and high-temperature state that can remain dormant for several days. The length of the dormant phase, known as the 'smouldering period', can be extremely variant depending on conditions of the strike, the type of tree, and environmental factors. The data used in this analysis has been adapted from a joint CSIRO and BOM study on the atmospheric conditions associated with lightning caused bushfires (Dowdy and Mills, 2009). There are likely significant processing errors associated with transcribing this data based on visual interpolation from a graph in the original report. However, only qualitative assessments will be based on these results, and have been crossed referenced with the conclusions of the original authors. Therefore these processing errors should not contribute to the overall conclusion. Figure 2 shows a logarithmic scatter plot of the smoulder periods from this study, computed as the number of days between the occurrence of lightning to when a lightning-fire is first observed.

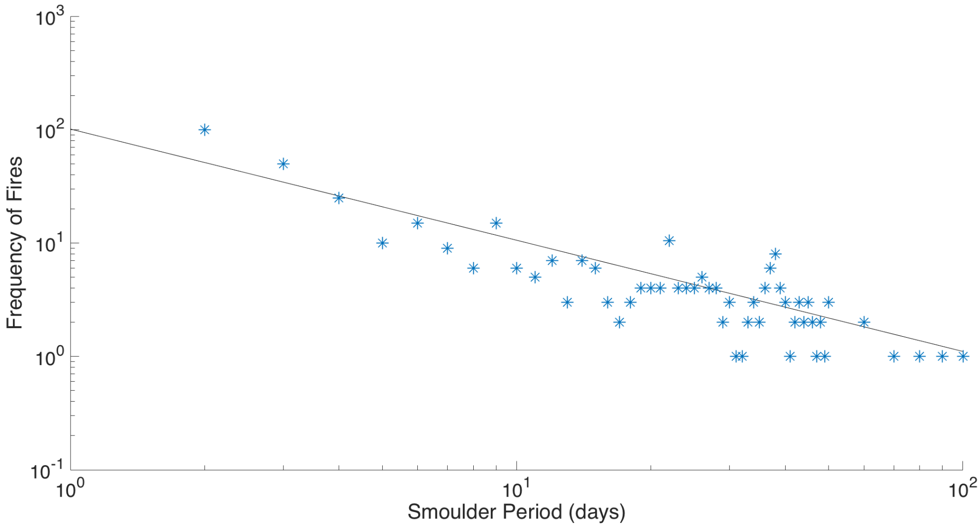

Figure 2: Logarithmic Regression of Smoulder Period, adapted from (Dowdy and Mills, 2009)

It should be acknowledged that the original data was created by combining lightning data and lightning-fire data, however there is no guarantee that this data is fully correlated. This type of error is a non-sampling error introduced through a systematic issue with this type of data collection. Since there was no way to directly measure the smoulder period by matching lightning strikes with lightning-fires, the use of separate data sets was required. While the methodology will not be explored here, the original study was able to statistically determine that 99% of the fires detected with a smoulder period up to 3 days are correct, and that correlating any fires with a longer period introduced errors far too significant for use. Based on the assumption that a longer smoulder period cannot be *worse* than a short one, since it increases the safety buffer during which time the system can detect it, this will not be an issue for the remaining analysis. Where required, an upper-bound of 3 days will be used and any fires that may have started after 3 days would be detected regardless.

3 Safety and Risk

3.1 Process Control

To understand the limitations of humans factors on the use of aerial vehicles, process control can be used to determine performance decays. Piloting fire-fighting and surveillance aircraft is often incredibly stressful, physically exhausting, and cognitively draining. These factors result in a loss in performance of individuals, which collectively results in a loss of performance for the system. Understanding the properties of such performance decays has been the subject of substantial research, and has been triangulated through different anthropometrics such as electroencephalogram (EEG) measurements, reaction times, and physical characteristics such as eye-movement (Saito, 1999). These anthropometric measures vary in the type of information that can be obtained, however higher reaction times are linked directly with higher states of fatigue, so will be used here. To demonstrate the expected effect of fatigue on a spotter-plane pilot that flies extended hours during the day, a simulated process control diagram has been constructed based on pilot reaction time measurements, shown in Figure 3.

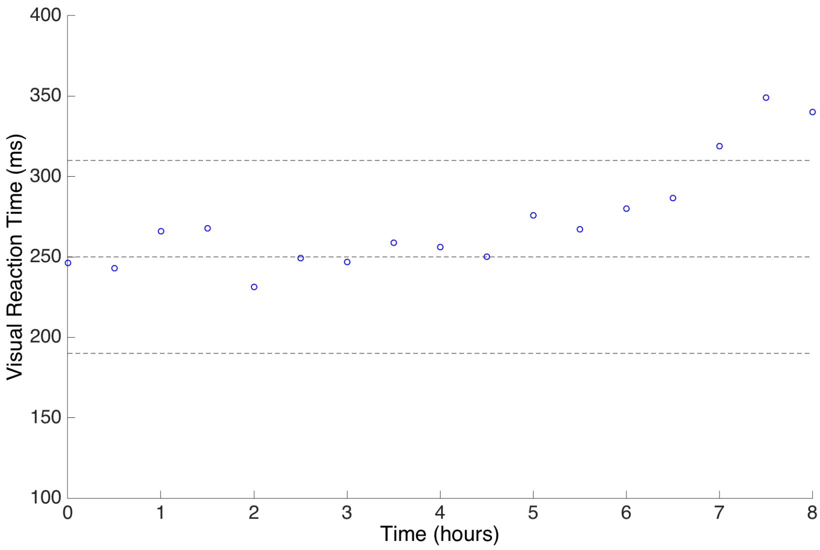

Figure 3: Hypothesised Decay in Reaction Time for a Prototypical Pilot (lower is better)

The data used in this plot was generated using a Gaussian spread about a piece-wise linear function, that accounts for sampling error and variation in the visual reaction time from -50ms to +50ms about the mean of 250ms. The important conclusion that can be drawn from this process control diagram, and the associated supporting research, is that human performance is extremely variable and will decay over time. This is an especially pronounced effect when the task is physically and mentally demanding, as fatigue will be introduced earlier and to a more severe degree. This is the fundamental reason for introducing safety metrics such as limiting pilots to 8-hours per day fly time. The risk increases as the pilot becomes more fatigued, expected to occur after only several hours of intensive flying (Dawson and Reid, 1997).

Removing this human-element avoids this issue entirely, as the performance of an autonomous UAS does not degrade in the same way over a single flight. This would enable longer flights and therefore more area can be covered in a single flight.

3.2 Interviews

To gain further understanding of the limitations on human-piloted aerial vehicles, a preliminary interview was conducted via email in November 2015. This specifically pertained to the current operational strategies for the Rural Fire Service (RFS) in Victoria. The interviewee, Mr. Dale Lovatt is currently working in Parks and Conservation services. The aim of this interview was to establish what role aerial vehicles played in tracking and detecting bushfires, and the limitations placed on the use of these assets. The full interview is provided in Appendix A. The limitations on the use of aircraft is summarised below:

- RFS State Air Desk do not allow fire-fighting aircraft to operate at night
- Pilot fatigue - limited to 8-hours flying per day
- Fuel use increases with temperature and altitude
- Smoke decreases pilot visibility

Such limitations are in place for the safety of the pilots, as well as the ground crews that must also operate close to the fire-front. The risk associated with having pilots fly during the night is too high, considering these aircraft do not have the sophisticated equipment that commercial airliners or UAVs have. This limitation is further compounded by the fact that pilots are limited to 8-hours of flying per day, and the implications on pilot performance of such fatigue is explored further in *Process Control*. Seeking further information from other sources, particularly from other regions of Australia and different fire departments is also important. This is taken into consideration for the *Future Work* section, and is reflected in the recommended Feasibility Study.

4 Current System

4.1 Lightning Detection

Existing systems for lightning detection are widely used in Australia, primarily based on the Lightning Position and Tracking System (LPATS) data that measures lightning flash location density. This works through triangulation of location from differences in arrival times of radio-frequency disturbances that occur due to a lightning strike (Kuleshov et al., 2002). The Australian Bureau of Meteorology (ABM) currently uses this technology combined with their lightning flash counter network, that comprises of 40 regional stations Australia wide. This system provides real-time information that can be used to coordinate efforts during bushfire season to facilitate early responses. Understanding where lightning occurs is a key step in early detection of lightning-fires, however the high-quantity of lightning strikes that can occur during a storm necessitates a filtering method to focus on the most probable strikes to result in a fire.

4.2 Bushfire Detection

There are currently several existing systems for early detection of bushfires. The most recent upgrade is that of the Sentinel Hotspots program, a satellite-based detection method that tracks hotspots across all parts of Australia (Geoscience Australia, 2015). With a 10-minute refresh rate and 0.5-2km resolution, this system cannot adequately detect the juvenile stages of a bushfire, such as superheated trees (Bureau of Meteorology, 2016). Similarly, other existing systems such as EYEfi, FireWatch, and Forest Watch, ground-based image analysis systems, are also designed for detecting fire fronts. These systems are very important, however are later-stage detection methods and therefore more applicable for tracking fires that have already taken hold (Sullivan et al., 2010).

4.3 Aerial Detection

Aerial detection aircraft play important roles in both flagging bushfires in their early stages, as well as tracking of the bushfire front and behaviour. For the 2014/15 bushfire season, Victoria had three fixed wing fire-spotting aircraft and two infrared line-scanning fixed wing aircraft in the fleet (Edwards, 2004). These aircraft have limitations placed on their operation, both for safety reasons as well as logistical reasons. These aircraft may be outfitted with thermal imaging equipment, such as Front-Looking Thermal Infrared (FLIR) cameras, that allow mapping of temperature gradients and identification of hotspots. Such hotspots can indicate locations that have been struck by lightning and are still in the smouldering period, and therefore require attention from firefighting personnel. The primary deficiency of these aircraft is the use of human pilots, which will be the focus improvement.

4.4 Systems View

The primary deficiency in the existing system that has been identified is the detection of bushfires in the formative stages; in particular, during the smoulder period. The process for early detection of such fires that have been caused by lightning strikes is shown in Figure 4. *Hotspot Detection* has been highlighted as this stage is currently insufficient and will be the focus for change in the proposed system.

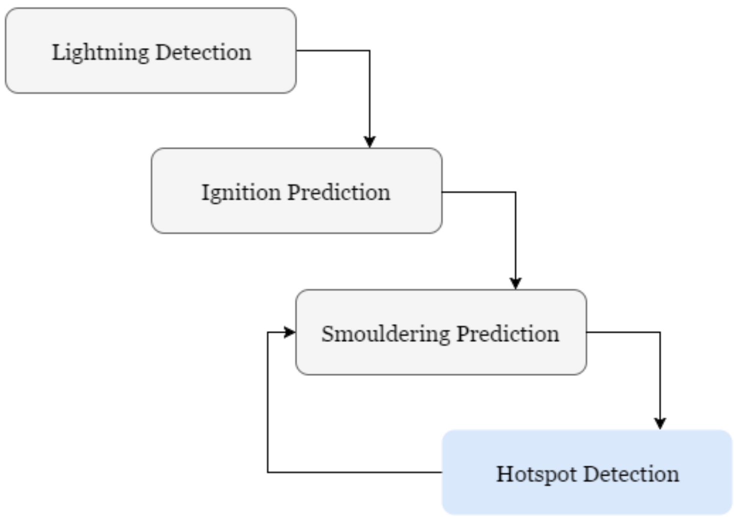

Figure 4: Flow Diagram of Proposed System Implementation

This stage is a high-leverage point for the system, since early-stage fires are considerably more controllable. By identifying bushfires in the earliest stage possible, ground forces can eliminate the risk before the situation escalates. Therefore by improving this element of the system, the greatest benefit can be obtained.

5 Proposed System

5.1 Unmanned Aerial Systems

The use of Unmanned Aerial Vehicles (UAVs) has taken off in recent years, with the advancement in the military and consumer space driving innovation and reducing costs (Christensen, 2014). The primary advantages of this technology directly addresses the deficiencies in current bushfire detection systems, such as removal of human-factors to improve safety and effectiveness, the capability for long-duration flights, and wide-scale land coverage through multiple smaller units.

The proposed system is to incorporate a UAS into the aerial fleet that will be used to strategically perform fly-overs of areas that are predicted to be likely ignition points after a lightning strike. This will require combining the current lightning detection system (LPATS) with smoulder-fire forecasting models to predict high-risk areas that a fire is likely to develop. By targeting high-probability locations, the individual UAVs will be able to canvass these at-risk sites closer to the detection time. By doing this, possible lightning-fire ignition points will be identified at a higher rate and therefore can be controlled through ground forces.

A convoy of UAV aircraft would be deployed shortly after the detection of probable lightning-fire points, and through use of similar thermal imaging equipment as currently used could map areas of hot-spots. Once deployed, the aircraft would fly without human-assistance based on satellite and ground based navigational equipment and would remotely communicate with the ground-station to optimise flight paths and relay data and images.

There are several key advantages to the use of a UAS over the existing fixed wing aircraft. A UAS can operate at night and in adverse weather conditions, which significantly improves the operational windows and therefore the ability to detect early stage bushfires. The use of multiple smaller craft also allows more area to be covered in a given time frame.

The Boeing Insitu ScanEagle UAV is proposed as the base-unit of the UAS, due to the technical capabilities and its use in similar scenarios in America. The ScanEagle is designed as an intelligence-reconnaissance aircraft, with a wingspan of 3.11m, over 24 hour endurance, and on-board electro-optic or infrared camera equipment. This is complemented by autonomous flight capability, satellite navigation, and communication systems. (Boeing Insitu Pacific, 2013)

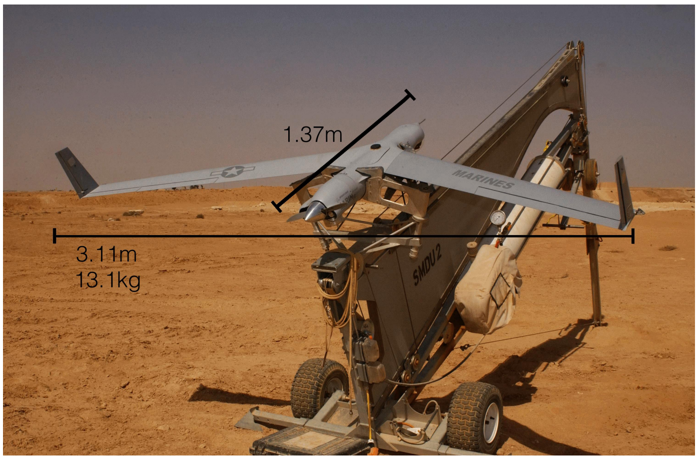

Figure 5: Boeing Insitu ScanEagle UAV Launching, Derivative under Creative Commons Licence, Available at: `https://upload.wikimedia.org/wikipedia/commons/6/6f/ScanEagle_UAV_catapult_launcher_2005-04-16.jpg`,

5.2 UAS Queuing Simulation

The use of a convoy of smaller aircraft instead of several larger aircraft is becoming a far more popular option for moving towards an autonomous aerial platform. The ability to create an interconnected network, or Unmanned Aerial System (UAS), of aircraft that can communicate and strategically coordinate roles can provide a highly efficient system. In particular, the application of such a system to monitoring large areas for hot-spots can provide the flexibility for large scale deployments during bushfire season to effectively and quickly cover vast areas of land. A simulation in MATLAB based on a queuing theory and simulating lightning events and fire-lightning using independent identically-distributed (IID) Poisson distributions was created. An explanation of the simulation methodology is included in the Appendix. This simulation was run with multiple UAV counts in various scenarios and was designed to determine the average wait times from when a lightning strike is detected and when a UAV is able to scan that area. If an event is not attended to within a defined period (the smoulder period, which is uniquely determined for each lightning-fire), then the system has failed to detect the fire in time. It must be emphasised that the purpose of this simulation is not to simulate any real or proposed system; it is simply to demonstrate the difference in system performance when there are multiple UAVs.

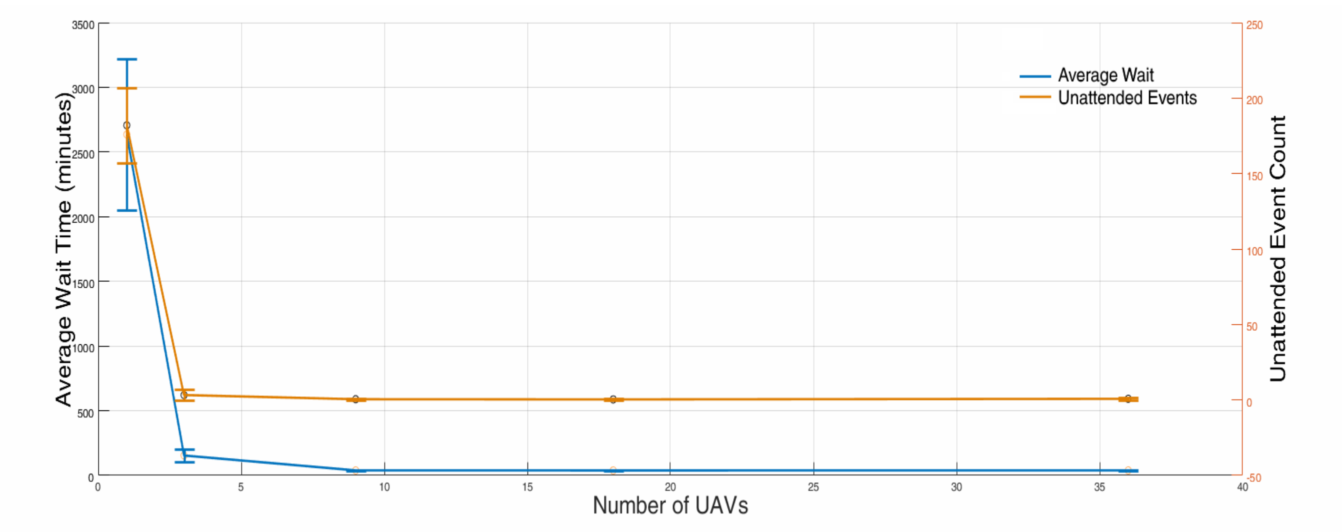

Figure 6: Average Wait Time and Unattended Event Count as a Function of UAV Count

Four different UAV counts were simulated multiple times ($n = 40$) and the mean and standard deviation was calculated for each data set for both average wait time and unattended event count. The results are shown in Figure 6. Note that while the simulation had lightning events that did not result in a fire, this was accounted for in all calculations and the UAV was only assigned to tasks where a fire was expected to occur. There is an apparent trend in Figure 6, whereby both the average wait time and unattended event counts reach a minimum point and stabilise when there are around three UAVs in the system. It has also been confirmed through hypothesis testing of population sets for that 160 data points collected that each UAV count from nine to thirty-six has statistically insignificant differences. The conclusion that can be drawn from this is that there is an optimal UAV count, whereby the law of diminishing returns because pronounced if any additional UAV units are added.

5.3 Data Coordination

A major issue with distributing load across more systems is re-integrating the information being returned from each branch of the system. By using convoys of aircraft that coordinate efforts to cover all areas that require attention, a significant amount of data will need to be analysed. The concept of data organisation is required to collate the various streams of data, while minimising errors and bottlenecks. Figure 7 shows the high-level data flow between key system components. The central Data Management Centre will be the primary telecommunications point, as well as computational centre, for all UAS operations.

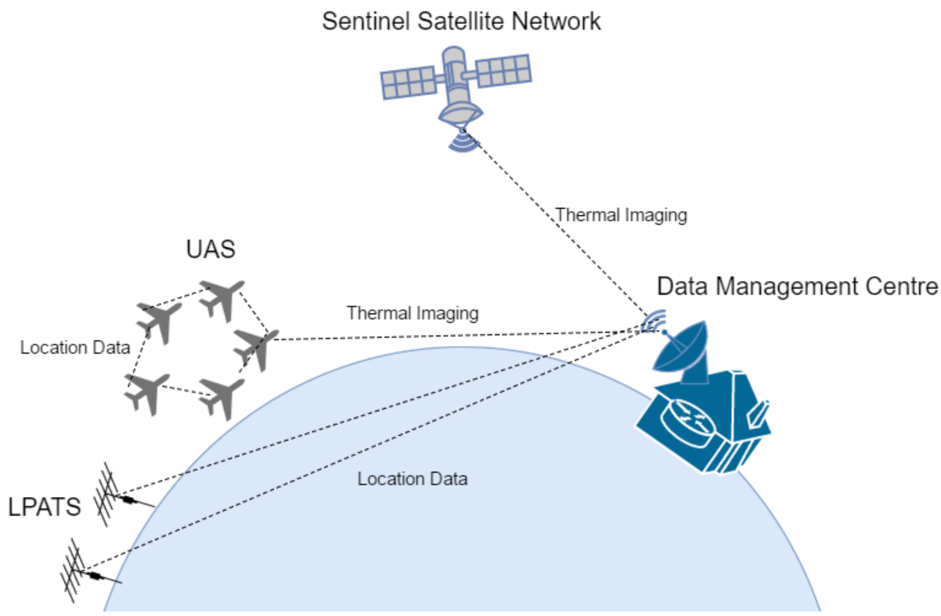

Figure 7: High-Level System Data Flow Diagram

The handling and coordination of this data is a complex exercise that will require in-built redundancy to minimise down-time. Building in a distributed-computational network for data analysis would provide this redundancy, and is another advantage of UAS technology (often referred to as 'swarming' of UAVs). Indeed, distributed-computing could potentially reduce another problem that can be identified from Figure 7: high-data throughputs. By requiring a consistent high-throughput connection to the data management centre, the UAS is less flexible to perform fully-autonomous tasks, such as fly-bys of more remote regions of land that are out of reach of telecommunications. If the UAS is capable of internally coordinating flight patterns with routine 'check-ins' with a ground station, this issue would be avoided. It is also important that operations officers, who make the executive strategic decisions, have accessible information presented to them by this system. Condensing these streams of data to provide effective visual maps for live updates and planning would ensure that these officers are able to make crucial decisions with all necessary information.

6 Ethical and Legal Considerations

6.1 Privacy

There are numerous ethical and social issues that are raised by the use of unmanned aircraft. While the coverage in commercial media is often focussed on the use of UAVs by amateur pilots, the concerns raised are equally applicable to the commercial use of such technology. The ability for UAVs to photograph large areas of land with high-resolution equipment raises various issues around privacy that, while not impacting the performance of the system, would present significant challenges in public perception and therefore support for the adoption of such systems.

Establishing systematic procedures for handling all data is a primary method of dispelling risks associated with collection of personally-identifying information (such as through photography). An advantage of this being adopted through existing departments, such as the CFA and RFS, is that such procedures could be implemented and enforced far better than in the amateur space. Designing regulations to account for the increased used of UAV technology in the public space, as opposed to the current largely military uses, would ensure that this technology is not improperly used. In Queensland, the use of UAV technology by emergency services requires that images are restricted to the incident operation and must follow all departmental privacy policies (Queensland Fire and Emergency Services, 2014). Such requirements would need to be mirrored in other states and other organisations.

An important technical aspect to ensuring privacy is maintained is encryption of data, and this has been accounted for in the recommended UAV model. The Boeing Insitu ScanEagle has military-standard encryption for video and data links to ground stations (Boeing Insitu Pacific, 2013). Indeed, the majority of such UAVs that have been designed in the military space will also provide such capability and features.

6.2 Public Safety

As previously described, bushfires pose a significant risk to the safety of Australians. While the devastation such fires can cause comes in many forms, the most disastrous is human loss-of-life. When considering any change to the existing structures and systems in place to prevent bushfires, the burden of proof must be significantly higher than it might otherwise be, due to the severe consequences for failure. Integration with the existing system should therefore be done with extreme care, and extensive testing is necessary to ensure viability. This will be taken into account in the *Future Work* section.

6.3 Regulations

Regulatory intervention is an important tool for standardising and setting limitations on the use of technology, and the existing regulations around the use of UAVs must be considered. In Australia, these regulations are set by the Civil Aviation Safety Authority (CASA) and are currently attempting to catch up with the rapid development of UAV technology in recent years. In the context of the use of UAVs for emergency services, limited work has been done to ensure the capabilities and opportunities such technology are reflected in policy. Once again, Queensland has moved to enable UAV support for emergency services under strict restrictions that are governed in the regulations at the departmental level (Queensland Fire and Emergency Services, 2014).

7 Economic Viability

7.1 Life-Cycle Analysis

Establishing the life-cycle cost of incorporating a UAS into the existing fleet of aerial-bushfire aircraft is a significant undertaking that cannot be fully explored in the scope of this report. A complete analysis is proposed as part of the Feasibility Study recommended in the *Future Work* section. The acquisition and ongoing costs are estimated here, and a higher-level examination of the costs is provided.

The estimated baseline acquisition costs for this system, based on the cost analysis performed for the United States Coast Guard on a similar implementation, is shown in Table 1.

Item	**Price per Unit (AUD)**	**Subtotal (10 units) (AUD)**
Airframe Unit Cost	$131,000	$1,310,000
Thermal Imaging Systems	$262,000	$2,620,000
Catapult Launcher	-	$325,000
SkyHook Wing-Tip Capture	-	$325,000
Total	$393,000	$4,580,000

Table 1: Estimated acquisition cost breakdown for ten ScanEagle UAV devices and associated equipment cost, based on Erdman and Mitchum (2013) and Ramsey (2004)

The costs were converted directly from USD to AUD ($1.00 USD to $1.31 AUD, as of 15-10-2016), however there will be increased overheads for importation, such as transportation, contractual, and legal costs. There are further associated costs for the implementation of this system, such as ongoing maintenance, specialist operations training, and infrastructure upgrades.

Ongoing maintenance costs can vary drastically depending on the implementation strategy. There are significant cost benefits for up-front investments and storage of particular spare parts, determined by the critical nature of the part and the Mean Time Between Failure (MTBF) rating. An estimation of $400,000 per year ongoing maintenance costs for all ten units will be used here, based on the US Coast Guard implementation (Erdman and Mitchum, 2013). As per the recommendations of Heiss (2012) on the subject of UAV operator alternatives, the training of existing personnel is recommended over using current fire-fighting pilots. This is a direct result of the autonomous operational capabilities of aerial vehicles like the ScanEagle, and this gives significantly more flexibility. The costs associated with the training is included in Table 2. Finally, the cost of upgrading existing infrastructure is included; specifically the cost of obtaining and holding the licence for radio-frequency spectrum required for operations.

Item	**Price per Unit (AUD)**	**Subtotal (10 units) (AUD)**
Yearly Maintenance	-	$400,000 per year
Initial Training	$65,000	$650,000
Training Certification	$100,000	$1,000,000
Spectrum Certificate	-	$32,000
Disposal Cost	$39,300	$393,000
Total	$204,300	$2,475,000 (+ $400,000 per year after)

Table 2: Estimated Operations and Maintenance cost breakdown for ten ScanEagle UAV devices, based on Erdman and Mitchum (2013)

7.2 Limitations

There are significant limitations in this high-level economic analysis. The estimations used are based on American implementations, and are therefore unlikely to translate across to the Australian market. The economics of scale have also not been considered; the cost of units does not correspond linearly to purchasing of multiple units. During the proposed Contract Development stage in *Future Work*, it is expected that negations with the manufacturer (likely Boeing) would result in decreased costs when multiple units are acquired, therefore reducing the average cost per unit. It should also be noted that market trends over time are not considered, such as inflation and changes in exchange rates. Ultimately, the cost analysis presented in this report is only a preliminary estimation and will require extensive work to accurately determine the economic viability. A payback period analysis has been excluded from this portfolio, due to both the aforementioned difficult in accurately assessing costs, as well as due to the complex analysis required for gauging system performance gains. Various factors, not all economic, would need to be considered in this assessment and it is unlikely there is a 'break-even' point for any single metric. A holistic analysis of this is the subject for future work in this field.

7.3 Seasonality

The occurrence of bushfires in Australia is heavily seasonal, and the multitude of climates that exist across Australia mean that there is a near constant demand for bushfire detection and elimination systems. Along the south-coast of Australia, summer and autumn are the highest risk seasons, while along the east and west coasts summer and spring are higher risk. The northern regions of Australia, including Northwest Western Australia and the Northern Territory, have the most bushfires during winter and spring. (Bureau of Meteorology, 2013).

A possible solution to ensure the use of a UAS is maximised, thereby providing the highest return on the investment, is to move the UAS between states depending on the season. Since there is significant overlap, for example many states have the summer period as a high-risk season, it is likely multiple UAS deployments will be required. Furthermore, the severity and damage (both economic and loss-of-life) is disproportionately felt by Victoria. It is clear that further consideration is required to determine the deployment options available to ensure that all regions of Australia are sufficiently covered by this system, without wasting resources for significant parts of the year. This is reflected in the chart in the *Future Work* section.

8 Future Work

As discussed in the *Public Safety* section, the importance of ensuring effectiveness of system performance is paramount. Therefore the implementation strategy will require a long period of time and multiple stage-gates. Shown in Figure 8 is a Gantt chart showing the expected stages and periods in the implementation process. Importantly, there is significant research and review stages that will address the effectiveness of the system and provide an opportunity to account for the dynamics of the system over an 11 year period.

The focus on performing both preliminary and ongoing studies is critical for ensuring the integration into the current system is as efficient and safe as possible, and to ensure that the changes result in ongoing improvements. It is also expected that there will be delays in acquisition, primarily due to logistics of contracting with private industry. Furthermore, regulations

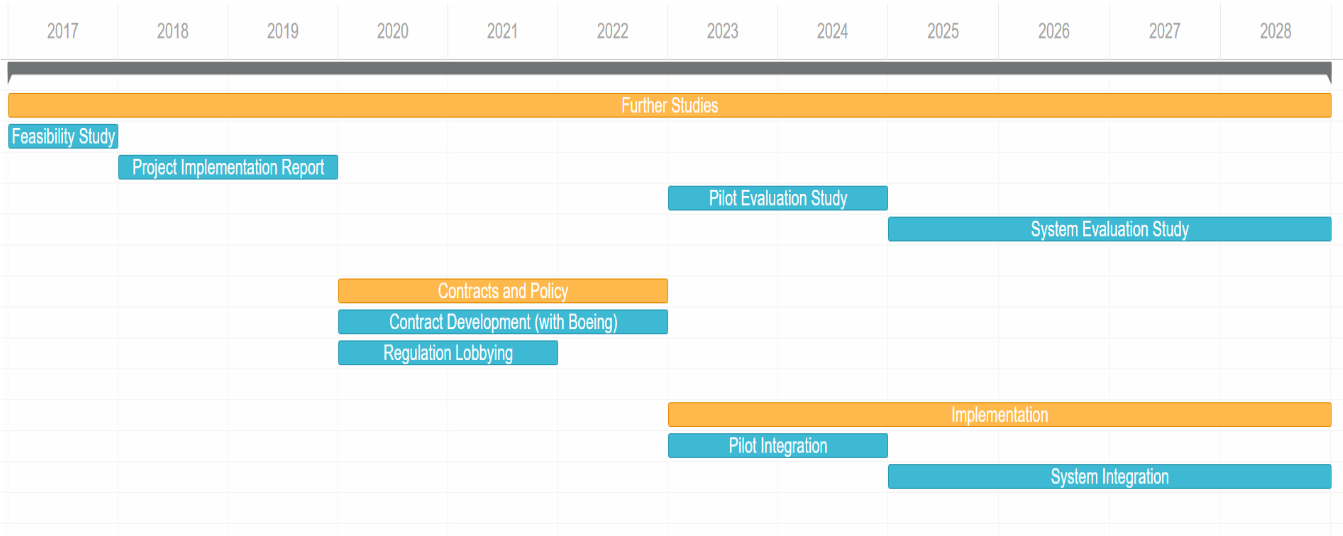

Figure 8: Gantt Chart for Future Implementation Strategy of UAS in Australia

and policies at both the government and departmental levels will need to be updated to provide the capacity for UAS implementation in emergency services departments.

It is also proposed that a pilot program is implemented to test the validity of the feasibility study, and to provide real-world testing of the system to confirm the performance and safety conforms with expectations. This pilot program would develop into the full system integration after evaluation and confirmation of the results.

9 Conclusion

The systems engineering analysis approach has provided insight into the broad and complex issue of bushfire detection. The proposed solution of implementing an autonomous UAS into the existing firefighting arsenal will require extensive future work, however the systems analysis has successfully demonstrated that it has the potential to be an effective and long term solution to a growing problem. The primary advantages are the capability for flying at night and in dangerous conditions, as well as the efficiency gained through utilising multiple units to form a UAS, are expected to improve system performance. An eleven year action plan has been proposed that will ensure this possibility is sufficiently investigated and all limitations and risks associated with changes to the current system are addressed.

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