FRONTIER SI

UAV DATA ACQUISITION IN AUSTRALIA AND NEW ZEALAND

USER NEEDS REPORT

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GLOSSARY OF TERMS

GNSS Global Navigation Satellite System

ASPRS American Society for Photogrammetry and Remote Sensing

CAA Civil Aviation Authority

CASA Civil Aviation Safety Authority

CHM Canopy Height Model

CRCSI Cooperative Research Centre for Spatial Information

CSV Comma Separated Values

DELWP Department of Environment, Land, Water and Planning

DEM Digital Elevation Model

DSM Digital Surface Model

GPS Global Positioning System

ICSM Intergovernmental Committee on Surveying and Mapping

IR Infrared

KML Keyhole Markup Language

LiDAR Light Detection and Ranging

NDVI Normalized Difference Vegetation Index

NIR Near Infrared

QA Quality Assurance

QC Quality Check

RGB Red, Green, Blue (visible light sensor)

RPA Remotely Piloted Aircraft

RPAS Remotely Piloted Aircraft System

RTK Real Time Kinematic

TIN Triangulated Irregular Network

UAS Unpiloted Aerial System

UAV Unpiloted Aerial Vehicle

USGS United States Geological Survey

UTM Universal Transverse Mercator

WA Western Australia

XML Extensible Markup Language

EXECUTIVE SUMMARY

Unpiloted aerial vehicles (UAVs) have come a long way from their military origins. In addition to being one of the latest must-have gadgets for tech enthusiasts, UAVs – or drones – are now indispensable tools across a wide range of sectors.

The mining industry uses UAVs for calculating stockpile volumes; foresters use them to count trees; local governments use them to count roof-top solar panels and assess the state of footpaths; environmental managers use them to count wildlife or look for landslide risk areas; and emergency services use drones during bushfires and for search and rescue operations. UAVs are also used in agriculture, forestry, surveying, construction, and even to document heritage buildings.

Whether they're fixed-wing, multi-rotor or hybrid versions, unpiloted aerial vehicles are not only relatively cheap to use, they can also be deployed more quickly and easily than other remote sensing methods such as piloted surveillance aircraft.

Despite the advantages of UAV capture, an ongoing issue with the low quality of the data provided by some UAV data suppliers is causing considerable frustration, cost and set-backs for users. This situation often arises because UAV data suppliers don't necessarily understand what the end-users need from the data.

This report aims to capture, explore and address that gap in understanding. FrontierSI, in collaboration with the Mineral Research Institute of Western Australia (MRIWA) and Department of Environment, Land, Water and Planning (DELWP) Victoria, has investigated how UAVs are being used to capture and acquire data, and how that data is being used.

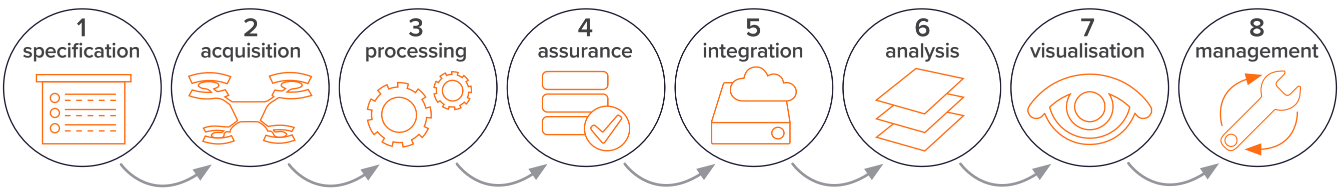
The research involved consultations with 135 people who either use, broker or supply UAV data, from 80 organisations across government, private sector, industry and research. Nearly 62 per cent of these participants were either suppliers of UAV data or capture their own UAV data for internal use. Broker organisations were those offering value-added services such as spatial analysis and feature extraction.

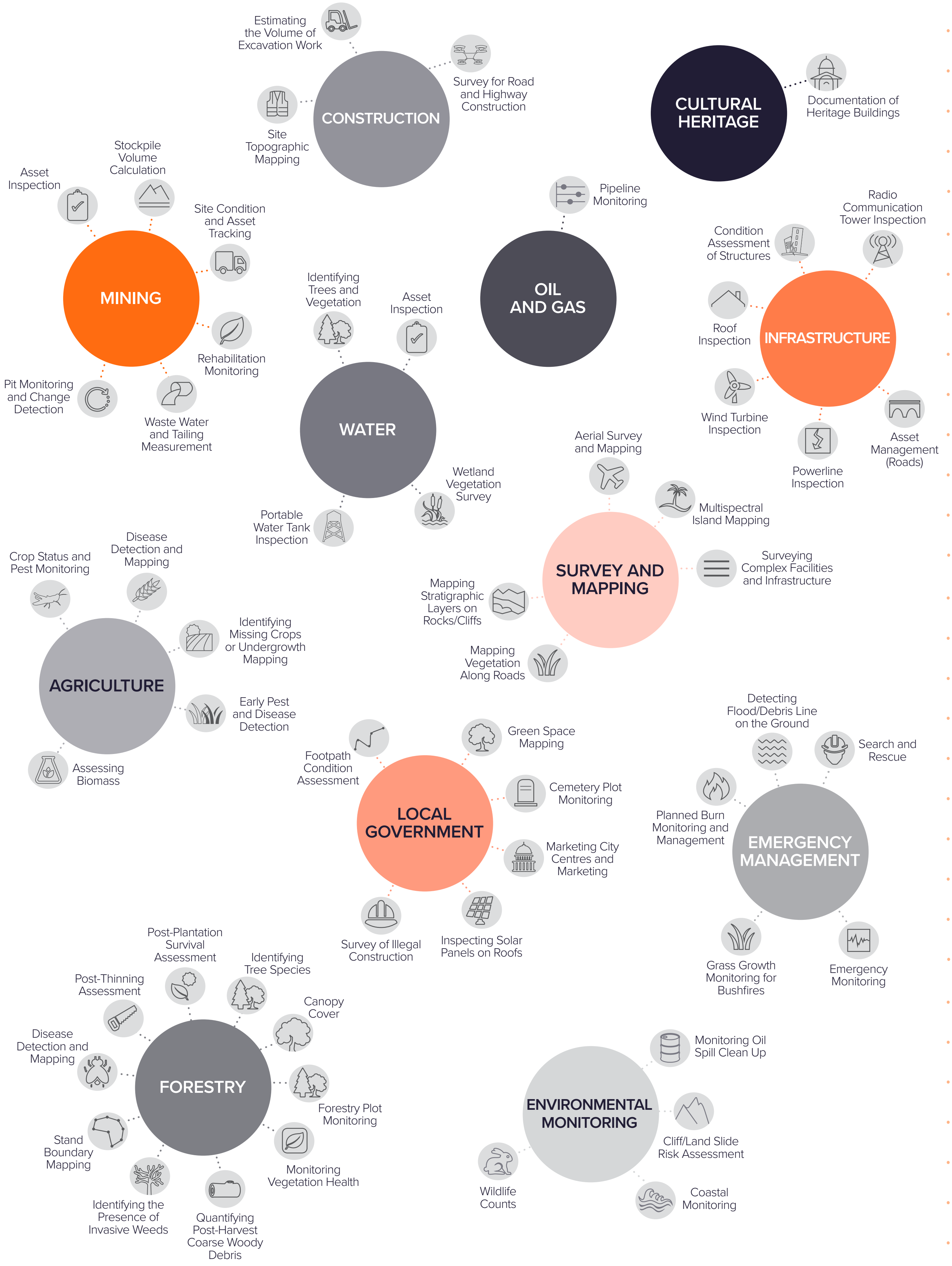
Overall, as illustrated in the figure in the next page, we profiled 56 distinct applications of UAV data across 12 different sectors; mining, environmental monitoring, agriculture, emergency management, local government, construction, infrastructure, forestry, oil and gas, cultural heritage, and water. These applications are described in the supplement section at the end of the report.

Given the huge range of sectors making use of UAV data, it's not surprising that the types of data being captured vary enormously as well. The most common data acquired by UAVs was photographic imagery of infrastructure and landscape features such as the ground surface, vegetation, buildings, water bodies and coastline. This also meant the most common payload carried by UAVs was optical cameras.

But in fields such as agriculture, forestry and asset inspection, the imagery requirements extend beyond the visible light spectrum to include infra-red and near-infrared, multispectral and hyperspectral imagery. These users often need to obtain crucial insights invisible to the naked eye, such as information about the health of plants. There is also a growing demand for Light Detection and Ranging (LiDAR) – sometimes called laser scanning – although cost and power consumption still limit uptake of this technology.

Despite the widespread use and popularity of UAV-acquired data, there are some stand-out issues; chiefly accuracy and image quality.





CONSTRUCTION
Estimating the Volume of Excavation Work
Survey for Road and Highway Construction
Site Topographic Mapping
CULTURAL HERITAGE
Documentation of Heritage Buildings
MINING
Asset Inspection
Stockpile Volume Calculation
Site Condition and Asset Tracking
Rehabilitation Monitoring
Waste Water and Tailing Measurement
Pit Monitoring and Change Detection
OIL AND GAS
Pipeline Monitoring
WATER
Identifying Trees and Vegetation
Asset Inspection
Wetland Vegetation Survey
Portable Water Tank Inspection
INFRASTRUCTURE
Condition Assessment of Structures
Radio Communication Tower Inspection
Roof Inspection
Wind Turbine Inspection
Powerline Inspection
Asset Management (Roads)
SURVEY AND MAPPING
Aerial Survey and Mapping
Multispectral Island Mapping
Surveying Complex Facilities and Infrastructure
Mapping Stratigraphic Layers on Rocks/Cliffs
Mapping Vegetation Along Roads
AGRICULTURE
Crop Status and Pest Monitoring
Disease Detection and Mapping
Identifying Missing Crops or Undergrowth Mapping
Early Pest and Disease Detection
Assessing Biomass
LOCAL GOVERNMENT
Footpath Condition Assessment
Green Space Mapping
Cemetery Plot Monitoring
Marketing City Centres and Marketing
Inspecting Solar Panels on Roofs
Survey of Illegal Construction
EMERGENCY MANAGEMENT
Detecting Flood/Debris Line on the Ground
Search and Rescue
Planned Burn Monitoring and Management
Grass Growth Monitoring for Bushfires
Emergency Monitoring
FORESTRY
Post-Plantation Survival Assessment
Identifying Tree Species
Post-Thinning Assessment
Canopy Cover
Disease Detection and Mapping
Forestry Plot Monitoring
Stand Boundary Mapping
Monitoring Vegetation Health
Identifying the Presence of Invasive Weeds
Quantifying Post-Harvest Coarse Woody Debris
ENVIRONMENTAL MONITORING
Monitoring Oil Spill Clean Up
Cliff/Land Slide Risk Assessment
Wildlife Counts
Coastal Monitoring

Around half of survey participants said data accuracy was a problem. Issues included lack of positional accuracy, incomplete data, images not being georeferenced, incorrect units, and gaps in coverage. Furthermore, these errors could take a long time to correct; some of those surveyed reported that it could take more than two weeks to identify errors, contact the data provider to get the data fixed, and then receive the corrected data.

One reason for the prevalence of accuracy issues may be the lack of published guidelines on data capture from UAVs, and the fact that what few guidelines do exist aren't being used. Most users were not aware of any formal standards or guidelines for UAV data capture, and only 12 per cent of people surveyed said they used an existing standard for their UAV data capture.

When it came to deciding parameters for data capture, most users said they consulted experts on the particular subject matter, which in many cases were the participant's own colleagues. Around one in five end-users of the data relied on advice from the data providers themselves. The technical specifications for data capture using UAVs are very different from those used in piloted aircraft surveys, so those guidelines do not transfer to the UAV setting. In most cases, the specifications were just set to identify, measure or map the smallest feature of interest.

Just under one-third of survey respondents said image quality was an issue. The challenge here is that image quality means different things to different users, so imaging needs can differ significantly depending on the application. A high-resolution but low-quality image may be useful in one setting, while another user may not need such a high-resolution image but does need an image that is sharp, with better colour balance and free from haze.

While UAV surveys are generally cheaper and easier than piloted aerial survey methods, they still face their own unique challenges that can be responsible for project delays and setbacks. These included weather-related factors such as wind or lighting, specification-related issues leading to delivery of the wrong product, data processing lags and software issues, timing-related problems where the opportunity to capture data at a specific moment is missed, site access issues, and equipment malfunctions.

Based on the findings, we have highlighted more than 40 quality assurance checks that could help determine if UAV-acquired data is high-quality and fit-for-purpose.

Clearly there is a need for assisted workflow and quality assurance tools to help end-users and data providers work out the specifications of the data they need, and to check and ensure the quality of the end result. FrontierSI will use the results of this report to inform development of such a tool – called QA4UAV.

UAV data capture technology is advancing rapidly, as are the possibilities for its use, so it is vital that we continue to monitor this exciting field and explore new potential applications.

1 INTRODUCTION

Originally used in the military for combat and surveillance, aerial drones, also known as Unpiloted Aerial Vehicles (UAVs) or Remotely Piloted Aircraft Systems (RPAS) became popular as a recreational product in 2013. Since then, as systems advanced, the commercial use of UAVs has grown. The technology advancements behind this were partly driven by developments in mobile technology, including improvements to stabilisation systems such as accelerometer, gyroscopes and higher precision GNSS.

The UAV market continues to evolve at a fast pace, with decreasing costs and improved capabilities that can satisfy the needs of many applications. These capabilities include increased flight ranges, improved endurance, flight automation, hovering, obstacle detection and collision avoidance. Furthermore, UAVs provide a more flexible and cost-effective option for regular data collections, providing faster insights than traditional data acquisitions for business and operational decisions. These features make UAV technology an attractive choice for a range of business applications, and accordingly there are a growing number of organisations across multiple sectors (government, mining, environmental management, utilities) now actively using UAVs for acquiring their data.

The proliferation of affordable UAVs has given rise to many data suppliers. CASA Reports [1] in February 2018 show that the number of commercial and private UAV operators continues to increase, with over 1,200 registered licensed commercial UAV operators across Australia. This is a 30 per cent increase from March 2017, and nearly 10 times the number of operators in 2014 [2]. A recent study by Gartner shows that this growth will continue, although it is expected to plateau within two to five years [3,4]. As the UAV market matures there has been an increasing level of consolidation and partnerships between hardware, software and service providers [5,6].

Recent UAV industry assessments indicate a surge in the number of novice data suppliers with little experience or understanding of spatial data products delivered to clients [9]. In addition, they may not possess sufficient experience in different sectors to obtain user needs by asking the right questions. Accordingly, these suppliers tend to adopt their own specifications which often don't fully match with users' requirements. In many cases, they rely on their peers' knowledge or look for answers in foreign online forums (e.g. Reddit) that do not necessarily account for Australian and New Zealand conditions. It is also not uncommon for suppliers to guess these specifications or adopt manned aircraft data acquisition standards.

On the flipside, the users of UAV data are often not fully aware of the potential requirements and benefits derived from UAVs, leaving much of the data capture decisions to operators. Accordingly, there is a gap between users and suppliers in understanding each other's needs and capabilities, often leading to the delivery of low quality, or not fit-for-purpose data which results in frustrations and delays within projects. Sometimes recaptures are required at additional costs for the suppliers or clients, even after a data acquisition is perceived as completed. These experiences often lead end-users to third-party quality assurance (QA) services to ensure the data is fit-for-purpose.

As the number of UAV projects and applications proliferates, so does the need to better communicate and understand the needs of end users. A standardised workflow for UAV data acquisition can potentially satisfy this need by creating a communication channel between users and suppliers to share their capabilities and requirements. Coupled with an automated QA process, this workflow ensures the fitness-for-purpose of data, reduces projects' risks and consequently creates a strong confidence in the market. Surprisingly, at present there is no standard workflow or tool which can manage the UAV data acquisition and assesses if the supplied UAV data and products meet user requirements.

1.1. About this report

This report is prepared by FrontierSI[1] to generate a better understanding of the data needs and technical specifications for capturing fit-for-purpose data for common UAV applications in Australia and New Zealand. It presents the outcomes of the first stage in the development of an automated software to manage the workflow for the acquisition of UAV products from the procurement perspective. This research captures a snapshot of the current Australian and New Zealand UAV market, including end user needs and their technical requirements. It will assist:

- End users to better understand the requirements for their application, and potential options for the data capture;
- UAV data suppliers to better understand the needs of end users within different market segment; and
- FrontierSI to better understand the QA requirements of end users and the priorities for supporting the UAV data procurement process.

[1] Formerly CRCSI

This report begins with a brief overview of current UAV technologies and trends based on industry reports, publicly available information, and the Australian Civil Aviation Safety Authority (CASA) as well as New Zealand regulations.

The second part of this report provides a brief explanation on the research approach setting out the scope and limitations.

The third part of this report provides a summary of the user needs research, including the participants, their areas of interest, and applications using UAVs. It also provides a summary of the outputs for applications within different industries/sectors. A more detailed explanation of application areas in each sector are provided as separate supplements at the end of the report. These sectors are *mining, environmental monitoring, agriculture, emergency response, government, survey, construction, infrastructure, forestry,* and *others (i.e. oil and gas, cultural heritage and water).*

The fourth and fifth sections of the report summarise the findings, and set out a vision for a standardised and flexible Quality Assurance (QA) tool for UAV data. They also include the conclusion and future steps for improving the understanding of UAV user needs.

1.2. How to navigate this document

The following figure helps the reader to navigate through this document:

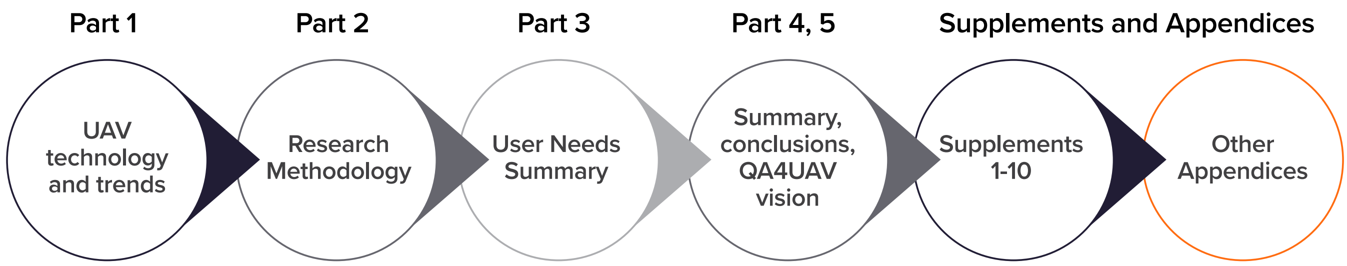


Figure 1: Structure of the report

1.3. UAV Technology and Trends Overview

UAVs are commonly regarded as remotely piloted or autonomous aerial vehicles, Unpiloted Aerial Systems (UAS) or Remotely Piloted Aircraft Systems (RPAS). This section presents an overview of UAV technologies, applications and current trends.

1.3.1. UAV Platforms

Currently there are several categories of UAV platforms with many variations within each. They include fixed-wing, single-rotor, multi-rotor and hybrid systems. Appendix F provides a summary table for a comparison of these platforms.

Fixed wing

Fixed wing UAVs encompass small, Medium Altitude Long Endurance (MALE), and High Altitude Long Endurance (HALE). The benefits of fixed-wing over rotor UAVs is that they are more energy efficient and cover larger areas while carrying heavier payloads. The main drawbacks of fixed wing UAVs include their inability to hover, instability in windy conditions, more complex launching and landing processes, and risk of being destroyed by wedge tailed eagles. They are also comparatively more expensive and difficult to use than rotor drones. Fixed wing UAVs are necessary when covering large area drone surveys. Their applications tend to focus on data rather than photography, therefore higher end processing is necessary to derive information such as stockpile volume calculations, tree counts and map overlays.

Multi-rotor

Multi-rotor UAVs are the most widely used platforms, for example the popular DJI Phantom. They include tri-copters, quad-copters, hexa-copters and octo-copters with 3, 4, 7 and 8 rotors respectively. The benefits of multi-rotor UAVs are that they are capable of vertical take-off and landing, and have good control and stable flight characteristics. They can hover and access tight spaces and are relatively low-maintenance. They are the easiest and cheapest UAV alternative, and are best suited to applications requiring aerial photography or video. The main drawbacks are that they have limited endurance and speed, so are not suited to large scale mapping. They are energy inefficient and their operation is currently limited to 20-30 minutes on battery when carrying a lightweight camera [20]. This category also includes water proof UAVs like SwellPro Splash that are essentially a quad-copter that can fly in the air and land on, float on and take-off from water. Remarkably they can move underwater if upside down and can be used for applications like aerial and underwater photography, fishing, water rescue, marine research and collecting water samples.

Hybrid

Hybrid UAVs include Vertical Take-off and Landing (VTOL) fixed wing which are essentially fixed-wing drones with rotors added. Hybrid UAVs combine the abilities of fixed wing and rotor, in that they are capable of vertical take-off and landing, can hover, have endurance, are low-maintenance, and can glide if an engine fails.

In addition to these platforms, there are other forms of UAVs (e.g. blimps, balloons and kites) utilised for aerial monitoring and imagery. Blimps and balloons are designed to be lighter-than-air to provide lift and continuously support payloads.

Kites are another alternative for undertaking remote sensing as they can provide substantial lift enabling considerable payloads. They can also provide more control than balloons and blimps on windy days. However, to be able to fly kites with a significant payload, there must be sufficient wind to ensure there is enough lift.

There are many manufacturers of UAV platforms. Research by DMR highlighted a total of 195 UAV manufacturers at the end of 2017 [10]. The top UAV manufacturers, according to Drone Industry Insights, include DJI, Parrot, Xiaomi, and SenseFly [11, 12].

1.3.2. Payloads

The payload is essentially the carrying capacity of a UAV, usually measured as the weight being carried. UAVs can be used to carry small payloads, perform deliveries and minor services, carry video and static cameras for photography and videography, and perform commercial and military inspections. Fundamentally pilots must ensure that a UAV can carry the desired payload for the required flight time. As a rule of thumb, the heavier payload a platform carries, the shorter its flight time will be.

UAV payloads can either be active i.e. sensors such as cameras, LiDAR, or other specialised instruments, or passive i.e. deliveries such as parcels, medical or rescue equipment etc. Appendix H summarises the types of payloads and some application examples for each.

1.3.3. Applications

Individuals, commercial entities, and government organisations have realised the benefits of UAVs for various uses which includes but are not limited to [6]:

- Aerial photography
- Express shipping and delivery
- Gathering information or supply essentials for disaster management
- Search and rescue operations
- Geographic mapping of inaccessible locations
- Building safety and asset inspection
- Precision crop monitoring
- Remotely operated cargo transport
- Storm tracking and weather forecasting
- Industrial inspection including bridges, roofs, cell towers
- Real estate and aerial photography
- Agriculture applications like crop surveying and analysis
- Insurance applications like risk assessment, claims adjusting, damage determination

UAVs have other applications in government like law enforcement, border surveillance, and fire management [6]. They are also being prominently used in:

- Agriculture
- Energy
- Mining
- Oil and gas
- Environmental monitoring
- Geophysics
- Survey
- Industrial operations
- Water sector
- Infrastructure
- Construction
- Insurance
- Law enforcement
- Emergency services
- Media
- Photography and videography
- Utilities and pipelines
- Scientific and research uses
- Interest groups and recreational uses

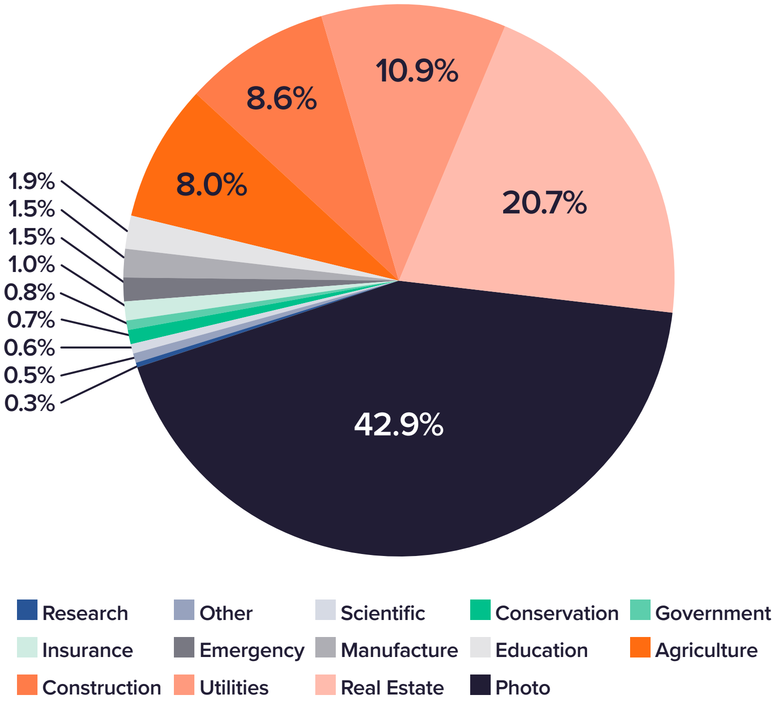


Figure 2: Top industries using drones (Source: Business Insider)

Business Intelligence [12] provided a summary of top industries using drones as part of their day-to-day business. Their insights into the drone industry indicate that industrial inspection and photography are the most popular *(see Figure 2)*.

1.3.4. UAV Project Workflow

The UAV data acquisition workflow varies across projects and organisations; however, it usually consists of the following steps:

1. Determining the specification for data capture
2. Data acquisition using the UAV platform and sensor
3. Processing of the collected data into the required products
4. Quality assurance on the data against the specifications
5. Integrating the collected data and products into the existing workflows and databases
6. Analysis of the data as an input into decision-making
7. Visualisation of the data and/or analysis results for communicating to a broader audience
8. Data management and archiving which includes storage, updating, metadata etc.

This process is illustrated in *Figure 3*. However, not all steps are necessarily included for all applications.

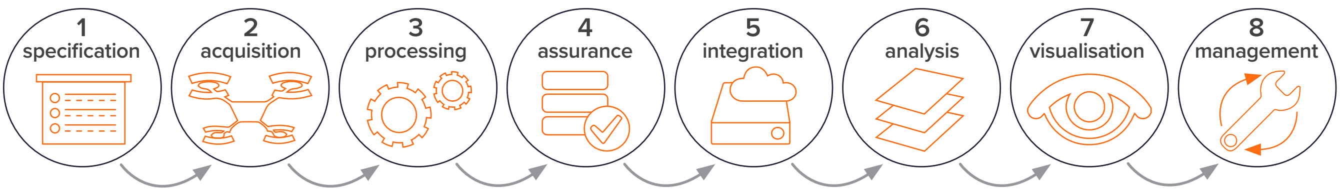


Figure 3: End-to-end drone data processing steps

1.3.5. UAV Industry Trends

The UAV industry continues to rapidly change and mature, with new and novel applications still permeating the industry. According to Drone Industry Insights [9], company churn, both in and out of the industry, remains strong. GoPro made a recent announcement that they are now moving away from the drone business. Many similar stories about companies entering and leaving the market indicate that the industry is still yet to mature. The current trends in the UAV market, according to the analysis of existing reports and market observations include [5, 9, 14, 15, 21, 22]:

- A shift in market focus and investment from UAV hardware development to software for data analysis and processing;
- Consolidation of software solutions through business partnerships for more end-to-end solutions;
- The market for use of UAVs for logistics and delivery is now operational and growing beyond conceptual plans. For example, Amazon is now using UAVs for delivery of their products;
- Continuous increase in the number of UAV certificate holders and pilots *(see Figure 4)*. This is expected to increase for the next 2 to 5 years;
- Strong specialisations for UAV suppliers within specific industries, such as agriculture and mining, along with custom hardware developments to support specialised data outputs;
- On-the-fly processing and analysis of outputs as the UAV is collecting the data;
- More focus on UAV integration with existing products and processes, and the use of Application Programming Interfaces (APIs) to visualise the outputs;
- Combined use of UAVs and Artificial Intelligence (AI) and Deep Learning for pattern recognition in applications such as asset inspection, forestry, weed control and emergency management;
- Increased adoption of UAVs for live coverage of indoor and outdoor shows, sports and entertainment;
- Drone-as-a-Service (DaaS) emerging as a business model;
- Institutions and regulating bodies attempting to explore opportunities and support growth, whilst limiting the threats and explaining the limitations of UAVs.

All the above-mentioned trends indicate new solutions are entering maturity and easier to integrate into existing workflows, and new capabilities and uses are still rapidly emerging.

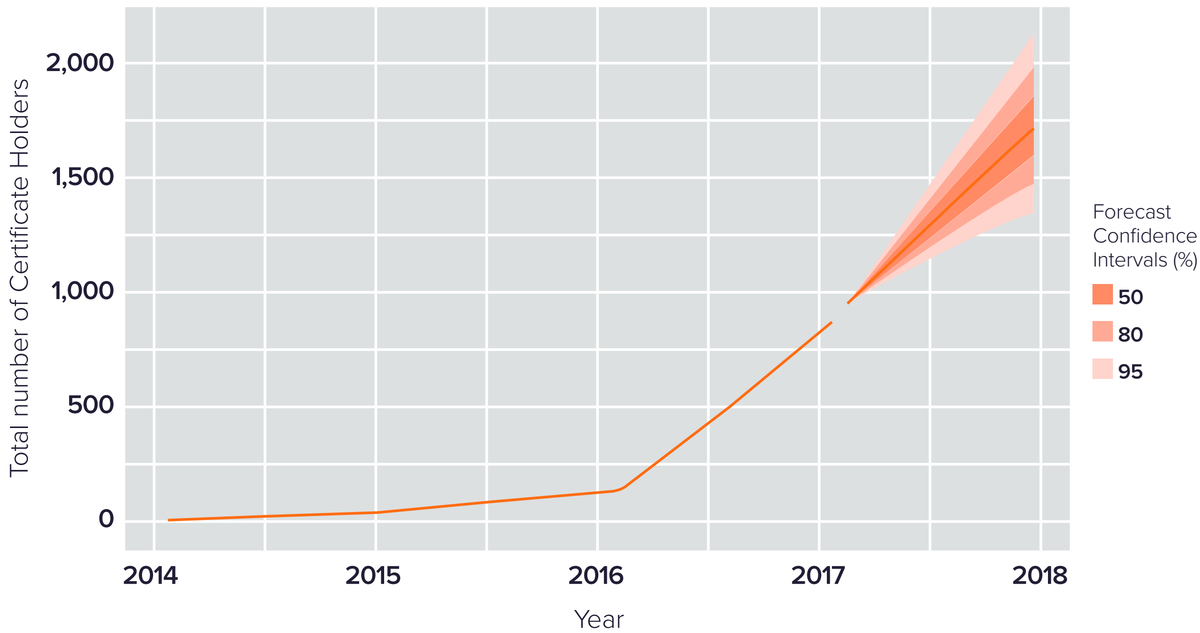


Figure 4: Total Number of CASA registered UAV certificate holders (Jan 2014 to Jan 2017)2 (Source: ATSB [22])

[2] The orange regions are the 50th, 80th and 95th per cent confidence intervals for the forecasts (up to Dec 2017) calculated using the weighted average of ARIMA and Exponential smoothing state space models.

2 APPROACH

This section provides a brief overview of the approach used to derive the UAV data user needs in Australia and New Zealand. *Figure 5* illustrates the stages used to generate this report.

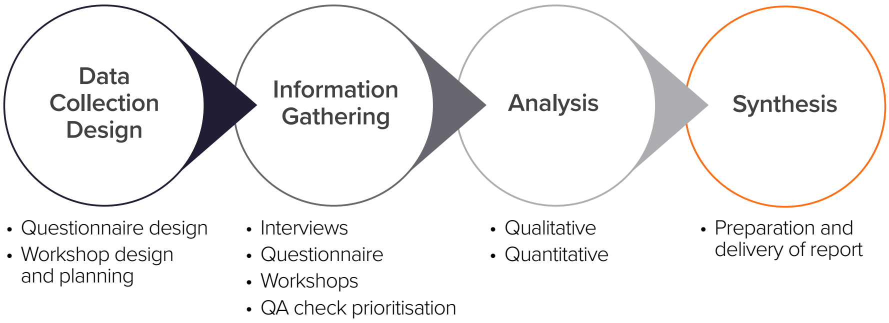


Figure 5: Stages of research

2.1. Information Gathering

Following the design and refinement of the survey, the information gathering achieved its aim of contacting at least 200 UAV users within Australia and New Zealand, and receiving a minimum of 100 responses to the questionnaire. The questionnaire was published in several forums including the Core Innovation Hub blog[3], AUSTMINE newsletter and Australian UAV newsletter. The survey was conducted during September to December 2017 and the questionnaire was closed following the final QA4UAV workshop on 2 November. The aim when distributing the questionnaire was to reach as broad a range of user types as possible.

In addition to the questionnaire, FrontierSI held five workshops:

- DELWP and their partners, Melbourne, 28 August 2017
- ANDS workshop, Melbourne, 9 October 2017
- Queensland workshop, Brisbane, 11 October 2017
- Western Australia workshop, Perth, October 2017
- New Zealand workshop, Christchurch, 2 November 2017

A total of 96 people from 33 organisations attended these workshops, participating in brainstorming sessions and focus groups. The information collected in the workshops included:

- Locations participants are actively using UAVs;
- The types of UAV platforms operated;
- The types of payloads and sensors used;
- UAV applications and their requirements;
- Strategies used to determine their project requirements;
- Ways that they interact with the UAV data and products;
- Software used for different stages of capture; and
- Challenges faced collecting UAV data.

A structured questionnaire with a set of closed- and open-ended questions was also employed to collect participant inputs to the above topics *(see Appendix A)*.

Several interviews were also conducted with UAV project partners. They included Australian UAV, ThinkSpatial, DELWP, Parks Victoria, SCION Research in New Zealand, Position Partners, Hort-Eye in the University of Melbourne, and Melbourne Water and Southeast Water *(see Appendix D for their details)*.

2.2. Scope and Limitations

The scope of this report has been limited to an analysis of the data gathered in the questionnaire, workshops and interviews. As such, the report has the following limitations:

- The scope only covers UAVs, and not the other drone types like high grade military drones or unpiloted rovers on the ground or underwater drones;
- This report provides an understanding of user needs and their collection requirements, and does not aim to provide a full UAV industry and trends analysis;
- The analysis is based on the data available to the project team through the questionnaire, interviews, and workshops, and other publicly available sources;
- This report, as mentioned in Section 1.1, is part of the QA4UAV project with more input sought from project partner organisations; this may lead to a small bias in the outcome of the survey.

[3] http://www.corehub.com.au/blogpost/analysing-uav-user-needs-to-improve-performance

3 UAV USER NEEDS SUMMARY

This section provides an overview and summary of the research findings for 56 applications across 12 different sectors within Australia and New Zealand. The application areas include mining, environmental monitoring, agriculture, emergency management, government, survey, construction, infrastructure, forestry, water management, cultural heritage, and oil and gas.

3.1. Overview of Participants

In total, 135 people from 80 organisations *(see Appendix C)* participated in the survey in this research. The distribution of respondents across different sectors is shown in *Figure 6*.

The survey participants were involved in different stages of the UAV data acquisition workflow *(see Section 1.3.4)*. *Figure 7* shows their involvement in various stages of this workflow. Of the organisations involved, 67 per cent were involved in acquiring UAV data themselves. Only 3 per cent of these people were involved in Research and Development (R&D). Of note, 58 per cent of participants were focussed on feature extraction and advanced analytics on UAV data.

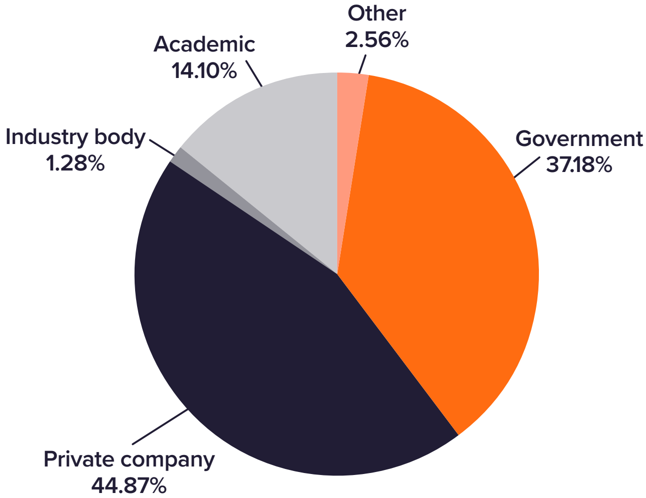


Figure 6: Participating organisations type[4]

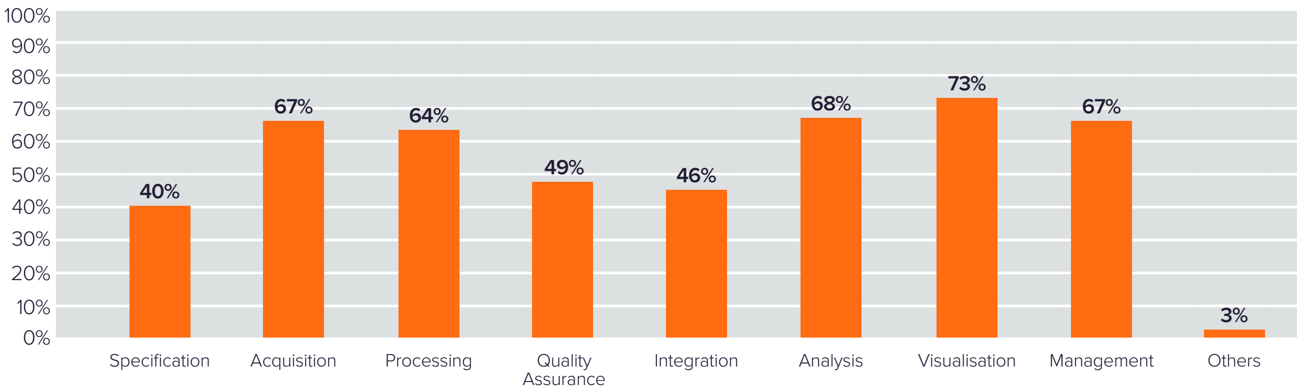


Figure 7: How do participating organisations interact with UAV data

3.1.1. Overview of UAV operators

The research focussed on both UAV suppliers and data users. A majority of participants (62 per cent) fly UAVs as part of their business operations. Of these participants only 50 per cent fly UAVs frequently *(see Figure 8)*.

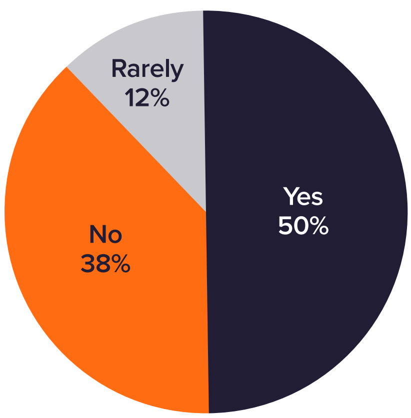


Figure 8: If participating organisations fly UAVs

[4] The "Other" category includes consultancy firms and open source initiatives

Countries of operation

The participant drone operators mainly fly UAVs across Australia and New Zealand. They have also operated in other regions including the Pacific Islands, South East Asia, Russia, Mexico, Brazil, Chile, Kazakhstan, Turkmenistan, Turkey, Georgia, and Antarctica. The areas identified are shown in *Figure 9*. Each point on the map represents UAV operations according to the respondents.

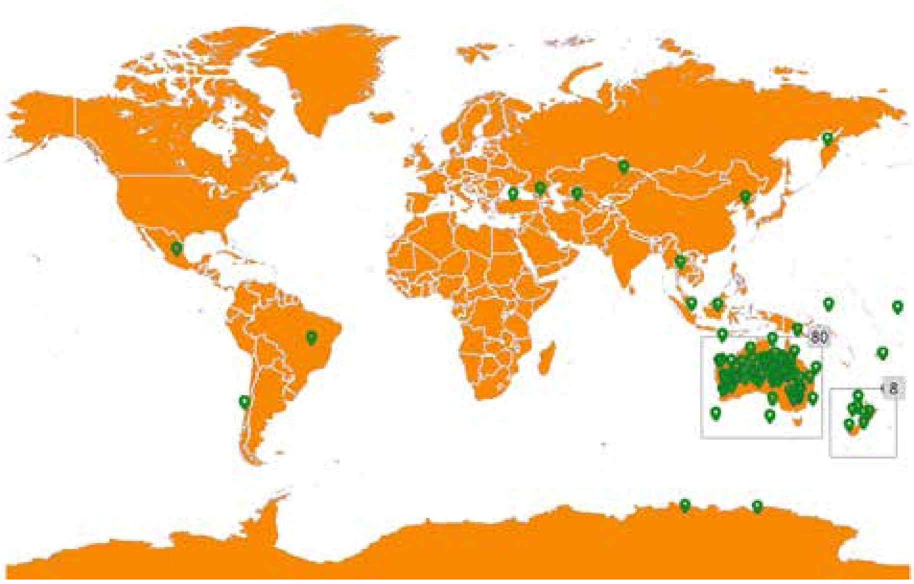


Figure 9: Regions of operation by UAV operators

UAV pilots in organisations

Figure 10 shows that out of those UAV operators 22 per cent rely on only one pilot. This percentage may include hobbyists and people using UAVs for real-estate photography. Further percentage breakdowns are shown in *Figure 10*, with 29 per cent of operators having more than 5 pilots. As an example, project partner ThinkSpatial has 14 certified pilots for one or more UAV platforms. Interestingly, the data showed that the number of pilots was strongly correlated to the number of UAV platforms companies owned.

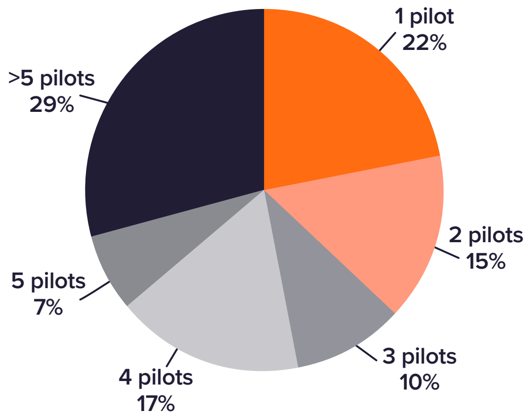


Figure 10: Number of pilots in UAV operators

Overview of UAV platforms

The UAV operators provided details on the types and models of their UAV platforms. While 27 per cent of those who fly UAVs operate only one platform, a significant percentage of operators (nearly 40 per cent) own more than 5 UAV platforms. Suppliers will also take multiple platforms to a job, and depending upon the conditions (e.g. weather or other factors), will select the optimal platform suited to the environment on the day.

A summary of the most common UAV platforms used by the UAV operators is shown in the word cloud in *Figure 12*. The larger the font sizes in this figure, the larger the popularity of the platform.

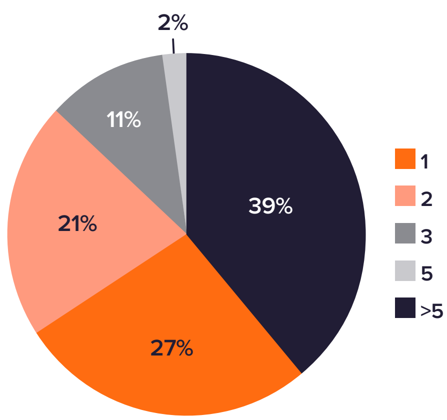


Figure 11: Number of owned UAV platforms

Figure 12: Word cloud summary of the most common UAV platforms used

Overview of Sensors

Depending on a variety of factors, UAV operators will select different sensors for data collection. The most common types of sensors are shown within a word cloud in *Figure 13*, these include RGB, NIR, IR cameras, multispectral and hyperspectral. Responses showed that LiDAR sensors are gaining popularity.

RGB cameras are the most popular sensor and their applications are widespread. Whilst they are mostly used for photography and videography, photogrammetric techniques can be applied on images to produce point clouds and surface models for a variety of applications. In comparison to RGB cameras, the applications of IR, NIR, multispectral and hyperspectral sensors are limited to specialist applications in areas such as agriculture, forestry or asset inspection where there is a need for more advanced products for uses such as assessing vegetation health and soil moisture.

Figure 13: Word cloud summary of the most common sensors for UAV data capture

Time series data

UAVs have a low barrier for entry, in comparison to other remote-sensing acquisition techniques, with low operating costs and on-demand access. They have significant advantages for frequent and regular data captures. As is evident in this research by the popularity, these features give UAVs advantages for acquiring time series data.

Of the participants 75 per cent indicated they acquire time series data. The frequency of the flights is highly project specific, varying from daily to weekly, monthly, or even annually. For instance, frequent data collection for change detection in mining or environmental monitoring is important especially for identifying changes in excavation or stockpile volumes, or even erosion in coastal areas.

Time sensitivity varies from one project to another and can be collected on a specific day, week, or a month of the year. Although there was a skew in data towards data collection in a specific week, the research found no significant difference in the percentage of responses that shows projects are more sensitive towards any of these periods *(see Figure 14)*.

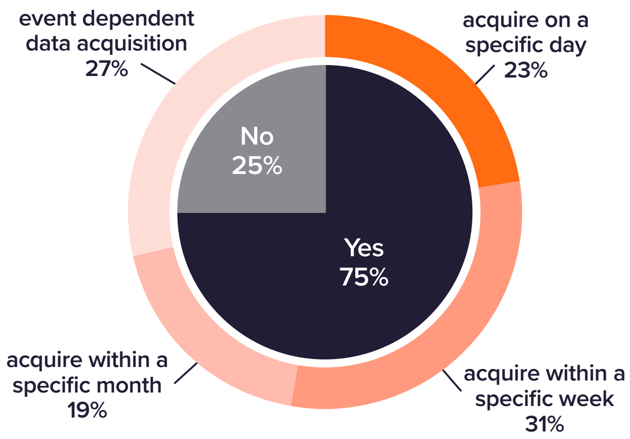


Figure 14: (inner pie) Percentage of participants collecting time series data; (outer ring) time requirements for data capture

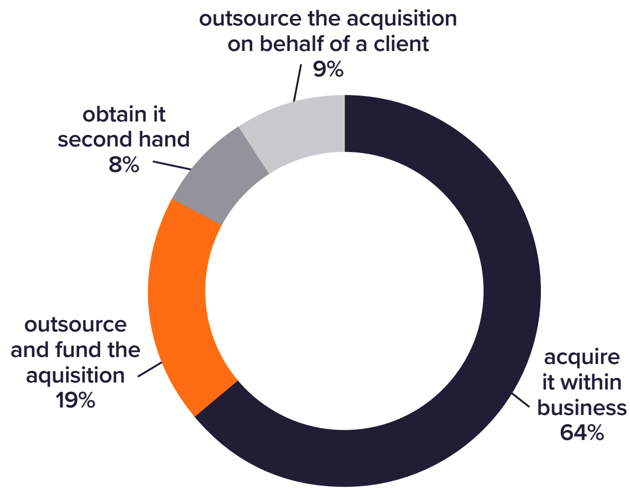


Figure 15: UAV data procurement methods in participating organisations

3.2. UAV data procurement strategy

Participants were asked to specify the methods they used to acquire UAV data. As shown in *Figure 15*, most participants obtain UAV data in house (64 per cent). This include individuals or organisations who collected data themselves for specific applications. Of the participants, 19 per cent are supplier dependent, outsourcing their UAV data acquisition.

Interestingly, 9 per cent of participants indicated they outsource the data acquisition on behalf of their clients. These are mainly organisations that provide value-added services.

3.3. Acquisition specification for project requirements

The survey respondents were asked to identify whether they use an acquisition specification for UAV data and if so, how they determine their project requirements.

- 87 per cent indicated they adopt technical specifications
- 13 per cent do not use specifications for data capture *(see Figure 16, inner pie chart)*.

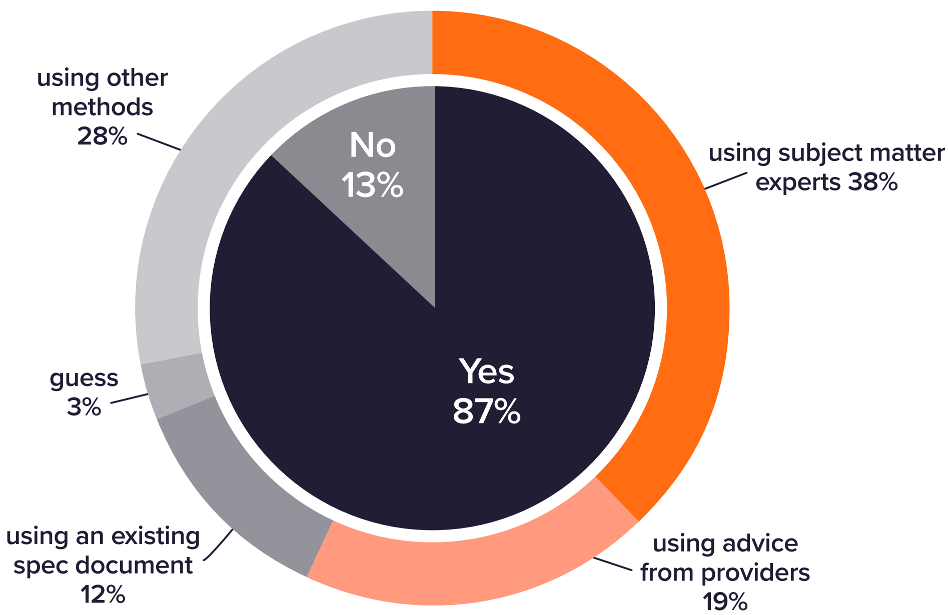


Figure 16: Percentage of participants using specifications for data capture (inner pie chart) and how they determine their project requirements (outer ring chart only covers those answers that were 'yes')

> *We use multiple methods depending on the type and complexity of the job and the client's requirements. Some clients have specifications which we match to our standard acquisition model. Some have specifications which require different sensors or a different acquisition model – we use either SME's or sensor providers (or similar) to provide us with guidance. Where the client wants data, but doesn't specify in what format we use a standard specification document we have developed based on practical experience.*
>
> Peter Plant, **3FB Aerworx Pty Ltd**

Out of those who use specifications, the most popular method is to employ subject matter experts (38 per cent) to determine the project requirements. These users tend to rely on their experienced peers for specifications. Nineteen per cent indicated a reliance on advice from providers as the experts. Only 12 per cent use an existing standard, which demonstrates the lack of standard requirements in acquisition. Three per cent try to guess these requirements based on previous experience in their other projects. Twenty-eight per cent use a combination of these methods for acquiring the data acquisition standards. For example, some participants mentioned that depending on the job (exploratory, survey, multispectral, etc.), they may use subject matter experts in conjunction with advice from providers. In-house testing usually complements that advice to determine requirements, capability and likelihood of success. A few responses, indicated the use of aerial imagery specification templates as a base, and then customised the specifications based on information from clients. For significant projects they would then also include subject matter expertise and advice from providers.

In other cases, people use trial and error along with test project to determine their requirements. This is especially prominent in research and academia where the UAV hardware is tested on new applications.

> *The diverse nature of our business largely precludes the use of a standard or pro-forma approach to specification of data. Engagements with providers (internal and external) are largely based upon the technical or engineering need for the data. i.e. what is the business/technical/engineering question that the data is required to answer?*
>
> Frank Courtney, **Melbourne Water**

Often, clients provide specifications according to their experience. For example, some suppliers like NINOX Robotics have 'customer requirements forms' containing questions for clients to answer prior to the data collection. Some users seem to have preferences towards survey accuracy standards, whilst others are used to photogrammetric specifications.

Interestingly, some organisations' specifications for UAV data captures are still based on piloted aircraft missions. Although it is familiar for some users, by applying these specifications to UAV captures, there will be gaps and some potential issues in the requirements. One example is side and forward overlap, where for piloted aircraft 30 per cent and 70 per cent respectively tend to be used. Applying this to UAV data captures will not be sufficient and will result in stitching problems for image mosaics.

In addition to the above-mentioned methods, there are academic articles for application specific specifications *(for example, see [19])* that can benefit UAV users.

> *We start out with advice from experts, continue to consult with them on occasions, but also perform our own research especially regarding introducing modern technology. We are predominantly interested in Specifications determined by the required outcomes for project delivery.*
>
> Lachlan Beveridge, **ThinkSpatial**

Many users agreed that specifications are application and outcomes dependent. Given the range of methods and non-standardised approaches, developing a standard workflow for capturing these specifications for various applications will have significant benefits to stakeholders.

3.4. Overview of Existing Standards

Participants were asked to indicate whether they were aware of any existing UAV standards and if so, to provide the source. As *Figure 17* shows, over 77 per cent were not aware of any standards. Additional comments by those aware of standards revealed a variety of sources for LiDAR and photogrammetry projects. Examples of these sources include:

- ASPRS standards for LiDAR specifications
- USGS lidar base specifications
- Academic and UAV literature
- Queensland Drone Strategy *(see [20])*
- ICSM specifications such as ICSM SP1 (Standard for the Australian Survey Control Network Special Publication)
- UAV Operating Certification – operating manual
- Guidelines similar to **http://culturalheritageimaging.org/Technologies/Photogrammetry/**

Furthermore, internal standards exist within larger organisations and government departments. This was highlighted by DELWP who have their own coordinated imagery team that determines the specifications.

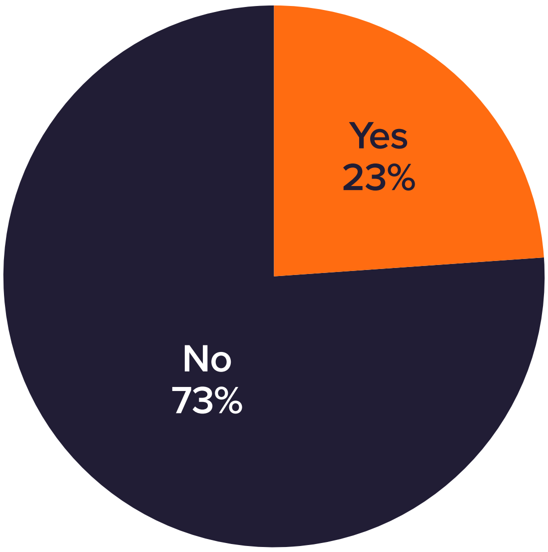


Figure 17: Level of awareness of participants regarding standards for UAV data capture

Melbourne Water indicated that they have some standards surrounding spatial / 3D data, largely derived from the GIS environments they maintain. It was highlighted that some government authorities such as VicRoads and Department of Main Roads (WA) have specific standards related to data acquisition, handling and management.

Some participants also indicated that the platform "Can I fly here?" [15] is used as a standard reference for flight planning and identifying areas with flight restrictions.

3.5. Software tools and data formats

This section provides a summary of the software tools used by participants for the UAV projects discussed in Section 1.3.4. This summary focusses on flight planning, post-processing, analysis and visualisation, and quality assurance. In addition, the common file formats used for storage or exchange of products in this workflow were identified.

3.5.1. Flight planning software

The most common tools used for flight planning, or as part of flight planning process, are shown in *Figure 18*.

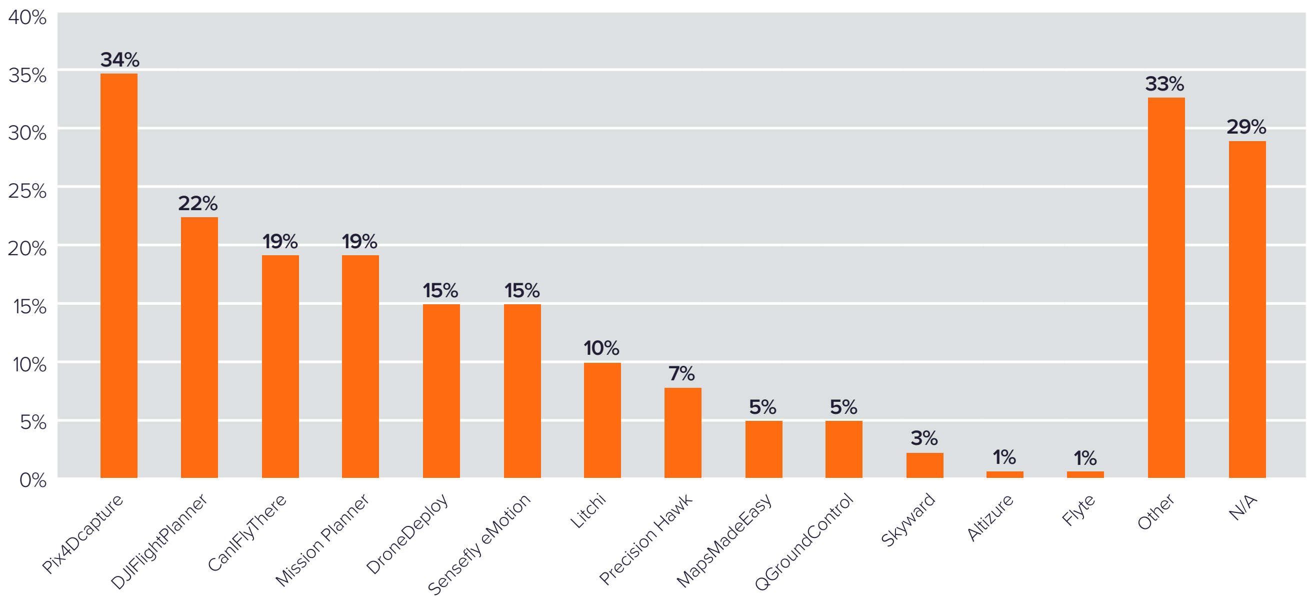


Figure 18: Common flight planning software

The most popular tool for flight planning is Pix4Dcapture, in fact, 34 per cent of the participants indicated it is both flexible and powerful. DJIFlightPlanner (22 per cent), 3DR Mission Planner (19 per cent), DroneDeploy (15 per cent), eMotion (15 per cent), and Litchi (10 per cent) are the other most popular flight-planning tools across Australia and New Zealand. Participants indicated that there is a correlation between the flight planning software and the UAV platform they use. For example, SenseFly Ebee UAVs work very well with eMotion software provided by the same company. However, 29 per cent of participants indicated that flight planning is not relevant to their role in their drone activities. Most of these users define their area of interest using Google Earth or TerraExplorer.

> *We use SenseFly eMotion for flight planning. It automatically adjusts the plan according to the requirements of the data capture and weather conditions specified! It communicates real time with the SenseFly Ebee UAV which makes it easier to adjust the plan in real time if necessary...*
>
> Jarryd Poiner, **ThinkSpatial**

CanIFlyThere is used by nearly 20 per cent of the participants as part of the flight planning process to understand if there are any restrictions associated with flying in the area of interest. Furthermore, "Oz Runways" is a choice of some organisations as a support for flight planning. As mentioned earlier, Google Earth and Maps are also used as part of this process. Other software in this category include *Precision Hawk, MapsMadeEasy, QGroundControl, SkyWard, Altizure, Flyte, etc.*[5]

3.5.2. Post processing software

The most common tools used for UAV data post-processing are shown in *Figure 19*.

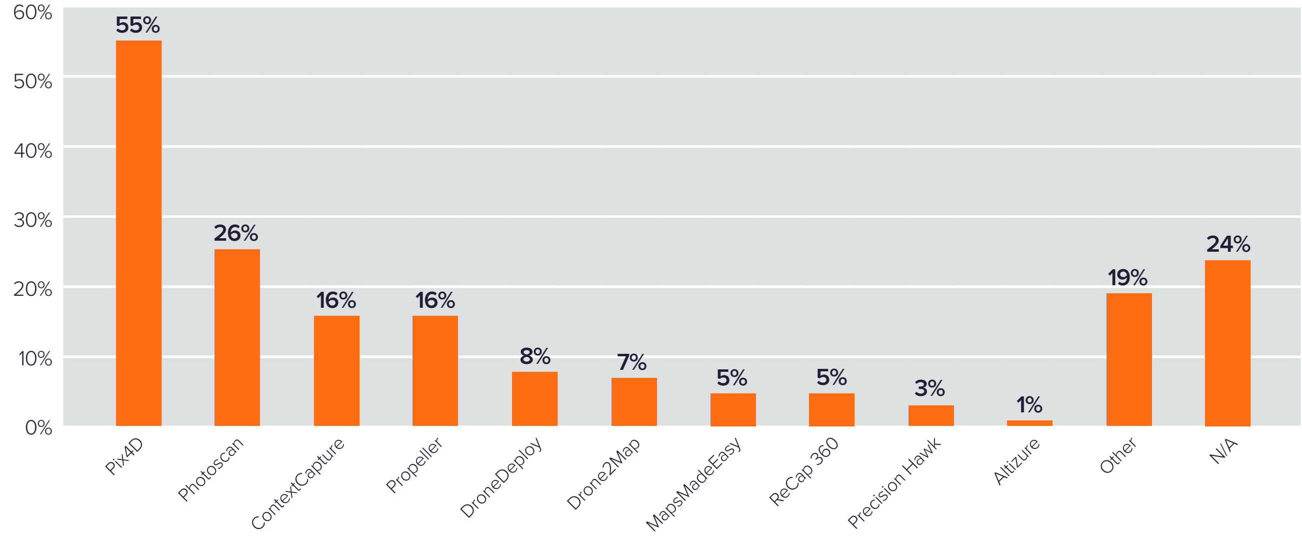


Figure 19: Common post-processing software

The most popular software for post processing is Pix4D used by 55 per cent of participants. Photoscan (26 per cent), ContextCapture (16 per cent), Propeller (16 per cent), DroneDeploy (8 per cent), and Drone2Map (7 per cent) are the next most popular. Other software packages include ReCap 360, Altizure, GlobalMapper, Precision Hawk, MapsMadeEasy, etc[6].

An evaluation of some of these software suites is provided in Appendix E. In the cases of more advanced sensors, custom scripts are used in environments such as MatLab or R.

3.5.3. Visualisation and analysis

The most common tools for UAV data analysis and visualisation are shown in *Figure 20*. Participants usually use off-the-shelf tools for analysis and visualisation. The most popular software tools include ArcGIS, Pix4D mapper, QGIS, Agisoft Photoscan Pro, Global Mapper and Propellor[7].

Users also indicated the use of other software packages like CloudCompare, ENVI, Meshlab, Virtual Surveyor and Trimble Business Centre[8].

[5] Mavinci Desktop, Tower, NAIPS, AscTec Navigator, DJI GS Pro, DJI Ultimate Flight, DJI GO, Autopilot Logic, Drone Log, and WeGCS include other software used for flight planning.

[6] Trimble Aerial Imaging, DATEM, Onebutton, Reality Capture, Vertical Earth, OpenDronMap, Adobe Cloud Creative for RAW format conversion, Correlator 3D, iWitnessPRO-Agilis, SimActive Corellator3D, and Altimap

[7] Other software in this category are Bentley Context Capture, DroneDeploy, MapInfo, Microstation, AutoDesk ReCap 360, Civil 3D, SAGA GIS, Precision Hawk Mapper, Grass GIS, Hexagon Apollo, MapsMadeEasy, and Altizure.

[8] Trimble UAS Master, Maptech Isite, Terra Explorer, DATEM, ArcGIS Pro, Potree, Vertical Earth, Drone2Map, Lp360, Ecognition, Pythagoras, iWitnessPRO-Agilis, and ThinkMap, Lastools, and ERMapper

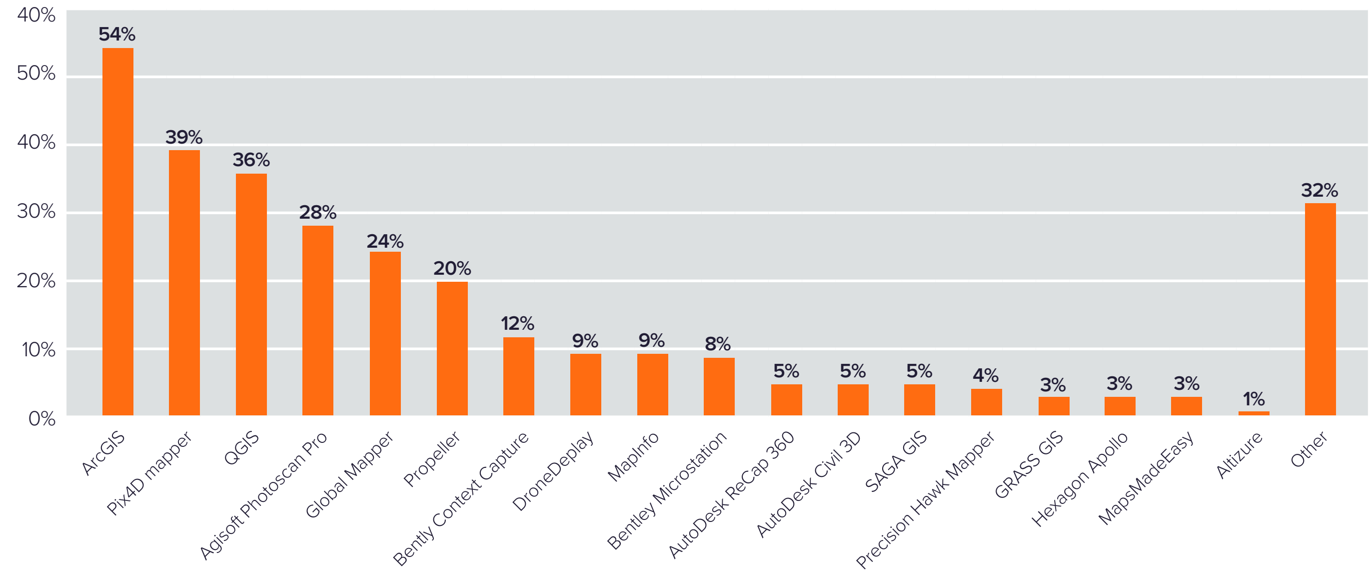


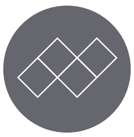
Figure 20: Common flight planning software

3.5.4. Commonly used file formats

File formats were compiled and provided for UAV applications within different sectors *(see Section 3.7)*. The breakdown of these file formats for each sector is further discussed in Supplements 1-10.

Flight Plan

The most valuable information during the flight planning is the area of interest. This information is usually provided in KML format and generated by Google Earth or other open and free software. In addition, photos of the field site are useful for planning purposes and are usually provided in jpg formats. Pixhawk text and FPL are also mentioned by some participants.



Imagery mosaic

Figure 22 shows the common imagery mosaics formats which include TIFF, ECW and JPG.

TIFF files can be converted to ECW, a lighter format, for use in web mapping applications.

Imagery Tiles and Raw Imagery

The raw imagery tiles are commonly delivered in JPG or (geo)TIFF formats. Nearly 85 per cent of participants used these formats. A few participants pointed out the use of PNG, DGN, ECW, ESRI GRID files for imagery tiles.

Additional comments highlighted the use of ESRI file Geodatabase for tiles and IIQ files, and 3FR files for raw imagery.

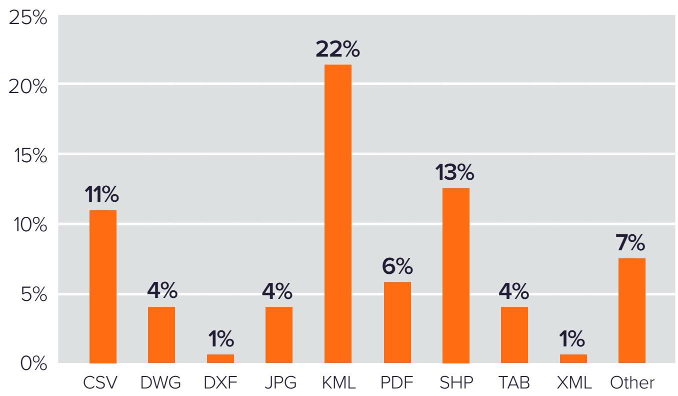


Figure 21: Common file formats for flight plan

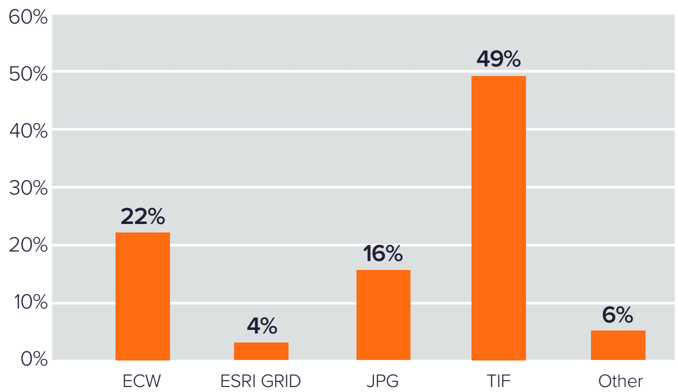


Figure 22: Common file formats for imagery mosaics

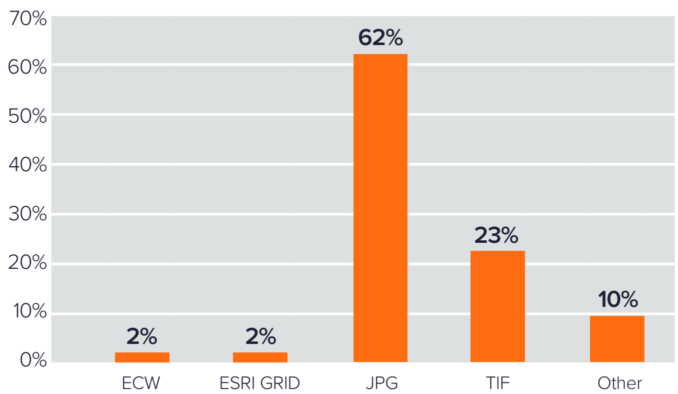


Figure 23: Common file formats for raw imagery and imagery tiles

Ground Control Points

Responses show that 58 per cent of users prefer CSV files for the delivery of ground control points. ShapeFiles are also common as nearly 20 per cent of users preferred this format. Interestingly, some users mentioned the use of .TXT files for delivery of ground control points.

Digital Elevation Model (DEM)

Most commonly used data formats for DEMs are (geo)TIFF files. ESRI GRID, ECW, and ESRI ASCII files are other formats used for the delivery of DEMs.

Sometimes instead of a DEM, clients ask for bare ground points in XYZ format. Usually these points are used for post-processing and derivation of products like a TIN.

Digital Surface Model (DSM)

The most commonly used data format for DSMs as shown in *Figure 26*, is TIFF. Of participants 68 per cent indicated the use of this format. ESRI geodatabases are other preferred formats for a few of the users.

Point Cloud

The most commonly used format for point clouds is LAS. ASPRS provides a comprehensive specifications for LAS files. LAZ is a compressed version of LAS file and is also used. Of responses 17 per cent show the use of XYZ format for point clouds.

3D Models

3D models are usually stored or exchanged in OBJ, 3MX or PLY files. However, participants also indicated the use of LAS Files, DXF, and 3D PDFs.

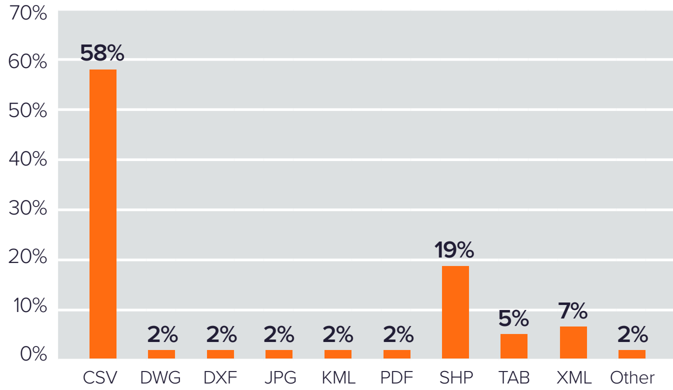


Figure 24: Common file formats for Ground Control Points

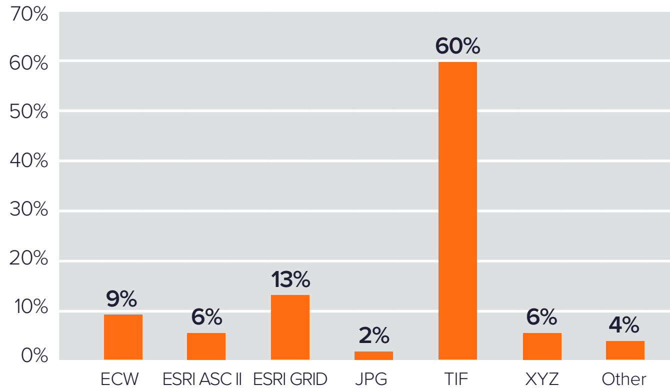


Figure 25: Common file formats for DEM

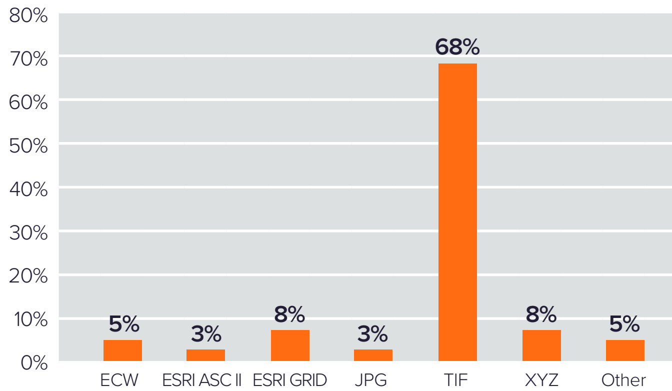


Figure 26: Common file formats for DSM

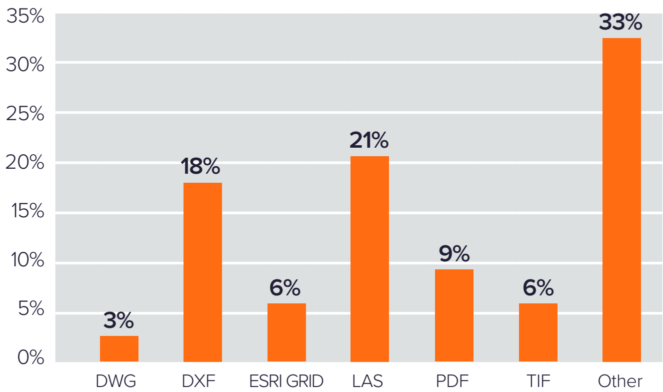


Figure 28: Common file formats for 3D Models

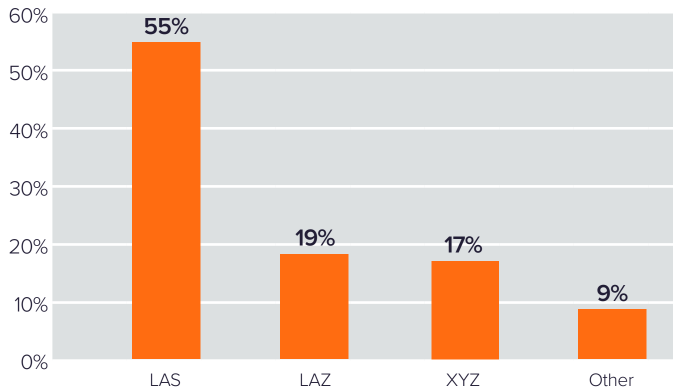


Figure 27: Common file formats for Point Cloud

Tile Index

Tile index files are used to define the layout of the tiled products. Nearly half of the participants use Shapefiles for tile indexes. TAB files, PDF, and in rare occasions, CSV files are used for this purpose.

Flight Trajectory

Flight trajectories are usually generated as part of flight planning. Nearly half of the responses indicated the use of KML when exporting the flight path or when it is communicated with the client. We found that 24 per cent of respondents indicated the use of shapefile and 6 per cent mentioned PDF for this purpose.

Contours

The most common file format for contours is Shapefile. Of the responses 45 per cent indicated the use of this file format. Participants also indicated they store and use contours in CAD files like DXF, DWG or DGN. Amongst these, DWG seem to be used more often.

Metadata and Project Report

Metadata is generally textual information and the format is mostly dictated by the user for project delivery. Most end users request metadata in PDF or XML formats. CSV files, Shapefiles, and KML are other less popular formats for delivery of metadata. PDF and word documents (.doc and .docx) are preferred formats for delivery of project reports.

Videos

Videos are also popular outputs of UAV projects and are mainly delivered in AVI, MP4, Mpeg formats.

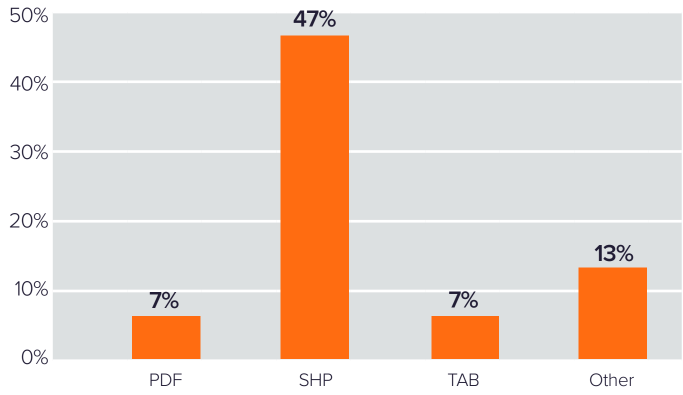


Figure 29: Common file formats for tile index

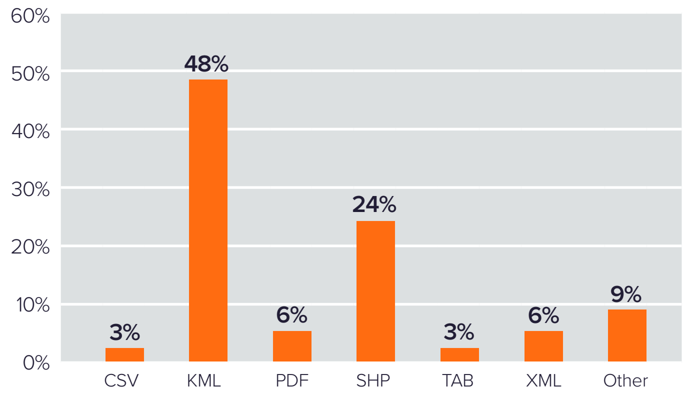


Figure 30: Common file formats for flight trajectory

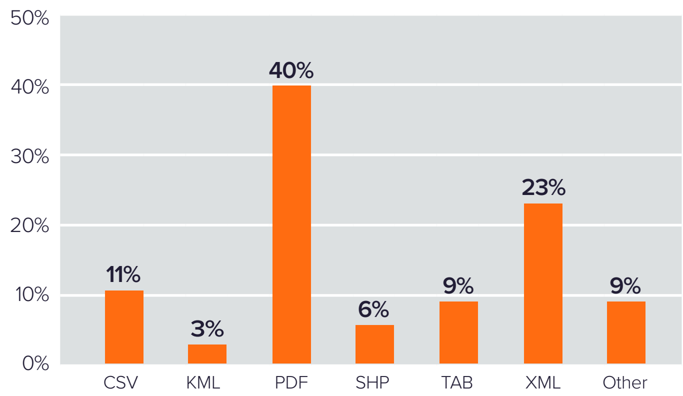


Figure 32: Common file formats for metadata

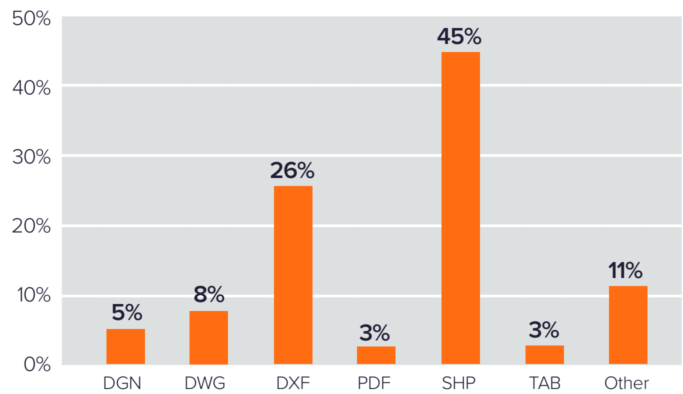


Figure 31: Common file formats for contours

3.6. Quality Assurance of UAV Data

3.6.1. Overview of Most Common Problems

Participants were asked to highlight problems they had experienced during the acquisition and use of UAV data. The accuracy of data was highlighted as the most widespread problem, followed by processing speed *(see Figure 33)*. These issues were highlighted by 51 per cent and 45 per cent respectively as their most significant concerns.

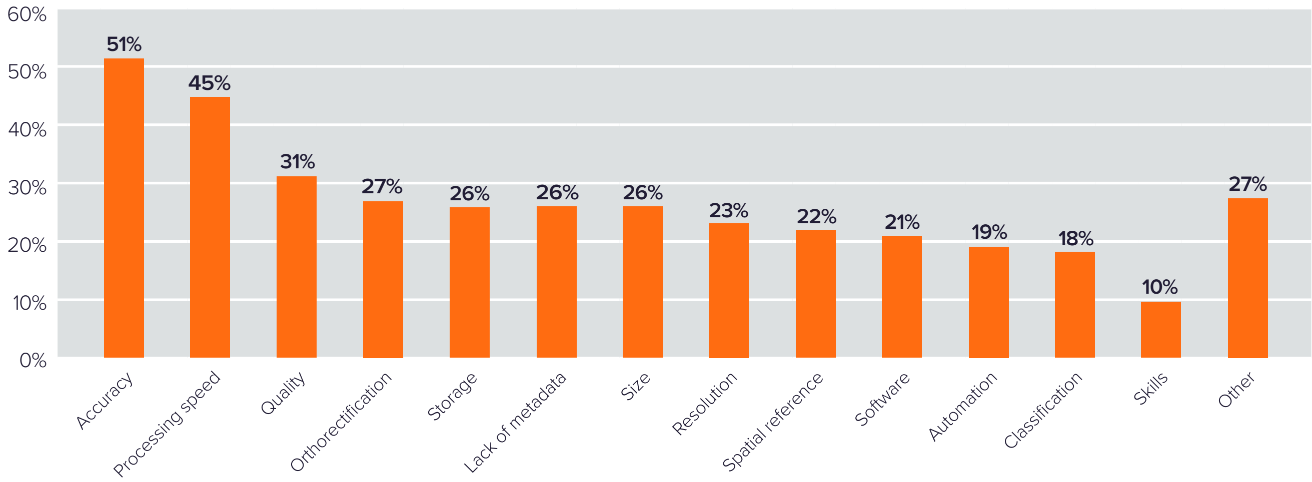


Figure 33: Common problems while using UAV data

Image quality is the third most common problems amongst the users (indicated by 31 per cent). However, it was found to have different meanings amongst different users. Many see quality in terms of image blur caused by speed or vibration, shadowing, parallax, over-saturation, exposure issues and image distortion. Others expanded the definition by including factors like sharpness, focus, colour balance, crispness, image colour range, cloud or haze free, and seamlessness of stitched images.

Changes in the lighting conditions during data collection, mis-triggers of the camera, and a lag time between signal (position) and camera trigger were other issues highlighted within image quality.

It was interesting to note that although many people consider image quality and resolution to be the same, image resolution is only one of the measures of quality. For example, the Parrot Sequoia image *(Figure 34 bottom)* is 16MP and has a narrower focal width, therefore produces a higher resolution image, than the comparative DJI image below. The DJI image *(Figure 34 top)* is only 12 Megapixels, but a better sensor, so the image is clearer even though its resolution is lower. The main difficulties in assessing image quality are creating a specific metric to identify which image is "better" or "fit-for-purpose" for its particular use. Based on our finding, image quality checks should further consider image exposure, clarity, contrast, brightness, shadowing, and colour balance.

> *Image stitching can be compromised in locations with tall forest or homogeneous crops. The lack of identifiable features, parallax issues and susceptibility to movement in windy conditions may all contribute to poor mosaic results.*
>
> James Rennie, **Australian UAV**

Figure 34: High resolution image but bad quality (top); and better-quality image of the same area but with lower resolution

Further issues experienced by participants are classified into the five categories highlighted in *Table 1*.

CATEGORY	PROBLEMS
Problems related to data	• Area of interest is not fully covered • Horizontal and vertical accuracy not sufficient • Images not georeferenced • Positional accuracy errors • Tie point errors due to survey area all looking the same i.e. crops, sand, water • Dataset tilt (if RTK not used) • Lack of spatial reference system for control • Voids and data gaps in the data due to not enough overlap • Incomplete or incorrect data (e.g. needs to be taken oblique, was taken nadir) • Coverage gaps and holes in products • Data delivered in the wrong format • Incorrect units within products • Missing link to tile index • Missing map information (e.g. datum) • Point cloud issues such as noise, unclassified points or poor classification • Featureless areas in the datasets
Processing problems	• Errors in the orthorectification of images • Image stitching lines and artefacts in mosaics • Poor point cloud noise filtering leaving noise in the dataset • Difficulties in automation of processing steps
Problems related to data collection	• Lack of control points and their distribution • Not recording the date of capture • Loss of GPS signal during data capture • Missing or incorrect attributes in vector or point cloud files (e.g. there are less attributes within a photogrammetric LAS file i.e. no PSID etc) • Sun angle and glint producing poor images • Lack of sufficient overlap between runs (due to poor flight planning) that impacts accuracy • Wrong timing of data collection (e.g. low tide missed for coastal surveys, or not enough thermal contrast between background and fauna to detect fauna)
Problems related to data management	• Lack of skills and capabilities to analyse the UAV data. • Large volume of data and problems related to their storage and transfer • Problems with software to work with the data • Challenges in presentation and visualisation of data
Equipment and Sensor Issues	• Equipment not meeting specifications • Incorrect camera settings for the sensor • Low camera lens clarity and dirt on sensor resulting in poor data/images • Band misalignment, for multi- or hyper-spectral sensors resulting in capturing incorrect frequencies • Lag between camera and positioning info resulting in incorrect location of images and further problems in creating mosaics

Table 1: The most common problems with UAV data

3.6.2. Overview of Delays and Setbacks

Delays and setbacks experienced by users were identified. They were classified into seven categories: i.e. weather related, specifications, data and processing related, timing, approvals and access, equipment related and others, and are summarised in *Table 2*.

CATEGORY	DELAYS AND SETBACKS
Weather related	• Delays caused by bad weather or other adverse conditions (e.g. fog, smoke, smog, sun angles) • Blur in images due to wind and UAV movement which require re-capturing of data • Staff needing to wait for suitable lighting conditions. Changes in lighting may affect the image quality and consistency.
Specifications	• Changes in specifications can result in changes in data capture plans and additional delays • Setbacks caused by mismatch between the supplied data and the user expectation. In these situations, data may need to be re-captured.
Data and processing related	• Data reprocessing • Processing lags and processing software issues • Re-captures • Original deliveries in incorrect formats • Data errors i.e. quality and accuracy • Missing areas in capture
Timing	• Missed opportunities to capture data in specific time window • Seasonal delays where suppliers should wait for a particular time of the year
Approvals and Access	• Obtaining approvals from authorities (e.g. CASA) • Access to the site (e.g. landholder access)
Equipment related	• Availability of equipment • Aircraft malfunction • Accidents with equipment or loss of equipment (e.g. attacks by animals) • Damage to sensors i.e. 8 weeks delay to replace sensor
Others	• Setbacks from using shortcut solutions (e.g. the cheapest option may end up as the costliest one) • Unwanted features in the images (e.g. bees in shot) • Lack of clarity about IP and ownership of data • Agreeing on terms and specifications in contracts • Flight planning

Table 2: Summary of delays and setbacks

Participants indicated it could take more than two weeks to determine errors in the acquired data, contact provider, send it back, get it fixed, and receive it back and have it re-checked. Hence, quality checks before delivery becomes a crucial part of the data acquisition process.

The range of problems and delays highlights that a workflow for managing data acquisition, together with a standard specification and quality assurance process become crucial to ensure issues can be rectified before the data is accepted by the client. By eliminating some of the delays and setbacks, time will be saved for both users and suppliers of UAV projects.

> *Manual inspection of the imagery is required in most cases to identify defects (e.g. blur or other issues). An automatic workflow for detecting these issues can be beneficial.*
>
> **ThinkSpatial**

> *Roughly 1 out of 5 UAVs get attacked by Eagles. Insurance for in-flight is important! It is now cheap and useful!*
>
> Jarryd Poiner, **ThinkSpatial**

> *Flight plan checks are necessary but can be difficult. Flight planning software doesn't always provide sufficient output that can effectively be used for flight plan checks.*
>
> **DELWP**

3.6.3. Quality Assurance checks

Results show that only some users perform quality assurance on the data, whilst many rely on the providers to perform the checks.

All participants thought that pilots should perform the basic, preliminary checks in the field to ensure they won't need to recollect the data; and then further quality assurance can be carried out in the office by the provider and/or user.

The preliminary checks performed in the field by pilots during and immediately following the flight include:

- Checking files for corruption
- Existence of data (if data was recorded; or for example, the sensor failed to trigger or the lens cap was left on)
- Data extent and coverage
- Overlap and internal voids (to ensure the project area has been covered completely and images are likely to stitch together)
- Raw imagery clarity

The extent of checks performed in the office by providers and users varied considerably, especially between tech-savvy and less-experienced users. The most common checks performed by participants included:

- Extent and coverage of the raw imagery and derived products
- File corruption for derived products
- File format and naming
- Gaps/holes/clouds and cloud shadow in images
- Edge matching and seamlessness (for DEM and contours: edge matching of features between tiles)
- Mis-calibration between flight runs
- Cross checks against other data (e.g. Check for accuracy of data using independent survey points)
- Visual checks for characteristics and fitness for purpose of data
- Products (e.g. point cloud or contours) checks
  - o Image quality
  - o DEM resolution, vertical accuracy
  - o Contour Interval, topology, and attribute accuracy
  - o Point cloud density, classification, and nominal point spacing
- Attribution checks
- Consistency: examining photography for quality of colour balancing between flight runs and tiles
- Positional accuracy
- Resolution
- On ground checking of control points
- Specifications vs. end user expectations
- Tiling, reference systems, and datum meet specifications
- Offset to existing imagery and satellite data
- Time series data checks (e.g. Use similar ground control points)
- Spatial metadata elements

Flight plan checks are also perceived as important to check. However, users highlighted it is too difficult to check plans prior to capture. This is mainly because planning, in most cases, is done on the flight day according to site and weather conditions. As the choice of UAV platform may vary depending upon these conditions, and often several platforms are taken to the site as options for capture.

3.7. UAV Use Cases – Analysis

One of the aims of this project was to establish a list of applications that use UAV data and their specifications for different uses. These applications *(summarised in Section 4)* were identified in 12 different sectors and grouped into 10 categories: i.e. Mining, Agriculture, Construction, Emergency management, Environmental monitoring, Government, Infrastructure, Survey, and Forestry. A few sectors (i.e. cultural heritage, oil and gas, water industry) with less participants providing inputs about them were grouped into a separate category called "Others". *Figure 35* shows the distribution of participants across these categories.

For each application in these categories, features of interest, project area size, sensors used, the horizontal and vertical accuracies, spatial and temporal resolutions, as well as key products/deliverables required were analysed. This section provides a summary of the requirements and specifications for the application.

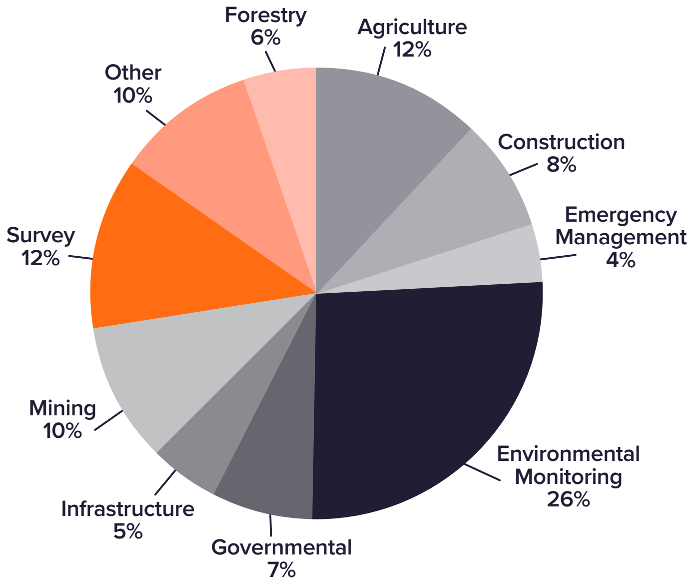


Figure 35: UAV application categories investigated in this research and their respective participants percentages

3.7.1. Features of interest

Survey participants were requested to provide a minimum of one and maximum of three example projects that represent the focus of their activities. They were asked to elaborate on the features of interest for these applications.

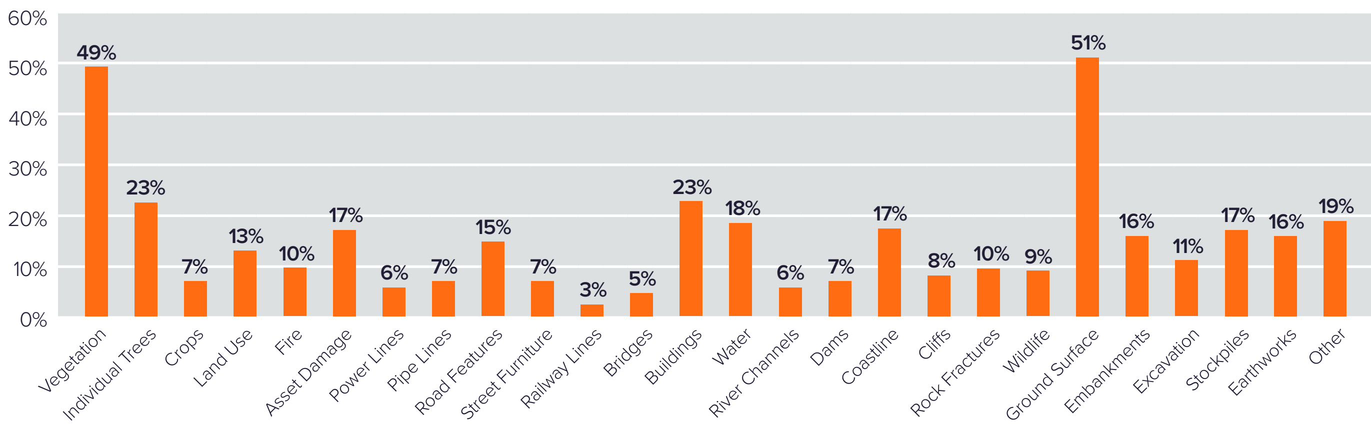


Figure 36: Features of interest across all application areas

Responses identified the 25 key features of interest presented in *Figure 36*. The most popular features of interest were the ground surface (51 per cent), vegetation (49 per cent), trees (23 per cent), and buildings (23 per cent). Many applications across all sectors are interested in these features. For example, change detection in mines or landslide risk monitoring require ground surface at a high resolution. Vegetations and trees were also mentioned many times in different applications such as forestry or infrastructure. Water bodies (18 per cent) and coastline (17 per cent) were also referenced frequently.

Most features highlighted in *Figure 36* with smaller percentages were found to be related to sector-specific applications. For example, stockpiles or earthworks with 17 per cent and 16 per cent are related to some of the mining applications.

Just under a fifth of participants, 19 per cent, indicated other features (grouped into 'Other' category in *Figure 36*) that were more specific to single applications. They include marine habitats, solar panels, turfs in communities, coral reefs, seagrass, sediment and wildlife (e.g. Koalas). Additional features in this category are RF feeders and antenna condition, roofing, gates and access areas and pipelines.

3.7.2. Project acquisition area size

The survey areas for UAV data acquisition projects are shown in *Figure 37*. The summary shows that over 60 per cent of users capture data over areas less than 2km^2.

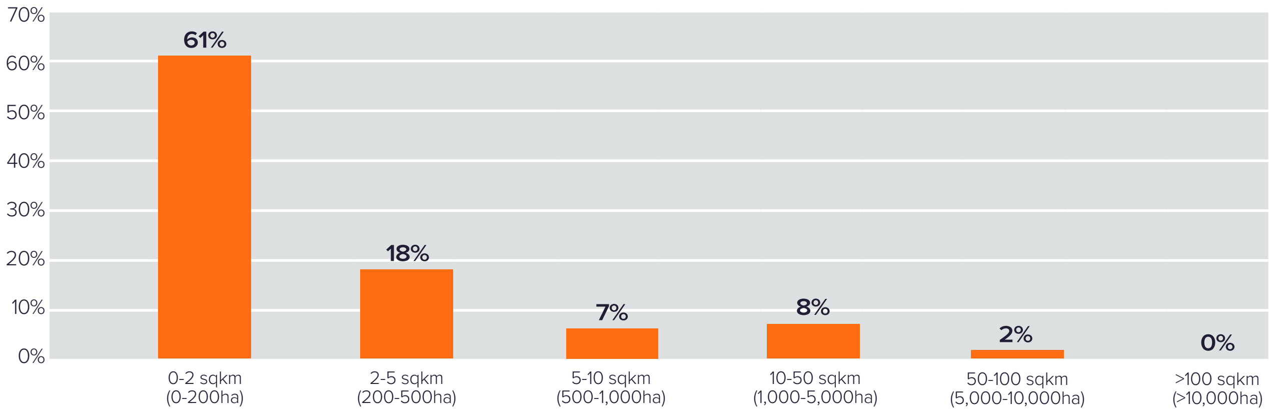


Figure 37: Project acquisition area size for all application areas combined

3.7.3. Image spatial resolution requirements

The image resolution for projects is usually set by the smallest feature of interest. As shown in *Figure 38*, 51 per cent of users require resolutions of below 3cm, whereas 22 per cent need a resolution between 4-6cm. Only 4 per cent mentioned their image resolution requirement to be more than 50cm. This highlights that UAVs are usually adopted for capturing high resolution data and at 10cm/pixel or higher.

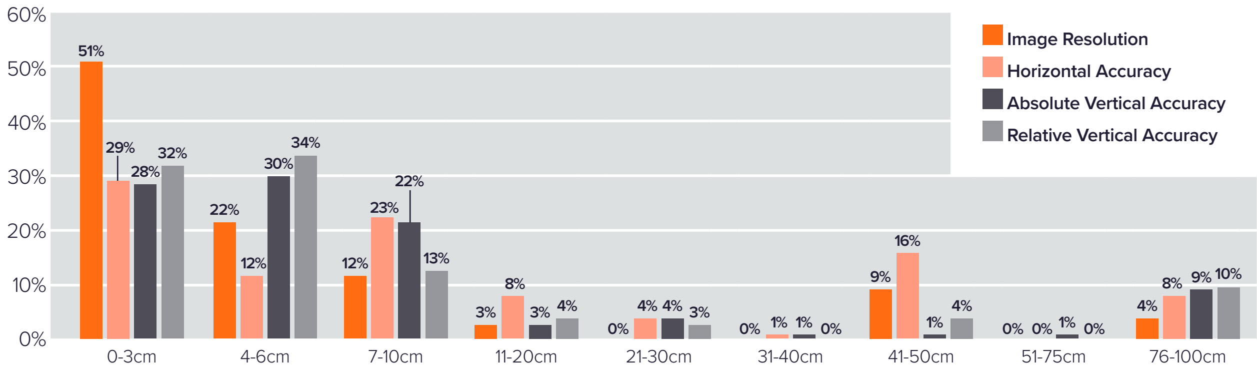


Figure 38: Image resolution, horizontal and absolute and vertical accuracy requirements for all application areas combined

To acquire these image resolutions, CASA and a few other sources[9] provide guidelines. For example, for achieving image resolutions between 2-4.cm, they recommend a maximum flying height of 120m above ground. This, however, may vary with the choice of UAV platform and type of sensors.

3.7.4. Horizontal accuracy requirements

The respondents were asked to provide information about acceptable horizontal accuracy of data for their applications. As shown in *Figure 38*, 29 per cent indicated they need horizontal accuracies of 3cm or higher. A few applications like infrastructure and roof inspection did not require any horizontal accuracy since the users only require pictures of assets to identify faults or damage.

> ***Currently, horizontal and vertical accuracy are rarely dictated by clients. The providers are mostly responsible for the accuracy and generally this information is included in the output report for clients.***
>
> **ThinkSpatial**

[9] E.g. Photogrammetry for forest inventory planning guide available at [17]

3.7.5. Absolute vertical accuracy requirements

The absolute vertical accuracy is a measure that relates the stated elevation to the true elevation with respect to an established vertical datum. Users indicated their tolerance for the vertical accuracy of data when compared with control points. As illustrated in *Figure 38*, 28 per cent indicated an absolute vertical accuracy requirement of less than 3cm. Vertical accuracies between 4-10cm were indicated as a requirement by 52 per cent of participants. Most interviewed UAV operators highlighted this range of vertical accuracy for many of their UAV data capture and delivery. Very few users (only 10 per cent) mentioned lower vertical accuracy requirements of 11-75cm. Quite a few applications (e.g. roof or asset inspection) required very low absolute vertical accuracy and in some cases, the vertical accuracy was not applicable to the application. Sometimes, only 2D analysis with the appropriate horizontal accuracy was needed, and hence users did not specify any vertical accuracy for their applications.

3.7.6. Relative vertical accuracy requirements

The relative vertical accuracy is an internal characteristic of the data and for some applications (e.g. elevation data) it becomes more important than the absolute vertical accuracy. It is controlled by the random errors in a dataset and is especially important for derivative products that make use of the local differences along adjacent flights, and elevation values, such as slope and aspect calculations [16].

As summarised in *Figure 38*, nearly 66 per cent of the responses indicated they require relative vertical accuracy to be less than 6cm. Thirteen per cent require this value to be between 7-10cm and 11 per cent highlighted an acceptable relative vertical accuracy between 11-75cm.

3.7.7. Project deliverables

Participants, depending on their applications, may require different deliverables. The research found imagery to be the most popular deliverable for 86 per cent of the applications *(see Figure 39)*. Digital Elevation Models and point clouds are the second and third most common deliverables for projects. Around 30 per cent of applications require both of these products as part of their delivery. Vector polygons (e.g. stockpile polygons with volume as an attribute), DSM, contours, CHM and videos are other popular deliverables for UAV applications.

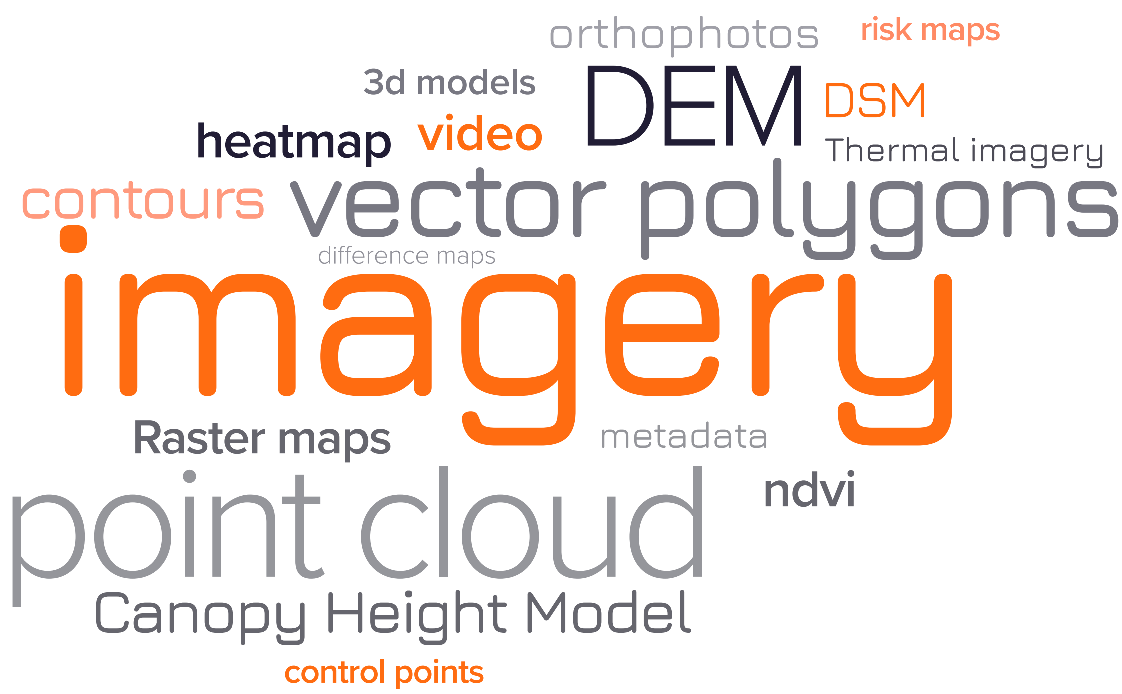


Figure 39: Common deliverables in UAV projects

4 SUMMARY OF FINDINGS

This research focussed on UAV data acquisition and the user requirements for applications across different sectors. A significant finding was that 60 per cent of users acquired UAV data in-house. The specifications for data capture are mainly determined by subject matter experts. Surprisingly, only 12 per cent of users relied on existing specifications for developing their requirements. This was recognised by the lack of awareness of industry supported specifications from over 70 per cent of users. While acknowledging specifications are application- and outcome-dependent, users highlighted that the development of a standard workflow or specification for their applications would provide significant benefits.

Amongst many identified software products in the UAV project workflow, Pix4D was the most popular for flight planning and post-processing of the data. The flight planning tools in most cases are chosen according to the type of UAV platform. For example, SenseFly Ebee UAVs work well with eMotion software. The most common visualisation (and analysis) software for UAV data is ESRI ArcGIS. Pix4D Mapper and the open source GIS application, QGIS were also found to be the preferred software for this visualisation purposes.

Unsurprisingly, the analysis of UAV use cases in this research showed that the most common deliverable in UAV projects is imagery. Other products include heatmaps, classified point cloud, DEM/DSM, videos, vector and raster maps CHM, and metadata. *Table 3* shows the most prominent file formats for the delivery of each product.

Many problems may be experienced during and following data acquisition. The most common issues are the data accuracy, quality, and processing speed.

The research identified more than 40 issues that users experience with UAV data. These problems are generally related to data collection and processing, and are often due to equipment and data errors. Image quality is still being defined amongst users, and often depends upon the context and their experience.

Inadequate skillsets and capabilities were often raised as one of the problems of working with UAV data. With the rise of UAVs and their increasing popularity, there is an expectation for professionals to learn additional skills to be able to effectively process and use the UAV data.

In this research, we identified more than 25 different factors which commonly led to delays and setbacks in UAV projects. Of these factors, 12 per cent were weather-related, 8 per cent were linked to changes to the specifications or a mismatch between delivered products and the specifications. And 23 were because of data and processing. Other factors (23 per cent) are related to issues such as flight planning and data IP. Users highlighted that they sometimes used shortcut solutions that may initially look cheap and attractive, however these turn out to be more expensive for users with significant delays in their projects. Integrating UAV data with other datasets was also identified as a challenge.

This research identified and extracted the data capture requirements for 56 distinct UAV applications across 12 different sectors. A summary of the requirements for these applications is provided in *Table 4*. Not too surprisingly, each of these applications had their own specific requirements, especially regarding the features of interest. Even still, ground surface and vegetation were the most popular features of interest amongst nearly all applications.

PRODUCT	FILE FORMAT
Flight plan	KML
Imagery mosaic	TIFF
Imagery tiles and raw imagery	JPG
Ground Control Points	CSV
DEM and DSM	(geo)TIFF
Point Cloud	LAS
Tile index	ShapeFiles
Flight Trajectory	KML
Contours	ShapeFiles
Metadata	PDF or XML
Project report	PDF, Word document
Video	AVI

Table 3: Prominent file formats for UAV data products

Table 4: Summary of UAV applications and their specifications for different sectors

CATEGORY	NAME	FEATURES OF INTEREST	AREA (KM²)	RESOLUTION (CM/PIXEL)	HORIZONTAL ACCURACY (CM)	VERTICAL ACCURACY ABSOLUTE (CM)	VERTICAL ACCURACY RELATIVE (CM)	TEMPORAL RESOLUTION	SENSORS
Mining	Stockpile survey / volume calculation	Stockpiles	2	≤ 3	3	5	5	Daily/weekly	RGB
	Rehabilitation monitoring	Ground surface, vegetation, trees, drainage, rivers, water bodies, sediments	5	≤ 10	10	10	10	Monthly to annual basis	Multispectral, LiDAR
	Pit monitoring and Change detection	Stockpiles, earthworks, roads, rocks	≤ 2	≤ 4	5	3	3	Every 2 days to weekly	RGB, LiDAR
	Asset inspection	Assets, rust and its coverage, cracks, leaks	≤ 2	≤ 1	N/A	N/A	N/A	Weekly to monthly	RGB, NIR, IR (or hyperspectral), or laser spectrometers
	Site condition and asset tracking	Site conditions, assets, location of trucks, plants	≤ 2	≤ 5	≤15	N/A	N/A	Daily, weekly	RGB
	Waste water and tailing measurement	Humidity, moisture level in the soil/ground	≤ 2	≤ 20	Not specified	Not specified	Not specified	Not specified	Multi- or Hyper-spectral
Environmental monitoring	Coastal monitoring	Ground surface, vegetation extent and types, coastline, rocky features, water	≤ 5	≤3 (ground) ≤5 (veg)	3	5	5	Not specified	RGB, NIR
	Wildlife counting	Vegetation, Wildlife – animals, algae and invertebrate species on rocky shores	≤ 5	≤ 5-7 (Infrared) ≤ 2 (RGB)	N/A	N/A	N/A	Seasonal and depending on species of interest	RGB, IR
	Monitoring oil spill clean up	Oil, ground, vegetation, embankments, roads, water, buildings	≤ 3	2	N/A	N/A	N/A	Hourly to weekly	RGB, Multispectral
	Cliff/land slide risk assessment	Ground surface, coastline, rock features, cliffs, vegetation	≤ 5	≤ 20	Not specified	Not specified	Not specified	Weekly, monthly, quarterly	RGB
	Bushfire burn severity mapping	Vegetation, individual trees, fire, roads, street furniture, buildings	5	≤ 40	100 – 200	≤ 50	≤ 50	Once and after an event	RGB, NIR, or Multispectral
	Waterway survey and riverbank monitoring	Vegetation types, their quality and health, erosion, sediments, ground surface	≤ 10	≤ 3	3	5	5	Annual (after rainfall)	RGB, NIR
Agriculture	Crop status and weed/pest monitoring	Topography, vegetation, crops, weeds/pests	≤ 2	≤ 10	N/A	N/A	N/A	Daily to weekly	RGB, NIR
	Disease detection and mapping	Vegetation, crops	≤ 5	(depending on species)	RGB, NIR, LiDAR or multispectral	N/A	N/A	Not specified	RGB, NIR, IR
	Identifying missing or undergrown plants	Crops/plants, ground surface	≤ 2	≤ 5	Not specified	Not specified	Not specified	every fortnight	RGB
	Growth and nutrient level detection	Vegetation, crops	≤ 5	≤ 15	Not specified	Not specified	Not specified	Not specified	Multi- or Hyper-spectral
	Early pests and disease detection	Vegetation, crops	≤ 5	≤ 15	≤ 50	Not specified	Not specified	Weekly	Multi- or Hyper-spectral
	Assessing biomass	Vegetation, crops	≤ 5	≤ 10	≤ 20	≤ 10	≤ 10	Not specified	LiDAR, IR

CATEGORY	NAME	FEATURES OF INTEREST	AREA (KM²)	RESOLUTION (CM/PIXEL)	HORIZONTAL ACCURACY (CM)	VERTICAL ACCURACY ABSOLUTE (CM)	VERTICAL ACCURACY RELATIVE (CM)	TEMPORAL RESOLUTION	SENSORS
Emergency management	Emergency monitoring (e.g. fire or flood)	Ground, fire, asset damage, buildings, water, coastlines	≤ 100	≤ 50	N/A	N/A	N/A	On-demand	RGB, IR
	Grass growth monitoring for bushfires	Vegetation, ground	≤ 5	≤ 10	≤ 100	20	20	Vary (daily in fire season)	RGB, NIR
	Planned burns/preventative fire management	Fire breaks, fire front, water, fire fuel, canopy height and structure	2 - 50	≤ 100	N/A	N/A	N/A	(LiDAR is an option)	RGB, LiDAR
	Detecting flood marks or debris line on ground	Flood or debris line	≤ 10	≤ 10	≤ 20	≤ 20	≤ 20	Hourly or every couple of hours	RGB, NIR
	Search and rescue	Humans/survivors	Event related	≤ 50	N/A	N/A	N/A	(LiDAR is an option)	RGB
Local government	Cemetery plot monitoring	Tombs/graves, vegetation, trees, buildings, plots	≤ 2	≤ 3	50	N/A	N/A	Every 6 months	RGB
	Marketing city centre and tourism	Buildings, vegetation, people, roads, street furniture, rivers and water bodies, coastline	≤ 4	≤ 5	N/A	N/A	N/A	On-demand	RGB
	Inspection of solar panels on roofs	Buildings, solar panels	≤ 2	≤ 2	N/A	N/A	N/A	On-demand	RGB, IR
	Survey of illegal construction	Buildings, ground, water, construction activities	2-10	≤ 10	A few meters	Not specified	Not specified	Monthly	RGB
	Footpath condition assessment	Cracks, dislodged pavement, uneven surfaces	Not specified	≤ 1	≤ 100	≤ 2	≤ 2	Annual or on-demand	RGB
	Green space mapping	Vegetation, trees and their foliage, water bodies, roads, footpaths and streets	≤ 2	≤ 10	≤ 50	≤ 20	≤ 20	Not specified	RGB
Survey and mapping	Aerial survey and mapping	Ground surface, excavation, earthworks, vegetation, trees, wildlife	≤ 10	≤ 3	≤ 3	≤5	≤ 5	N/A	RGB, LiDAR, NIR, IR
	Mapping stratigraphic layers on cliffs/rocks	Cliffs and rock features	≤ 2	≤ 5	≤ 10	≤ 10	≤ 10	Not specified	RGB, RGB + LiDAR
	Mapping vegetation along roads	Ground surface, vegetation, tree canopy, road features	5-10	≤ 3	≤ 5	≤ 5	≤ 5	Usually quarterly	RGB, LIDAR
	Surveying complex facilities/ infrastructures	Pipelines, overpasses, buildings, roads, towers, cranes, vegetation	2-5	≤ 1	≤ 5	≤ 5	≤ 3	Weekly	Multi- or Hyper-spectral
	Multispectral island mapping	Ground surface, vegetation, trees, rivers and water bodies, coastline	2-5	≤ 10	≤ 5	≤ 10	≤ 10	Not specified	Multispectral, LiDAR

CATEGORY	NAME	FEATURES OF INTEREST	AREA (KM^2)	RESOLUTION (CM/PIXEL)	HORIZONTAL ACCURACY (CM)	VERTICAL ACCURACY		TEMPORAL RESOLUTION	SENSORS
						ABSOLUTE (CM)	RELATIVE (CM)		
Construction	Estimating the Volume of Excavation Work	Stockpiles	≤ 2	≤ 5	≤ 10	≤ 10	≤ 10	*Not specified*	RGB
	Road and Highway Construction	Ground surface, vegetation, trees, drainage, rivers, water bodies, sediments	≤ 5	≤ 3	≤ 1	≤ 1	≤ 1	*Not specified*	RGB, LiDAR
	Site Topographic Mapping	Stockpiles, earthworks, roads, rocks	≤ 20	≤20 (general) ≤50 (flat areas)	≤ 20	≤ 3	≤ 3	*Not specified*	RGB, LiDAR
Infrastructure	Asset Management – Roads	Road characteristics and conditions, tree canopy	≤ 10	≤ 3	≤ 10	Enough to detect 100mm elevation change		Not specified	RGB, LiDAR
	Radio Communication Tower Inspection	Asset damage, antenna conditions	≤ 2	≤ 1	N/A	N/A	N/A	Not specified	RGB
	Condition Assessment of Structures	Ground surface, asset damage, coastline, rock features	≤ 2	≤ 20	≤ 20	≤ 20	≤ 20	Not specified	RGB, LiDAR
	Roof Inspection	Building envelope, roofing and roof features (e.g. gutters)	≤ 2	≤ 2	50	N/A	N/A	On-demand	RGB, Thermal (IR)
	Powerline Inspection	Power poles, power lines, access ways, loose equipment, rust and corrosion on assets	500m -20km in length	≤ 3	≤ 10	≤ 10	≤ 10	Every 4 years	RGB, LiDAR
	Wind Turbine Inspection	Location of turbines, structural, hydraulic, and mechanical issues	≤ 2	≤ 2	Not specified	Not specified	Not specified	Depends on the location of turbines	RGB, IR
Forestry	Identifying Tree Species	Trees	≤100	≤ 50	N/A	N/A	N/A	Annual	Multispectral
	Canopy Cover	Ground surface, canopy structure and height	≤ 2	≤ 3	≤ 10	≤ 10	≤ 10	Annual / on-demand	RGB, LiDAR
	Forestry Plot Monitoring	Ground surface, canopy structure and height	≤ 10	≤ 15	Not specified	Not specified	Not specified	Annual	Multispectral or RGB, LiDAR
	Monitoring Vegetation Health	Vegetation, trees	≤ 5	2-10	≤ 7	≤ 15	≤ 15	Ad-hoc or regular (quarterly/monthly)	NIR + RGB
	Quantifying Post-Harvest Coarse Woody Debris	Woody debris, stumps	≤ 2	≤ 1	≤ 100	≤ 100	≤ 100	N/A	RGB
	Identifying the Presence of Invasive Weeds	Invasive weeds / plants	≤ 2	≤ 2	≤ 2	≤ 8-10	≤ 8-10	Not specified	Multispectral
	Post plantation survival assessment	Trees	≤ 2	1-2	N/A	N/A	N/A	N/A	RGB or multispectral
	Post-thinning assessment	Stocking, tree height and spacing	≤ 1	8-12	≤ 10	≤ 10	≤ 10	Once per thinning event	RGB
	Stand boundary mapping	Boundary of forest, trees	≤ 1	≤ 100	< 1,000	N/A	N/A	Once per event	RGB or LiDAR/ Multispectral
	Disease detection and mapping	Disease effects, trees	≤ 1	5-7	≤ 100	N/A	N/A	Annual	RGB

CATEGORY	NAME	FEATURES OF INTEREST	AREA (KM^2)	RESOLUTION (CM/PIXEL)	HORIZONTAL ACCURACY (CM)	VERTICAL ACCURACY		TEMPORAL RESOLUTION	SENSORS
						ABSOLUTE (CM)	RELATIVE (CM)		
Others	Pipeline monitoring (oil and gas sector)	Pipelines, asset damage, flare, buildings, water bodies	≤ 2	≤ 3	≤ 10	≤ 2	≤ 2	Not specified	RGB, IR
	Record/documenting heritage buildings/structures	Heritage building, vegetation, trees	≤ 2	≤ 2	≤ 10	≤ 10	≤ 10	Not specified	RGB
	Portable water tank inspection (water sector)	Water tank, Asset damage, pipelines, buildings, water bodies	≤ 1	≤ 10	≤ 2	≤ 2	≤ 2	Depends on location and conditions	RGB, IR

Although UAVs are flown to capture data for large areas up to 100km^2, our findings showed that a typical area of interest is usually below 2km^2. The choice of the UAV platform depends on many factors such as platform and pilot availability as well as the requirements for the project. The general recommendations for use of UAV platforms for different project sizes were:

- Coverage of 5-30ha: multi-rotor;
- Coverage of 30-200ha: small fixed wing (e.g. Ebee);
- Coverage of 200-5,000ha: custom large fixed wing with longer flight time and faster flight speed;
- >5,000ha: use different technology. It is better to go with other methods like piloted aircraft or satellite.

The findings show that although UAVs may not be an appropriate technology for projects areas over 5,000ha, a small percentage of users (under 6 per cent) mentioned they adopt UAVs for these larger projects.

It was found that the most common sensor for UAV data capture is RGB. Where these sensors are used in over 85 per cent of the identified applications in all sectors, we found the other sensors such as multi- and hyper-spectral sensors have more limited applications and are specific to sectors like agriculture, forestry and environmental monitoring. IR and NIR sensors are also common in these sectors but have broader use in the other sectors. The findings of this research show that the use of LiDAR sensors is still not common, mainly due to their cost. Suppliers rely on the use of RGB sensors and photogrammetric techniques to generate point clouds.

The spatial and temporal resolutions and the accuracy of data varied significantly across different applications. However, as a rule of thumb, these specifications are set by the users to be able to identify, measure, or map the smallest feature of interest in the data. For most applications, a resolution of better than 10cm/pixel was needed.

Users indicated a forward (minimum 65 per cent) and a side overlap (minimum 60-70 per cent) are generally required for UAV surveys. The default value in many flight planning software is 60 per cent.

5 QA4UAV VISION

The findings of this research have provided a better understanding of UAV data user needs and enabled the design of an efficient online workflow to be developed by FrontierSI. With a user-friendly interface, the workflow should enable technical and non-technical users to specify their needs for UAV data acquisition. The checks to be included in this tool were discussed in Section 3.6.3. The project, with the working title "QA4UAV", will also provide users with a report which includes metrics indicating the quality of data and to what extent it is fit-for-purpose for their application.

The users in this research were requested to share their preferences for either a desktop application or cloud-based service. Although each had advocates and some users even expressed an interest in both; interest seemed to gravitate towards a desktop application. This was mainly due to:

- Providers needing a quick and basic QA that they can use in the field to avoid returning to site. Basic checks (e.g. image colour, blur, over exposure) in the field using cloud-based software would require an internet connection which is not often available
- The size of the data set (e.g. raw imagery or point cloud) can often be too large to upload into the cloud; this is especially the case for many users that have slower internet connections
- The sensitivity / confidentiality of the data may be an issue when needing to upload data to the cloud
- Potential file corruption during uploading data to cloud
- Some users keeping their data on their own cloud. If the tool is also on the cloud, measures need to be taken to ensure that these communicate with each other properly.

According to users' feedback, QA4UAV will be a desktop-based application that also has a web user interface. This allows users to maintain data locally while running the QA checks. The web components of the tool enable providers and users to work together in collaborative virtual spaces to define the requirements of the project and communicate the quality assurance results (performed locally). The web component of the software will include a user-friendly process to capture the requirements of the users using simple questions that are sourced in the findings of this research.

Additional information about the QA4UAV project is available at **www.qa4lab.com/qa4uav**

6 CONCLUSIONS

The benefits of UAVs are being increasingly recognised and their applications are becoming widespread. In this report, we highlighted a gap between UAV data providers and users in understanding their project requirements, often leading to the delivery of low quality, or not fit-for-purpose data resulting in frustrations and delays within projects. We further identified a need for providers to better understand the requirements of clients and, in a similar manner, the users to better understand what they can ask from data suppliers. The aim of this research was to engage users across different sectors to reduce the above-mentioned gap in understanding of the main UAV applications and their technical requirements for capturing fit-for-purpose datasets. With over 135 responses from 80 organisations, the user needs of nearly 60 distinct applications across 12 different sectors were identified. The supplements 1-10 at the end of this report are dedicated to explaining the details of these applications and their technical requirements. Like other data capture methods, it becomes difficult to generalise technical specifications for all UAV applications and they should be determined on a project basis. This research showed that these technical requirements are typically determined according to type and size of features of interest to be captured in the project. While some users understand the requirements of their project or seek immediate advice from experts, it was found that it can be a hurdle for many others (especially non-technical users). Accordingly, a need for a standardised workflow to guide users through the procurement of UAV data was highlighted.

We also listed the most common problems with UAV data capture and those factors that can result in delays and setbacks in projects. Although existing software like Pix4D or Photoscan can provide some level of QA and reporting for users during or following data processing, many important checks highlighted in Section 3.6.3 cannot be performed without cumbersome manual work or scripts to detect issues. Some QA checks are simple, however, many of them are complex and require knowledge of technical disciplines such as photogrammetry and computer vision. An independent software tool capable of performing automated checks will help users to ensure their acquired data is fit-for-purpose. The vision for QA4UAV was presented in this report. The outcomes of this research will contribute to the development of the functional requirements for QA4UAV which provides a workflow for users to:

- Determine their data capture specifications;
- Ensure the quality of captured data in the field;
- Perform a rigorous QA on the acquired data in the office; and
- Work collaboratively with providers in the delivery of their projects.

In this research, it was attempted to capture as many UAV applications as possible with the available resources. It was recognised that the UAV applications covered here were only a subset of a larger pool of UAV use cases. Accordingly, a more detailed and comprehensive research is envisioned to investigate more application areas to uncover the requirements of each.

REFERENCES

[1] CASA (2018) *Remotely Piloted Aircraft (RPA) Operators Certificates*. Available at: *www.casa.gov.au/aircraft/standard-page/uas-certificate-holders?WCMS%3ASTANDARD%3A%3Apc=PC_100959%20*
[last accessed 5 July 2018]

[2] Parliament of the Commonwealth of Australia (2018) *Eye in the sky – Inquiry into drones and the regulation of air safety and privacy*, Canberra, Australia.

[3] Gartner (2017) *Top Trends in the Gartner Hype Cycle for Emerging Technologies in 2017*. Available at: *www.gartner.com/smarterwithgartner/top-trends-in-the-gartner-hype-cycle-for-emerging-technologies-2017/*
[last accessed 5 July 2018]

[4] Goldman Sachs (2018) *Drones: Reporting for Work*. Available at: *http://www.goldmansachs.com/our-thinking/technology-driving-innovation/drones/*
[last accessed 5 July 2018]

[5] Drone Industry Insights (2017) *Drone Partnerships Gone Wild*. Available at: *www.droneii.com/drone-partnerships-gone-wild*
[last accessed 5 July 2018]

[6] Business Insider (2017) *Exploring the latest drone technology for commercial, industrial and military drone uses*. Available at: *www.businessinsider.com/drone-technology-uses-2017-7/?r=AU&IR=T*
[last accessed 5 July 2018]

[7] Forbes (2017) *Future Trends In The Gartner Hype Cycle For Emerging Technologies, 2017*. Available at: *www.forbes.com/sites/gartnergroup/2017/08/18/future-trends-in-the-gartner-hype-cycle-for-emerging-technologies-2017/#7c2aac904b97*
[last accessed 5 July 2018]

[8] Capterra (2016) *Commercial Drones in 2017: What's Now and What's Next*. Available at: *https://blog.capterra.com/commercial-drone-in-2017/*
[last accessed 5 July 2018]

[9] Drone Industry Insights (2018) *Drone Market Environment Map 2018*. Available at: *www.droneii.com/drone-market-environment-map-2018*
[last accessed 5 July 2018]

[10] Hard, R. (2017) *Top Industries Using Commercial Drones (Infographic)*. Available at: *www.linkedin.com/pulse/top-industries-using-commercial-drones-infographic-ian-r-hardy/*
[last accessed 5 July 2018]

[11] Drone Industry Insights (2016) *Drone Market Environment Map 2016*. Available at: *www.droneii.com/drone-market-environment-map-2016*
[last accessed 5 July 2018]

[12] Business Wire (2016) *Growth in Commercial Drones Bring Multiple Benefits Along with New Risks, Allianz Warns*. Available at: *www.businesswire.com/news/home/20160913005273/en/Growth-Commercial-Drones-Bring-Multiple-Benefits-New*
[last accessed 5 July 2018]

[13] ACUO (2016) *A New Safety Focus for the Australian Remotely Piloted Aircraft Systems (RPAS) Sector*. Online report available at: *www.acuo.org.au/assets/docs/blog/ACUO-Submission-to-the-Senate-Standing-Committee-for-Rural-and-Regional-Affairs-and-Transport.pdf*
[last accessed 5 July 2018]

[14] Robohub (2018) *Indoor drone shows are here*. Available at: *https://robohub.org/indoor-drone-shows-are-here/*
[last accessed 5 July 2018]

[15] CASA (2018) *"Can I fly there?" Drone Safety Application.* Available at:
www.casa.gov.au/aircraft/standard-page/can-i-fly-there-drone-safety-app
[last accessed 5 July 2018]

[16] ASPRS (2004) *ASPRS Guidelines Vertical Accuracy Reporting for Lidar Data version 1.0.* Released by ASPRS on 15 May 2004.

[17] Forestry and Wood Products Australia (2017) *Deployment and integration of cost-effective high resolution remotely sensed data for the Australian forest industry.* Prepared by Stone, C. and Osborn, K. for FWPA. Published in Melbourne, Australia.

[18] Chapman, A (2016), *Types of Drones: Multi-Rotor vs Fixed-Wings vs Single Rotor vs Hybrid VTOL*. Drone Magazine, June Issue (3).

[19] Torres-Sanchez, J., Lopez-Granados, F., De Castro, A. I., Pena-Barragan, J. M (2013) *Configuration and Specifications of an Unmanned Aerial Vehicle (UAV) for Early Site Specific Weed Management.* PLoS ONE 8(3): e58210. doi:10.1371/journal.pone.0058210.

[20] Queensland Government (2017) Queensland Drones Strategy. Available at:
www.premiers.qld.gov.au/publications/categories/plans/assets/queensland-drones-strategy.pdf
[last accessed 5 July 2018]

[21] Ehsan, S., & McDonald-Maier, K.D. (2009). *On-Board Vision Processing for Small UAVs: Time to Rethink Strategy.* 2009 NASA/ESA Conference on Adaptive Hardware and Systems, 75-81.

[22] Australian Trasport Safety Bureau (2017) *A safety analysis of remotely piloted aircraft systems 2012 to 2016: A rapid growth and safety implications for traditional aviation.* Available at:
www.atsb.gov.au/publications/2017/ar-2017-016/
[last accessed 5 July 2018]

SUPPLEMENTS

MINING
SUPPLEMENT 1

Mining is one of the largest industries in Australia, accounting for 15 per cent of the country's economy[10]. The use of UAVs in this sector is becoming increasingly popular[11]. They are employed in a range of activities, most commonly including stockpile management and volume calculation, and monitoring road conditions to ensure road safety. UAVs are also used for effectively clearing the exclusion zones to ensure a safe distance between personnel, equipment and an impending explosion. Inspection of machineries were traditionally performed during complete plant shut down; but with the introduction of UAVs, this task can be completed whilst the mine is still in operation. UAVs are already helping the mining sector to reduce costs of administration, reduce operational risk and errors and minimise equipment use and damage. The application of UAVs in mining is now extended, but not limited to:

- Assisting in optimal haul road design, planning, construction
- Geotechnical monitoring such as pit survey, slope management and erosion identification
- Construction progress monitoring
- Terrain mapping and change detection
- Asset management equipment inspection (e.g. rust, cracks, leaks, stability issues, damage to roads)
- Infrastructure condition monitoring
- Capturing areas of cultural heritage near mining sites
- Security and surveillance (e.g. incident identification, perimeter control and patrol)
- Native animals and vegetation species identification
- Project oversight and business information management[12, 13]

This section summarises the main applications of UAVs in mining and the user requirements to make the data fit-for-purpose.

[10] www.australianmining.com.au/news/mining-sector-accounts-15-per-cent-australias-economy-deloitte/
[11] www.airoboticsdrones.com.au/mining/
[12] How drones are changing mining (available at **BHP website**)
[13] www.airoboticsdrones.com.au/mining/

STOCKPILE SURVEY/ VOLUME CALCULATION

To calculate the amount of extracted ore, stockpiles are surveyed in mines. Ground-based survey methods using GPS, total stations and laser scanners have been the industry standard for surveying stockpiles for many years. However, these methods are challenging as surveyors are required onsite to manually survey the locations and volume of stockpiles. This can be slow and problematic particularly on hazardous slopes. UAVs provide a safe and fast alternative solution for surveying stockpiles and calculating their volumes. It also provides additional products, such as imagery and 3D models that are missing in ground-based survey.

The key feature of interest in this application are the stockpiles. The location and volume of stockpiles are used to assess their value, and to effectively manage materials for transportation. Miners using UAVs typically require spatial resolutions of up to 3cm, and horizontal and vertical accuracy of less than 3cm and 5cm respectively. The area on interest in this application is usually 2km^2 or less, with the data acquired from a standard RGB camera. Based on the requirements of CASA, UAVs usually fly up to 400ft (110m) (Otherwise an exemption approval is required), and at this altitude using an off-the-shelf camera (i.e. 20-megapixel resolution) the resolution requirements can still be met. The key deliverables for stockpiles include 2D polygons across the mine site with their volumes as an attribute. Imagery, 3D models or point clouds are also often delivered.

RESOLUTION
$\leq$ 3cm

SENSORS
RGB

FEATURES OF INTEREST
STOCKPILES

PRODUCTS
VECTOR POLYGON DATASET (E.G. SHAPEFILE) WITH VOLUME OF STOCKPILES AS AN ATTRIBUTE

REHABILITATION MONITORING

The ability to successfully rehabilitate mined areas is fundamental to the mining industry's social license to operate. UAVs offer rehabilitation practitioners the ability to measure rehabilitation performance effectively, and over the spatial scales that are typical to many mine rehabilitation projects.

The main question to answer in this application is "How much improvement is there in the health and density of vegetation in the mine and its surroundings?" The findings of this study highlighted users are interested in monitoring features like surface elevation, vegetation height and extent, trees, water bodies and drainage and sediments. Users indicated an interest in collecting data with UAVs for an area of up to 5km^2. The area of interest covers the old mine site and its surroundings, usually buffered by up to 1-2km. Users often require a multispectral sensor, to monitor the vegetation at a maximum resolution of 10cm. While RGB bands of the multispectral sensor can be used to produce imagery of the area, using the NIR spectrum can provide more information on the health of the vegetation and trees. Furthermore, other frequencies of the sensor can be used to identify sediments and pollution levels. Typical vertical and horizontal accuracy specifications were 5cm and 10cm respectively.

This study found that the temporal resolution for data capture may vary amongst users; and usually ranges from monthly up to an annual basis. The typical deliverables for rehabilitation monitoring include DEM, NDVI maps, and high-resolution imagery.

RESOLUTION
$\leq$ 10cm

SENSORS
MULTISPECTRAL, LiDAR

FEATURES OF INTEREST
GROUND SURFACE, VEGETATION, TREES, DRAINAGE, RIVERS AND WATER BODIES, SEDIMENTS

PRODUCTS
RAW IMAGERY, CANOPY HEIGHT MODEL, DEM/DSM

PIT MONITORING AND CHANGE DETECTION

Change detection is an important aspect of mining operations. UAVs in this application provide valuable information about the surface and structural changes of the pit. Mine managers can use ‘difference maps’ to monitor changes as the result of excavation, haul road development, or other activities in the pit. They can also determine slopes and identify areas at risk of collapse. Users are mainly interested in features like the pit’s surface and structure that may include stockpile changes, road generation, rock features and surfaces. Collecting such information over time provides insights into movement of the materials and changes in the location and volume of stockpiles. This information can help with auditing contractors and detecting compliance issues (e.g. restrictions related to stockpiles distance from each other).

Most users indicated they need high resolution orthoimages at 4cm resolution. However, some accept data with lower resolutions down to 20cm. In case of one of the responses a 1m resolution was still acceptable. The temporal resolution of data collection varied amongst responses and ranging between every two days to weekly. This variation in requirement of users presents a challenge for the development of an industry-wide specification. Users had similar responses related to the accuracy of data and highlighting 5cm and 3cm as acceptable horizontal and vertical accuracy respectively.

An RGB camera was the most common sensor used for this application. Using photos with sufficient overlap and photogrammetry techniques, a point cloud and accordingly a 3D model of the pit is derived and compared with previous surveys.

Although it is still uncommon, some users highlighted the use of LiDAR on UAVs. The advantage of LiDAR over RGB sensors is that it can penetrate vegetation, collecting more-detailed data about the surface and structure of the pit.

The deliverables for this application included high-resolution orthophotos, Digital Surface Models (DSM), 2D or 3D difference maps, and classified point clouds of the pit.

RESOLUTION
≤ 4cm

SENSORS
RGB, LiDAR

FEATURES OF INTEREST
STOCKPILES, EARTHWORKS, ROADS, ROCKS

PRODUCTS
ORTHOPHOTOS, DSM, DIFFERENCE MAPS, CLASSIFIED POINT CLOUD

ASSET INSPECTION

Industrial asset inspection traditionally used ladders, ropes or rigs for inspectors to climb and access assets and machineries; This frequently exposed them to various risks and hazardous situations. Inspections also require machinery to be shut down resulting in significant financial implications for the mine. UAVs offer a new way to inspect hard-to-access locations, giving inspectors a safer, on-demand, and more cost-effective method of gathering insight into the condition of assets.

The features of interest in this application include trucks, pipes, plant, machineries, conveyor belts, and other assets. Interstingly, the smallest features captured for asset inspection included cracks, leaks, rust and rivets. Inspectors needed to know where the rust, leaks, or other faults were and the extent of coverage. UAVs can help them to capture high resolution images and videos at a sub-centimetre (<1cm/pixel) resolution. This resolution is crucial so the UAV needs to fly close to the asset and at the same height when looking obliquely. The sensors used in this application can range from RGB cameras for visual inspection to thermal, IR, and laser spectrometers for leak detection.

UAV data for asset inspections do not necessarily need to be aligned with other features in the mine, therefore the absolute accuracy can be waived, with a greater emphasis on the relative accuracy so that potential 3D models are correct.

Users indicated that the frequency of inspection for each asset type is different and depending on the use, may vary between weekly and monthly. The desired deliverables for this application included high-resolution imagery (RGB or thermal), videos about the assets and 3D models.

RESOLUTION
≤ 1cm

SENSORS
RGB, NIR, THERMAL, HYPERSPECTRAL, LASER SPECTROMETRES

FEATURES OF INTEREST
ASSETS, RUST AND ITS COVERAGE, CRACKS, LEAKS

PRODUCTS
IMAGERY, THERMAL IMAGERY, VIDEOS

SITE CONDITION AND ASSET TRACKING

Mine sites are dynamic. Stockpiles are accumulated and transferred in matter of days, trucks and machineries are constantly on the move, and even new roads are created for transferring goods and assets in or out of the quarry. Although many trucks are equipped with GPS trackers, they may be from different manufacturers and different systems are used simultaneously to be able to track the location of these assets. These pose challenges to mine mangers who need to continuously monitor the conditions of the site and location of assets throughout the lifecycle of the mine.

Users usually employ fixed wing UAVs for this application. This is mainly due to their efficiency and capacity to cover larger areas. The area of interest in this application is up to 2km^2 with focus on features of interest like ground surface, roads, plants, assets, machineries, stockpiles, hydrological features and water bodies. UAVs are now deployed regularly to capture up-to-date data about these features at a high resolution. The data is typically collected using RGB cameras and at a 5cm/pixel resolution or higher.

The participants had little interest about the vertical accuracy of the data. On the other hand, they require a minimum horizontal accuracy of 15cm. This is mainly because in some cases, the collected data is overlayed with plans to assess the progress of the work. The frequency of data collection may vary according to the user requirements and can be daily or weekly. The key deliverable for this application is the orthophotos of the pit.

RESOLUTION

≤ 5cm

SENSORS

RGB

FEATURES OF INTEREST

GROUND, ROADS, PLANTS, ASSETS LIKE TRUCKS, MACHINERIES, STOCKPILES, HYDROLOGY AND WATER

PRODUCTS

IMAGERY (ORTHOPHOTOS)

WASTE WATER AND TAILING MEASUREMENT

Mining activities can produce significant amount of waste like waste water containing pollutants and tailing. These can pose high environmental risks in mining areas and need to be monitored and treated. Certain departments in mining companies typically deal with treatment of waste and ensuring the mine site and the surrounding environment is free of contamination. Although ground testing or other field analysis are usually employed, UAVs are becoming popular as a complementary and cost-effective surveillance of waste facilities and detect contaminants in soil and nearby streams. Using multi- or hyper-spectral sensors payloads, UAVs can help measuring humidity/moisture, and pollutants levels in the soil and water which are reported for further detailed analysis.

The typical area of interest can be as large as 5km^2. This area covers the pit and its surroundings, usually buffered by up to 1-2km. The key features of interest are the humidity and pollutant/waste levels.

The resolution required by the users is typically 20cm/pixel or higher. Participants indicated this resolution is enough to detect the polluted areas and identify the type of contaminant. The vertical and horizontal accuracy is less relevant in this application and as long as the data is not too far off from the reality, it is acceptable.

The deliverables for this application include raster data containing the pollutants and waste levels on the ground or in the water.

RESOLUTION

≤ 20cm

SENSORS

MULTISPECTRAL / HYPERSPECTRAL

FEATURES OF INTEREST

HUMIDITY AND MOISTURE LEVEL IN SOIL AND GROUND, POLLUTANTS

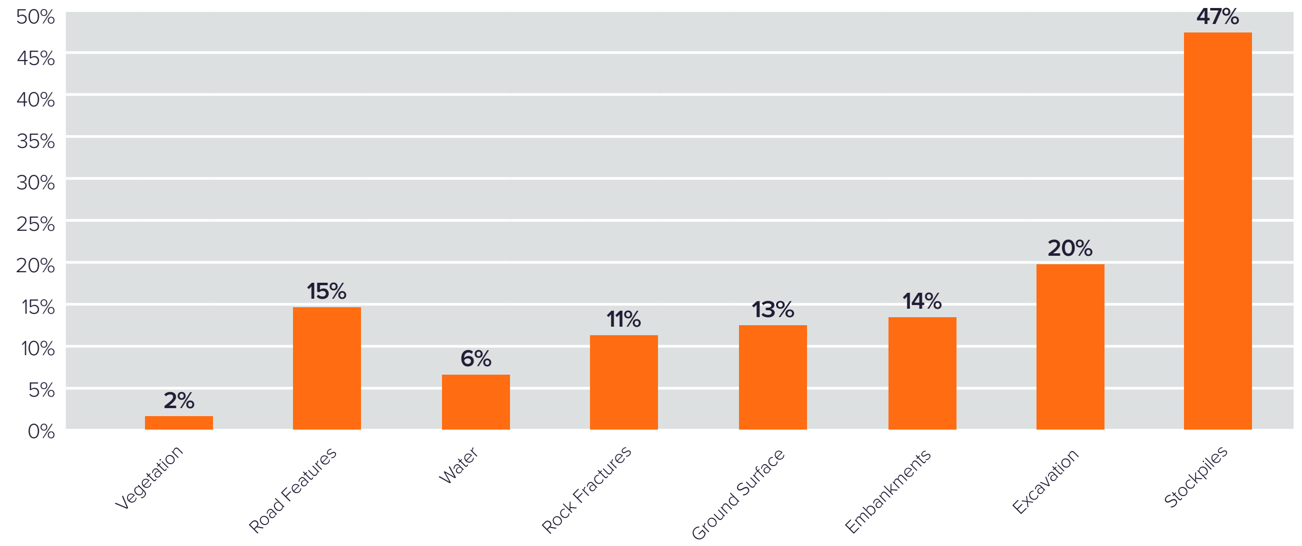
PRODUCTS

RASTER DATA CONTAINING THE POLLUTANTS AND WASTE LEVELS ON THE GROUND OR IN THE WATER

MINING SUMMARY

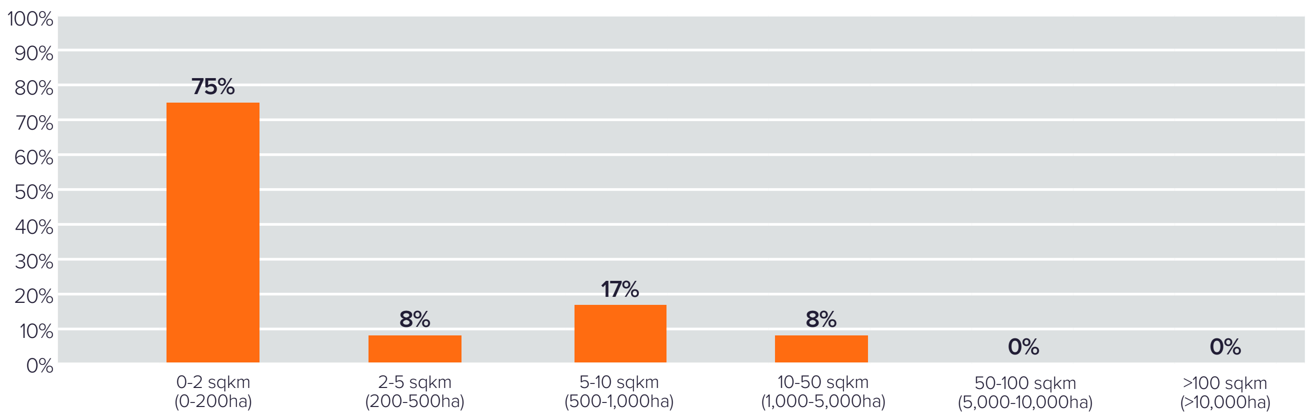
Features of Interest

The most significant feature of interest in the mining sector is stockpiles. Stockpiles volumes were mentioned by approximately half of the participants. Changes in the terrain (ground surface) due to excavation and transportation of materials are also important in mining for pit monitoring and identification of areas with risk of collapse. Users were also interested in asset inspections of machineries, pipes, etc. The users' interest in roads is typically used for management and optimisation of traffic.



Project Acquisition Area Size

Although data acquisition projects for mining vary in size and they can be up to 50 square kilometres, most responses (75 per cent) highlighted they use UAVs for automatic data capture for areas of 2 square kilometres or less. Most of them indicated the use of fixed wing UAVs for coverage of this area. However, they mentioned some applications like asset inspection and blast exclusion clearance require multi-rotors as they're able to hover over assets or the blast area.



Accuracy and Resolution

Although a few (12 per cent) users indicated lower resolutions (i.e. at 20cm/pixel) for their mining applications, 88 per cent of the responses highlighted resolution requirements at 10cm/pixel or higher. The temporal resolution requirements for data capture, in most applications, was also high (mostly daily to weekly). Where achieving such high spatial and temporal resolutions pose a challenge for other data capture methods (e.g. satellite imagery), UAVs seem to be an appropriate method for meeting these requirements. The summary of responses to resolution requirements for mining applications are shown below.

The acceptable absolute vertical and horizontal accuracy for mining applications are usually 20cm or higher. A few responses indicated a vertical accuracy down to 30cm can still be acceptable. Smaller horizontal and vertical errors become necessary for applications like stockpile surveys that need accurate DSMs for the calculation of stockpile volumes. As users highlighted, errors in calculating these volumes may have significant financial implications for the mine operator.

Interestingly, some responses indicated horizontal and vertical accuracies as low as 1m. These lower resolutions were mainly related to asset inspection applications where accuracy of the imagery/videos was not important to the users.

Commonly Used File Formats

The most commonly used file formats for the captured UAV data and its products for mining applications are summarised in the following table. Each row of the table is ordered from most to least common formats for the product.

PRODUCT	COMMON FILE FORMATS
Flight plan	KML, CSV, JPG
Imagery mosaic	ECW, TIFF
Imagery tile	TIFF, ECW, DXF, PNG
Raw Imagery	JPG, JPG2000, GeoTIFF
Ground Control Points	CSV, XYZ
Digital Elevation Model (DEM)	TIFF, ESRI GRID, ESRI ASCII
Digital Surface Model (DSM)	TIFF, ESRI GRID, ESRI ASCII, XYZ
Point Cloud	LAS, XYZ, DWG
3D Models	DXF, LAS
Tile Index	SHP, PDF
Flight Trajectory	KML
Contours	SHP, DXF, DWG
Metadata	CSV, PDF
Project Report	PDF, Word (doc, docx)

ENVIRONMENTAL MONITORING

SUPPLEMENT 2

Environmental monitoring covers a wide range of applications which include both natural and human-driven temporal changes in the environment. It involves monitoring processes and activities to characterise and monitor changes in the environment. Remote sensing has played a crucial role for successful monitoring of the environment in the last few decades. Recently, there has been an increase in the use of UAVs in this domain. This is due to the flexibility of UAVs and their ability to collect data in areas that the use of other data capture methods cannot satisfy the requirement of users, because it is either too costly or difficult. In this study 26 per cent of UAV users were involved in environmental monitoring, including many different uses and interests in UAVs. These applications included, but were not limited to:

- Vegetation mapping and inspection
- Forest hydrology (forest water use)
- Fauna counting
- Coral reef mapping
- Coastal monitoring and shoreline dynamics
- Feral (land and marine) animal counting and tracking
- Terrain mapping, surface type identification and landscape conditions
- Environmental restoration
- Coastal and river-based erosion and landslide risk assessment
- Weed species identification and monitoring
- Wildfire count and impact assessment
- Sea ice elevation
- Marine mangrove monitoring
- Monitoring environmental disasters (e.g. oil spills)

The study participants provided requirements for the use of drones within their application areas and projects. This section summarises the applications and their user needs. These include *coastal monitoring, vegetation mapping, wildlife counting, monitoring oil spills and clean-up, landslide risk assessment and bushfire burn severity mapping.*

COASTAL MONITORING

Coastal monitoring has significant importance to Australia and New Zealand as both countries have thousands of kilometres of coastline. Monitoring erosion and vegetation in the coastal zone areas are two important applications for UAV users. UAVs provide an on-demand solution for more frequent and high-resolution monitoring of topography and vegetation over time. Some users indicated less detailed data at 10cm resolution or lower depending on their needs and features of interest. The key features of interest in this application included ground surface and elevation changes in coastal landscapes, rocks, cliffs, coral reefs, seagrasses and estuaries. Some users highlighted an interest in monitoring the height of these features above the high tide mark.

End users indicated a 3cm resolution or less for elevation and 5cm for capturing the smallest vegetation types (e.g. grass). The vegetation of interest included small grasses (0.1m^2), bushes and trees. The 5cm resolution should be maintained across area sizes up to 2km^2. The horizontal accuracy and vertical suggested for coastal monitoring is <3cm and <5cm respectively. Users indicated a minimum of 60 per cent side overlap required for capturing imagery.

To collect data about elevation and vegetation together, both RGB sensors and NIR are required. Interestingly for image quality, some participants indicated a preference for shadows. The sun angle is another crucial factor that should be carefully considered in flight planning. Sun angles of between 30-70 degrees are appropriate. The deliverables for coastal monitoring include Imagery, point cloud, DEM, Canopy Height Model (CHM), vegetation extent in polygon format and metadata.

RESOLUTION

≤ 3cm (GROUND)
≤ 5cm (VEGETATION)

SENSORS

RGB, NIR

FEATURES OF INTEREST

GROUND SURFACE AND ITS CHANGES OVER TIME, VEGETATION EXTENT AND TYPES, COASTLINE, ROCKY FEATURES, WATER

PRODUCTS

RAW IMAGERY, POINT CLOUD, DEM, VEGETATION EXTENT POLYGONS, CANOPY HEIGHT MODEL, METADATA

WILDLIFE COUNTING

UAVs are regularly used to count and monitor animals (e.g. koalas, red foxes, and cats) as part of business activities. Some of these animals, like koalas, are nocturnal making them more difficult to track. UAVs are the choice for many users in this application due to its low cost and ability to monitor animals without causing them to scatter.

The focus in this application is on wildlife, with particular interests in their type, size, count, habitat, and mobility type (swim, walk, fly, etc.).

IR (thermal for counting and identifying location of animals) and RGB/video (identifying wildlife type and tracking its movement) are commonly used for wildlife counting. The resolution is typically between 5-7cm/pixel for IR and 2cm/pixel for RGB. Some of the responses indicated that users who were only interested in counting animals could use lower resolutions, such as 1m/pixel.

The size of areas to capture and timing of data collection may vary and can be as large as 5km^2 depending on the interest of the users. The data capture is seasonal, depending on the species of interest. Users indicated the followings requirements to be considered in flight planning in order not to interrupt animal activities:

- safe distance from the animals
- high altitude of the platform, or low noise
- time of capture day or night
- the UAV platform (and accordingly its noise level)

Users indicated the deliverables include imagery (GeoTIFF and orthophoto), thermal imagery, video capture and georeferenced data. Other products may include heatmaps, raw imagery, and metadata.

RESOLUTION

≤ 5-7CM (FOR IR SENSOR)
≤ 2CM (RGB CAMERA)

SENSORS

RGB, IR

FEATURES OF INTEREST

ANIMALS (KOALAS, RED FOXES, CATS), VEGETATION, ALGAE AND INVERTEBRATE SPECIES ON THE ROCKY SHORES

PRODUCTS

RAW IMAGERY, THERMAL IMAGERY, HEATMAPS, VIDEO, METADATA

MONITORING OIL-SPILL CLEAN UP

Oil spills are catastrophic events for the marine environment. UAVs can provide on-demand data about the oil coverage and clean-up progress. Users within the oil-spill clean-up application highlighted interests in ground surface, water, oil, embankments, vegetation, road features, and buildings.

UAVs are used to monitor small areas of clean-up. The resolution is typically 3cm using RGB cameras. Some users highlighted the use of multispectral sensors to detect more refined and transparent oil that is difficult to see through RGB imagery. The data capture is time sensitive for this application and begins immediately after spillage and may continue for months.

The temporal resolution of data collection usually depends on the requirements of decision makers, and can range from hourly to weekly. The deliverables include temporal images of the clean-up sites, DEM/DSM in coastal areas, buildings and roads shapefiles, and vegetation maps.

RESOLUTION
≤ 3cm

SENSORS
RGB,
MULTISPECTRAL

FEATURES OF INTEREST
GROUND, WATER,
OIL, EMBANKMENTS,
VEGETATION, ROAD
FEATURES, BUILDINGS

PRODUCTS
TEMPORAL IMAGES,
DEM/DSM, BUIDINGS
AND ROAD SHAPEFILES,
VEGETATION MAPS

LANDSLIDE RISK ASSESSMENT

Landslides can be triggered by storms or other environmental phenomena like earthquakes. Monitoring and risk assessments are essential to predicting landslides or rockfalls, and to mitigate their impact. UAVs are used for regularly monitoring cliff and landslide risks. The key features of interest for this application include the ground surface, cliffs, rock features and coastline. Vegetation cover and their type is also of interest since vegetation and trees can provide ground and soil stability. Users indicated areas of up 5km^2 being monitored but more typically areas up to 2km^2. A 20cm resolution is seen as sufficient for this application but a higher resolution (at 5cm) has led to better, more detailed risk assessments.

Use of RGB sensors and photogrammetry techniques to generate DEMs and 3D models are most common amongst users. The frequency of data collection depends on the perceived risk and can vary between weekly, monthly or quarterly. The deliverables here include orthophotos, DEM, point cloud, and vegetation cover maps. Risk maps, oblique imagery, and graphs of movement of earth along slopes and boulders are additional products required by users.

RESOLUTION
≤ 20cm

SENSORS
RGB

FEATURES OF INTEREST
GROUND SURFACE,
COASTLINE, ROCK
FEATURES AND CLIFFS,
VEGETATION

PRODUCTS
IMAGES, DEM/DSM,
VEGTATION MAPS,
POINT CLOUD, RISK MAPS

BUSHFIRE BURN SEVERITY MAPPING

Monitoring bushfires and their impacts for first response are important for emergency response and commencing the recovery process. UAVs can provide a relatively cheap solution for on-demand data collection about the burn severity in forests and damage to infrastructure in built up areas. The users in this application were interested in features such as vegetation and trees, fire extent, street furniture, road features and buildings.

The area of interest depends on the extent of fire, and is typically acquired from a standard RGB camera. Multispectral sensors are used if additional information about vegetation are required. Most users require orthoimages at 40cm/pixel or less. However, some need higher resolution data at 10cm/pixel. Accuracy within this application is relaxed, with user feedback showing an acceptance of 1-2m in both vertical and horizontal. However, they highlighted that if a higher accuracy is required, they generally use RTK.

Burn severity mapping is time sensitive. Often the time frame for data capture is limited to 3-4 days after the fire. Shadowing in photos is an issue with recovery planning. Responses suggested the minimum and maximum sun angles of 35° and 65°. The deliverables include images of the burnt area, NDVI map, damage to buildings and roads maps, vegetation maps, and fire extent polygons.

RESOLUTION

≤ 40cm

SENSORS

RGB, MULTISPECTRAL OR NIR

FEATURES OF INTEREST

VEGETATION, INDIVIDUAL TREES, FIRE, ROAD FEATURES, STREET FURNITURE, BUILDING

PRODUCTS

GEOREFERENCED IMAGERY, DAMAGE TO BUIDLINGS AND ROADS, VEGETATION MAP, SHAPEFILES OF FIRE EXTENT, THERMAL MAP

WATERWAY SURVEY AND RIVERBANK MONITORING

Land clearing and grazing pressures increase the possibility of waterway erosion. UAVs provide a cost-effective alternative to ground-based traditional or LiDAR surveys. High accuracy photogrammetric survey using UAVs facilitate erosion assessments to inform planning, strategy and structural design. Users were particularly interested in ground and riverbank surfaces, vegetation types and health, existing erosion areas and sediments.

Responses indicated survey areas of up to 1000 hectares (10km^2). This application requires high resolution imagery, of about 2-3cm/pixel captured using multiple sensors including RGB camera and NIR. User feedback required high accuracy control points and a good knowledge of river levels. The interval for surveys are annual or shortly after major rainfalls to review impacts. The deliverables for this application include imagery, DEM/DSM, vegetation maps, 3D models of riverbanks and point clouds.

In one workshop users indicated concerns with photogrammetry in dense or high vegetation, in these areas an alternate data collection method such as LiDAR could be used. Interestingly, Australian UAV raised that *"neither photogrammetry nor LiDAR will work in rivers full of water. In this circumstance, a great option is to call upon the bathymetric survey boat to work in tandem with the UAV. The boat and UAV datasets stitch together readily to provide a complete picture."*

RESOLUTION

≤ 2-3cm

SENSORS

RGB, NIR

FEATURES OF INTEREST

VEGETATION TYPES, THEIR QUALITY AND HEALTH, EROSION, SEDIMENTS AND GROUND AND RIVER BED SURFACES.

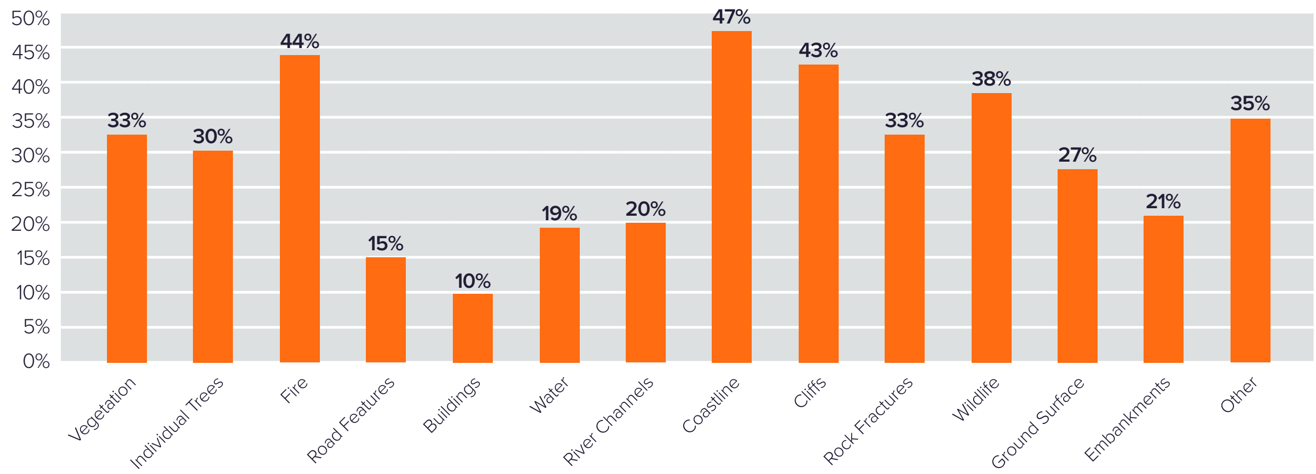
PRODUCTS

IMAGERY, DAMAGE TO BUIDLINGS AND ROADS, VEGETATION MAP, SHAPEFILES OF FIRE EXTENT.

ENVIRONMENTAL MONITORING SUMMARY

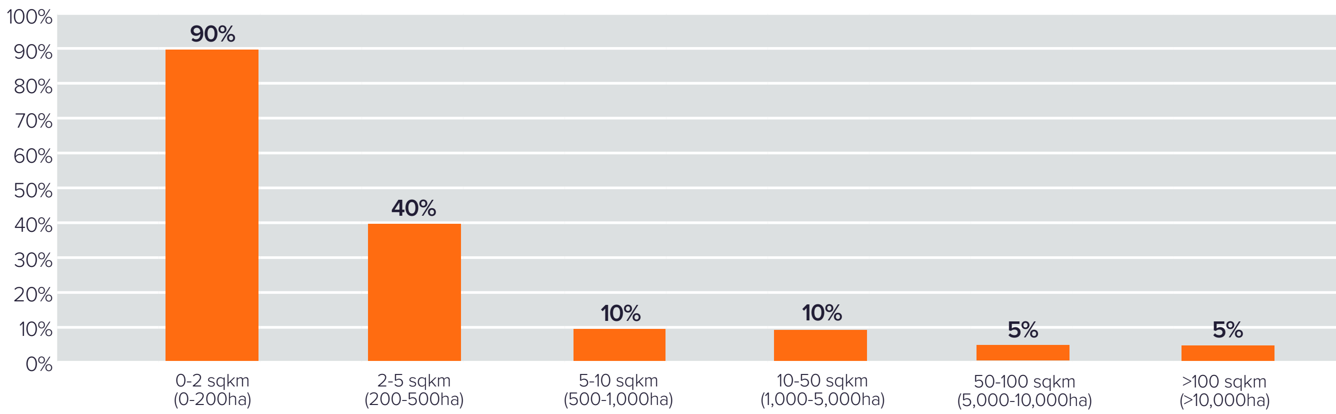
Features of Interest

Environmental monitoring spans many applications, in sectors such as forestry, river health and bushfires, therefore the list of features of interest are diverse. The most notable features in environmental monitoring are coastlines and cliffs, fire hotspots and vegetation. The ground surface is of significant importance here, especially for coastal monitoring and landslide risk analysis.



Project Acquisition Area Size

Most projects in environmental monitoring which utilise UAVs have coverage areas less than 5km^2. Of responses 90 per cent indicated their data collection is limited to 2km^2. The uses in larger survey areas included monitoring entire forests for hydrology and generating spatio-temporal evapotranspiration maps.



Accuracy and Resolution

The explored environmental monitoring applications were diverse, and hence their resolution and accuracy requirements. Although lower resolutions at 40cm/pixel were mentioned by a few participants (e.g. related to landslide risk monitoring), responses were mainly skewed towards much higher resolutions at 10cm/pixel or even higher at 2cm/pixel.

User responses indicated high expectations for horizontal and vertical accuracy for many of the applications in this category. Most accuracy requirements fell under 5cm. In contrast, accuracy was not important to some of these applications like bushfire burn severity required lower accuracies or wildlife counting. Interestingly, 20 per cent of respondents indicated vertical accuracy of down to 50cm and horizontal accuracy as low as 100-200cm would suffice for their applications (e.g. bushfire severity mapping or wildlife counting).

Commonly Used File Formats

The most commonly used file formats for the captured UAV data products for environmental monitoring applications are summarised in the following table. Each row of the table is ordered from most to least common formats for the product.

PRODUCT	COMMON FILE FORMATS
Flight plan	KML, CSV, SHP, word (doc, docx)
Imagery mosaic	TIFF, JPG, ECW, DGN, KML
Imagery tile	TIFF, JPG, ECW, A65, KML
Raw Imagery	JPG, JPG2000, TIFF
Ground Control Points	CSV, SHP, PDF
Digital Elevation Model (DEM)	TIFF, OBJ, PLY
Digital Surface Model (DSM)	TIFF, ESRI GRID, XYZ
Point Cloud	LAS, XYZ, CSV
3D Models	PDF, OBJ, PLY
Tile Index	SHP
Flight Trajectory	SHP, PDF, KML
Contours	SHP
Metadata	PDF, CSV
Project Report	PDF

AGRICULTURE

SUPPLEMENT 3

The use of UAVs for precision agriculture, farming and crop management has become very popular around the globe[14]. This is mainly due to the ability of drones to provide on-demand or live data using a variety of sensors for the analysis of crop health and growth. Farmers need to know everything that is happening on their farms to make informed decisions. As one of the examples, using UAVs and NIR sensors, farmers can continuously monitor the stress in plants and detect it days before it becomes visible to naked eye.

The common applications of UAVs in agriculture include but not limited to:

- crop health and growth monitoring
- soil moisture and geomorphology
- weir and dam design
- pest monitoring
- stock location management
- weed identification
- monitoring buds and flowering
- crop disease detection
- grass growth and fire fuel monitoring adjacent to fields
- Spraying and treating weeds

This section summarises the main applications of UAVs in the agriculture sector and their requirements to make the data fit-for-purpose.

[14] http://www.abc.net.au/news/rural/2017-03-07/drone-use-increasing-for-ndvi-mapping/8328456

CROP STATUS AND WEED/PEST MONITORING

The monitoring of crops and identifying pests and weeds are two important uses of UAVs. Farm managers are particularly interested in their topography, vegetation, crops, and weed/pest identification. Users required a minimum resolution of 10cm/pixel. The frequency of data collection varies from every few days to weekly.

The most common sensors for crop monitoring include RGB, NIR, and LiDAR. Often multi or hyperspectral sensors are used to identify species. Users indicated little interest in specifying vertical and horizontal accuracy. In workshops, users felt that as long as they can roughly identify the location of weeds and unhealthy crops, they can take counter measures. The deliverables include DEM, imagery, NDVI map, crop maps and canopy height models.

RESOLUTION

≤ 10cm

SENSORS

RGB, NIR, LiDAR OR MULTISPECTRAL

FEATURES OF INTEREST

TOPOGRAPHY, VEGETATION, CROPS, WEEDS/PESTS

PRODUCTS

IMAGES, DEM, VEGETATION STATUS MAPS, CROP TYPE MAP, CANOPY HEIGHT MODEL

MISSING PLANTS RECOGNITION

Farmers usually plant crops in rows for more effective farm management. Ideally crops planted at the same time grow together and their distribution is uniform across rows. However, typically some plants are missing or undergrown for reasons like frost or pests. In this case, farmers need to identify these crops and manage them. UAVs can play a key role in identifying missing plants. Using RGB cameras, they can take aerial photos which are used in algorithms for recognising the slow growth or missing plants. Usually, a DSM of the farm is generated using sophisticated algorithms, ground is differentiated and the crops are detected. Using this information, colorised maps can be generated that help farmers identify the location of these disease affected crops.

The area size for this application is usually 45-50ha; but can be as large as 2,000ha in one day. The resolution usually depends on the type and size of crops. Typical resolution for this application is 5cm/pixel.

The frequency of data collection is every fortnight. Users indicated more regular data capture is a waste of resource since the rate of growth in crops is limited. The key deliverables for this application include imagery, DSM, and maps of the location of the undergrown or missing crops.

RESOLUTION

≤ 5cm

SENSORS

RGB

FEATURES OF INTEREST

CROPS/PLANTS, GROUND SURFACE

PRODUCTS

IMAGERY, DSM, RASTER-BASED MAPS OF CROPS

DISEASE DETECTION

To detect crop disease there is usually a change in the leaf temperature of plants and crops. Timely information about signs of disease can helps treatment. UAVs can be used to detect plant stress and help farm managers regularly monitor their crops for early symptoms.

In this application, farmers are mainly interested in vegetation and crops. The spatial coverage is generally less than 500 hectares ($5km^2$). Farm mangers tend to fly UAVs every few days or on a fortnightly basis for monitoring farms. The resolution of data is typically 3cm/pixel. This resolution can identify individual plants and changes in their health. The sensors used are a combination of RGB camera and NIR (and sometime IR) sensors. Fluorescence imaging using drones was also mentioned by users to map and estimate differences in the photosynthetic activity of plants. The deliverables for this application include imagery, heatmaps and NDVI maps. UAV operators indicated RGB imagery as the most common delivery for crop disease detection.

RESOLUTION
≤ 3cm

SENSORS
RGB, NIR, IR

FEATURES OF INTEREST
VEGETATION, CROPS

PRODUCTS
IMAGES, NDVI INDEX MAP OF CROPS, HEATMAP OF CROPS

EARLY PESTS AND DISEASE DETECTION IN CROPS

Using RGB, thermal or NIR, pests and disease in crops can be detected. However, at this point it is already too late and the disease is already there; hence there is a need for early detection of potential pests and diseases. When a plant is attacked by a pest/disease, it immediately reacts by decreasing or increasing the level of reflectance due to processes within the plant cells. These reflectance fluctuations are usually invisible to RGB, NIR or IR cameras but can be picked by multi- or hyper-spectral sensors that can capture wider bands other than those mentioned above. Participants indicated that the future of plant disease detection will be in the use of these sensors for early detection of these problems.

Similar to what previously discussed in the disease detection application, here, farmers are also mainly interested in vegetation and crops. The spatial coverage is similarly less than 500 hectares ($5km^2$).

Although accuracy is not an issue with this application, users indicated a horizontal accuracy of 50cm or higher is acceptable. While a 15cm/pixel was mentioned as a typical spatial resolution, users indicated that it usually varies depending on the required number of measurements across each plant. This number depends on the typical size of plants and determines the requirement of the resolution and pixel size.

The temporal resolution for data collection is every few days or weekly. The deliverables of the project include raster datasets related to specific selected wavelengths captured using the sensors.

RESOLUTION
≤ 15cm

SENSORS
MULTI- OR HYPER-SPECTRAL

FEATURES OF INTEREST
VEGETATION, CROPS

PRODUCTS
RASTER DATASETS

GROWTH AND NUTRIENT LEVEL DETECTION

The growth rate and level of nutrient are important indicators for farmers to make informed decisions for effectively managing their farms. This information is usually obtained via different vegetation indices. Some of these indices are related to growth of the crops, and some are for the plants' water status. Using UAVs and multi- or hyper-spectral sensors, data about different bands across the electromagnetic spectrum can be collected and using algorithms, relevant vegetation indices (e.g. NDVI) can be generated.

The main benefit of UAVs to this application is that it can collect data in a short period of time and provides consistent data across the farm. Longer period data collection process may result in data inconsistencies due to changes in environmental conditions, temperature or humidity during the day.

The key features of interest in this application include the vegetation and crops. The area of interest may vary and can be as large as 5km^2. The main sensors for this application include multi- or hyper-spectral cameras. Typical spatial resolution for this application is 15cm/pixel.

The main deliverables of this application are different vegetation indices and raster maps of their distribution across the area of interest.

RESOLUTION
≤ 15cm

SENSORS
MULTI- OR HYPER-SPECTRAL

FEATURES OF INTEREST
VEGETATION, CROPS

PRODUCTS
RASTER MAPS OF VEGETATION INDICES

BIOMASS MEASUREMENT AND MAPPING

Calculating the biomass volume has value to agriculture and forestry sectors. This volume can help better understand the fuel load in forestry and bushfire management. Farmers, on the other hand, may grow certain crops (e.g. corn) to produce biomass energy. Biomass calculations help to better estimate production. This process is essentially the calculation of the volume of crops/plants from their 3D geometry. LiDAR sensor mounted on a UAV can be used to collect data about the structure and volume of crops in the farm. IR sensors can be a complement to the LiDAR to provide additional information about the water status and stress levels of plants.

The key feature of interest for this application is crops/plants. The area of interest for data collection can be as large as 5km^2.

Since LiDAR is the main sensor, the more number of points collected per square metre, the more accurate the crop volume calculations. The horizontal and vertical accuracies are ≤20cm and ≤10cm respectively.

The deliverables in this application include Canopy Height Model (CHM) and moisture level of plants in a form of raster representation.

RESOLUTION
≤ 10cm

SENSORS
LiDAR, IR

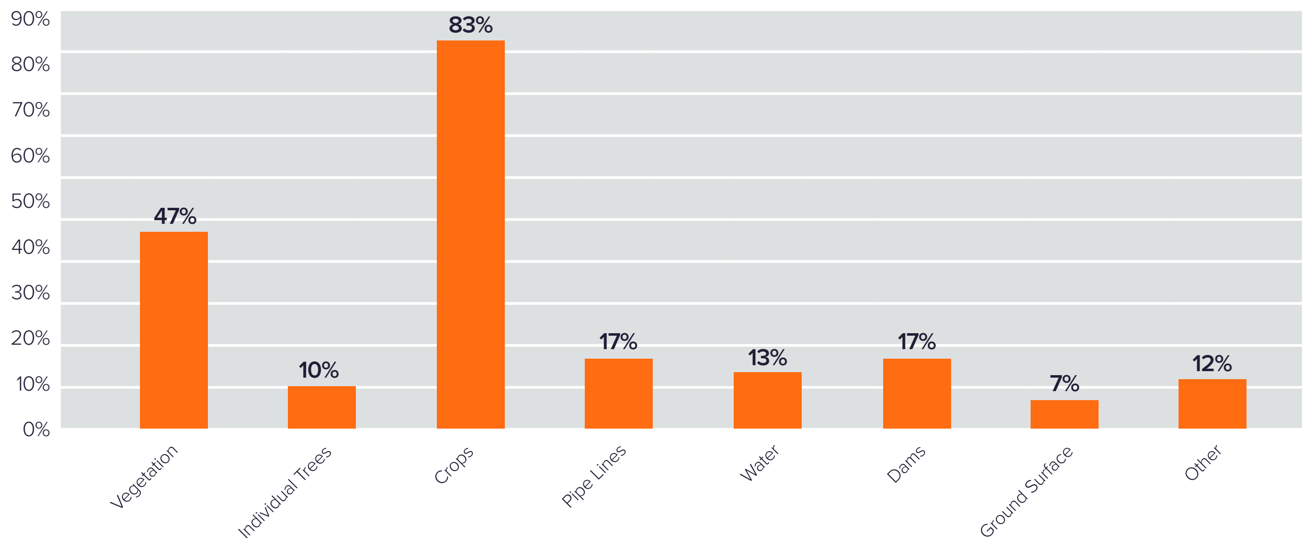
FEATURES OF INTEREST
VEGETATION, CROPS

PRODUCTS
CHM, RASTER MAPS

AGRICULTURE SUMMARY

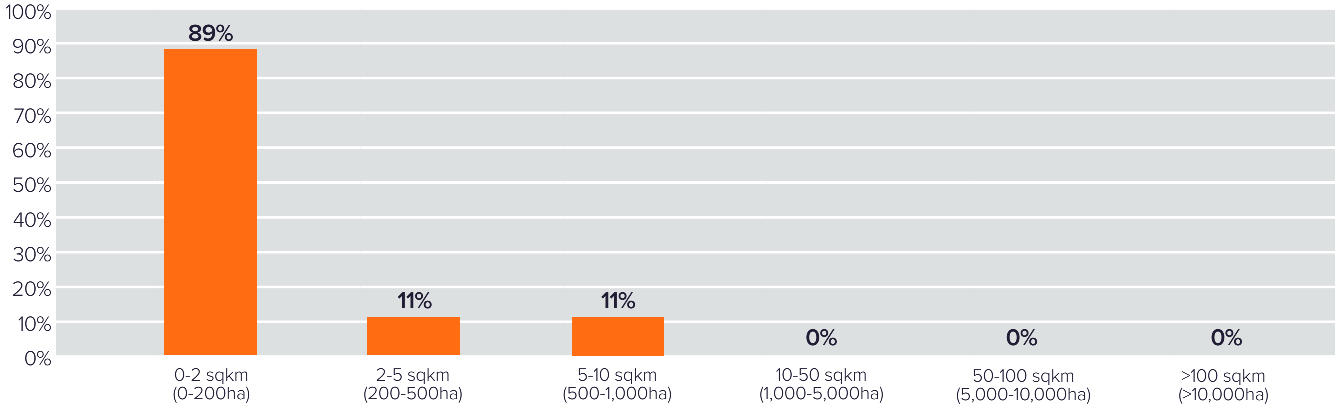
Features of Interest

As expected the most significant feature of interest in agriculture are the crops, with 83 per cent of users declaring an interest. Farmers and farm managers are also interested in vegetation types, trees and irrigation-related features such as pipelines and dams. Furthermore, it was mentioned that data about pests and weeds help with effective control strategies.



Project Acquisition Area Size

The project size in most agriculture applications sector is 2km^2 or smaller. While 89 per cent of responses indicated this, a few participants (11 per cent) highlighted area sizes of between 5 and 10 km^2. As expected, this correlates with farm size.



Accuracy and Resolution

As it was evident from the responses, precision agriculture requires high resolution data. Nearly all agriculture applications discussed in this supplement require spatial resolution of 15cm/pixel or higher.

The acceptable horizontal accuracy of data is mostly 20cm or higher. Interestingly, some responses (related to pest and disease detection or assessing biomass) indicated less emphasis on horizontal accuracy and can be as low as 50cm and even 1m. Users explained that they only need to know about approximate, and not exact, location of affected crops and other features of interest.

Except biomass assessment which requires relatively high horizontal and vertical accuracy (<20cm and <10cm respectively), other agriculture applications were not sensitive to vertical accuracy. This was because the use of data for these applications does not require the third dimension.

Commonly Used File Formats

The most commonly used file formats for the captured UAV data and its products for mining applications are summarised in the following table. Each row of the table is ordered from most to least common formats for the product.

PRODUCT	COMMON FILE FORMATS
Flight plan	CSV, PDF
Imagery mosaic	TIFF, JPG, 12da
Imagery tile	TIFF, JPG, JPG2000
Raw Imagery	GEOTIFF, JPG, JPG2000
Ground Control Points	CSV
Digital Elevation Model (DEM)	TIFF, ESRI GRID
Digital Surface Model (DSM)	TIFF, ESRI GRID
Point Cloud	LAS, XYZ, DWG
3D Models	n/a
Tile Index	SHP
Flight Trajectory	KML, SHP
Contours	DXF
Metadata	PDF
Project Report	PDF

EMERGENCY MANAGEMENT

SUPPLEMENT 4

UAVs have become an important tool for first responders during and following emergencies. UAVs provide an overhead assessment to gauge the impact of the disaster and potential search for survivors. Appendix G provides a wide range of applications of UAVs in emergency and disaster management. Some of these applications overlap with activities in other sectors. A few notable ones that were highlighted by users are:

- post disaster assessment and surveillance
- detection of fire hotspots
- air monitoring
- access and fire breaks planning
- fuel load assessment
- identification of hazardous areas
- oil spill response
- identification of flood mark lines
- burn severity assessment
- emergency (e.g. flood or tsunami) planning, and
- search and rescue

Most of these applications require imagery or video of the affected areas. However, the time of capture, type of event and its scale, and the way they impact the environment determine the type of UAV used, the resolution of data and features of interest.

This section summarises the main applications of UAVs in emergency management and the user requirements to make the data fit-for-purpose.

MONITORING EMERGENCIES SUCH AS FIRE AND FLOOD

UAVs can play a key role in acquiring data for creating situational awareness about emergencies. Fire, tsunamis and floods are some examples of emergencies raised by UAV users. These people are interested in data about the ground surface, likely ignition areas, existing fires, asset damage, dams, buildings and waterbodies. Identifying people is critical in this application.

The spatial coverage of data by UAVs is dependent upon the emergency, however imagery is usually acquired at a minimum resolution of 50cm/pixel. The decision on resolution depends upon the smallest features of interest. Users indicated a primary interest in being able to recognise buildings and asset damage in the data.

The sensors used in emergencies tend to be both RGB and thermal (IR). Authorities monitor the situation with UAVs to assess the effectiveness of mitigation efforts.

The IR thermal can penetrate through smoke and assess the fire condition where the use of RGB cameras becomes irrelevant.

The deliverables can include imagery, heat maps, flood extent polygons, buildings and other infrastructure damage, people's locations, and video footage of the affected areas.

RESOLUTION

≤ 50cm

SENSORS

RGB, IR

FEATURES OF INTEREST

GROUND SURFACE, FIRE, ASSET DAMAGE, DAM, BUILDINGS, WATER BODIES, COASTLINES

PRODUCTS

IMAGERY, HEAT MAPS, FLOOD EXTENT, BUILDING DAMAGE, ASSET DAMAGE, PEOPLE, LOCATION, VIDEOS

GRASS GROWTH MONITORING FOR BUSHFIRES

Grass fire is one the most serious concerns during the hot and dry seasons in Australia and can pose a considerable threat to natural resources and human settlements. Continuous monitoring of grass growth and its treatment can reduce the risk of grass fire breakouts. UAVs provide a flexible technology for capturing data about grass coverage and biomass. Dry vegetation is considered as fuel. Accordingly, knowledge of moisture levels is also important. The area of data capture is usually less than 500ha with a minimum 10cm/pixel resolution. The data collection interval varies depending upon seasons. In the highest danger season, daily monitoring of grass growth might be required.

The sensors to be used for this application include RGB camera and NIR. The latter is mostly used for moisture level detection. Some users opted for LiDAR to get a better understanding of the structure and length of grass. The deliverables include imagery, maps of vegetation types, vegetation moisture level maps, DEM and classified point clouds.

RESOLUTION

≤ 10cm

SENSORS

RGB, NIR

FEATURES OF INTEREST

GRASS, VEGETATION, GROUND SURFACE

PRODUCTS

IMAGERY, MAP OF VEGETATION TYPES, DEM, CANOPY HEIGHT MODEL (CHM)

PLANNED BURNS AND PREVENTATIVE FIRE MANAGEMENT

Preventative bushfire measures (e.g. reducing fuel load, identifying water resources, ensuring the quality of roads and fire breaks) are necessary for mitigating fire risk. Planned controlled burns are one of the commonly taken measures to minimise the fuel in high-risk areas. UAVs can be used collect real-time data for remote monitoring and progress of preventative activities. Important locations and priority areas can be detected as part of this process using RGB cameras, NIR or even LiDAR.

The survey area varies depending on the burn area, however it is usually less than 2km^2, but can be as large as 50km^2. UAV users are mainly interested in fire breaks, roads, fire fronts, water resources, and fuels (e.g. vegetation and trees). The information is time sensitive prior to, during, and following an operation. Typical resolutions for this application are 1m or higher. If road conditions and vegetation details are required, higher resolutions (i.e. 20cm) are preferred. The deliverables include imagery, canopy height models and vegetation type, moisture levels of vegetation, and DEMs. Road condition maps are also beneficial in this application.

RESOLUTION

≤ 1m

SENSORS

RGB, NIR, LiDAR

FEATURES OF INTEREST

FIRE BREAKS, FIRE FRONT, WATER RESOURCES, FIRE FUELS, CANOPY HEIGHT AND STRUCTURE

PRODUCTS

IMAGERY, MAP OF VEGETATION TYPES/ STRUCTURE, DEM, CANOPY HEIGHT MODEL (CHM), MOISTURE MAP

DETECTING FLOOD MARKS OR DEBRIS LINES ON GROUND

After a flood assessment teams are deployed to determine the flood extent. In most cases, UAV users were interested in the flood mark or debris lines on the ground which can help determining the depth of flood. They usually use a low altitude UAV equipped with a RGB sensor at a minimum resolution of 10cm. The spatial location of these lines should be within sub metre horizontal accuracy and under 200mm for vertical accuracy. Accordingly, the recommendation for image overlap was 65-70 per cent or more. This application is time sensitive and the data should be collected shortly after the water is recedes.

The key deliverables of this application include imagery (orthomosaic photo), DEM, flood/debris line shapefiles and ground control points.

RESOLUTION

≤ 10cm

SENSORS

RGB

FEATURES OF INTEREST

FLOOD/DEBRIS LINE

PRODUCTS

IMAGERY (ORTHOMOSAIC PHOTOS), DEM, FLOOD/ DEBRIS LINE SHAPEFILE, GROUND CONTROL POINTS

SEARCH AND RESCUE

UAVs can have a significant contribution to search and rescue though identifying survivors, delivering water supplies, equipment, or medical needs. Users highlighted that UAVs (equipped with speakers and microphones) can be used for remote communication between first responders and survivors. The key features of interest are identifying people both on water and land and their condition.

This information can be collected using RGB and/or other visible sensors including IR (thermal). For communication purposes, users suggested UAVs should carry LTE cell on wings or satellite communications devices as additional payloads.

For detecting people, a 30-50cm resolution is preferred. Deliverables included heat maps, video and imagery.

RESOLUTION
≤ 50cm

SENSORS
RGB, IR

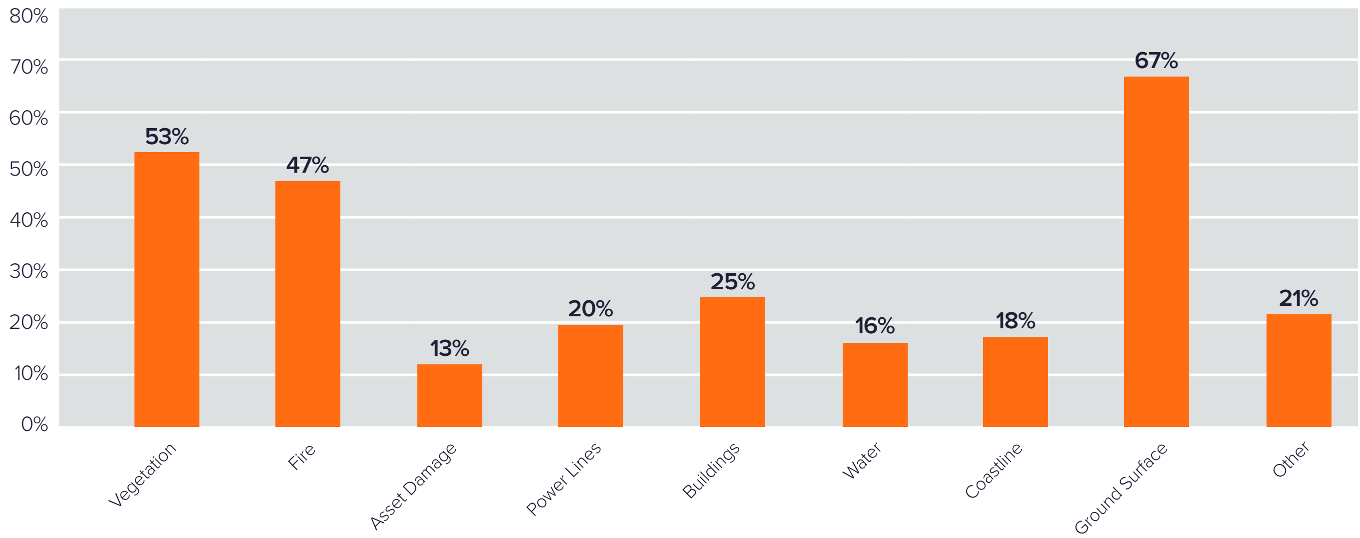
FEATURES OF INTEREST
PEOPLE/SURVIVORS

PRODUCTS
HEAT MAP, VIDEO, GEOREFERENCED IMAGERY

EMERGENCY MANAGEMENT SUMMARY

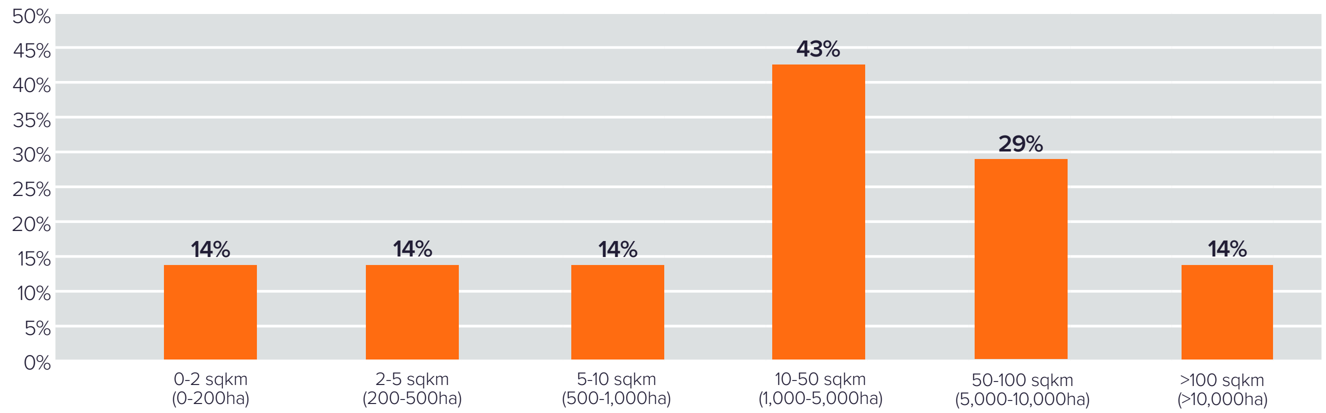
Features of Interest

The features of interest in emergency management vary depending on the type of emergency. In this study, 67 per cent of users required data on the ground surface. Fire sources i.e. vegetation and trees (53 per cent), and fire (47 per cent) were other features of interest.



Project Acquisition Area Size

The project size in most emergency response applications vary depending on the type of application. In the majority of cases, users indicated large areas of over 10km^2 *(see Figure below)*. For these large areas, users used fixed-wing UAVs. However, they indicated that multi-rotor is potentially crucial for communicating with survivors.



Accuracy and Resolution

The identified emergency management applications were diverse, and hence their resolution and accuracy requirements. The image resolution of applications in emergency management varied between 10 and 50cm/pixel. Where higher resolutions suit applications like fire fuel monitoring and flood/debris mark detection, in other cases (e.g. search and rescue and planned burn monitoring), lower resolutions down to 50cm or even 1m were still acceptable. Users explained that they are interested to know about approximate, and not exact, location of people/survivors and other features.

The spatial accuracy was found to be not relevant to many applications in this category (e.g. emergency monitoring and search and rescue). Participants mentioned that the data is acceptable as long as the features of interest are captured within a few metres of their real location. A small number of applications such as the detection of flood marks required high accuracy data at 20cm or higher.

Commonly Used File Formats

The most commonly used file formats for the captured UAV data and its products for emergency management applications are summarised in the following table. Each row of the table is ordered from most to least common formats for the product.

PRODUCT	COMMON FILE FORMATS
Flight plan	TAB, SHP
Imagery mosaic	ECW, ESRI GRID, JPG, TIFF
Imagery tile	ECW, ESRI GRID, JPG, TIFF
Raw Imagery	ECW, JPG, JPG2000, TIFF
Ground Control Points	SHP, XML
Digital Elevation Model (DEM)	ESRI GRID, TAB
Digital Surface Model (DSM)	ESRI GRID, TAB
Point Cloud	LAS, XYZ
3D Models	ESRI ASCII
Tile Index	SHP, TAB
Flight Trajectory	TAB, SHP
Contours	SHP, TAB
Metadata	SHP, TAB, XML
Project Report	PDF

LOCAL GOVERNMENT

SUPPLEMENT 5

UAVs are benefiting local government operations. Councils are now using drones to maintain and manage public amenities and physical assets. UAVs are delivering insights about facilities, assets and infrastructure, and are used to monitor public areas. The following are some of the applications of UAVs that are benefiting councils:

- promoting tourism
- inspecting properties and other utilities
- transport monitoring
- land development and land use management
- cultural heritage maps and visualisation
- asset inspection and management
- building compliance

This section summarises the main applications of UAVs in local government and the user requirements to make the data fit-for-purpose. These applications include cemetery plot photography, surveying illegal construction, marketing of city centres, and solar panels on building roofs.

CEMETERY PLOT PHOTOGRAPHY

As cemeteries grow and their complexity increases over time, their management becomes progressively more difficult. Usually special software and up-to-date data is used to effectively manage plots and their surroundings, access roads, greenery, and other aspects of the cemetery. For example, if tree roots are not monitored regularly, they can destroy graves. Cemeteries are continuously surveyed and plots are photographed to identify the graves and create a detailed map of the area and a look up system that helps people to find a specific grave quickly. UAVs are a flexible means for mapping cemeteries to a high level of detail.

This study shows that the key features of interest include graves, vegetation, individual trees, buildings and plots. Participants highlighted that data is usually acquired for an area of about $2km^2$ or smaller, and at a resolution of 3cm or higher. Usually RGB cameras are used in this application. Photographs are often re-captured every six months for monitoring plots. However, if a new grave is added, new photographs might be required. The key delivery for this application is oblique imagery.

RESOLUTION
≤ 3cm

SENSORS
RGB

FEATURES OF INTEREST
TOMBS/GRAVES, VEGETATION, INDIVIDUAL TREES, BUILDINGS AND PLOTS

PRODUCTS
OBLIQUE IMAGERY

MARKETING CITY CENTRES AND TOURISM

UAVs are being used in the marketing of city centres. Exciting pictures and videos of the city are captured and compiled for promotional and tourism purposes. This is commonly referred to as “Aerial Marketing” and partially overlaps with the use of UAVs for the real-estate market. The key feature of interest here is the city landscape and may include buildings, people, vegetation, land use, road features, street furniture, bridges, rivers and water bodies, and coastlines.

The participants indicated the area of interest may vary in size and be as large as $4km^2$. This area is big enough to cover city centres and their surroundings. This application typically requires RGB cameras and a spatial resolution of 5cm or higher. The data capture for this application is not captured regularly, and depends on the clients’ request. Interestingly the participants indicated the photo/videography are seasonal.

The key deliverables for this application include imagery and videos of the city and tourist attractions.

RESOLUTION
≤ 5cm

SENSORS
RGB

FEATURES OF INTEREST
BUILDINGS, VEGETATION, PEOPLE, ROAD FEATURES, STREET FURNITURE, BRIDGES, RIVERS AND WATER BODIES, AND COASTLINES

PRODUCTS
IMAGERY, VIDEOS

INSPECTION OF SOLAR PANELS ON BUILDINGS' ROOFS

The prevalence of solar panels is growing as the technology is becoming cheaper and more accessible. Solar panels are prone to small defects that are hard to detect with the naked eye. These defects may include deterioration of cable insulation, failure of components, corrosion, components filling with water, or other damaged parts. Drones are not only adopted for inspecting large solar farms, they are now used to inspect single home units. Some defects such as corrosion are only detectable in high resolution images. Other defects, especially those that lie in the interior of the panels are generally inspected using thermal imaging.

The key features of interest include buildings and solar panels. Participants highlighted that they usually fly UAVs for project sizes of $2km^2$ or less and at a resolution of up to 2cm. In most cases, the area is limited to one property/building. The data collection is based on requests from clients for the inspection, with time series data not required for residential properties.

The main sensors used for this application are RGB and IR (thermal) cameras. Where visual examination is limited to external components, thermal imaging can detect additional damage. The key deliverables for this application are imagery, thermal imagery, and videos. Accuracy was not mentioned in the majority of responses since the users are not interested in the exact location of damages in space and the data is usually not used along with other georeferenced data.

RESOLUTION
≤ 2cm

SENSORS
RGB, IR

FEATURES OF INTEREST
BUILDINGS, SOLAR PANELS

PRODUCTS
IMAGERY, THERMAL IMAGES, VIDEOS

SURVEY ILLEGAL CONSTRUCTION

"Illegal construction" is a construction activity without a valid permit and can be a major environmental violation around natural reserves or preserved areas. In cities, it can be a big issue due to illegal settling or "land grabbing". Furthermore, construction with valid permits can exceed the restrictions specified in the permit. UAVs enable councils to frequently survey and monitor the areas under their authority and detect any illegal constructions.

Users are mainly interested in features like ground surface, water, buildings, and construction activities (construction site, machinery, etc). Information about these features are usually collected using RGB sensors and at a resolution of 10cm or higher across areas of interest varying between 2 and $10km^2$. The key deliverables include imagery and DSMs. Combining DSMs with imagery provides an effective way for monitoring construction progress over time. The frequency of data collection was suggested to be monthly. In extreme cases, some participants indicated flying drones on a fortnightly basis.

RESOLUTION
≤ 10cm

SENSORS
RGB

FEATURES OF INTEREST
BUILDING, GROUND SURFACE, WATER, CONSTRUCTION ACTIVITIES

PRODUCTS
IMAGERY, DSM, VIDEOS

FOOTPATH CONDITION ASSESSMENT

Damage to footpaths mainly arise from aging infrastructure, vehicle overrun or through upward pressures from tree roots underneath. As a result, footpaths develop problems that may include cracks, dislodgements or uneven surfaces. Currently, councils use crowed sourcing methods and citizen reports (e.g. report forms on their website or phone) for identifying these problems. UAVs are now considered as a relatively cheap alternative for regular monitoring of foot- and bike-paths.

The required resolution for this application is 1cm/pixel or higher. This resolution is necessary for even small cracks to be identified in images. Where there is less-sensitivity towards horizontal accuracy (e.g. <1m), this application requires a high vertical accuracy at <2cm. This arises from the need for detection of 15-35mm unevenness in the surface of pavements.

Such unevenness is a hazard for pedestrians and can cause tripping.

Data about the condition of footpaths is collected on an annual basis. Users highlighted the key deliverables may include orthophotos and DSM.

RESOLUTION

≤ 1cm

SENSORS

RGB

FEATURES OF INTEREST

CRACKS, DISLODGED PAVEMENT, UNEVEN SURFACES

PRODUCTS

ORTHOPHOTOS, DSM

GREEN SPACE MAPPING

For effective management of green/open spaces under their authority, local governments map these areas and to produce digital maps and aerial photographs. Often, feature extraction techniques are used to identify and map vegetation, trees and their foliage, water bodies, roads/footpaths, and street furniture. This information is then employed for change detection, visualisation and planning. The main challenge for local governments is, however, to keep these digital resources and maps up-to-date and accurate.

UAVs, as a relatively cheap alternative to satellite imagery and manned aerial vehicles, can be employed to regularly map green spaces at a high-resolution of 5cm or higher. Users with experience in local government indicated RGB sensors are usually used in this application with minimum horizontal accuracy of 50cm. The area of interest for data collection is typically less than 2km^2. The temporal resolution of data capture may vary and usually depends on the purpose of data collection.

The key deliverables of this application mainly include orthomosiacs, photogrammetric point clouds, and vector datasets representing extracted features like trees and street furniture.

RESOLUTION

≤ 5cm

SENSORS

RGB

FEATURES OF INTEREST

VEGETATION, TREES AND THEIR FOLIAGE, WATER BODIES, ROADS/ FOOTPATHS, AND STREET

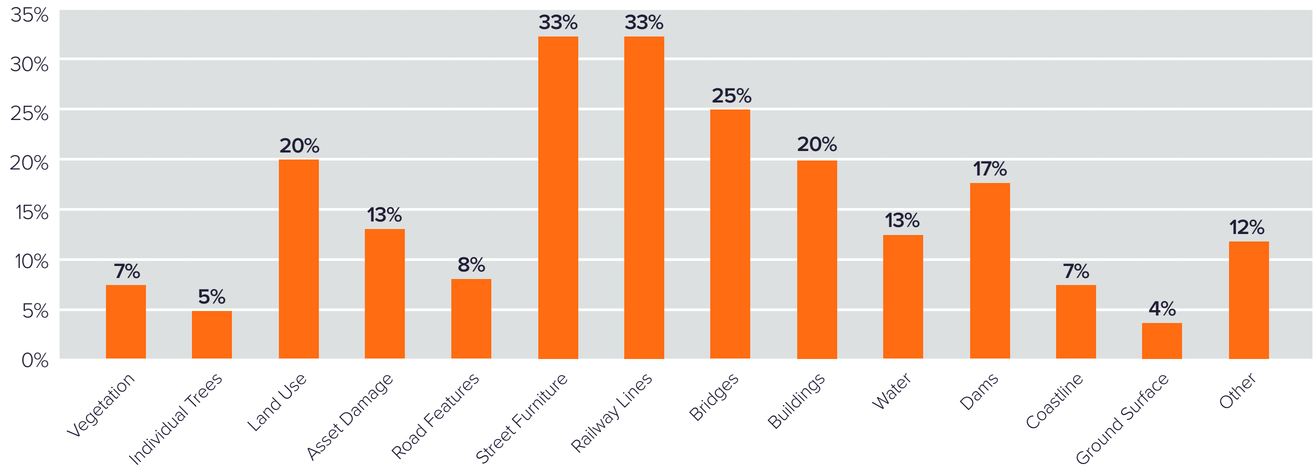
PRODUCTS

ORTHOMOSIACS, PHOTOGRAMMETRIC POINT CLOUD, AND VECTOR DATASETS

LOCAL GOVERNMENT SUMMARY

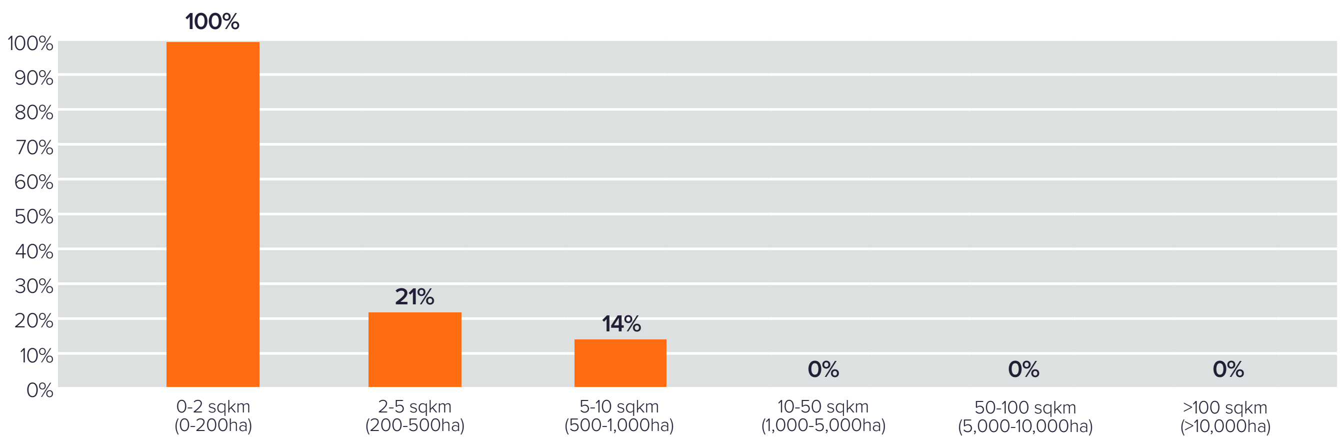
Features of Interest

The key features of interest for local government applications are the street furniture, transport facilities (e.g. railway lines) and buildings and infrastructure. These applications are diverse and accordingly the features of interest can vary significantly from one to the other. Vegetation and trees, footpath or pavement damage and land use are other features of interest in this application. In this study, 12 per cent of the participants indicated other features such as cemetery plots, footpaths, or solar panels that were discussed in this section.



Project Acquisition Area Size

The project size for most applications in local government are 2km² or smaller. While all users indicated this, a few responses (21 per cent) indicated area sizes of up to 5km² for applications like aerial marketing. Flying UAVs for larger areas as big as 10km² was also mentioned by the users but it's less common.



Accuracy and Resolution

The identified local government applications were diverse, and hence their resolution and accuracy requirements. All applications required high resolution imagery at 10cm/pixel or even higher at a centimetre/pixel. This was especially the case for footpath condition assessments which require the detection of small cracks in pavements.

Interestingly, the requirements for horizontal accuracy were generally low ranging from 50cm to a few metres. This was similar to the vertical accuracy of these applications with exception of two; i.e. footpath condition assessment and greenspace mapping. They require 20cm or higher vertical accuracies for detecting slight changes in footpath elevation as well as accurately mapping vegetation and trees in urban green spaces.

Commonly Used File Formats

The most commonly used file formats for the captured UAV data and its products for mining applications are summarised in the following table. Each row of the table is ordered from most to least common formats for the product.

PRODUCT	COMMON FILE FORMATS
Flight plan	TAB, KML, PDF, SHP
Imagery mosaic	TIFF
Imagery tile	JPG, JPG2000
Raw Imagery	TIFF, GeoTIFF
Ground Control Points	CSV, XML
Digital Elevation Model (DEM)	DGN, DWG, DXF, ESRI ASCII, XYZ
Digital Surface Model (DSM)	DGN, DWG, TAB, SHP, ESRI ASCII
Point Cloud	LAS, LAZ, TAB, XYZ
3D Models	DWG, DXF
Tile Index	TAB, SHP
Flight Trajectory	TAB, KML, PDF
Contours	TAB, DXF
Metadata	TAB, XML
Project Report	PDF

SURVEY
SUPPLEMENT 6

UAVs provide a fast and affordable alternative for surveyors. UAVs can also reduce safety risks by acquiring data remotely. Surveyors are using UAVs for a range of applications to supplement traditional surveys including:

- aerial survey and mapping
- more detailed surveys for mapping stratigraphic layers on cliffs and rock outcrops
- property management
- mapping vegetation along roads and pathways
- surveying complex facilities such as oil refineries
- multispectral mapping
- rail corridors

This section summarises the main applications of UAVs in surveying and the user requirements to make the data fit-for-purpose.

AERIAL SURVEY AND MAPPING

Aerial survey and mapping may include aerial photography, LiDAR or potentially other remote sensing sensors. Applications of aerial surveys captured by surveyors are broad covering uses in archaeology, fishery, geophysical applications, mining and minerals etc. The features of interest can be diverse and may include ground surface, excavations, earthworks, vegetation, individual trees and land use. Many responses indicated a resolution of 3cm/pixel over areas of interest of up to 10km^2. The accuracy for these surveys are 3cm horizontally and up to 5cm vertically.

The types of sensors used depend upon on the features of interest, these may include RGB, NIR, LiDAR or Thermal (IR). The deliverables for this application are also diverse.

RESOLUTION

≤ 3cm

SENSORS

RGB, LiDAR, NIR, IR

FEATURES OF INTEREST

GROUND SURFACE, EXCAVATIONS, EARTHWORKS, VEGETATION, INDIVIDUAL TREES, LAND USE, AND WILDLIFE

PRODUCTS

IMAGERY, HEATMAP, POINT CLOUD, AND DEM/DSM

MAPPING GEOLOGY AND CLIFFS

Stratigraphy is a branch of geology primarily concerned with layering in sedimentary rocks. The popularity of UAVs in this aplication is increasing due to its ability to capture high quality data over vertical rock and ground surfaces (especially in inaccessible locations) to produce 3D models of stratigraphic layers. UAV users are mainly interested in vertical surfaces over small areas. Multi-rotor UAVs have the advantage that they can hover against vertical surfaces and capture features to a high degree of accuracy and resolution. These surfaces are often captured at a resolution of 5cm/pixel with a horizontal accuracy of 10cm and vertical accuracy up to 10cm.

Users indicated that RGB cameras are sufficient for this application. However, for achieving a more accurate 3D model, LiDAR may be used in conjunction with these sensors.

The key deliverable is a high-resolution 3D model of cliffs and stratigraphic layers on rocks and cliffs. Imagery and point clouds are additional products users require.

RESOLUTION

≤ 5cm

SENSORS

RGB OR RGB+LiDAR

FEATURES OF INTEREST

CLIFFS AND ROCK FEATURES

PRODUCTS

IMAGERY, POINT CLOUD, 3D MODEL

MAPPING VEGETATION ALONG ROADS

UAVs have provided significant advantages for surveying vegetation along roads, especially on highways where there are safety concerns. Furthermore, UAVs avoid potential traffic disruptions. Users are most interested in the ground surface, vegetation, tree heights, canopy extent and the road assets. In some responses, powerlines and light posts were also of interest.

The sensors of preference for users are RGB cameras and LiDAR. They required data at a high resolution of 3cm/pixel and with an accuracy of less than 5cm in both horizontal and vertical. The deliverables in this application included classified point clouds, imagery, DEM/DSM and Canopy Height Model (CHM).

RESOLUTION

< 3cm

SENSORS

RGB, LiDAR

FEATURES OF INTEREST

GROUND SURFACEM VEGETATION, TREE CANOPY, ROAD FEATURES

PRODUCTS

IMAGERY, CHM, ROAD LINEAR MEASUREMENTS

SURVEYING COMPLEX FACILITIES AND INFRASTRUCTURE

UAVs equipped with LiDAR and RGB sensors can collect 3D images to create highly accurate, 3D models of complex infrastructure. UAVs are used to capture asset condition and to identify areas in need of repair. This data can be collected without the need for disrupting the operations in busy environments such as oil and gas, and manufacturing.

Features of interest in this application include pipelines, overpasses, buildings, roads, towers and cranes. Users typically require a high-resolution survey at 1cm/pixel with horizontal and vertical accuracy requirements under 5cm. In addition to LiDAR and RGB sensors, IR sensors can also be used to identify faults in equipment and utilities. Facilities can be continuously monitored and accordingly, the data collection may be as frequent as daily or weekly for specific areas. Users often completed a survey of the whole facility every month or quarterly. The key deliverables include 3D models, point clouds, imagery and heat maps.

RESOLUTION

≤ 1cm

SENSORS

RGB, LiDAR, IR

FEATURES OF INTEREST

PIPELINES, OVERPASSES, BUIDINGS, ROADS, TOWERS, CRANES, VEGETATION

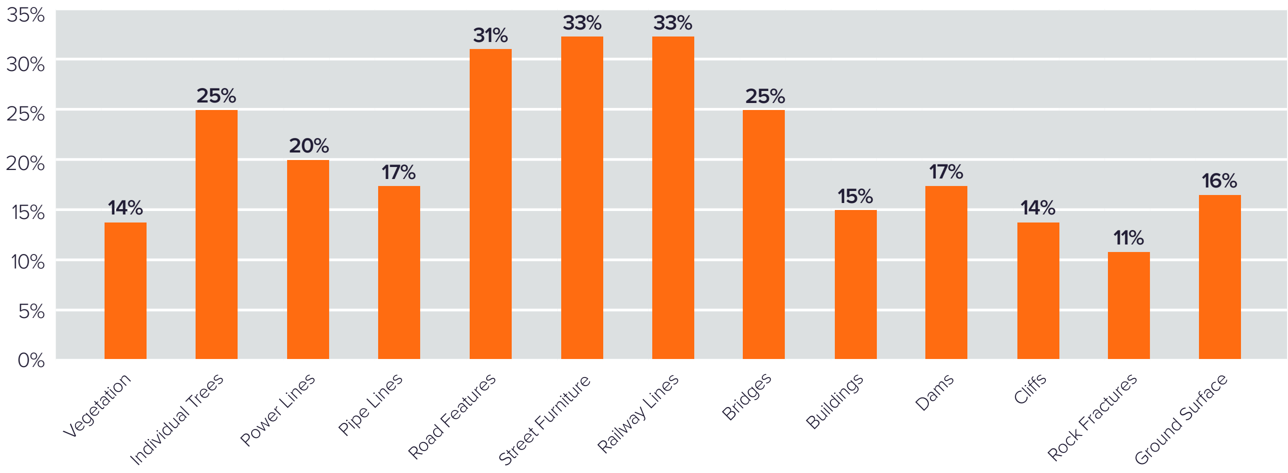
PRODUCTS

3D MODELS, POINT CLOUD, IMAGERY, HEATMAPS, VEGETATION MAP

SURVEY SUMMARY

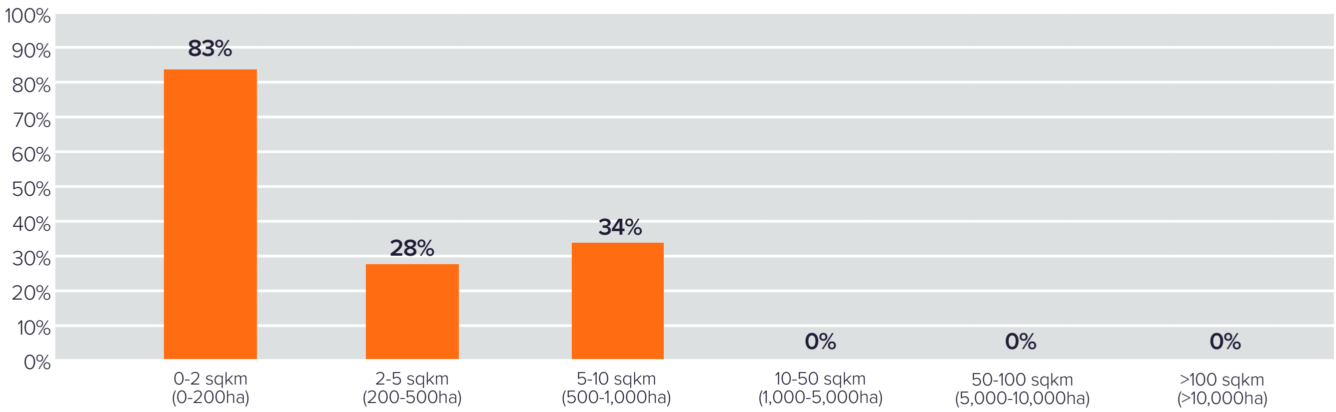
Features of Interest

Survey applications overlap with various industries, and as such have varied features of interest, including roads, railways, trees, vegetation, powerlines, dam walls and street furniture.



Project Acquisition Area Size

The project size in survey applications are usually 2km² or less. Of users, 28 per cent indicated larger areas of 5km², or even as large as 10km² for road surveys. Users required multi-rotors to map geological features and industrial facilities.



For larger application areas like road surveying or island mapping, fixed wings UAVs are more suitable.

Accuracy and Resolution

The identified "survey" applications were diverse, and hence their resolution and accuracy requirements. Most survey participants indicated high resolutions of up to 3cm or 5cm is ideal. Some respondents mentioned the acceptable resolution for the same applications can be down to 10cm. However, for sensitive applications such as surveying complex facilities and infrastructure, the resolution should not be any lower than 1cm/pixel.

Nearly all participants required a horizontal accuracy of up to 10cm for survey applications. The majority of the responses indicated this value should be higher than 5cm. This was particularly the case with surveying complex facilities where assets and pipes may be in close vicinity (i.e. centimetres) of each other.

Commonly Used File Formats

The most commonly used file formats for the captured UAV data and its products for surveying applications are summarised in the following table. Each row of the table is ordered from most to least common formats for the product.

PRODUCT	COMMON FILE FORMATS
Flight plan	KML, CSV, SHP, XML
Imagery mosaic	TIFF, ECW, JPG
Imagery tile	TIFF, JPG, ECW
Raw Imagery	JPG, TIFF
Ground Control Points	CSV, DGN, DWG, DXF, SHP, XML, XYZ
Digital Elevation Model (DEM)	TIFF, LAS
Digital Surface Model (DSM)	TIFF, LAS
Point Cloud	LAS, LAZ, TAB, XYZ
3D Models	OBJ, PLY, LAS
Tile Index	SHP
Flight Trajectory	KML, XML
Contours	DGN, DWG, DXF, SHP
Metadata	PDF, XML, JPG
Project Report	PDF, KML

CONSTRUCTION
SUPPLEMENT 7

UAVs can be used to inspect the construction of large structures to improve communications and safety. They can also reach inaccessible locations. Some companies have been using UAVs to enhance safety at construction sites, as they have real-time data on safety violations. Applications of UAVs for construction include:

- Site topography mapping
- Construction monitoring (e.g. level crossing)
- Estimating the volume of excavation work,
- Roof inspection during post-construction phase
- Road construction
- Monitoring safety violations
- Marketing tools for real estate agents during final stages of construction

UAVs can scan job sites from the air and send images to computers to build three-dimensional models of different stages in construction.

This section summarises the main applications of UAVs in construction and the user requirements to make the data fit-for-purpose.

ESTIMATING THE VOLUME OF EXCAVATION WORK

Monitoring excavations are important for accurate planning and monitoring, and auditing. UAVs can fly frequently and on-demand to provide imagery, elevation models, and difference maps that can be used to estimate excavation progress.

The key features of interest include the ground surface and excavation volumes. Users indicated that they need high quality data at about 5cm/pixel resolution and maximum of 10cm horizontal and vertical accuracy. Accurate volume estimates feed into payments to subcontractors for processing and transferring excavated materials. The data is usually collected using RGB cameras and converted to a surface model using photogrammetric techniques.

Deliverables include imagery, DEM/DSM, difference maps, and/or excavation volumes in shapefile/TAB formats with polygons and attributes indicating the volume.

RESOLUTION

≤ 5cm

SENSORS

RGB

FEATURES OF INTEREST

GROUND SURFACE, EXCAVATION VOLUMES

PRODUCTS

IMAGERY, DEM, EXCAVATION VOLUME SHAPEFILES

ROAD CONSTRUCTION

In road construction, mistakenly adding a quarter-inch of extra material over 15 kilometres can raise the final bill by more than $250,000. To avoid such errors managers are increasingly seeking to improve the overall precision and accuracy of monitoring construction projects. UAVs equipped with RGB cameras or LiDAR sensors and operating using RTK GPS can help achieve higher accuracies in road construction projects.

The features of interests include vegetation, drainage, topography, and road infrastructure. The data is collected using RGB cameras and LiDAR, at resolutions of 3cm or higher and over areas spanning up to 5km^2. The vertical and horizontal accuracy is extremely important. The maximum acceptable accuracy should be sub centimetre level. This application may require the UAV to fly lower than usual to achieve the requirements. The main deliverables include imagery, 3D models, point clouds, vegetation maps and DEMs.

RESOLUTION

≤ 3cm

SENSORS

RGB, LiDAR

FEATURES OF INTEREST

VEGETAION, DRAINAGE, TOPOGRAPHY, ROAD FEATURES, HERITAGE AREAS AND WILDLIFE HABITATS

PRODUCTS

IMAGERY, 3D MODELS, POINT CLOUD, VEGETATION MAPS, DEM/DSM

SITE TOPOGRAPHIC MAPPING

Topographic maps are often used to calculate metrics such as slope, cost estimates, cut and fill and material volumes. UAVs fill a gap between high accuracy, time intensive total stations and laser scanners, and traditional aerial mapping services.

Users are interested in high resolution data defining the ground elevation, roads and channels at a minimum resolution of 20cm/pixel. The main sensors used for topographic mapping are RGB or LiDAR. Usually LiDAR or photogrammetric point clouds are created and then contours are extracted from these products. The minimum requirement for horizontal and vertical accuracy is 20cm and 3cm. Users highlighted that the resolution can vary depending upon steepness/flatness.

The main deliverables include orthometric images, point clouds, DEM/DSM, and contours.

RESOLUTION
≤ 20cm

SENSORS
RGB, LiDAR

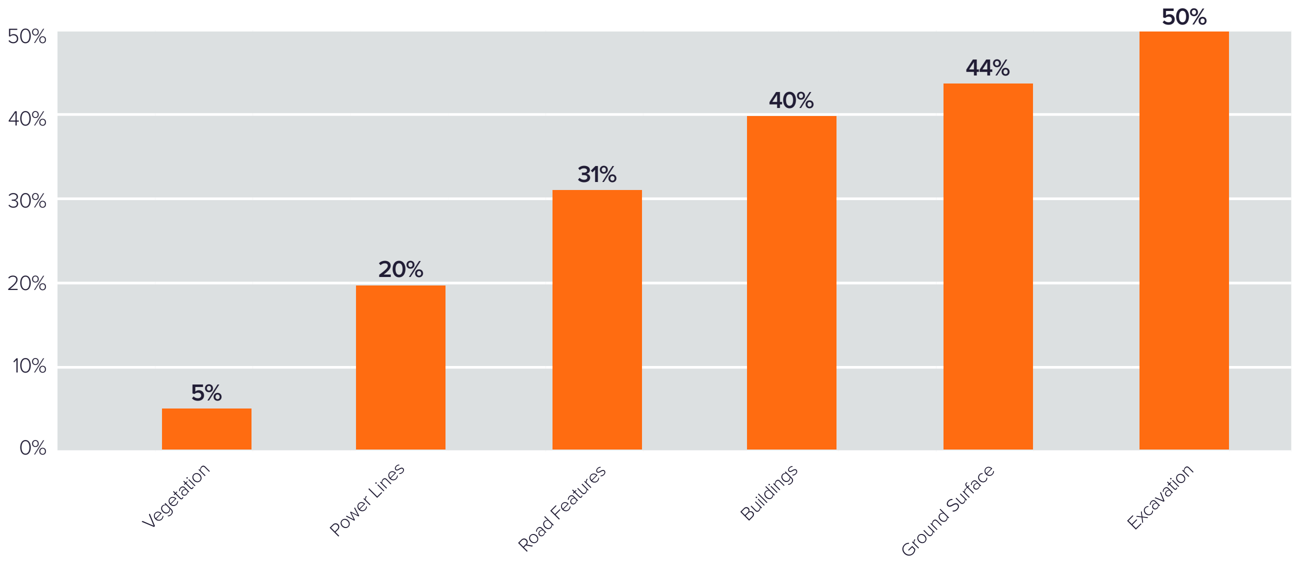
FEATURES OF INTEREST
GROUND SURFACE, ROADS, HYDRO FEATURES LIKE CHANNELS

PRODUCTS
IMAGERY, ORTHOMETRIC DEM, DSM, POINT CLOUD, CONTOURS

CONSTRUCTION SUMMARY

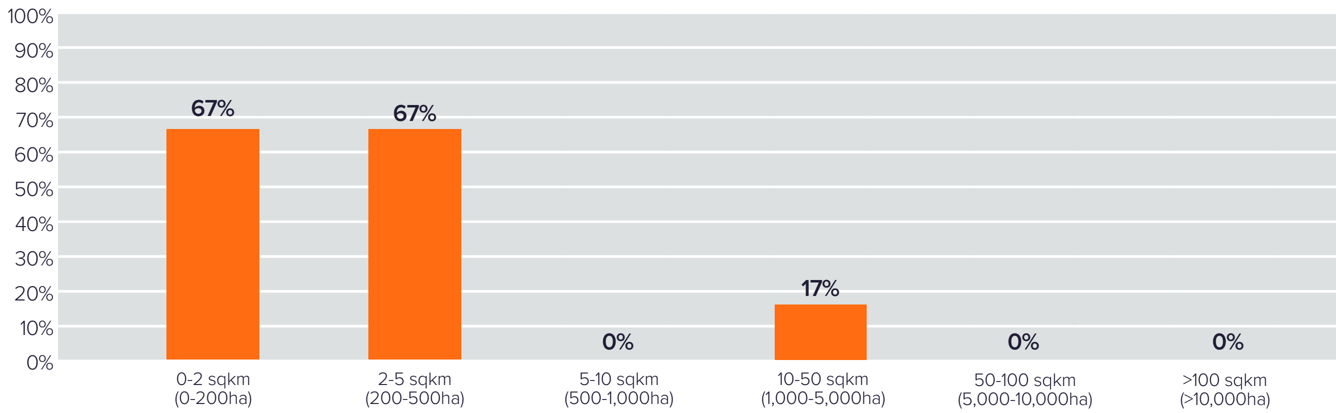
Features of Interest

The most common features of interest in construction are excavations (50 per cent), ground surfaces (44 per cent), buildings (40 per cent) and roads (31 per cent).



Project Acquisition Area Size

The project size in most of construction applications are 5km^2 or less. A few responses (17 per cent) indicated areas of up to 50km^2 which mainly focusses on large-scale projects such as shopping centres or airports.



Accuracy and Resolution

The image resolution requirements for applications in construction may vary; but expectedly, most of them need a high-resolution imagery at 3-5cm/pixel. Applications such as site topographic mapping, especially in flat areas, can be an exception and may require lower spatial resolution at 20cm/pixel (or as low as 50cm/pixel). All participants indicated a horizontal accuracy of up to 10cm. In some cases, a horizontal accuracy down to 20cm was also acceptable. They also indicated very high vertical accuracy (typically 1-3cm) requirements for their applications. This level of accuracy is expected for construction applications where detailed designs and plans are produced according to the captured data.

Commonly Used File Formats

The most commonly used file formats for the captured UAV data and its products for mining applications are summarised in the following table. Each row of the table is ordered from most to least common formats for the product.

PRODUCT	COMMON FILE FORMATS
Flight plan	DWG, KML, PDF, XYZ
Imagery mosaic	TIFF, JPG
Imagery tile	TIFF
Raw Imagery	JPG, TIFF
Ground Control Points	CSV, SHP
Digital Elevation Model (DEM)	TAB, TIFF, Raster in Geodatabase
Digital Surface Model (DSM)	TAB, TIFF, Raster in Geodatabase
Point Cloud	LAS, TAB
3D Models	OBJ, PLY, LAS, e57
Tile Index	SHP, TAB
Flight Trajectory	KML, TAB, SHP
Contours	DXF, SHP, TAB
Metadata	TAB, SHP, XML
Project Report	PDF

INFRASTRUCTURE
SUPPLEMENT 8

Infrastructure can be large, complex, and often remote. It is now becoming faster, safer and cheaper to use UAVs for infrastructure inspections rather than conventional means. They are an ideal alternative for working at heights, and accessing hazardous or restricted areas (e.g. wind turbines, mines, and pipelines). A great advantage of UAV technology is that they can be used whilst the infrastructure is still in operation.

UAVs can be used for inspecting features such as roads, bridges, cell towers, wind turbines, off-shore platforms, power lines etc. High resolution images or 3D models can be captured as a permanent record of the asset. This section summarises these applications and their user requirements to make the data fit-for-purpose.

ASSET MANAGEMENT – ROADS

Maintaining road conditions according to the standards improves travel experience and increases safety. Local governments and parks authorities continuously survey road conditions to ensure they meet requirements. The key features of interest include road characteristics such as width, surface type and condition. Additional interests are subsidence, blockages, cracks and vegetation overhang.

This application usually requires a time series to monitor condition using RGB cameras or LiDAR at a resolution sufficient to capture cracks. Users required resolutions of 3cm/pixel across project areas as large as 10km^2. Furthermore, users indicated a need for high accuracy positioning. The vertical accuracy of data should be sufficiently high that elevation changes of 100mm are detectable.

The deliverables for UAV data acquisition include time series imagery, canopy height models and shapefiles for delivery of road features, including crack locations.

RESOLUTION

≤ 3cm

SENSORS

RGB, LiDAR

FEATURES OF INTEREST

ROAD WIDTH, SURFACE TYPE AND CONDITION, ROAD SUBSIDE, PAVEMENT CRACKS, TREE CANOPY ON THE SIDE OF ROADS

PRODUCTS

IMAGERY, CHM, ROAD LINEAR MEASUREMENTS

RADIO COMMUNICATION TOWER INSPECTION

Communication towers are routinely inspected for potential faults and maintenance. Inspections are now being regularly performed by UAVs. The frequency of inspections vary depending on the type and location of towers. Towers also tend to be inspected after severe winds or storms. According to industry best practices, more frequent inspections should be performed for structures in coastal environment with salt water and corrosive atmospheres. It is also the case for areas subjected to frequent vandalism.

Tall towers are difficult, costly and risky for people to climb for inspections. For this reason, UAVs are becoming popular as a faster and safer alternative. The key features of interest include asset damage, RF feeders and antenna condition. While spatial accuracy is not necessarily relevant to this inspection application, the spatial resolution must be at least 1cm/pixel for users to detect faults, rust, and other issues. The main deliverables of the inspection are the detailed photographs (or videos) of the communication tower.

RESOLUTION

≤ 1cm

SENSORS

RGB

FEATURES OF INTEREST

ASSET DAMAGE, RF FEEDERS AND ANTENNA CONDITION

PRODUCTS

PHOTOGRAPHS

CONDITION ASSESSMENT OF STRUCTURES

To ensure the integrity of structures like dams or seawalls, their conditions are continuously monitored for faults or instability. For example, dam wall cracks (length and sometimes depth of crack) can grow very quickly if not treated, potentially leading to catastrophic failure.

The key features for condition assessment include the ground elevation, visible asset damage or instability and changes in crack size and length. Users prefer RGB sensors to survey structures at a minimum of 20cm/pixel. This is reduced if crack detection is required.

The deliverables include imagery, point clouds, 3D models, DEM, and reports of location and classification of conditions and faults. Georeferencing and geotagging of images attached to asset ID are also a requirement.

RESOLUTION
≤ 20cm

SENSORS
RGB, LiDAR

FEATURES OF INTEREST
GROUND SURFACE, ASSET DAMAGE, COASTLINE, ROCK FEATURES.

PRODUCTS
IMAGERY, DEM/DSM, DAMAGE REPORTS, 3D MODEL

ROOF INSPECTION

UAVs enable the safe and efficient delivery of digital photography and close-up video of rooves. UAVs capture images of gutters, drains, down pipes and vents for water drainage. Other features include skylights, lead flashing, windows and solar panels. Over time, solar panels may develop defects, which can easily be fixed if detected early. Thermal detection helps to identify these problems.

RGB and thermal (IR) sensors are used with resolutions of 2cm/pixel and horizontal accuracy of ±50cm. The vertical accuracy is less relevant to this application. The deliverables include imagery, videos and thermal images.

RESOLUTION
≤ 2cm

SENSORS
RGB, IR (THERMAL)

FEATURES OF INTEREST
BUILDING ENVELOPE, ROOFING AND ROOF FEATURES LIKE GUTTERS

PRODUCTS
IMAGERY, VIDEOS, THERMAL IMAGES

WIND TURBINE INSPECTION

Inspecting the condition of wind turbines is critical to maintaining the quality of fabrication, maintenance and performance. UAV inspections can cover up to 10 or 12 turbines daily, reviewing each blade from between four to nine minutes. This compares to a manual inspection rate of two to five turbines a day.

The key features of interest in inspecting wind turbines is their condition including structural issues (cracking, deformation, corrosion, etc), hydraulic issues (leaks, weakness, incursion/impacts), and mechanical issues (generator equipment).

The sensors used for inspection include RGB cameras and thermal (IR) sensors. Accessibility for landing and take-off can provide challenges. Deliverables include imagery and thermal imagery. Videos were also mentioned by participants as useful additional records.

RESOLUTION
≤ 2cm

SENSORS
RGB, IR

FEATURES OF INTEREST
LOCATION OF TURBINES AND STRUCTURAL, HYDRAULIC, AND MECHANICAL ISSUES

PRODUCTS
IMAGERY, VIDEOS, THERMAL IMAGES

POWERLINE INSPECTION

While it is risky and difficult for people to access and inspect power lines at height, UAVs provide a more flexible and relatively cheap solution. Inspections usually look for damage to poles and cables, including deterioration to timber components, and rust or corrosion to metal components.

The key features of interest in power line inspection include power poles, locations of the assets, loose equipment, rust and vegetation encroachment. The type of sensors used include RGB and LiDAR for generating point clouds for inspection.

Time series data (e.g. every 4 years) is required to monitor change in the conditions of power infrastructure over time. Participants typically required images at 3cm/pixel or higher, and with horizontal and vertical accuracy levels of ±10cm.

The data capture along the powerline can be between 500m to 20km in length. Users indicated that UAVs maintain a 5m stand-off distance from the powerlines. This is to ensure safety of the UAV and to avoid collisions. The deliverables include imagery, videos, point clouds and Canopy Height Models (CHM).

RESOLUTION

≤ 3cm

SENSORS

RGB, LiDAR

FEATURES OF INTEREST

POWER POLES, POWER-LINES, LOCATION OF ASSET, ACCESS WAYS, LOOSE EQUIPMENT, RUST AND CORROSION ON ASSET.

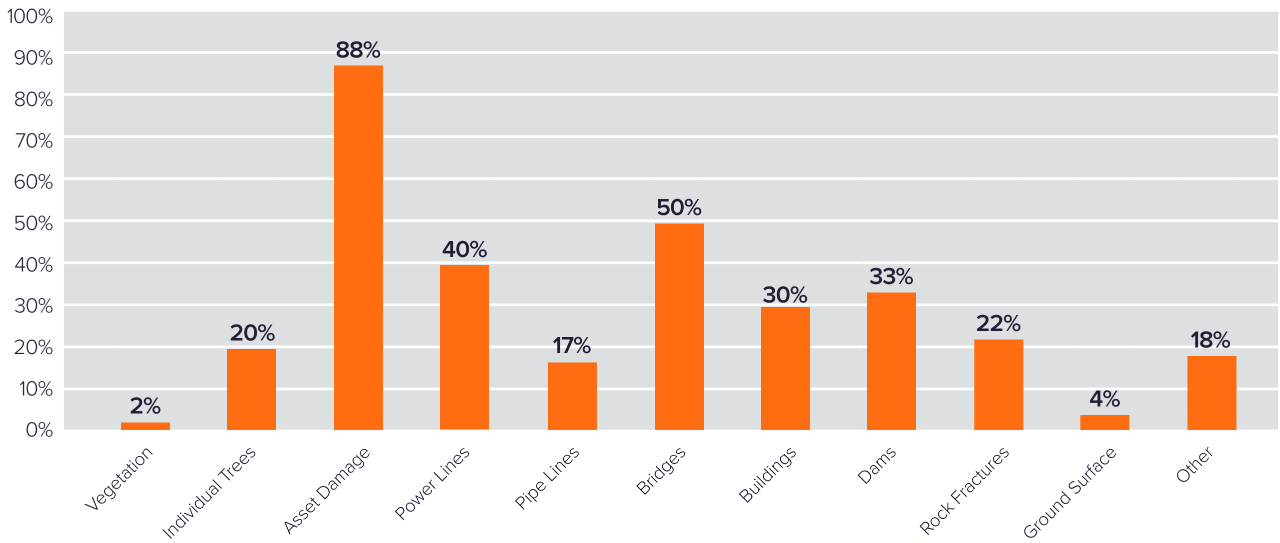
PRODUCTS

IMAGERY, VIDEOS, CHM, POINT CLOUD

INFRASTRUCTURE SUMMARY

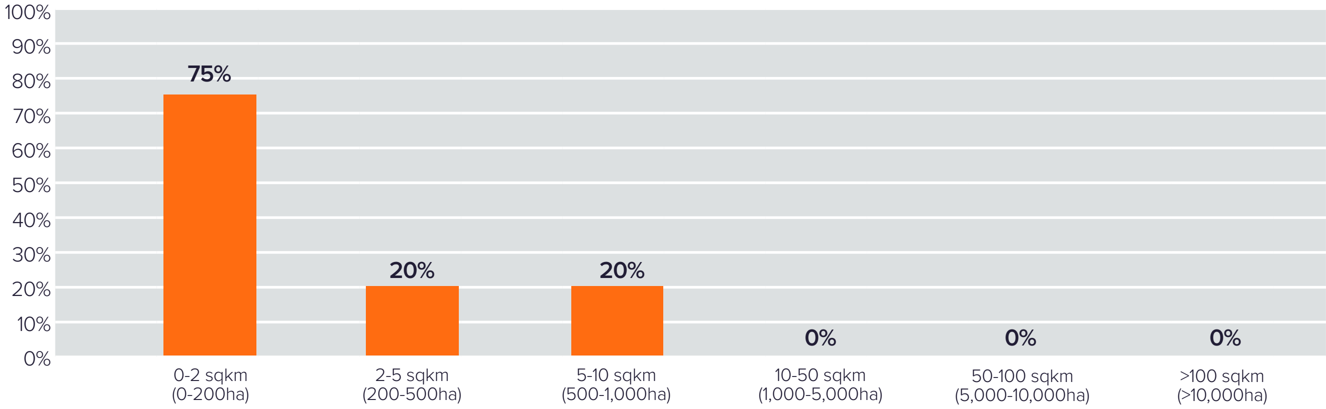
Features of Interest

The most common feature of interest in the infrastructure category is asset damage. In fact, 20 per cent of participants indicated trees pose a significant threat to powerlines. The other features of interests include buildings, bridges, dams and trees.



Project Acquisition Area Size

Of the users surveyed three quarters (75 per cent) indicated that the size of the area for their project is less than $2km^2$. A few mentioned larger areas up to $10km^2$ were mostly related to roads and powerline inspection.



Accuracy and Resolution

The image resolution requirements for infrastructure related applications may vary. Of the participants 70 per cent indicated a resolution of 3cm/pixel or higher is ideal. For some applications such as the condition assessment of assets, lower resolutions of up to 20cm would still be acceptable.

Most participants require relatively high horizontal accuracy between 10-20cm. For some infrastructure applications such as roof inspection, the emphasis was more on the resolution than accuracy. The horizontal accuracy of these applications can be as low as 50cm.

The majority of these applications were not sensitive to vertical errors. They were mostly related to asset inspection and management where the deliverables are either high resolution imagery or videos.

Commonly Used File Formats

The most commonly used file formats for the captured UAV data and its products for mining applications are summarised in the following table. Each row of the table is ordered from most to least common formats for the product.

PRODUCT	COMMON FILE FORMATS
Flight plan	KML, XYZ, CSV, DWG, DXF, VIDEO (MPG)
Imagery mosaic	TIFF, ECW, ESRI ASCII
Imagery tile	TIFF,
Raw Imagery	JPG
Ground Control Points	CSV
Digital Elevation Model (DEM)	TIFF, XYZ
Digital Surface Model (DSM)	TIFF, XYZ
Point Cloud	LAS, DXF
3D Models	KML, XML
Tile Index	SHP
Flight Trajectory	KML
Contours	DWG, DXF, PDF
Metadata	PDF, Word
Project Report	PDF

FORESTRY
SUPPLEMENT 9

Remotely sensed data is already widely used within forestry applications. This information has traditionally been sourced from satellite and airborne sensors, however UAVs are emerging as a popular alternative for data collection. The current uses of UAVs within forestry include:

- Plantation forestry
- Inventory management
- Tree height mapping
- Tree survival counts
- Identification and mapping of cutover areas
- Mapping of wind damage
- Plantation health and disease
- Communication of forest change
- Post-planting stocking and survival
- Weed mapping and classifying species
- Analysis of regeneration
- Monitoring fire and its impact
- Quantifying gaps
- Post-harvest waste assessment and soil displacement estimation

Four band cameras, multispectral and hyperspectral sensors are now being used by UAVs within forestry. The spectral information in combination with 3D structural data enables the monitoring of mixed tree plantations, weed mapping and tree health. This section summarises the main applications of UAVs in forestry and the user requirements to make the data fit-for-purpose.

IDENTIFYING TREE SPECIES

Tree species identification is a complex and time-consuming part of forest management. Understanding tree species across forests enables informed decisions for effective planning and coordination of conservation efforts.

Trees and their characteristics are the key features of interest. Although RGB sensors can be used to visually differentiate species, the main instruments for this purpose are multispectral sensors. The spatial resolution for this application is typically 50cm/pixel over areas up to 100km^2. Users indicated that this resolution may not be enough to identify tree species for some trees and a higher resolution may be required.

The minimum horizontal accuracy for this application is 50cm or higher. The deliverables for this application include tree species maps or vectors with trees attributes.

RESOLUTION
≤ 50cm

SENSORS
MULTISPECTRAL

FEATURES OF INTEREST
TREES

PRODUCTS
TREE SPECIES MAP, POINTS WITH TYPES AS ATTRIBUTES

CANOPY COVER

Measuring forest canopy cover is crucial for inventory management. Low altitude imagery from UAVs can be employed to characterise forest ecosystems at a high spatial and temporal resolution. With rich information from UAVs, 3D models of forests and their changes in structure can be detected. Users are also using UAVs to fly under the dense canopy of tall trees for additional data.

The features of interests are ground surface, undergrowth, tree canopies and heights. The main sensors are RGB cameras and LiDAR. LiDAR can penetrate through branches and canopies to give information about undergrowth. This application requires high resolution data at 3cm/pixel or higher over interest areas of up to 2km^2. Users indicated that the absolute vertical and horizontal accuracy should not exceed ±10cm.

The main deliverables include CHMs. In some cases, imagery can complement a CHM to produce a photo realistic 3D model of the forest.

RESOLUTION
≤ 3cm

SENSORS
RGB, LiDAR

FEATURES OF INTEREST
GROUND SURFACE, CANOPY STRUCTURE AND HEIGHT

PRODUCTS
CANOPY HEIGHT MODEL, IMAGERY

FORESTRY PLOT MONITORING

Plot monitoring is a process that captures data about vegetation and trees structure. Although in many ways it is similar to canopy cover identification, it looks further into the function and composition of trees and vegetation in the forest.

The features of interest include tree canopy species and their structure including height and density of trees and undergrowth (approximate height and distance apart). RGB and LiDAR are common sensors for this application especially for the structure, size, height of vegetation. However, users indicated that if the type, function and health of vegetation are of interest, then a multispectral sensor should be used.

Plot monitoring requires high resolution data captured at 15cm/pixel over a typical area of interest of up to 10km². The deliverables may include imagery, CHM, point cloud, NDVI and vegetation species map.

RESOLUTION

≤ 15cm

SENSORS

MULTISPECTRAL, RGB, LiDAR

FEATURES OF INTEREST

GROUND SURFACE, CANOPY STRUCTURE AND HEIGHT

PRODUCTS

CANOPY HEIGHT MODEL, IMAGERY, POINT CLOUD, VEGETATION SPECIES AND HEALTH MAP

MONITORING VEGETATION HEALTH

Vegetation and tree health monitoring is critical for forest ecosystem health and sustainability. In recent years, UAVs have become popular due to their ability to capture high resolution data using a variety of sensors.

The features of interests include trees, vegetation and their spectral reflectance for assessing health/condition. The resolution required, depends on the requirements of the user, and may vary from 2 to 10cm/pixel. Users indicated an acceptable horizontal and vertical accuracy of ±7cm and ±15cm respectively.

Sensors may include a combination of NIR+RGB or multi/hyperspectral sensors. Data collection for vegetation health monitoring can be regular or on ad-hoc basis following events such as bushfires or droughts. Some users indicated quarterly data collection is enough, whilst a few suggested a more frequent basis. The key deliverable for this application are NDVI maps. Interestingly, some of the health problems can be identified through georeferenced imagery. Hence, imagery is requested in some projects.

RESOLUTION

≤ 2-10cm (RECOMMENDED: 5-7CM/PIXEL)

SENSORS

NIR + RGB OR MULTI/HYPER SPECTRAL

FEATURES OF INTEREST

VEGETATION, TREES

PRODUCTS

OBLIQUE IMAGERY, NDVI MAP

QUANTIFYING POST-HARVEST COARSE WOODY DEBRIS

Quantifying post-harvest Coarse Woody Debris (CWD) enables forest managers to audit estimates between pre-harvest yields, measured post-harvest yields and the potential yield left after harvesting. Satellite imagery with resolutions of 4m result in poor CWD estimations; whereas higher resolution aerial photography using UAVs produce much better results.

The features of interest include woody debris and stumps on the ground. These features can be identified by RGB sensors. Users indicated projects sizes vary from as small as 5ha to as large as 500ha. The acceptable horizontal accuracy of this data can be ±1m. This is because the volume of debris is much more important than the exact location and elevation of features.

This data is generally collected after harvest. The main products include the volume of debris on the ground, and a raster representing their spatial distribution.

RESOLUTION

≤ 1cm

SENSORS

RGB

FEATURES OF INTEREST

WOODY DEBRIS, STUMPS

PRODUCTS

RASTER REPRESENTING STUMPS/WOODY DEBRIS, VOLUME OF DEBRIS

IDENTIFYING THE PRESENCE OF INVASIVE WEEDS

Native plants in one geographic area can become an environmental or agricultural problem in another. Identifying, treating, and containing the spread of invasive species protects the local native species. This is an important application in forestry and agriculture. High resolution data from UAVs can identify specific weeds in large areas.

The features of interest include specific invasive weeds. Projects can be as large as 2km². Users highlighted a fine spatial resolution of 2cm/pixel as a requirement. The upper bound of vertical accuracy is ±8-10cm.

Data acquisition frequency depends on the specific weed of interest and its lifecycle. The weed monitoring uses multispectral sensors. The deliverables for this application include maps of weed species and georeferenced imagery.

RESOLUTION
≤ 2cm

SENSORS
MULTISPECTRAL

FEATURES OF INTEREST
INVASIVE WEEDS/PLANTS

PRODUCTS
IMAGERY, RASTER REPRESENTING DIFFERENT WEEDS AND PLANT TYPES

POST-PLANTATION SURVIVAL ASSESSMENT

Forest managers are interested in the mortality and survival rates of trees following their planting. High mortality is an impediment to successful tree-planting programs. The key features of interest from UAV surveys include trees and seed leaves.

This application requires resolutions of 1-2cm/pixel or higher which enables forest managers to identify each tree or the seed leaves. The typical project area size can be as large as 2km².

The data collection is time sensitive and is typically performed once and soon after the plantation was completed. RGB cameras are usually used for this application. However, users indicated they alone may not be able to fulfill the requirements and multispectral sensors may be used instead.

The key deliverables for this application include imagery, orthomosaics and photogrammetric point cloud.

RESOLUTION
≤ 2cm

SENSORS
RGB, MULTISPECTRAL

FEATURES OF INTEREST
TREES, SEED LEAVES

PRODUCTS
IMAGERY, ORTHOMOSAICS, POINT CLOUD

POST-THINNING ASSESSMENT

“Thinning” is a process in forestry management where trees are selectively removed to improve the growth and health of the others. Forest managers are interested to know how many trees are left following the thinning process and where their locations are. Users indicated that currently in most cases, trees are not marked for thinning and they are selected on the spot and during the operation. Accordingly, it may not be uniform across the area of interest.

The key features of interest include stocking, tree height and their spacing. Usually RGB sensors are used in this application to capture data about an areas size of up to 100ha. The effective spatial resolution for this application is between 8 and 12cm/pixel at an approximate flight height of 200m above the ground. Good quality data with not many artefacts enable automated tree detection.

The horizontal and vertical accuracy is 10cm. The data collection is time sensitive and the data is usually collected soon after the thinning process. The temporal resolution of the data collection is approximately 3 times in 15 years or once per thinning event.

The key deliverables for this application include imagery and photogrammetric point clouds. One of the main challenges in this application is to differentiate the DTM and darker under canopy from the trees to extract these features.

RESOLUTION
8-12cm

SENSORS
RGB

FEATURES OF INTEREST
STOCKING, TREE HEIGHT, TREE SPACING

PRODUCTS
IMAGERY, POINT CLOUD

DISEASE DETECTION AND MAPPING

UAVs provide new tools and high-resolution data for improved forest health monitoring. For example, UAV data is used to detect and map diseases in red needle cast trees in New Zealand. When the disease attacks the tree, it causes the needles to discolour from green to light brown. Users indicated onboard RGB cameras can be employed to detect these coloured needles and the disease extent can be mapped across the forest.

The main feature of interest are the needles and disease affected trees. Users indicated the required resolution for this application is 5-7cm/pixel. They highlighted that UAVs are typically employed to map 20ha at a time; however, their coverage can be extended to up to 2km^2.

The key sensor used for this purpose is the RGB. NIR or IR are good complements for RGB for early detection of diseases. The vertical accuracy of the data is not a concern for the users. They, however, require a sub-metre horizontal accuracy that enables them to identify affected trees. The data is collected once a year and near October when the needles are still on trees. The key deliverables include orthomosaics and in some cases, photogrammetric point cloud.

RESOLUTION

≤ 5-7cm

SENSORS

RGB, IR/NIR

FEATURES OF INTEREST

NEEDLES ON TREES AND DISEASE EFFECTS

PRODUCTS

ORTHOMOSAICS, POINT CLOUD

STAND BOUNDARY MAPPING

A forest stand is “a contiguous community of trees sufficiently uniform in composition, structure, age and size class distribution, spatial arrangement, site quality, condition, or location to distinguish it from adjacent communities”[15]. A forest is basically a *“collection of stands”*. UAVs are now replacing older methods such as satellite imagery or field observation and are employed to identify and map stand boundaries or update them following harvesting, re-planting, or similar activities. These boundaries can be used to estimate the net stocked area of stands.

Although LiDAR and multispectral sensors were mentioned in discussions, users usually use RGB sensors to collect data for this application. This is due to the lower cost of this sensor over LiDAR or multispectral.

The area of interest for this application typically varies between 10 and 100+ hectares. Users indicated that their resolution requirement is 1m/pixel or higher. They further highlighted that high accuracy data is not required for this application and a consumer GPS accuracy (typically <10m) would be sufficient. Typical deliverables in this application include the RGB orthomosaics.

RESOLUTION

≤ 2cm

SENSORS

MULTISPECTRAL

FEATURES OF INTEREST

INVASIVE WEEDS/PLANTS

PRODUCTS

IMAGERY, RASTER REPRESENTING DIFFERENT WEEDS AND PLANT TYPES

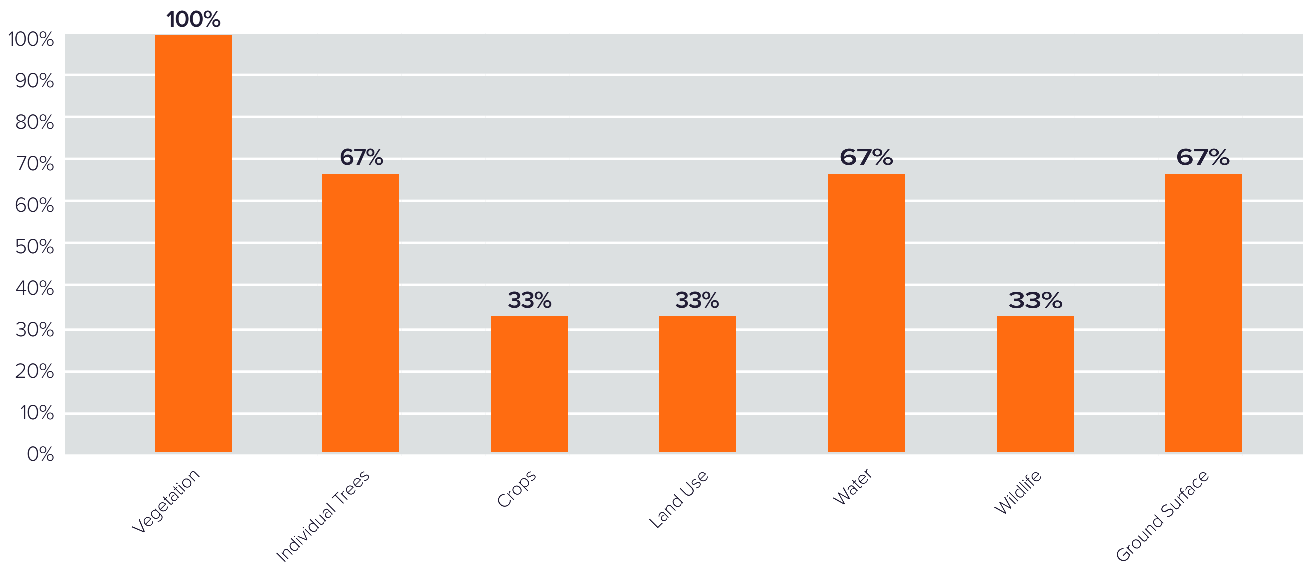
[15] https://en.wikipedia.org/wiki/Stand_level_modelling

FORESTRY SUMMARY

Features of Interest

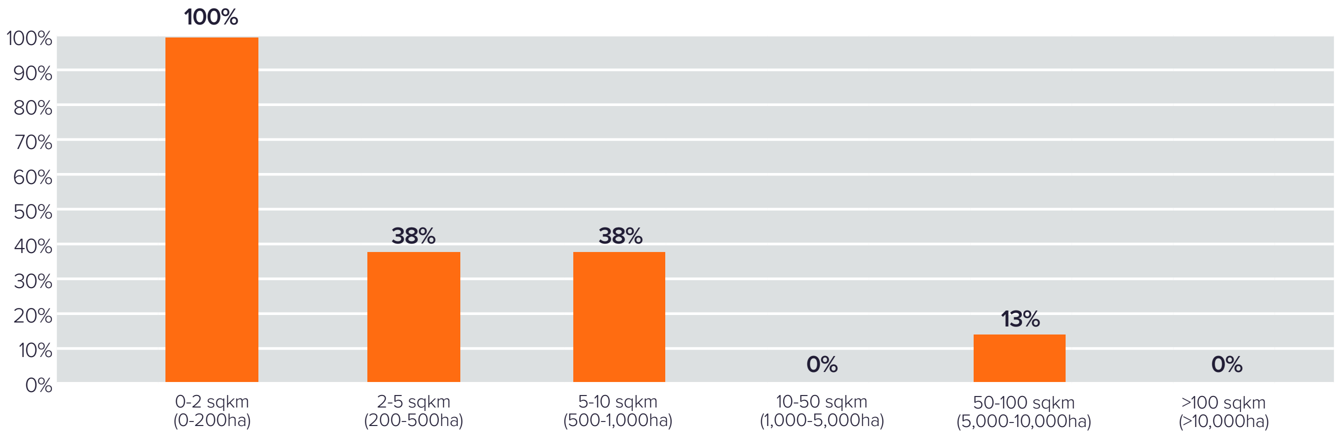
As expected, the key features of interest in forestry applications include vegetation and trees. Ground surface was also high on participants priorities, with 67 per cent indicating it as important.

The other features of interest include canopy structure and height, wood debris and stumps, and invasive species of weeds and plants.



Project Acquisition Area Size

The project size for forestry applications is usually less than 2km^2, although 38 per cent of participants indicated that they have had projects with areas between 2km^2 and 5km^2 and sometimes as large as 10km^2.



Accuracy and Resolution

The required image resolution in forestry may vary from one application to another. Of the survey participants, 88 per cent indicated high resolutions of up to 3cm and nearly 50 per cent require image resolutions of between 4 and 10cm/pixel. A small portion of responses (13 per cent) indicated spatial resolutions as low as 1m/pixel. These responses were related to applications such as stand boundary mapping with low resolution and accuracy requirements.

The analysis of forestry applications makes a distinction between two main groups with different horizontal accuracy requirements. One (including applications such as monitoring vegetation health and canopy cover mapping) requires high accuracy between 2cm and 10cm, and the other (including stand boundary mapping or post-harvest debris quantification) are less sensitive to accuracy with requirements ranging from 100cm to 10m.

Vertical accuracy requirements on the other hand are more consistent in most forestry applications ranging between 8cm and 15cm.

Commonly Used File Formats

The most commonly used file formats for the captured UAV data and its products for forestry applications are summarised in the following table. Each row of the table is ordered from most to least common formats for the product.

PRODUCT	COMMON FILE FORMATS
Flight plan	KML, SHP
Imagery mosaic	ECW, TIFF
Imagery tile	ESRI GRID, JPG, TIFF
Raw Imagery	JPG, TIFF,
Ground Control Points	CSV, XYZ, SHP
Digital Elevation Model (DEM)	TIFF, LAS
Digital Surface Model (DSM)	TIFF, LAS
Point Cloud	LAS, XYZ, DXF
3D Models	OBJ, PLY
Tile Index	NOT SPECIFIED
Flight Trajectory	CSV, KML, SHP, XML
Contours	SHP, DGN, DXF
Metadata	CSV, SHP, XML
Project Report	PDF, XML

OTHER APPLICATIONS

SUPPLEMENT 10

These application areas relate to cultural heritage, water, and oil and gas. This section summarises these applications and their specific user requirements to make the data fit-for-purpose.

PIPELINE MONITORING (OIL AND GAS INDUSTRY)

Monitoring offshore oil and gas installations and pipelines are extremely valuable and can help identifying faults or leaks. UAVs are highly effective for pipeline monitoring in on- and off-shore facilities.

Participants highlighted that features of interest include pipelines, asset damage, flare and buildings. They indicated data is usually collected using RGB and IR sensors. This application requires high resolution data at 3cm/pixel or higher. The minimum acceptable horizontal and vertical accuracy suggested by the participants are ±10cm and ±2cm respectively.

The deliverables include imagery, location and type of asset damage (e.g. leaks or cracks).

RESOLUTION
≤ 3cm

SENSORS
RGB, IR

FEATURES OF INTEREST
PIPELINES, ASSET DAMAGE, FLARE, BUIULDINGS, WATER BODIES

PRODUCTS
IMAGERY, LOCATION AND TYPE OF ASSET DAMAGE

RECORDING/DOCUMENTING HERITAGE STRUCTURES

The recording of historic and culturally significant structures using UAVs have advantages over traditional methods. This is because UAVs can quickly capture complete high resolution images for the generation of 3D models. They can also create mosaics, maps and drawings to be used for risk analysis and management of heritage buildings and structures.

The features of interest include buildings and surrounding vegetation. The data capture is usually performed using RGB sensors and at a resolution of 2cm/pixel or higher. The desirable horizontal and vertical accuracy is ±10cm. Users did not indicate a temporal resolution. The deliverables include orthophotos and photorealistic 3D models.

RESOLUTION
≤ 2cm

SENSORS
RGB

FEATURES OF INTEREST
HERITAGE BUILDING, VEGETATION, TREES

PRODUCTS
ORTHOPHOTOS, 3D MODELS WITH TEXTURE

PORTABLE WATER TANK INSPECTION (WATER INDUSTRY)

Many assets in the water sector (e.g. pipelines, portable or elevated water tanks, towers, spills) need to be inspected regularly for compliance, maintenance, safety and environmental impact. When compared to using helicopters and boats, UAVs are cost effective, easy to mobilise and tend to reduce hazards to operators. The features of interest include asset damage, pipelines, buildings, water locations and tanks. These are usually captured within areas up to 2km^2 using RGB and IR sensors. The lowest image spatial resolution for this application is 10cm/pixel with vertical and horizontal accuracy of up to ±2cm.

The temporal resolution for capturing the data was on a quarterly-basis or every six months. The deliverables include image, thermal images and videos.

RESOLUTION
≤ 10cm

SENSORS
RGB, IR

FEATURES OF INTEREST
ASSET DAMAGE, PIPELINES, BUILDINGS. WATER BODIES, WATER TANKS

PRODUCTS
IMAGERY, THERMAL IMAGES, VIDEOS

APPENDICES

APPENDIX A – SURVEY QUESTIONNAIRE

Quality Assurance Software for UAV Aerial Photogrammetric Data

Contact Information

Thank you for showing an interest in contributing to our research which is seeking to determine the requirements for different mapping applications using UAVs. The end result will be an online tool with intuitive questions which can be used to automatically generate specifications for each application.

This questionnaire is designed for those who acquire and/or use photogrammetric UAV data, with results to inform the specifications and development of quality assurance (QA) software. However, users of aerial imagery from other platforms are also encouraged to complete the questionnaire as there is potential for the QA software to be expanded beyond UAV. Please provide responses based on your experience within your organisation.

*The questionnaire covers the acquisition, specification requirements, processing, applications, challenges faced, and expectations for a quality assurance package. It shouldn't take longer than 20mins to complete, with most of the questions requiring short answers, check boxes, or slider bars. Please note that details marked with * are mandatory and questions with square check boxes allow multiple options to be selected.*

* 1. First name:

* 2. Last name:

* 3. Organisation:

* 4. Organisation Type:

* 5. Email:

6. Phone:

UAV Strategies

* 7. Please rank the most common ways you procure UAV data?

- Acquire it within your business — N/A
- Outsource and fund the acquisition — N/A
- Outsource the acquisition on behalf of a client — N/A
- Obtain it second hand — N/A

* 8. Do you use an acquisition specification for UAV data and what is the primary way you determine the project requirements?

- Yes - using subject matter experts
- Yes - using advice from providers
- Yes - using an existing specifications document
- Yes - guess
- No
- Yes - Other method (or multiple methods) of determining requirements (please describe)

* 9. Are you aware of any standards? If so, what source?

- Yes
- No

Source of standards

* 10. How do you interact with UAV data?

- Flight Planning
- Specification Development
- Acquisition
- Post Processing
- Quality Assurance
- Visualisation
- Feature Extraction
- Analysis
- Data Integration
- End User
- Data Management
- Other (please specify)

11. If relevant, what flight planning software do you use for UAV?

- Airware Red Bird
- Altizure
- CanIFlyThere
- Mission Planner (Conservation Drones)
- DJIFlightPlanner
- DroneDeploy
- Flyte
- Litchi
- MapsMadeEasy
- mdCockpit
- Pix4Dcapture
- Precision Hawk
- QGroundControl
- Sensefly eMotion
- Skycatch
- Skyward
- N/A
- Other (please specify)

12. If relevant, what post processing software do you use with raw UAV data?

- [ ] Altizure
- [ ] ContextCapture
- [ ] DroneDeploy
- [ ] Drone2Map
- [ ] MapsMadeEasy
- [ ] Photoscan
- [ ] Pix4D
- [ ] Precision Hawk
- [ ] Propeller
- [ ] ReCap 360
- [ ] Skycatch
- [ ] Skyward
- [ ] N/A
- [ ] Other (please specify)

13. If you perform quality assurance checks, please briefly describe the checks done and the process' used. For example;

- Delivery Completeness - manually check all requested files have been delivered
- Corruption - open all files to ensure they are not corrupt
- Image Quality - visualise the imagery to ensure quality
- Vertical Accuracy - manually check against ground control

14. If relevant, what visualisation and analysis software do you use with UAV data?

- [ ] Agisoft Photoscan Pro
- [ ] Altizure
- [ ] ArcGIS
- [ ] AutoDesk ReCap 360
- [ ] AutoDesk Civil 3D
- [ ] Bentley Context Capture
- [ ] Bentley Microstation
- [ ] DroneDeploy
- [ ] Global Mapper
- [ ] GRASS GIS
- [ ] Hexagon Apollo
- [ ] MapInfo
- [ ] MapsMadeEasy
- [ ] Pix4D mapper
- [ ] Precision Hawk Mapper
- [ ] Propellor
- [ ] QGIS
- [ ] SAGA GIS
- [ ] Skycatch
- [ ] Other (please specify)

* 15. Have you experienced problems using UAV data?

- [ ] Accuracy
- [ ] Automation
- [ ] Classification
- [ ] Lack of metadata
- [ ] Orthorectification
- [ ] Processing speed
- [ ] Quality
- [ ] Resolution
- [ ] Size
- [ ] Skills
- [ ] Software
- [ ] Spatial reference system
- [ ] Storage
- [ ] Other (please specify)

UAV Project Examples

The next 3 pages are the most important sections of the questionnaire. They will help inform us about the technical requirements for your UAV applications. The more projects and applications that are provided will give you a greater contribution to the standards. They are designed for you to choose 1-3 specific UAV project examples and describe the requirements and specifications for each.

The results will help us identify the range of applications and understand the specific acquisition and data requirements of each application, so that we can design a series of simple questions to automatically generate tender specifications for each application. The tender specifications can be used in the procurement or project planning process which will simplify the acquisition process for users and ensure they get fit-for-purpose data.

Please choose your most common application examples. It would be highly valuable if you can provide all 3 examples.

In this section, please select and describe an example project that is typical of your UAV usage.

* 16. Which UAV application area is relevant to the project example chosen?

* 17. Briefly describe the specific application (as per the examples given in the dropdown for the above question):

* 18. What types of features were of interest?

- ☐ Ground Surface
- ☐ Embankments
- ☐ Excavation
- ☐ Stockpiles
- ☐ Earthworks
- ☐ Landfills
- ☐ Vegetation (general)
- ☐ Individual Trees
- ☐ Crops
- ☐ Other (please specify)
- ☐ Land Use
- ☐ Fire
- ☐ Asset Damage
- ☐ Power Lines
- ☐ Pipe Lines
- ☐ Road Features
- ☐ Street Furniture
- ☐ Railway Lines
- ☐ Bridges
- ☐ Buildings
- ☐ Water
- ☐ River Channels
- ☐ Damns
- ☐ Coast line
- ☐ Cliffs
- ☐ Rock Fractures
- ☐ Wildlife

* 19. What was the coverage area of the project example?

- ☐ 0-2 sqkm (0-200 ha)
- ☐ 2-5 sqkm (200-500 ha)
- ☐ 5-10 sqkm (500-1000 ha)
- ☐ 10-50 sqkm (1000-5000 ha)
- ☐ 50-100 sqkm (5000-10,000 ha)
- ☐ >100 sqkm (>10,000 ha)

* 20. What file format/s were used for each product required in the project example?

					Ground									
12da	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
CSV	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
DGN	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
DWG	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
DXF	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
ECW	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
ESRI ASCII	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
ESRI GRID	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
FPL	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
JPG	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
KML	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
LAS	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
LAZ	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
PDF	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
PNG	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
SHP	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
TAB	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
TIF	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
XML	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
XYZ	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

* 21. What were your image resolution requirements for the project example?

N/A — 50cm — 100cm ☐

* 22. What were your horizontal accuracy requirements for the project example?

N/A — 50cm — 100cm ☐

* 23. What were your absolute (compared to control) vertical accuracy requirements for the project example?

N/A — 50cm — 100cm ☐

* 24. What were your relative (internal to the data) vertical accuracy requirements for the project example?

N/A — 50cm — 100cm ☐

25. If relevant, what were your DSM/DEM resolution requirements for the project example?

N/A — 2.5m — 5m ☐

* 26. Are you able to provide a second UAV project example?

◯ Yes

◯ No

UAV Project Example 2

In this section, please select and describe a second example project that is typical of your UAV usage.

...the same questions are presented as for Project Example 1

UAV Project Example 3

In this section, please select and describe a third example project that is typical of your UAV usage.

...the same questions are presented as for Project Example 1

Quality Assurance Software

* 48. Please rate the importance of aspects of a photogrammetric UAV dataset that you would be interested in quality checking?

	Low	Moderate	High	Very High	N/A or Unsure
Flight plan	○	○	○	○	○
Sensor settings	○	○	○	○	○
Date of data capture	○	○	○	○	○
Version and point data record format of LAS point cloud files	○	○	○	○	○
Validity of LAS point cloud header	○	○	○	○	○
File naming & formats	○	○	○	○	○
Data extent	○	○	○	○	○
Internal holes	○	○	○	○	○
Classification of point cloud	○	○	○	○	○
Imagery resolution	○	○	○	○	○
Imagery overlap	○	○	○	○	○
Image shadowing	○	○	○	○	○
Image clarity	○	○	○	○	○
Image colour balance	○	○	○	○	○
Image spatial accuracy	○	○	○	○	○
Point cloud spatial accuracy	○	○	○	○	○
DSM/DEM spatial accuracy	○	○	○	○	○
Offset between overlapping data	○	○	○	○	○

49. Can you think of any additional checks of interest?

* 50. Would you prefer desktop or cloud based software for the QA checks data processing component?

- ◯ Desktop
- ◯ Cloud
- ◯ Either

51. Do you have any further comments regarding the development of the workflow?

* 52. Would you like to be involved in a workshop to discuss the development of the workflow in depth?

- ◯ Yes
- ◯ No

53. Can you suggest anyone else who may be interested in completing this questionnaire or being involved in a workshop? Please provide name, contact details and organisation.

* 54. Is it OK for the CRC for Spatial Information to follow up with you on the answers you've provided?

- ◯ Yes
- ◯ No

* 55. Is it OK for the CRC for Spatial Information to publish your organisations name in the list of respondents?

- ◯ Yes
- ◯ No

Thank you for completing this questionnaire.

By submitting this questionnaire you are accepting the following conditions.

Consent Form

I acknowledge that the information collected in this survey may be used in publications by the CRC for Spatial Information and their partners in their research.

I have read and understand the following information:

1. The questionnaire will contribute to the research and development of quality assurance software for photogrammetric UAV data.

2. Participation in the survey is entirely voluntary and interviewees can withdraw at any time without any negative consequences.

3. The names of interviewees will be suppressed unless otherwise agreed.

4. All raw data from the questionnaire and interviews will be securely stored and accessible in either hard copy or electronic form by project staff only, as far as the law allows, and will not be shown to anyone else.

5. Individuals who indicate in any way that they wish to withdraw from participating in the research will be told they have no obligation to continue - this will terminate their participation. All notes made relating to the interviews held with the participant will be returned to them or retained by the CRC for Spatial Information for incorporation into the report if they so wish.

If you have any queries or concerns about the research, you can contact Jessica Keysers on the details provided below:

Jessica Keysers

Phone: (03) 8344 9179

E-mail: jkeysers@crcsi.com.au

APPENDIX B – ADDITIONAL POLL QUESTIONS IN WORKSHOPS

1. What is the name of your organisation/business?
2. Are you from government, private sector or research?
3. What is your drone interest area? i.e. transport, mining, water, acquisition etc.
4. Do you fly drones?
5. How many UAV pilots does your organisation have?
6. Are your acquisitions time sensitive (i.e. due to environmental changes)? If so, to what time range?
7. Do you acquire time series data?
8. In which country/s do you acquire/procure UAV data?
9. What UAV platforms do you use? e.g. DJI Phantom *(you can submit multiple responses)*
10. What UAV sensors do you use? e.g. NIR *(you can submit multiple responses)*

APPENDIX C – LIST OF PARTICIPATING ORGANISATIONS

1. AECOM
2. Airobotics
3. AUAV
4. Aurecon SA
5. Australian Antarctic Division
6. Australian UAV
7. Australian UAV
8. Bayer CropScience
9. Beca (NZ)
10. CCST (NZ)
11. CITIC Pacific Mining
12. City of Busselton
13. City of Kalamunda
14. Christchurch City Council (NZ)
15. CleanTeq
16. CRC-SI
17. Custom Aerial Solutions
18. Deakin University
19. Department of Economic Development, Jobs, Transport and Resources
20. Department of Biodiversity, Conservation and Attractions
21. Department of Environment, Land, Water & Planning
22. Department of the Environment and Energy
23. Department of Transport (Western Australia)
24. Department of Primary Industries and Regional Development
25. Department of Natural Resources and Mines
26. Department of Water and Environment and Regulation
27. Drone Services Fiji
28. East Gippsland Shire Council
29. Elevo Pty Ltd
30. Emergency Management Victoria
31. Esri Australia
32. Five rings Aerospace
33. Forest Fire Regions
34. Fortescue Metal Group
35. Frankston City Council
36. Fugro
37. GHD
38. Geospatial Research Institute (NZ)
39. Global Drone Solutions
40. Guava Insights
41. Haefeli Lysnar
42. Harrison Grierson (NZ)
43. Heritage Victoria
44. JCU
45. Landgate Walis
46. Mapizy
47. Melbourne Water
48. MRIWA
49. National Computational Infrastructure (NCI)
50. Newcastle University
51. Norske Skog Paper Mills
52. Nova Systems
53. Ocean Pixel Imaging
54. Parks Victoria
55. PF Olsen
56. Perth VR
57. Position Partners
58. Queensland University of Technology
59. Regional Group Collective
60. Roy Hill
61. Scientific Aerospace
62. Scion, New Zealand
63. Silverpond
64. SkyCam New Zealand
65. Southeast Water, Victoria
66. Spatial Analytics
67. Stratus Imaging
68. Saunders Havil
69. Southeast Queensland Water
70. Terra Firma Australia
71. The University of Melbourne
72. The University of Queensland
73. ThinkSpatial
74. Tiny Bytes
75. University of Canterbury (NZ)
76. UNSW Sydney
77. UTAS
78. University of Queensland
79. Vertical Earth
80. WABSI

APPENDIX D – INTERVIEWEES DETAILS

A small number of interviews following a condensed version of the workshop agenda were also conducted with interested parties who could not attend one of the workshops. These included:

DELWP, 4 September 2017

- Darren James – Statewide Coastal Leader
- Bill Storer – Bairnsdale Environmental Planning & Assessment
- Hans Van Elmpt – Traralgon GIS Coordinator

Parks Victoria, 8 September 2017

- Richard Page – Manager Service Applications

AUAV, 26 September 2017

- James Rennie – Director & Chief UAV Operator

Position Partners, 25 February 2018

- Luis Elneser – Survey Technical Support

SCION, New Zealand, 27 February 2018

- Grant Pearce – Geomatics Scientist
- Robin Hartley – Manager of UAV Operations, Geospatial Scientist, UAV Pilot

University of Melbourne, 5 March 2018

- Dr Richard Collmann
- Dr Sigfredo Fuentes

Melbourne Water, 6 June 2018

- Heath McMahon
- Frank Courtney

Southeast Water, Victoria, 6 June 2018

- Andrew Gordon

APPENDIX E – COMMON SOFTWARE FOR DIFFERENT STAGES OF UAV DATA PROCESSING

SOFTWARE	PROCESS STEPS	FLIGHT PLAN/ CAPTURE	ORTHO-MOSAICS	POINT CLOUD CREATION	3D MODELS	ANALYSIS TOOLS	OTHER COMMENTS
Pix4D (Swiss)	capture	–	Yes	No	No	No	• Imagery capture & processing • Desktop or cloud processing • Mining, mapping, agriculture
	mapper	–	Yes	Yes	Yes	Yes	
DroneDeploy (US)		–	Yes	Yes	Yes	Yes	• Imagery capture & processing • Processing in the cloud • Focus on agriculture
Bentley (US)	Context Capture	–	No	Yes	Yes	Yes	• Imagery processing • Design and construction
	Microstation	–	No	No	No	Yes	• CAD software
Autodesk (US)	ReCap 360	–	No	Yes	Yes	Yes	• Imagery & LiDAR processing • Design and construction
	CAD Civil 3D	–	No	No	No	Yes	• CAD software
Precision Hawk (US)	Flight (& Viewer)	–	Yes	No	No	No	• Imagery capture & processing • Desktop or cloud processing • Focus on agriculture
	Mapper	–	No	Yes	Yes	Yes	
Propeller (Aus)		–	No	Yes	Yes	Yes	• Imagery processing in cloud • Focus on asset inspection • AeroPoints world's first smart ground control points
Skycatch (US)		–	Yes	Yes	Yes	Yes	• Imagery capture & processing • Processing in the cloud • Focus on construction
Skyward (US)		–	Yes	No	No	No	• Manage pilot, equipment and project scheduling
Agisoft PhotoScan Pro (Russian)		–	No	Yes	Yes	Yes	• Imagery & multispectral imagery processing • Network processing & Python • GIS, cultural heritage, object measurement
Menci APS (Italian)		–	No	Yes	Yes	Yes	• Imagery processing • Desktop processing
Trimble Inpho UAS Master (US)		–	No	Yes	Yes	Yes	• Imagery processing • Desktop processing
ESRI (US)	Drone2Map	–	No	Yes	Yes	Yes	• Imagery processing • Powered by Pix4D
	ArcGIS	–	No	ArcGIS Pro	ArcGIS Pro	Yes	• GIS software

SOFTWARE	PROCESS STEPS	FLIGHT PLAN/ CAPTURE	ORTHO-MOSAICS	POINT CLOUD CREATION	3D MODELS	ANALYSIS TOOLS	OTHER COMMENTS
Altizure (Chinese)		–	Yes	Yes	Yes	Yes	• Imagery processing (drone photos to 3D model) • User-generated 3D model visualisation (online) • Mobile app & cloud processing • Free, except for 3D model download
MapsMadeEasy (US)		–	No	Yes	No	Yes	• Imagery processing • Processing in the cloud
12D (Aus)		–	No	No	No	Yes	• Terrain modelling, surveying and civil engineering software
MapInfo (US)		–	No	No	No	Yes	• GIS software
ER Mapper (US)		–	No	Yes	No	Yes	• Image processing software
FME (Canadian)		–	Yes	No	No	No	• Imagery capture & processing • Desktop or cloud processing • Focus on agriculture
QGIS (US)		–	No	No	No	Yes	• GIS software
PhotoVis (Aus – GHD)		–	No	Yes	Yes	Yes	• Developed by VAR team • Improvement to 'Propeller' • 3D modelling & visualisation
Airware Red bird (French/US)		–	Yes	Yes	No	Yes	• Imagery capture & processing • Processing in the cloud • Mining and construction
Opendronemap (US)		–	No	Yes	Yes	Yes	• Open source image processing • Build using github

APPENDIX F – UAV PLATFORMS, PAYLOADS, AND APPLICATION AREAS

PLATFORM	BENEFITS	DRAWBACKS	PAYLOADS	APPLICATIONS
Fixed wing	• Energy efficient • Good endurance • Fast • Fly high • Cover large areas • Carry heavier payloads • Can be powered by gas	• No vertical take-off • Cannot hover • Not stable in wind • Launching and landing is hard • Attacked by Wedge Tailed Eagles • Expensive • Difficult to use	• Optical camera • Thermal camera • Multi/Hyper-spectral camera • LiDAR • Particle sensor • Magnetometer	• Mapping • Agriculture • Pipeline and power line inspection • Stockpile volume calculations • Tree counts • Military • Surveillance
Single-rotor	• Vertical take-off • Can hover • Fast forward flight • Endurance (with gas power) • More efficient than multi-rotor • Carry heavier payloads	• Requires maintenance • Vibrates • Noisy • Unstable on landing • Dangerous blades • Expensive	• Cameras • LiDAR • Passive payloads e.g. sprayers	• Agricultural spraying • Surveillance
Multi-rotor	• Vertical take-off • Can hover • Access tight spaces • Stable flight • Good camera control • Low maintenance • Easy to use • Cheap	• Limited endurance • Limited speed • Cover small areas • Inefficient • Carry light payloads • Cannot use gas power	• Small still or video camera • Passive payloads	• Aerial photography and video for o Inspection o Film making
Hybrid	• Vertical take-off • Can hover • Good endurance • Low maintenance • Can glide if engine fails	• Adversely affect by wind • Not perfect at hovering or forward flight • Still in development and not many on the market	• Potentially all active sensors • Passive payloads	• Mapping • Logistics & delivery e.g. Amazon's Prime Air drone
Blimps, Balloons and Kites	• Mapping • Logistics & delivery e.g. Amazon's Prime Air drone	• Adversely affected by wind (except kites within reason) • Minimal mobility • Blimps – very slow moving • Kites – high demand on pilots • Helium can be costly; • Transportation of inflated balloons or blimps can be difficult • Generally silent	• Potentially all active sensor	• Weather • Google Loon • Monitoring • Mapping • Air quality testing • Surveillance • Advertising

APPENDIX G – APPLICATIONS AND BENEFITS OF UAVS IN EMERGENCY MANAGEMENT

MISSION TYPE	SUB-MISSION TYPES	CAPABILITIES	BENEFITS
General[16]	• Pre-disaster mapping and assessment • Rapid post-disaster assessments • Route identification and clearance • Communications support • Search and rescue • Relief supplies	• Allows development of baseline data • Provides near real-time information on incident • Autonomous or remotely piloted flight to position and patrol • Rapid mapping of incident • Provides communications support	• Force multiplier • Lower cost air operations per flight hour • Reduces risk of injury for officials • Supports rapid acquisition of situational awareness • Identifies safe access and egress routes for emergency services personnel and evacuees • Allows personnel involved in incident the ability to communicate
Earthquake Management	• Monitoring land movement • Post damage assessment • Tsunami	• Allows development of baseline data • Provides near real-time information on incident • Autonomous or remotely piloted flight to position and patrol • Rapid mapping of incident	• Force multiplier • Lower cost air operations per flight hour • Reduces risk of injury for officials • Supports rapid acquisition of situational awareness • Identifies safe access and egress routes for emergency services personnel and evacuees • Supports search for victims which can be rescued by manned aircraft
Fire Management	• Fuel load assessment • Power line detection and mapping • Water source assessment • Fire detection • Fire front detection/assessment • Fire fighting • Plume analysis and monitoring	• Allows development of baseline data and pre-incident risk assessment • Rapid detection of fire • Provides near real-time information on incident • Autonomous or remotely piloted flight to position and patrol • Rapid mapping of incident scene and identification of hazards for manned aircraft • Identifies and assesses water storage points • Ongoing monitoring of fire and fire behaviour • 3-dimensional plume mapping and monitoring • Provides communications support	• Force multiplier • Lower cost air operations per flight hour • Ongoing operations in adverse conditions and during hours of darkness • Reduces risk of injury for officials • Supports rapid acquisition of situational awareness • Assists manned aircraft water bombing operations • Provides enhanced understanding of gas plume behaviour • Identifies safe access and egress routes for emergency services personnel and evacuees • Allows personnel involved in incident the ability to communicate

[16] Provided by Griffin (2014): (available at https://www.aph.gov.au/DocumentStore.ashx?id=e9ea5731-e81f-477f-8c40-bbd8fe6e37f5&subId=461324)

MISSION TYPE	SUB-MISSION TYPES	CAPABILITIES	BENEFITS
Flood Management	• Flood plain prediction • Flood mitigation assessment • Flood assessment and monitoring • Search and rescue	• Allows development of baseline data and pre-incident risk assessment • Identifies potential breaches in flood protection barriers and systems • Provides near real-time information on incident • Autonomous or remotely piloted flight to position and patrol • Rapid mapping of incident scene and identification of hazards for manned aircraft • Enhances capabilities to rapidly search for persons missing in flood water • Provides communications support	• Force multiplier • Lower cost air operations per flight hour • Reduces risk of injury for officials • Supports rapid acquisition of situational awareness • Assists manned aircraft search and rescue operations • Identifies safe access and egress routes for emergency services personnel and evacuees • Allows personnel involved in incident the ability to communicate
Man Made Disasters	• Hazmat incidents • Biological incidents • Chemical or radiological Incidents • Structural failure	• Allows development of baseline data and pre-incident risk assessment • Provides near real-time information on incident • Autonomous or remotely piloted flight to position and patrol • Rapid mapping of incident scene and identification of hazards • 3-dimensional plume mapping and monitoring • Reduces exposure of personnel to dangerous substances • Provides communications support	• Force multiplier • Lower cost air operations per flight hour • Reduces risk of injury for officials • Supports rapid acquisition of situational awareness • Provides enhanced understanding of gas plume behaviour • Identifies safe access and egress routes for emergency services personnel and evacuees • Allows personnel involved in incident the ability to communicate • Can be used to enforce exclusion zones
Search and Rescue	• Search and rescue support	• Systematic area search • Person and vehicle detection and tracking • Real time instruction/communication with victims • Transportation of rescue and life support equipment	• Force multiplier • Lower cost air operations per flight hour • Identifies safe access and egress routes for emergency services personnel and victims • Supports search for victims which can be rescued by manned aircraft
Weather Events	• Cyclone/hurricane management and response • Drought management • Severe storm management • Storm tides and surges	• Allows development of baseline data and pre-incident risk assessment • Provides ongoing and long-term monitoring • Identifies potential breaches in flood protection barriers and systems • Provides near real-time information on incident • Autonomous or remotely piloted flight to position and patrol • Rapid mapping of incident scene and identification of hazards • Enhances capabilities to rapidly search for persons missing in flood water • Provides communications support	• Force multiplier • Lower cost air operations per flight hour • Reduces risk of injury for officials • Supports rapid acquisition of situational awareness • Early identification of stressed vegetation and biodiversity loss • Assists manned aircraft search and rescue operations • Identifies safe access and egress routes for emergency services personnel and evacuees • Allows personnel involved in incident the ability to communicate

APPENDIX H – UAV PAYLOAD TYPES

TYPE	PASSIVE / ACTIVE	DESCRIPTION	APPLICATION EXAMPLE
Optical camera	Active	Capture visible light rays	Photography, Video & Photogrammetry
Thermal camera	Active	Detect long-infrared radiation or heat signatures	Inspection of solar cells, Search & rescue, Wildlife protection
Multi/Hyper-spectral camera	Active	Multi-spectral cameras capture visible light, infrared (heat) and some ultraviolet light. Hyper-spectral cameras capture a finer resolution of those bands.	Agriculture, Forestry, Mining
LiDAR	Active	Measure distance and generate 3D point clouds	Surveying & Mapping
Particle sensor e.g. spectrometer	Active	Measure gas, radiation, vapour, etc.	Environmental monitoring
Magnetometer	Active	Measure magnetism	Geophysics
Parcels	Passive	Customer product orders	Logistics & Delivery
Collection	Passive	Water samples	Environmental monitoring
Medical equipment	Passive	Defibrillator, blood, vaccine, EpiPen	Medical
Supplies	Passive	Life raft, water, food	Rescue
Signs	Passive	Banners advertising products or services	Marketing
Sprayers	Passive	Pesticide, herbicide, fertiliser	Agriculture

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Australian UAV

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