LUMEN

Engineering for
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UAV Surveying Business Opportunity

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MEM Final Report

Lumen

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REVISION HISTORY

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ABSTRACT

Lumen has determined that there is an opportunity for it to leverage its existing UAV hardware for use in photogrammetry surveys and wishes to augment its current design services. Lumen is not a surveying company so has little experience in this field. Assessing this opportunity required an analysis of the output capability, determination of the restrictions imposed from both internal and external sources, and a realisation of the financial implications. It also needed to assess the competition and how it could fit into the market for this service.

EXECUTIVE SUMMARY

Lumen is an engineering consultancy that provides engineering services over numerous disciplines. One of those disciplines is overhead power line design. It has determined that there is an opportunity to use existing UAV hardware to assist in data collection for its design projects.

This project was about determining the capability of Lumen and its current hardware to perform photogrammetry surveys. The results of the surveys would be used to assist in its overhead line design. Acquiring adequate survey data is critical to allowing good engineering decisions to be made and to enable high-quality outputs.

To determine the scope of this opportunity Lumen needed to determine what exactly adequate results would look like, how the survey would be performed, what restrictions surround the use of this technology – whether that is internal or external, how the restrictions would affect them, and the financial implications.

To enable all of these, the project was split into three main sections:

1. A technology report outlining and determining the capability and how it compares to competitors
2. A compliance report outlining the rules and regulations, the restrictions imposed, and how these affect the available opportunities
3. A financial analysis determining the expected costs and returns, costs to clients, and comparisons to the wider market

Overall, the project aimed to answer the following questions:

1. Can the current UAVs be used to provide adequate survey data for use in design?
    a. If so, how?
    b. If not, what must Lumen do to generate adequate results?
2. How do the outputs from Lumen performing this survey method compare with other methods?
3. What are the restrictions, rules, and regulations surrounding the use of UAVs for this purposes, and how do they affect the company?
4. What are the risks involved in providing these services?
5. What are the potential financial implications to Lumen and to clients?

It was determined that Lumen's hardware can produce adequate results, but specific processes were necessary. One of the UAVs caused unnecessary difficulties due to some of its features. This was the DJI Mavic Air. The other UAV that Lumen owns, the DJI Mavic 2 Zoom, was deemed suitable but not ideal. As a result of analysing the technical capabilities, restrictions, and financial implications, it was determined that to provide the best overall outcome, Lumen should invest in different hardware such as the DJI Mavic 3.

Over the course of the project, it became apparent that Lumen's appetite was to provide a service in only a small, auxiliary capacity. Even before considering the legal requirements, this imposes some restrictions on the usability and possible financial return. When the legal requirements were considered, it was determined that there are many restrictions hindering Lumen's ability to provide this service. It can still provide the service and will likely generate a small amount of additional profit, but it is unsubstantial.

This operation would be cost competitive for clients. Lumen's aim is not to generate significant income, but to provide better outcomes and services

Overall, it can be expected that if Lumen provides these services, it can generate adequate results at a competitive rate, and would be able to make a small amount of additional profit. The overall risks are relatively low, but so are the opportunities.

1. INTRODUCTION

Lumen is an engineering consultancy that specialises in a range of difference engineering disciplines. One of its core focuses is on overhead line engineering and design. It provides these services to numerous clients in the power transmission, sub-transmission, and distribution markets.

Overhead line design and engineering requires high quality spatial information of assets that are being replaced, upgraded, or analysed. It also requires information of the surrounding ground and area, as well as other nearby assets. This spatial information is collected via different surveying methods and used by the engineers to develop high quality solutions for their clients.

It allows the designer to make choices that can optimise properties such as asset strength, asset location, and asset longevity. It is the base from which all designs start. Because of this, it is incredibly important to capture accurate, high-quality data as it will provide the opportunity for designers to make the best decisions possible.

Lumen aims to be a nimble and adaptable engineering consultancy that goes above and beyond for its clients. This adaptability means that it is often searching for new ways that it can meet it client's needs.

Lumen has two available unmanned aerial vehicles (UAV) – the DJI Mavic Air and Mavic 2 Zoom. It has determined that there is a potential opportunity for it to collect the spatial data used for these projects by utilising the UAVs for photogrammetry surveying. Photogrammetry is the process of collecting overlapping images and using special software to transform the images into spatial information.

Lumen believes that the opportunity can be capitalised on as it understands the engineering context of a survey in this area better than a typical surveyor might. This means that Lumen can provide a service to its clients that is potentially cheaper, quicker, or better, and will mean that the engineering solutions that Lumen provides can be improved.

These UAVs are low-cost and not typically used for this purpose. Their capability in this context is unknown.

The purpose of this report is to determine the opportunities available to Lumen and how they might impact the company. To do this, the following questions must be answered:

1. Can the current UAVs be used to provide adequate survey data for use in design?
    a. If so, how?
    b. If not, what must Lumen do to generate adequate results?
2. How do the outputs from Lumen performing this survey method compare with other ways of collecting spatial information?
3. What are the restrictions, rules, and regulations surrounding the use of UAVs for this purposed, and how do they affect the company?
4. What are the risks involved in providing these services?
5. What are the potential financial implications to Lumen and to clients?

To answer these questions the project was split into three distinct sections.

Questions 1 and 2 were answered in section 4 of this report, the technology report. This section focussed around the capability of the UAVs to provide adequate survey data. It involved testing, processing, and comparing the data with similar datasets from other survey methods. The goal was to reach a conclusion about their capability, what the process involves, and what would be the next steps for Lumen.

Questions 3 and 4 were answered in section 5 of this report, the compliance report. This section aimed to determine and understand the legal and regulatory limitations that would or could be imposed on Lumen providing these services as well as understand the risks involved. This section is critical to determining how this process could fit into the company's overall strategy.

Finally, question 5 was answered in section 6 of this report, the financial analysis. It aimed to determine the financial implications of providing these services, both to Lumen and to the client. To do this, it needed to understand the processes involved, the time taken, all associated costs, the restrictions around operations, and how it would price jobs for clients. It also aimed to determine if, or how, Lumen could provide these services and increase profitability.

2. LITERATURE REVIEW

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MEM Literature Review

The Use of Remote Sensing Technology for Use with Power Lines

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October 2021

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REVISION HISTORY

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CONTENTS

ABSTRACT

The purpose of this study is to look at the use of remote sensing (RS) technology for asset management purposes. More specifically, it will look at the of both LiDAR (Light Detection and Ranging) and Photogrammetry in the creation of Digital Elevation Models (DEM) and point cloud data, particularly with the use of Unmanned Aerial Vehicles (UAV) for power line modelling. The goal was to understand the potential applications, benefits, and drawbacks of both UAV LiDAR and UAV photogrammetry and determine a conclusion regarding their efficacy for the mentioned application. The review was performed using a combination of qualitative and quantitative research and information. It was determined that both UAV LiDAR and UAV photogrammetry are acceptable methods of data collection for the creation of 3D ground surfaces and for power line modelling, although photogrammetry is much more constrained technically. Both methods can provide high levels of accuracy, but photogrammetry can be performed much cheaper.

1. INTRODUCTION

Lumen is an engineering consultancy that undertakes asset design, management, maintenance, and assessments. These include commercial building design, earthquake repair and assessments, transmission line maintenance or upgrade design, transmission line structural assessments, energy audits, and corrosion prevention. These may be performed using anything from visual inspections to sophisticated computer models. Data collection is necessary for all these tasks, whether that is documenting the condition of something, finding the location of an object in space, or ensuring processes are being followed. In the management, design, and upgrade of Transmission lines, they are often modelled or reconstructed in computer software using data collected from aerial surveying. This is a form of data collection known as remote sensing.

Remote sensing is the process of collecting data about an object from a distance (i.e. without physical contact) (USGS, ND). Remote sensing collects and records data reflected from a surface. Data collected can be used to manage assets or can be used in the design of them, among other applications. It is used as an alternative to or in addition to field work due to various reasons. The most obvious reasons are that it can be safer, less resource intensive, and can generate data in areas impossible or impractical for a site visit (Uysal et al., 2015).

Remote sensing is typically split into two categories – active or passive. Active remote sensing is when a signal or pulse is emitted and its reflection is detected, the object is illuminated (not necessarily by visible light) by the sensing instrument (National Resources Canada, 2019). Examples include light detection and ranging (LiDAR), sound navigation and ranging (Sonar), and radio detection and ranging (Radar). Passive remote sensing measures energy that is naturally available – energy that is emitted by or reflected from an object. Cameras are examples of passive sensors. A visible light camera captures energy that is reflected such as sunlight, whereas a thermography camera captures infrared energy emitted by an object.

This review aims to review both categories of remote sensing in the creation of 3-dimensional computer models for ground surfaces, as well as their use and relevance for power line reconstruction in computer models. This study will focus mainly on LiDAR (active) and photogrammetry (passive) and these will be briefly compared to more traditional tools such as total stations (active).

Terrestrial LiDAR and terrestrial photogrammetry are largely excluded as they are constrained by only being able to capture data on small scales due to being stationary (Geo-Plus, ND). Instead, the review focuses on the aerial applications, particularly the use with unmanned aerial vehicles (UAV). This is mainly because aerial applications can capture much larger datasets in a given time (Geo-Plus, ND). The size of the dataset available is important because given the context of the project (i.e. surveying for power lines) the application of these technologies concerns the use of corridors that may be many acres or hectares in area and could stretch many kilometres.

This literature review will evaluate how each technology is used, what they are used for, and their limitations. The overall goal is to obtain a summary of the differences and determine their efficacy regarding power line management or design. An assessment of both qualitative and quantitative research is necessary as neither type alone will be able to provide a full picture of the state of the technology or how applicable it is for the intended application.

2. REMOTE SENSING TECHNOLOGIES (LIDAR AND PHOTOGRAMMETRY)

Both LiDAR and photogrammetry are types of remote sensing. LiDAR rapidly emits pulsed light that reflects off objects and back to a sensor (Velodyne Lidar, ND). The distance to an object and its position is calculated using the time it takes for the pulse to return (Sullivan, 2020). This happens millions of times and the end result is generally in the form of a point cloud.

Photogrammetry is the process of collecting many overlapping images and uses stereo matching to plot the same objects from different images to create 3-dimensional point clouds (Propeller Aero, 2020) or surfaces. Complex computer algorithms can feature match objects to ensure the same objects are referenced. LiDAR is a direct measure of distance to an object where photogrammetry creates a surface or points by matching objects in multiple images.

The systems are similar in the sense that they detect signals or energy and after processing can produce point clouds, digital elevation (DEM), terrain (DTM), or surface models (DSM) (Fagerman, 2019). They often have similar but not identical use cases. The differences lie in the application and specific use of each, but these are driven mostly by the strengths and weaknesses of each. While both technologies will often do, it comes down to which is the best for the job based on individual requirements. If only a single solution can be chosen, it will likely be determined by which is best for the majority of potential use cases. Some of the factors to consider are: budget and initial outlay, investment and ongoing costs, accuracy, resolution, time, object(s) being surveyed, required penetration, and outputs needed.

LiDAR systems are generally much more expensive and are more complex pieces of equipment – they are often difficult to integrate, technical, and prone to faults (Logan Campbell, 2018). They also require inertial measurement units (IMUs) (Fagerman, 2019), INS/GNSS systems, base stations (Luccio, 2021), and often require bespoke, custom mounting solutions to connect them to drones or UAVs. By design they are more complex to use and operate, without considering any post processing that is required. On the other hand, photogrammetry may require bespoke or custom solutions – mainly if using special camera equipment where they require calibration or custom shutter triggers (Logan Campbell, 2018), or aftermarket cameras not designed to integrate with the drone. Drones almost always come with integrated cameras or have camera options available from the manufacturer, meaning that integration is typically easier and simpler, although some UAV manufacturers do also offer integrated LiDAR systems.

Typically, LiDAR systems will cost orders of magnitude more than photogrammetry systems (Logan Campbell, 2018). Due to the cost it would be easy to assume that LiDAR is the superior option and that it would have much greater accuracy but this appears not to be the case, especially when photogrammetry is paired with robust operating procedures. According to some, and depending on the application, photogrammetry is as accurate or even more accurate than LiDAR (Wingtra, 2021) (Polat & Uysal, 2018) (Kršák et al., 2016).

Taking the cost, complexity, and accuracy into account, it would seem that photogrammetry is the obvious solution however, there are some major drawbacks associated with it. Firstly is the lack of penetration (Jayathunga et al., 2018). Being unable to penetrate vegetation in any meaningful way automatically excludes photogrammetry from any project where terrain is needed but vegetation is present. Power lines often run through vegetated areas but clearances to ground are still needed. Lack of penetration would make determining clearances impossible. Secondly is the requirement for good weather conditions (Sullivan, 2020). For photogrammetry to be useful it must be able to see all relevant objects. This means that lighting conditions are incredibly important, as is height above an object or ground, contrast, fog, rain, and weather in general – although LiDAR is also hampered by rain and fog. While better sensors and camera equipment will be able to overcome small shortcomings caused by weather, they will not be able to make up for all. Poor lighting conditions can mean that points then become difficult to match (Scout Aerial, ND) which in turn leads to poorer outputs.

3. REMOTE SENSING METHODS (MANNED VS UNMANNED)

Aerial LiDAR and photogrammetry can be performed using both manned and unmanned aircraft. Manned aircraft such as helicopters and aeroplanes have been the most used aerial vehicles for collecting LiDAR and photogrammetry data but unmanned aircraft is a growing alternative (Young, 2018).

The argument for using unmanned aircraft surveying is threefold. Cost, safety, and less so efficiency, are key drivers when making the decision for a manned vs unmanned survey. An unmanned aircraft appears safer both to human life and assets. The most obvious reason is that people are not aboard, followed by the size, weight, and speed of the aircraft. For example, a helicopter with LiDAR may need four people aboard (Luccio, 2021) plus external monitoring whereas a UAV may only need a couple of people at the site. It is immediately obvious that if something goes wrong, multiple people are being put at risk, whereas this is not necessarily true for unmanned aircraft.

Manned aircraft have much higher mobilisation costs (McClelland et al., 2018), have higher capital costs, and will have higher operational costs. UAVs can fly much lower (100 m for UAV, 2400 m for manned aircraft (McClelland et al., 2019)) and thus capture a greater resolution (Young, 2018). They are also quicker to mobilise, but may take longer to acquire the full breadth of needed data (Luccio, 2021). A downside to UAVs is that they have much shorter range. A UAV may cover 10 km^2 per flight or 60 km linearly in a day (Young, 2018) whereas a manned flight may cover 1000 km^2 or more per flight (Wingtra, ND-a).

At some point, there must be a break-even point where the cost of using a drone outweighs that of a helicopter or aeroplane due to the differences in flight speed and range. According to one study this is somewhere around the 20 km – 40 km corridor length (Luccio, 2021). No specifics are given as to what makes this the break-even point, but numerous reasons can be speculated. Manned aircraft fly much higher and faster (15 ms^{-1} for a low cost UAV (Kršák et al., 2016), 140 km/h or 39 ms^{-1} for a helicopter (Jayathunga et al., 2018)) than UAVs so can capture more data in a given time. The majority of drone use is line-of-sight (Transpower, 2017) which would mean that the surveyor would have to move to new sites regularly if capturing large areas, effectively eliminating one of the advantages of aerial surveying. Beyond line-of-sight (BLOS) UAV flight is legal within New Zealand and possible, provided the operator has the correct CAA certification and the equipment to do so, however, further considerations would be needed to ensure that there would be no adverse effects to people or property. The main issue here seems to be neither technical nor regulatory, but rather personal concern with regard to losing the UAV (Fagerman, 2019). It would seem that becoming confident in BLOS usage of drones could push the advantages in their favour. As UAVs gain prominence and more capabilities, future regulatory changes could pose a risk to any operator using drones for commercial purposes, although what these changes could be are unknown.

The number of projects requiring greater than 20 km of corridor survey is assumed to be in the minority rather than majority although, if 20 km is the break-even point then this would reduce the number of viable projects that a UAV could be used for, but it is unknown by how much. In terms of the power line industry, transmission lines are almost always going to be longer than this however, it doesn't mean that UAVs could not still be used for short sections. It would mean that they would not be used for an entire line survey. The outcome from this could be that manned aircraft would continue to be used for whole network modelling, but UAVs could be used for small sections that have been damaged, need updating, or need to be assessed.

4. ACCURACY

When mapping or modelling, accuracy is important because it will facilitate better and more accurate design, perhaps eliminating the need for large tolerances. In mapping this could mean accurately locating boundaries which could then mean assets (such as roading, power infrastructure, or buildings) are less likely to be placed in the wrong location or encroach on other's land. Regarding power line modelling, it allows confidence when determining clearances to objects, or in determining loads and distortions of structures, amongst other things. This part will focus mainly on the what (i.e. how accurate) rather than the how (i.e. how to achieve this accuracy). It is important at some point to determine how the accuracy is achieved as it will increase the understanding of each solution's viability, but the accuracy itself is more of a driver to choosing a solution than the method of achieving it.

There are two types of accuracy of concern: relative and absolute. Absolute accuracy is how close the measured point is to a known or true position, while relative accuracy is the error in location of one point or object in relation to another. Absolute accuracy is harder to achieve due to needing very accurate location monitoring. Relative accuracy is easier to achieve as highly accurate positioning systems are not necessarily needed. Absolute accuracy would be important if combining datasets where the assets in one dataset were not captured in the other. It would allow better approximations of distances between the assets and better analysis of how they interact with each other. In something such as transmission line modelling, absolute accuracy is of less value unless combining multiple line assets into one large model (Hosking, 2021).

As previously mentioned, LiDAR is typically much more expensive than photogrammetry so it would be easy to assume that by default it is more accurate. Whilst this can be the case, it appears to be both use case specific and highly dependent on the photogrammetry set-up used. LiDAR accuracy is commonly accepted to be around ±150mm (Oh & Lee, 2017) and this is also typical for Transpower's own surveys (Beca, 2016). This appears to be quite consistent as other results ranged from 0.11 m to 0.17 m (Polat & Uysal, 2018), 0.05m (Teng et al., 2017), 5 cm to 20 cm (Baltsavias, 1999), 0.07 m excluding outliers (Azevedo et al., 2019), and 0.08 m (Chen et al., 2018), whilst the reports on photogrammetry can vary substantially. Any future solutions adopted should aim for at least this level accuracy as it appears sufficient for most uses.

In the past, photogrammetry was noted to have low resolution (Sun et al., 2006), likely due to the cameras available. Camera development has meant that photogrammetry is now likely to achieve higher resolution (or point density) than LiDAR (Polat & Uysal, 2018). While higher resolution does not necessarily translate to higher accuracy, it will allow better detection of small objects or ground changes and so in some respect accuracy is then better because these changes are detected.

It appears that most of the research agrees that UAV photogrammetry can be as accurate as LiDAR but not all agree on the exact accuracy, and it likely is highly dependent on the configuration of UAV/camera/ground control points (GCP)/base station used. Some estimate the vertical accuracy is as good as 3cm and horizontal of 1 cm (Wingtra, ND-b) while others state 6.6 cm vertical accuracy (Uysal et al., 2015), 4 cm (Elkhrachy, 2021), or 1 inch (Logan Campbell, 2018), all for ground data. For power lines the results vary greatly with some being 3.9 cm to 6.2 cm (Oh & Lee, 2017), or even as poor as 0.5 m (Zhang et al., 2017). It is, however, universally agreed that photogrammetry is the more cost-effective option given that the right data collection circumstances are met.

Wingtra, a fixed wing UAV manufacturer, solely produces UAVs that utilise photogrammetry. While they are likely somewhat biased in the information that they provide due to wanting to sell their equipment, it does appear to be impartial when comparing photogrammetry to manned and unmanned LiDAR surveys. Their results generally follow the findings of other research in that photogrammetry has higher resolution, as good or better accuracy, is cheaper, but also lacks penetration capabilities (Wingtra, ND-a), although the differences appear to be exaggerated when compared with other studies.

Photogrammetry accuracy seems to depend on a number of factors – although most of them appear easy to overcome. The camera obviously has a large role in overall accuracy. Things to be taken into account are: shutter type (global vs rolling) (Logan Campbell, 2018), number of pixels (affecting resolution), pixel pitch (Oh & Lee, 2017) and sensor size (Michez et al., 2020). Rolling shutter records line by line rather than the entire image at once. This can lead to distortion in images where movement occurs – which would limit speed at which an aircraft can be flown. Other things include the use of base stations for more accurate positioning, if needed. The use of ground control points can also greatly improve accuracy with the optimum appearing to be at least 5 (Day et al., 2016), although the use of GCPs partially eliminates one of the advantages of using aerial approaches, namely, the need to access a site.

5. COST

There are many potential costs to be considered when undertaking commercial UAV usage. This includes but is not limited to: initial outlay for the equipment, training, maintenance and calibration, software, wages/salary, potential downtime, licensing, insurances, and upgrades.

It has proven difficult to find information regarding cost comparisons for more than just equipment cost. It is possible that there are just too many variables to accurately assess costs across a wide range of uses and equipment, and so much of the literature makes broad, sweeping statements about the costs, particularly between LiDAR and photogrammetry.

UAV LiDAR has been shown to be cost comparable with manned LiDAR at $8.12 USD per acre versus $8.09 USD per acre (McClelland et al., 2018), but it is assumed that this is for a specific size of area captured and it is unclear how the costs are affected for larger or smaller areas. It is noted that there are high mobilisation costs for manned aircraft and this likely means that small scale surveys are much more cost-effective for UAVs.

A high-end photogrammetry system may cost $20,000 - $30,000 USD whereas a LiDAR sensor alone may cost $100,000 USD (Wingtra, 2021), although drones with cameras can cost as little as $1,500 USD (Logan Campbell, 2018). There is evidence that the low-cost drones are adequate. Other LiDAR sensors such as DJI's Zenmuse L1 cost only USD $13,000 plus another $10,000 for the drone, this would make it highly competitive with or even preferable to high-end photogrammetry if the accuracy requirements can still be met.

Investigation will be needed to gauge financial viability, but it is currently unclear what this would look like. It may be solely down to cost per area for a given accuracy, but it is likely to need to consider many more variables and possibly include some subjective decision making.

6. USES

UAV LiDAR and UAV photogrammetry have similar use cases. They can both be used for forestry (Moe et al., 2020), mapping (Fagerman, 2019) (Mostafa, 2017), used in 3D elevation models (Polat & Uysal, 2018), agriculture, autonomous vehicles (Velodyne Lidar, ND), and more. Furthermore, LiDAR can be used for mapping underwater or pollution monitoring (Xian et al., 2020). The relevant area to this project is use with power lines and ground surveying. Use with power lines appears to be a relatively unknown area for photogrammetry and results seem to vary substantially however, LiDAR's use and effectiveness for detecting power line positions has been well established for some time.

6.1. USE WITH POWERLINES

Power line surveying is one of the main use cases for aerial laser surveying (ALS) or LiDAR (Baltsavias, 1999), especially where objects would be difficult to see with optical applications. Given that UAVs can now be programmed to fly specific routes and photos can automatically be shot, it is an area in which recent research suggests is feasible for use.

Within New Zealand LiDAR has been a solution used by Transpower to collect data on their powerlines since 2000 (Strata Energy, 2009). It was used to as a tool to identify where thermal upgrades could be applied to the transmission network. It was and continues to be used to gather accurate location data that can assist with determining clearances to ground, nearby obstacles (Power Systems Consultants, 2003), vegetation, internal clearances (i.e. wire to structure), to help with reconfiguring or connecting new lines, to make loading assessments, and make decisions based on all of the previous findings (Hosking, 2021). A number of other lines companies – Westpower (Westpower, 2012), Aurora (Aurora Energy, 2020), and PowerCo (PowerCo, ND) have also used the technology to help manage their assets, and so the use of LiDAR is well established and proven as an effective tool.

It is important to note based on the published information that all these cases used LiDAR systems on manned aircraft, whether it be helicopters or aeroplanes. This would make sense based on the notion that a 20 km – 40 km corridor length is the break-even point for switching from UAV to manned aircraft, and the fact that UAVs have only recently gained prominence, as transmission and distribution lines can be many hundreds of kilometres in length.

It is clear based on the previous information that photogrammetric techniques are more than suitable if the proposed use cases only require ground information and no power line location as they can be highly accurate – this could be for preliminary or proof-of-concept studies where design is required, rather than asset management. Clearance to vegetation is also a use case that would work (Moe et al., 2020) unless ground data beneath the vegetation was needed as it has limited penetration capability.

As with LiDAR, the following use cases can be applied to UAV photogrammetry for power lines: corridor and vegetation clearance (Sun et al., 2006) (Pastucha et al., 2020), 3d model reconstruction (Jiang & Jiang, 2019), and clearance determination.

The use of photogrammetry to directly determine the power line location for studies on loading or clearances appears to be only a recently studied phenomenon. When compared with total station and terrestrial laser scanning, one study showed the UAV provided results in which the wires were consistently above the positions generated with both terrestrial laser scanning and total stations (Pastucha et al., 2020) but the values were able to get within 15cm for medium voltage and 30cm for a high voltage of 400kV. The high-voltage survey was also flown at over double the altitude of the medium-voltage one, which could be a reason for the results difference. Another reason could be that the sections were not surveyed under the same weather conditions. This could easily lead to differing values of actual location due to different temperatures altering sag in the line. The field surveys using a total station and terrestrial laser scanning were completed over four days where weather conditions differed greatly whilst the aerial surveys took only four hours each. This is further evidence of the benefit of these systems, given that the accuracy is adequate. The results appear comparable to the ALS results. The issue is with difficulty seeing the lines (Sun et al., 2006) which then means post processing may also require manual user adjustments to find poles, fit catenary curves, and adjust images to make the lines more visible. Another study concluded that the differences generated were between 4cm and 6.2cm to those generated from a total station survey (Oh & Lee, 2017) using a low cost DJI Phantom 4 drone. Given that some accuracies are reported closer to 0.5m (Zhang et al., 2017), which would not be acceptable, these results are promising, especially considering that 0.15m is the standard for LiDAR.

It can be deduced that LiDAR UAVs would be an acceptable solution for short corridor sections, but photogrammetric techniques still appear dubious due to possibly needing manual inputs (Pastucha et al., 2020) or image altering algorithms to be able to see the wires, unless conditions are perfect. It is also not clear – partly due to the apparent lack of literature – whether different processes would need to be followed for different types of power line. For example: large, high voltage, high power capacity transmission lines will use much larger diameter wires than low voltage or low power distribution lines and so the solution may need to be tailored.

Transpower have noted that UAVs are unlikely to cause physical damage to their assets but do pose a risk to the power system (Transpower, 2017). The drones can get caught in the wires meaning that the transmission line may need to be switched to a safe state or removed from service in order to retrieve it. This is not ideal and finding ways, both processes and technical, of maintaining clearance will be essential to any drone operations involving the lines, from both a network and corporate point-of-view.

7. MATURITY

As of 2021, both LiDAR and photogrammetric systems in general are at a high level of technology maturity. Their use and accuracy is both well established and proven for many use cases. This is obvious for a number of reasons. Several of the references used are over 20 years old and even at the time appeared to be reaching an acceptable level of maturity (Baltsavias, 1999). Also evident is the fact that many companies with critical assets have used or continue to use these systems, particularly LiDAR, to create models of their assets. All of the power line companies mentioned have recently used or plan to use remote sensing in the management and design of their assets. It is not clear if any of these companies plan to use unmanned LiDAR in the future.

Alternatively, using LiDAR and photogrammetry with UAVs and drones is currently at a relatively low level of maturity. This is evident in the fact that most of the literature sourced is recent (within 5-6 years). There is still enough information to prove each methods applicability, accuracy, and reliability, although the results for photogrammetry vary. Whilst LiDAR sensors for drones have been available for some time DJI, the world's largest drone manufacturer, has only recently (2020) released its own integrated solution. This is likely to make LiDAR a much more appealing solution as it will likely be easier to use, less complex, and cheaper.

8. LIMITATIONS

Limitations of UAV LiDAR and photogrammetry can be categorised in three ways:

1. Technical/technological limitations
2. Regulatory limitations
3. Corporate limitations

8.1. TECHNICAL LIMITATIONS

Both UAV LiDAR and UAV photogrammetry have technical limitations. The UAVs are limited by the weather conditions that they can fly in while maintaining safe operating procedures. This means that choosing a UAV that can operate under a wide variety of conditions is important. They are also affected by the speed they can fly, and they have a limited range per flight due to their small battery size.

With photogrammetry the technical limitations lie largely in the camera equipment. As mentioned, the camera must be able to see the object(s) or ground intended to be surveyed. For this to happen good lighting is needed and ideally ground sample distance (GSD) should be small enough to capture the object. GSD is the physical distance that the centre-centre distance between two pixels represents in the photos (Propeller Aero, 2021). It is effectively the resolution of the image but is affected by the height above ground that the drone flies, focal length (Oh & Lee, 2017), sensor size (Elkhrachy, 2021), and overall resolution. In order to ensure and consistently obtain conductor in the photos, the ground sample distance should be lower than the conductor diameter (Pastucha et al., 2020), although due to their continuity, having a GSD slightly larger than the conductor diameter does still generally allow their location to be determined (Oh & Lee, 2017). A typical range of conductors may be anywhere between 8mm and 40mm. While it is possible to tailor the GSD by altering flight height or focal length, it is important to get equipment capable in the first place. On top of this, there are requirements for good weather and illumination.

LiDAR has much fewer limitations. It needs high accuracy navigation to precisely determine the location of an object, is complex, and most importantly, it's expensive. A lot of LiDAR systems have cameras integrated as this allows features to be matched and makes LiDAR overall more useful.

8.2. REGULATORY LIMITATIONS

Operators must adhere to rules set by the Civil Aviation Authority (CAA). The CAA is the agency responsible for establishing, maintaining, and monitoring aviation safety and security standards within New Zealand. There are two main parts of the CAA's that code relate to the use of unmanned aircraft – parts 101 and 102.

Part 101 lists rules that must be adhered to, unless authorised under part 102. There are many rules under Part 101 that could limit the feasibility of Lumen undertaking UAV surveying operations. They dictate allowable height above the ground at 120m – although based on other research this should be adequate for data collection, that the operator must retain visual line of sight to the aircraft – this could limit it if large areas are needed, obtain consent from property owners or people who are being flown over, and not operate aircraft greater than 25kg (CAA, 2021). The biggest barrier here is obtaining consent as it will likely be a time intensive and therefore costly part of an operation.

The restrictions stipulated in Part 101 can largely be circumnavigated by an operator possessing a Part 102 certification. To gain this certification operators must prove that when operating outside of the rules of Part 101 they can manage the risks and ensure safety is maintained. They will have to show that they understand the risks involved, demonstrate procedures, provide specifications of the aircraft, and more (CAA, 2015). By developing robust processes and gaining experience under Part 101 beforehand, this appears highly achievable to acquire. The main benefits of this are the ability for beyond line-of-sight flight meaning that larger areas can be surveyed much quicker, and that consent is not necessarily required – although it would likely be wise to still acquire it where feasible.

Further consideration shall be taken at a later stage, but it is important to acknowledge the role these legal requirements play in limiting any potential UAV operations, and to consider possible future changes to the regulations.

8.3. CORPORATE LIMITATIONS

In addition to the legal requirements, it is important to seek out rules and regulations relating to other stakeholders regarding the use of unmanned aircraft. It is possible that asset owners may prohibit the use of UAVs near their assets, or they may require very strict controls over processes. For example, as of 2017 Transpower would only consider operations that meet CAA part 101, meaning that things such as beyond line-of-sight use would not be allowed (Transpower, 2017). This would immediately rule out large corridor sections. They also required detailed mission planning, operators to be members of the UAVNZ group, pilots must have had at least 50 hours of experience, and more. It is important that these types of limitations are thoroughly investigated prior to any engagements as they could limit or derail operations from the outset.

9. DISCUSSION AND OUTCOMES

Most of the information found and used for this literature review is relevant to the rest of the project, particularly the next stage – which is a technology review. The impact of legal limitations defined by CAA parts 101 and 102 will be further developed later in the project, as will the corporate limitations – as it becomes more evident what and where the technology will become applicable or useable to Lumen. The technology review and this literature review do not intend to analyse the specifics of making each technology work, rather, it is about the use cases applicable to Lumen, and how and where each application could fit into current operations. It is then about weighing up the benefits and drawbacks of each in a practical way.

Most of the reviewed literature was recently published (within 5 years), especially regarding use with UAVs. It is likely also a sign that these specific applications of LiDAR and photogrammetry are at a relatively low state of maturity, although they have clearly been demonstrated to work as well or perform closely with manned aircraft-based systems – perhaps even better due to the proximity in which they can approach. The prevalence of drone use has increased substantially in recent years as commercially available systems have come to the market. This is what has likely triggered the increased pace of research and the comparisons between both UAV systems.

It is clear from the studies that UAV LiDAR and photogrammetry are more-than-capable solutions for creating ground profiles or for corridor mapping, although whether they are the best solution is largely going to be dependent on the scale of data needed and the specific application required. It is also clear that both UAV LiDAR and UAV photogrammetry can be acceptable solutions for 3D powerline reconstruction and modelling, although it appears that LiDAR has been the preferred and more reliable option historically. Whether the attractive price of photogrammetry, or future technical improvements can increase the prominence remains to be seen. It appears to be an area where research is and will continue to take place, particularly in China. Whether the New Zealand context would change anything is unknown, although it seems unlikely.

As mentioned, LiDAR is expensive and complex. While the addition of fully integrated UAV LiDAR systems is highly likely to drive complexity down, it is probably some time off from being price competitive with some photogrammetry systems. Very high-end cameras and drones can cost as much as some of the cheaper LiDAR systems (around $30,000), but these are by no means cheap. For a company that may be weary of moving into this space, a company that may expect low utilisation, or a risk-averse company, this initial outset may be enough to halt any further plans.

One of the questions needing to be answered is whether low-cost drones ($1000-$4000) would be able to either undertake ground-only surveying, or power line extraction. Initially the results seem promising for both use-cases and especially for ground only surveying. Most of the studies mention the substantially lower cost of photogrammetry but do not explicitly state the costs involved, although one was explicit in that a DJI phantom 4 ($2399 AUD) was used and provided good results. On the whole this make it somewhat difficult to properly gauge the performance in relation to the costs, but if that study is correct then it bodes well for photogrammetry. Of course, it would be easy to recommend using Wingtra's very high specification drone and camera set up but this would cost in the region of $25,000 USD and at that point it may be the wiser decision to buy DJI's LIDAR system as it is approximately the same price, given that LiDAR is a far more proven technology in regard to power line extraction.

Lumen has multiple low-cost drones and so some form of verification of the noted results would go a long way in determining if they are suitable for either application. The right technology to use will become clearer as the use case(s) become more defined, while it is also highly dependent on the specifications needed and the outputs wanted.

Out of this literature review comes the following questions:

- What are the most likely applications? (i.e. full survey including the power lines, corridor mapping for future designs/concept designs, surveying short vs. long sections, surveys for underclearance assessments)
- What are the requirements for accuracy? (Absolute accuracy, relative accuracy, horizontal, vertical)
    - What are the specifications needed to meet these requirements?
- What does financial viability look like?
    - Does it mean making a profit from the use of the technology alone, winning jobs that may not have been awarded without the extra capabilities generated, or taking bigger roles in projects and therefore generating more revenue?
- What are the companies for whom Lumen works' requirements?
- What are the constraints that will determine the best technology or approach?

Ultimately, the decision of whether to use either of these solutions comes down to two factors: whether the job can be completed to the required specification, and cost. In deciding whether to use either UAV LiDAR or photogrammetry, specific criteria must be determined. The criteria will largely consist of accuracy for a given cost, and whether technical requirements are able to be met.

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3. METHOD

To be able to understand the outcomes possible and how to achieve them, the following steps were taken:

This project was split into three main sections:

1. Technology assessment
2. A compliance assessment
3. Financial assessment

The technology assessment was about determining the technical capability of Lumen's hardware and how it compares to other survey methods. To achieve this, the following steps were taken:

1. High-level drone training was performed
2. Basic testing and determination of each step of the photogrammetry process was performed
    a. Each test had additional components allowing for competency to be built and established
3. A suitable site was established that allowed high quality comparisons with other survey methods
4. Determine the key metrics
5. Test data process
    a. Variables altered one-by-one to assess the impact
    b. Export data
6. Comparison of export data to known data sets
7. Assess the data against the other datasets via some key metrics
8. Determine the weaknesses of current hardware and steps taken to improve it

It was necessary to analysis this section in unison as it was subject that determined the overall direction of the project. This stage was performed using the DMAIC process of Define, Measure, Analyse, Improve, and Control. The metrics were first defined. Then the tests were performed. Then the comparisons were then made. Then site plans, flight procedures or processes were altered. Finally these values were established as controls.

The compliance assessment was about understanding the risks, restrictions, and rules. It involved the following steps:

1. Research into the overarching UAV requirements
2. Consultation and interviews with training providers, council representatives, and client representatives to understand their need and requirements
3. Analysis of the constrains, risks, and opportunities to determine how Lumen
4. A risk matrix was performed to visualise the contextual restraints

This section needed to be assessed as it would bring greater context to the overall operating environment and allow for analysis of the opportunities and risks.

The financial assessment was about determining the cost implications to both Lumen and to clients. To do this, the following steps were taken:

1. Liaison with external clients and service providers to gather price information
2. Extrapolation of data using the variables determined to analyse approximate costs of other methods
3. Cost approximation for Lumen to perform a survey, based on testing experience
4. An NPV analysis, opportunity cost analysis, and analysis of the overall costs compared to other methods

Upon summarising this section, it was then possible to make overarching conclusions for the entire project.

4. TECHNOLOGY REPORT

4.1. INTRODUCTION

The purpose of this section is to determine if Lumen can use a DJI Mavic Air or Mavic 2 Zoom to provide a survey service using photogrammetry.

To facilitate high quality engineering for overhead line design, survey data of ground or assets must be acquired. For the most part, this is acquired by either traditional surveying or with manned aircraft LiDAR.

The survey data generated from each of these varies substantially, and each has its own place in the market. For example, traditional surveying is normally used by companies who may lack major budgets for their line design or upgrade, whilst LiDAR has been used by companies such as Transpower (Transpower, N.D.) with extensive and critical asset systems.

In addition, the outputs of each survey method differ. Traditional surveying provides very spare datasets which is good mainly for specific points requiring very high accuracy, above ground objects that are low in quantity, or small ground survey areas.

Manned LiDAR is used where high accuracy, high data density, and speed over a large area is needed. Because manned LiDAR is performed from fixed or rotor wing aircraft, it can gather data over many 10's or 100's (Wingtra, 2021) of square kilometres per flight, whereas traditional surveying may be able to capture data over 1-2 kilometres per day (Resonant Surveyors, 2020) at the required minimum density. The other difference is that due to the equipment used, manned LiDAR is very expensive and benefits greatly from economies of scale. It is only financially viable over large survey areas, whilst traditional surveying is slow so only viable for small areas.

Recent technological developments mean that the gap between traditional surveying and manned LiDAR is able to be filled by either UAV LiDAR or UAV photogrammetry. UAVs are an emerging technology and are able to fill this gap as they can perform surveys over large areas quickly, but cost substantially less to acquire and operate than manned aircraft. UAV LiDAR is a bespoke technology that while cheaper than manned LiDAR, still requires significant investment. Photogrammetry only requires a camera and some software and most current UAVs already have cameras onboard.

Lumen has two low-cost drones with onboard cameras, the DJI Mavic Air and Mavic 2 Zoom, and needs to determine if they can be used for surveying purposes. These are not typical photogrammetry drones so their capability is not well understood. In addition, photogrammetry for transmission line surveys is an emerging area of research and also not currently well understood. Finally, Lumen has no prior experience with photogrammetry so needs to understand the methods to make it work.

This report aims to answer the following questions:

- Can Lumen utilise its current drones for surveying via photogrammetry?
    - If so, how?
- Is there anything it can do to improve the outputs?
- How does it compare to the alternative survey methods?

This outcome of this section is important because it effectively guides the rest of the report and helps to determine the direction that the project takes. It is critical to understand if or why variables may need to be altered and how.

By providing a new service, Lumen is already pushing the bounds of its professional competencies and it must determine a way that the process can be performed to generate acceptable results.

LUMEN

Engineering for
a better future

UAV Surveying Technology Report

Photogrammetry and A Comparison with Other Survey Methods

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January 2022

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REVISION HISTORY

REVISION	DATE	DESCRIPTION	PREPARED BY	REVIEWED BY
0.1	15/11/2021	First draft and notes	Tom Savage	N/A
0.2	27/12/2021	Second draft, outputs updated, comparisons created, all relevant information added	Tom Savage	N/A
0.3	19/01/2022	Draft for review, for comment	Tom Savage	DT, PG
0.4	25/01/2022	Final draft incorporating comments	Tom Savage	-
1.0	25/01/2022	Version 1	Tom Savage	-

28/01/2022

CONTENTS

EXECUTIVE SUMMARY

Lumen has a need to obtain high-quality survey data for its overhead line design projects and has determined a possible opportunity. UAVs can be used with photogrammetry to undertake surveys and create 3-dimensional models for design. Lumen currently has two UAVs available for use and wishes to know if or how they could be used for this purpose.

Lumen's position means that if possible, it could use these drones for surveys of its overhead line projects, particularly ones where timeframes are critical or where supplementary data is needed. It would understand the job context better than a surveyor so could provide certain advantages. Lumen would know what aspects are critical to achieving high quality results and therefore could eliminate any errors that may occur when engaging surveyors – reducing the need for rework. It would also give Lumen more control of the design processes, which could mean better, more efficient design for both Lumen and the client.

The purpose of this report was to determine if the UAVs that Lumen currently owns can be used to perform adequately accurate surveys using photogrammetry, how to achieve the results, and how they compare to other survey methods. A number of on-site tests were conducted and the following conclusions were formed:

- Lumen's UAVs can produce adequate survey data good enough for design. The data is both accurate and dense but it requires a highly specific process to achieve this
- Both UAVs produce adequate results but the DJI Mavic Air should not be used as it has poor battery life and positioning systems. This means that extra time is needed in both the flight phase and processing phase
- The results generated were within the specifications provided by LiDAR operators and are largely comparable

To achieve these results specific processes had to be followed. Optimising factors such as ground control points, flight heights of 60-70 m or less, camera shutter speed, flight speed, and more were required.

The tests performed were under less-than-ideal conditions and can be assumed to be a worst case. The accuracy achieved using the selected settings was consistently around 6 cm.

The Mavic 2 Zoom is recommended over the Mavic Air as it has much better battery life. In addition, Lumen should consider buying another drone such as the DJI Phantom 4 Pro or Mavic 3 as every aspect of their performance will be better than the current drones. The Mavic 3 is recommended the most as it has a larger battery life but, as it is newly released it does not yet work with the flight planning software. Lumen should wait for it to work before investing. It will also provide some redundancy if they are needed in other areas of the business.

The following table provides a summary Lumen's photogrammetry and how it compares to other survey techniques:

Table 1: Technology Overview

Tech	Deployment	Typical accuracy	Typical survey density	Mobilisation cost	Safety risks	Training requirements (to Lumen)
UAV Photogrammetry	UAV	60-100 mm	H	L	M	H
LINZ LiDAR	Office (LINZ)	±200 mm V, ±1000 mm H (specification) 100 mm expected	M	L	L	L
UAV LiDAR	UAV	150 mm specified <30 mm expected	H	M	M	N/A
Manned LiDAR	Fixed wing, helicopter	150 mm specified <40 mm expected	M	H	H	N/A
Traditional Survey	Walking	<3 mm if required	L	L	L	N/A

The table shows that the results are comparable to other methods. Using the results of the testing, the following

recommendations were generated:

Table 2: Technology Section Recommendations

Recommendation	Person(s) Responsible	When by
Offer service using the Mavic 2 Zoom.	Team Managers	Immediately, until an upgrade is bought.
Consider a Mavic 3 drone investment	Team Managers	When it works with flight planning software
Use DroneDeploy for flight planning.	Operator	When a survey is performed
Use DroneDeploy if only ground data is needed, Metashape for sites requiring wires and attachment points.	Operator	Decide based on survey requirements
Determine which of the flight paths in section 3 is used primarily based on time (from 2-4). Each subsequent type should produce higher certainty of obtaining adequate results.	Operator	Decide based on survey requirements
Finalise photogrammetry procedure	Tom Savage	March 2022

1. INTRODUCTION

Power line assets are critical in facilitating almost all aspects of modern life therefore, it is essential to ensure that design and maintenance are carried out effectively. To carry out effective design and maintenance data must be collected on the asset and/or surrounding area. Typically, this has been carried out in two ways – traditional surveying techniques, and manned aircraft Light Detection and Ranging (LiDAR).

Manned aircraft LiDAR has typically been reserved for surveys over very large areas 10 km^2 – 1000 km^2, and for companies with significant assets. This is because mobilisation and running costs for manned aircraft are high, as are the sensors, and it is a niche market. Despite this, the use of manned LiDAR is becoming more prevalent for smaller projects as the technology develops and it is noted that numerous lines companies have considered the use of, or used, manned LiDAR recently. Whilst manned LiDAR uptake appears to be increasing for small projects, two emerging technologies could challenge it and may be able to provide the benefits of LiDAR, with less of the drawbacks – unmanned aircraft (UAV, drone) LiDAR, and UAV photogrammetry. Manned photogrammetry is not considered as it is neither commonly used, nor can it be performed by Lumen.

Many of Lumen's lines projects, particularly in the distribution or sub-transmission space, only cover short distances or are performed over small areas. The surveys have typically been performed using traditional surveying techniques. which has time and data density constraints. These emerging technologies present an opportunity for Lumen and the client to gather data in alternate ways that could benefit all stakeholders.

The focus of this document is on the use of Lumen's current, low-cost, drones for UAV photogrammetry. There is a need to assess the capability of these drones to determine whether they could be used, and in what capacity. This report aims to collate information from field testing, research literature, manufacturer information to form a valid conclusion.

This document also focusses on the use of four survey techniques: traditional surveying, manned LiDAR, UAV LiDAR, and UAV photogrammetry, and will discuss the advantages and disadvantages of each method. It will also consider the use directly by Lumen, but as Lumen is neither a surveying company nor an aircraft company it will only be considering UAV LiDAR and photogrammetry.

The main goals of this document are:

1. To determine if the Lumen owned drones can perform surveys to the standards needed and if not, what would need to be changed to do so.
2. Establish how these drones and outputs compare to the other survey methods or better equipment.

2. Data Collection Options and Overview

This section will discuss each of the four methods and outline the advantages and disadvantages of each. It also discusses the option of Lumen performing work in-house and how it could benefit the company. The table below lists the methods considered.

Table 3: Four Survey Methods Considered

Method and Technology	Survey tech	Deployment method
Traditional Surveying	GPS or theodolite	Walking
Manned Aircraft LiDAR	LiDAR	Manned aircraft
Unmanned Aircraft LiDAR	LiDAR	UAV
Unmanned Aircraft Photogrammetry	Photogrammetry	UAV

Of the four methods, only UAV photogrammetry can currently be performed in-house – Lumen has two drones that are able to be used. To perform traditional surveying the company would need to employ surveyors and buy survey equipment which could add significant costs to the business, especially if underutilised. To perform UAV LiDAR the company would need to invest in expensive drones and LiDAR sensors.

Photogrammetry is the least understood of the four methods when referring to powerline survey and inspection and it has the least data available to verify its application. This is evident because most of the literature is recent (Jiang & Jiang, 2019) (Oh & Lee, 2017), there are few papers and websites that refer to it, and only one software package currently supports powerline detection (Agisoft, 2021). Whilst it may not be well established for powerline inspections, its capabilities for ground surveys are well established and it is known that it can generate results as good as or better than LiDAR, under ideal operating conditions (Logan Campbell, 2018).

Whilst Lumen has two drones available, they have not previously been used for photogrammetry, and it is unknown whether they are adequate, particularly as online information generally concludes that they are not due to various reasons (Pix4D, 2016). Lumen wishes to determine whether they are acceptable for photogrammetry and whether it should pursue performing surveys in-house, especially for projects where mobilisation speed is critical, or data control would lead to better outcomes. The drones available are the DJI Mavic Air and DJI Mavic 2 Zoom, and they are typically used for aerial inspections with the live video feed being reviewed in real-time. The photogrammetry sub-section will discuss these in more detail.

The deployment method used makes a substantial difference to the applicable use case for each method. Manned aircraft have substantial investment and operating costs. UAVs do still require initial investments, as does the equipment for a traditional survey but they are much smaller. Manned aircraft are quicker than UAVs and can capture data at a faster rate (Jayathunga et al., 2018). Due to the associated costs with manned aircraft, and the speed taken, they are generally used for large projects where they benefit from economies of scale (Wingtra, 2021).

2.1. TRADITIONAL SURVEY

Traditional surveying is terrestrially based and uses tools such as total stations, theodolites, and GPS receivers. Some of the data that Lumen uses is captured using this method, particularly on smaller projects for distribution companies. Recently, there has been a trend where these companies are shifting to, or at least considering alternative methods because of the value they provide (PowerCo, ND) (Westpower, 2012)– whether that is monetary or not.

On a sample project for Lumen, 3057 data points were collected over an 8 km corridor. Assuming only a 5-10 m corridor width (which is quite small) this would equate to only 0.02-0.04 points per m^2. The survey also took four days to complete, not including post-processing.

The key advantages and disadvantages of this method are:

2.1.1. Advantages

- Quickest mobilisation time
- Large market and many providers available
- They often provide additional services such as verifying boundaries and mapping
- Low risk of stakeholder complaints
- It can be the most accurate of all the methods with a point accuracy of 3 mm or better (ANZLIC Committee on Surveying & Mapping, 2014)
- Particularly useful for above ground objects such as attachment points

2.1.2. Disadvantages

- Over large sections (hundreds of metres to kilometres) it may be the slowest collection method, especially when the number of points captured is considered. For line survey this could make a big difference due to temperature differences in the conductors in the same strain sections, which could make modelling difficult
- Given the extended time to perform a survey, it may be the least cost-effective overall depending on project size, and any initial cost benefits may tend toward zero
- It creates the least dense dataset. For ground surfaces this may mean that interpolation is needed as the resolution is unlikely to be high enough to accurately identify all relevant features.
    - Due to this poor resolution the accuracy of any interpolated points may be considerably less accurate than other methods, particularly if elevation changes occur, or notable ground features are present

It is noted that the datasets have the lowest resolution of all the methods and that interpolation may be required to determine ground profiles or other features. This means that whilst the points that are surveyed are incredibly accurate, any interpolated ground between these points is essentially a guess, and it could be substantially wrong.

Typically, a surveyor will determine point locations at approximately mid-span so that conductor to ground clearances can be determined, however, if assets are being replaced or moved then these points become less useful as the ground at the new lowest conductor location is unknown and therefore clearances may be incorrectly determined. The solution would be to collect more data, but this may add time and cost in the initial phase.

[redacted]

2.2. MANNED LIDAR

Manned LiDAR is a process that uses LiDAR sensors and equipment attached to manned aircraft such as helicopters or fixed wing aircraft. Due to the nature of the equipment, it is typically performed an altitude of approximately 5,000 ft (Landpro, 2021) from fixed wing aircraft or 1000 ft using a helicopter (Transpower, N.D.). Of all the options, it can capture data at the highest rate and cover the greatest area, although there are some drawbacks associated with it. Multiple lines companies have already procured the use of this technology to help manage their assets, the most notable being Transpower. Others such as Orion, Westpower, and PowerCo have also used this technology.

Fixed wing LiDAR was used for a recent Lumen project. The route length was 15 km and approximately 118,000,000 points were captured over an area of 21,000,000 m^2, or 5.6 points per m^2. According to the ASPRS positional accuracy standard, with this point density an accuracy of between 50 and 100 mm should be expected which would align with the research literature (Polat & Uysal, 2018) (ASPRS, 2014). The error provided by the supplier was 30 mm, although this is applied to the ground control points (GCP) and it is unknown what confidence interval was used. It must be taken at face value and assumed to be correct.

In Transpower's specification a relative error of 150 mm (Beca, 2016) between any two points is allowed for, and the research literature showed that it is likely to range from 50-150 mm (Oh & Lee, 2017). The New Zealand National Aerial LiDAR Base Specification, which applies to government and council funded free-to-use LiDAR (available on the LINZ website), requires a minimum accuracy of ±200 mm vertically or ±1000 mm horizontally with a 95% confidence interval (Land Information New Zealand, 2021).

2.2.1. Advantages

- Least disruptive to ground operations
- Highest capture rate
- Largest survey area per flight
- Relatively dense point cloud
- Well established and has been used by the transmission line industry for 20 years
- Good vegetation penetration

2.2.2. Disadvantages

- Highest safety risks
- Depending on workflow and required outputs, the least accurate of the four methods (although still high accuracy)
- Requires bespoke, expensive equipment
- Only viable for large areas
- Requires trained professionals

The LiDAR survey mentioned had a notable lack of conductor points captured. For this project, it did not prevent poor outcomes as most of the line was due to be replaced but if the project required different outcomes, this data would have proved substandard.

2.2.3. LINZ Manned LiDAR

The National Elevation Program aims to collect and collate high accuracy elevation datasets for much of New Zealand. To do so it uses manned LiDAR and is governed by The New Zealand National Aerial LiDAR Base Specification mentioned above. When available, the data can be found on Land Information New Zealand's (LINZ) website. LINZ plan to release this high-resolution elevation data of much of New Zealand to the public, for free. It aims to have 80% of New Zealand surveyed and the data available by 2024 (Land Information New Zealand, N.D.).

Main centres such as Auckland, Wellington, and Christchurch already have elevation data available which Lumen has used successfully for several projects.

The data is highly accurate and often of a density adequate for Lumen's uses. When much of the country's data is available it is possible that Lumen could forgo the use of surveyors, LiDAR providers, and photogrammetry entirely if the data is good enough.

2.3. UNMANNED LIDAR

Unmanned LiDAR is a process that uses LiDAR sensors attached to UAVs. Unlike manned LiDAR it is typically performed at altitudes up to 120 m, but this can vary significantly. Whilst the sensors are not as powerful as the sensors for manned LiDAR, their primary advantages are that they are much cheaper to buy, mobilise, and operate. UAV LiDAR surveys provide higher resolution and may provide a higher accuracy than their manned counterparts (Young, 2018). The downsides are that the distances over which they can be used are much smaller due to both battery and platform constraints as well as legal constraints. Rarely can UAVs be operated at beyond line-of-sight within New Zealand, so they are limited to line-of-sight or extended line-of-sight flights – which limits the flight length significantly. It may also be difficult to gain clearance to work near or within road corridors, or over public and private land. UAV LiDAR is likely to be a more cost-effective solution than manned LiDAR up to corridors of approximately 10-15 km or areas of 10 km^2 according to some studies (Wingtra, 2021).

Unmanned LiDAR has not been used in any of Lumen's previous projects but when quoted, one provider indicated that accuracy would be in the range of 30-50 mm and the point density would be 4-5x higher than manned LiDAR however (Fox, 2021), the documentation provided only suggested an accuracy of 150 mm, as is the case with manned LiDAR.

If Lumen decides that one day it wishes to operate UAV LiDAR it must recognise how the equipment manufacturers quote accuracy. Some systems claim accuracy of 10 mm (Riegl RiCopter) (Riegl, N.D.), while others claim 5-10 cm (DJI, N.D.). It will largely depend on how much is willing to be spent, and the processes used to achieve this, but it is assumed that the 5-10 cm accuracy is standard and for Lumen's purpose is more than good enough. If buying UAV LiDAR equipment, it is important to note that there are distinctions between the accuracy quoted and actual expected accuracy. For example, DJI quote system accuracy of 5-10 cm which can be assumed to mean the actual accuracy. Others such as Reigl quote positioning accuracy of the drone and ranging accuracy of the laser/LiDAR unit which means that the actual expected accuracy is unknown but is likely to be the sum of these. It is also important to note that achieving the best results requires that camera equipment is also used to provide some context to the point cloud.

It is possible that it could be used as an intermediate step between traditional surveying and manned LiDAR.

2.3.1. Advantages

- Cheaper than manned aircraft to own and operate
- It is an area Lumen could operate, if it wished
- Can service more areas than terrestrial solutions (although less than manned aircraft)
- Higher resolution and accuracy than manned LiDAR
- Live point cloud can be displayed in the app, allowing for better capture of tricky sites and <u>less</u> processing. Quickest processing time
- Good vegetation penetration
- Can be performed without disrupting <u>most</u> ground operations

2.3.2. Disadvantages

- Drones and equipment still require a significant investment, unlikely to be cost effective for occasional use
- May not be able to service all areas that manned aircraft can (i.e. very hard to reach locations)
- Cannot service as large areas as manned aircraft
- If operated by Lumen it would require a lengthy training programme and likely not viable unless additional compliance is sought (i.e. CAA Part 102)
- Lower accuracy than normal surveying and potentially lower than photogrammetry
- Processing more difficult than photogrammetry and requires more experience (more difficult to process, does not necessarily mean there is more required)

2.4. UNMANNED PHOTOGRAMMETRY

Photogrammetry is the process of taking many overlapping images and using software to create 3-dimensional point clouds. A point cloud is a set data points in space that represent the 3D location of an object. Its main applications are in mapping, vegetation management, and surveying. The outputs are similar to those created using LiDAR. When compared to LiDAR, it is lower cost and easier to apply. As all LiDAR equipment is expensive it is expected that regardless of which sensors are used, it will provide adequate results whereas with photogrammetry this is not necessarily the case. The outcomes are heavily dependent on numerous factors such as the camera resolution, shutter type, positioning system, vegetation cover, as well as non-equipment related characteristics such as flight path (see section 3), and altitude.

Photogrammetry appears to provide the best of both traditional surveying and LiDAR. Under ideal conditions (good lighting, little vegetation, good camera system and positioning system) it can have very high accuracy), although in areas with complex topography or vegetation this very quickly rises to 1.8-18 cm (mean of 6.7 cm) (Uysal et al., 2015) (Elkhrachy, 2021) (Logan Campbell, 2018).

Whilst photogrammetry can be performed by anyone, it also appears to have the most compromises of any other method. For example, altitude may have to be lowered if using a low-resolution camera, which then means that the survey area per flight decreases due to battery limitations.

The main advantages and disadvantages are as follows:

2.4.1. Advantages

- Highest point density
- Can be performed without disrupting most ground operations
- Full colour model
- Good for areas not serviceable using terrestrial surveying
- Potential for accuracy greater than LiDAR
- Surveys much quicker than normal surveying, and can be quicker than UAV LiDAR, although slower than manned LiDAR
- Data can be reprocessed if additional information is required
- Cheapest and easiest market entry out of all options
- Easy to learn and understand
- Can be mobilised very quickly provided permission is granted

2.4.2. Disadvantages

- Relies on being able to “see” objects. This means that poor exposure or contrast between objects may make detection difficult. It needs adequate lighting sources. Things such as snow or fog would make the survey difficult
- Uniform textures may make point matching difficult
- Cannot reliably penetrate vegetation. If there are trees or hedges for much of the survey, then ground may not be detected
- Not well established for powerline reconstruction and surveying
- May require additional processing depending on equipment used
- Accuracy linked to flight height
- Strict rules around drone use will limit its application in urban areas
- Lower wind limitations

2.4.3. Lumen Drones

Lumen currently has two drones available. They are the DJI Mavic Air and DJI Mavic 2 Zoom. These are both consumer level drones, but the Mavic 2 Zoom is much newer and has additional capabilities such as greater flight time and a zoom camera. A large portion of this report centres around determining whether they are adequate for what the company wishes to achieve – high accuracy, quick surveys using photogrammetry.

They are not typically used for this purpose so it is important to understand the limitations and how they could affect outcomes.

Both of these cameras have electronic rolling shutters. That is, a shutter that exposes and reads the image line-by-line. These types of shutters are generally used in low-cost camera equipment and are not typically used for photogrammetry because the combination of a rolling shutter and camera movement can introduce artifacts and distortion into the images (Pix4D, 2016a). It must be determined how this affects the outputs. In addition to this, each has a relatively poor on-board positioning system which makes accurate georeferencing impossible without additional processes and may also affect output quality. Both drones have integrated 12-megapixel resolution cameras.

The drones differ in that the Mavic 2 Zoom has zoom capabilities and approximately 50% longer battery life. Assuming a requirement to land with approximately 20% battery to avoid any safety issues, and accounting for battery used to start and end a mission, the Mavic Air has a useable flight time of 12.6 to 14.7 minutes while the Mavic 2 Zoom has 20.7-22.8 minutes. The limitations caused by these short flight times are discussed later. It is also important to note the differences or advantages that equipment upgrades can bring.

If Lumen wished it could undertake UAV LiDAR surveys, but this would require significant investment whereas UAV photogrammetry may not require much. This will be considered mainly during the financial analysis, but the results of the comparisons here will be taken into account.

2.5. CONSIDERATIONS

If Lumen were to perform its own survey it should be able to demonstrate that it has an inherent advantage of some form. The obvious advantage is that Lumen understands the line project context so knows what is important to survey. It would also be able to mobilise rapidly to ensure deadlines are met if the schedule is tight. It would also gain more control over the design process. The outcome of this should be better and quicker design as there would be less need to liaise with surveyors or other external parties. It would also be an opportunity to further develop client relationships as the engineers would be part of the design process from the start. It could eliminate some communication issues that may typically arise with surveyors. For example, a surveyor may not know the caveats of line design and could miss important and useful information, which would create rework and more expense for the client.

The main downside is that if a design was performed poorly due to a survey error, Lumen would be liable for the cost to fix it whereas it may not necessarily be currently. The other downside is that current rules regulations are restrictive and may limit the useable scope.

3. PHOTOGRAMMETRY TEST METHODOLOGY

This section outlines the method for testing the drones' accuracy, and outputs. This is not the full testing procedure but is the one that produced the final results. Additional testing took place prior to choosing this exact method. It involved testing various image overlap settings, flight heights, and flight speed. It also tested various camera settings – both automatic and manual modes. When using automatic modes, the tendency was for the drone to use a low shutter speed which meant that there was image blur in the photos and would make matching more difficult. It didn't necessarily produce poorer results, but the likelihood that it would increase.

Part of the additional testing was due to unfamiliarity with all the processes and systems used, so involved trial and error to determine both the best steps to take and the best settings to use. This used a significant portion of time.

Firstly, a test site was chosen. [redacted]. This site was chosen due to various reasons. It had a good variety of sloping and complex terrain, as well as multiple sets of powerlines and other desirable features that allowed adequate conclusions to be reached, however, the tested area was quite small at approximately 120 m long by 80 m wide. [redacted] Even though the site was small, it was likely a site where this sort of system would perform worst [redacted] It was therefore deemed that if results were adequate in this location then it would bode well for future use. [redacted]

Secondly, the flight types to be used were determined. DroneDeploy was the flight application of choice and all available flight types were used and analysed. These were all tested independently of each other. After each flight, the drone would return to its 'home' position, the batteries were swapped, and the next test was performed. The flight types used are as below.

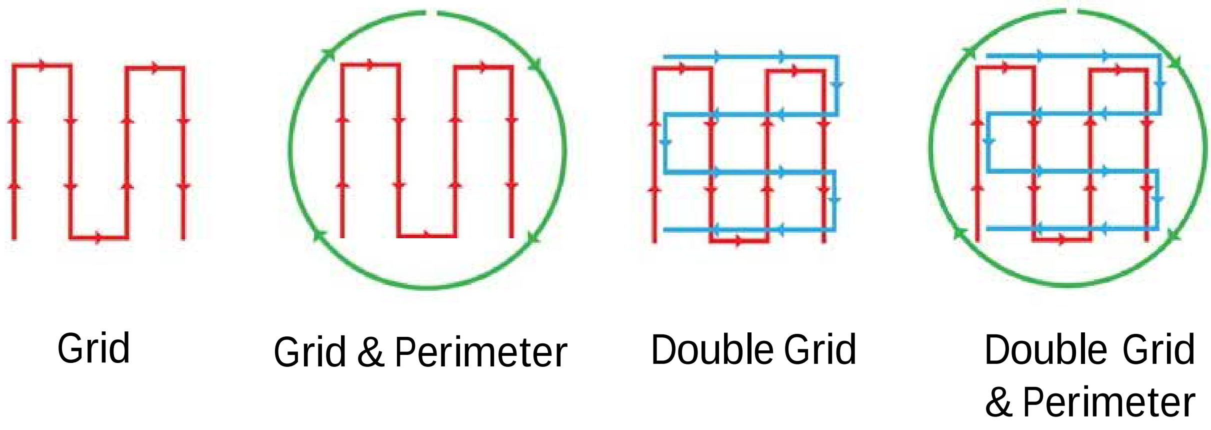

Figure 1: Drone Flight Paths Used

1. Test 1 – grid flight. Parallel flight lines capturing overlapping images. This captures nadir images only.
2. Test 2 – grid and perimeter. Parallel flight lines plus a perimeter sweep. This captures nadir images during the grid portion of the flight and oblique images during the perimeter sweep.
3. Test 3 – double grid. Two axis parallel flight lines capturing overlapping images. This captures nadir images only.
4. Test 4 – double grid and circular. Two axis parallel flight lines plus a perimeter sweep. This captures nadir images during the grid portion of the flight and oblique images during the perimeter sweep.

It was important to test all the available flight paths above as each type takes a significantly different time to perform the flight for a given survey area. The best-case scenario would be if a grid pattern produced adequate results as it takes the least time overall. This would mean larger areas could be surveyed during a single flight.

Thirdly, flight settings were determined. Due to time and drone constraints, it was impossible to test all variations of flight settings so only a few were considered.

Initially a 60m height was chosen to allow more-than-adequate clearance to the powerlines. Upon analysis this was deemed to be approximately the highest useable altitude for these drones as above this altitude the ground control point resolution in the image would become too poor to accurately locate the centre point. In addition, as accuracy of approximately 5-10 cm or better was desired, the GSD needed to achieve this was approximately 2-3 cm. With this flight height, the calculated GSD was 2.1 cm but due to the variability in ground elevation, the final GSD was around 2.8 cm.

The flight speed was set at the maximum that DroneDeploy would allow for this altitude, 4 ms^{-1}. The software determines allowable speed based on altitude. At 70 m the flight speed can be set to 5 ms^{-1} and at 80 m it can be set to 6 ms^{-1}.

Next, the image overlaps were set to 80% forward and 80% sideways. The recommendations are at least 80% forward overlap and 60% sideways overlap.

Finally, the camera settings were determined. These were determined from a combination of recommendations and samples taken. As the automatic camera settings tended to use a slow shutter speed that would introduce image blur, it was decided to use manual settings. It is recommended that the shutter speed is set such that the image blur is equal to 1 GSD (Hammer Missions, 2020). In addition, the ISO settings in the camera had to be chosen. A higher ISO can introduce graining into images so it was desired to keep this as low as possible. On the test day that determined overall results, an ISO of 100 and a shutter speed of 1/400 s was used. At the flight speed of 4 ms^{-1} this would make the image blur 1 cm.

Next, approximate locations for GCPs were determined. From the desktop they were chosen to be approximately around the perimeter of the survey area (as recommended by DroneDeploy) (DroneDeploy, 2021) with two centralised. In reality, this was not possible due to the ground undulations and vegetation at the site. Locations were then chosen at places with the least ground slope. Even so, the locations were less than perfect. As with the site itself, this was deemed to be a good indicator of the potential quality as these were not ideal test conditions. The GCP locations were measured with a Trimble Catalyst with 1-2 cm accuracy. Some GCPs also folded slightly and were not visible from some angles.

Once the flights were performed, the software was tested. The software packages tested were:

- DroneDeploy for flight planning. Others such as Pix4D capture, 3Dsurvey Pilot, DJI GS Pro (iOS only), Litchi were considered but DroneDeploy was the only one used at it has support for both of the available drones
- DroneDeploy, Agisoft Metashape Professional, and Pix4Dmapper were used for processing. DroneDeploy was selected because it was already being used for flight planning, and as an all-in-one solution it has potential to streamline the process. Agisoft Metashape Professional and Pix4Dmapper were used as they were prevalent amongst the research literature as well as in online forums.

It was deemed that many of the software processing settings had no discernible difference on the outputs however, some did. Results with rolling shutter correction turned both on and off were generated. The software was also tested using default image metadata as well as altered data. This was because the Mavic Air provided altitude relative to the start point which would create accuracy errors. The start point location was measured with the Trimble Catalyst and allowed for the metadata to be updated post-survey.

Finally, once outputs were generated, results were imported into PLS-CADD for comparison with Transpower and LINZ Survey (both LiDAR) data.

As the testing conditions were not ideal due to the site and ground control point placements, it is believed that the results provide a realistic expectation of outcomes. At a better site, the results could be expected to be better.

4. EVALUATION CRITERIA

This section outlines three separate sets of evaluation criteria upon which the future decisions and recommendations will be based. These are as follows:

1) Lumen photogrammetry criteria
2) Software evaluation criteria
3) Data collection method comparison criteria

4.1. LUMEN PHOTOGRAMMETRY CRITERIA

Lumen's drones are low-cost, consumer level drones. Because of this, they have some inherent disadvantages when compared to higher-end or alternative equipment. The positioning systems are poor, the resolution is relatively low, they have small image sensors, and they have electronic rolling shutters. Nevertheless, with well-defined processes it is possible to achieve results comparable to those using higher-end equipment.

Rather than assessing the individual features of the equipment (i.e. resolution), the most important thing to assess is the output quality achieved with this equipment when using well defined processes. It is also important to note how each area could be improved if better drones or cameras were used. The output criteria to evaluate are:

Table 4: Lumen Drone Output Criteria

Criteria	Comment
Accuracy	Accuracy is linked closely to flight height, which may be dependent on the time available or constrains such as battery life. It is also heavily linked to processes used to capture data. Environmental factors such as lighting can also affect outputs.
Survey Time (Total)	Survey time corresponds closely to cost. It is also highly dependent on numerous factors such as flight height and battery capacity as well as environmental factors such as wind. The total time includes factors such as planning, travel and processing. From experience the survey time on site is expected to be only 5%-15% of the overall time used.
Point Density	This is based on a combination of factors. The upper limits are constrained by a combination of altitude, resolution, and sensor size whilst anything below this limit is a result of processing techniques used.
Difficulty	How difficult is the entire photogrammetry process? This is subjective but worth knowing as it can help Lumen determine if it is worth the effort or risk.

Note that a number of these criteria are interconnected, and the properties are often inversely proportional. For example, accuracy is heavily linked to flight height therefore, to increase accuracy flight height could be reduced. This has an effect in that with a fixed field of view, the image footprint will be smaller and therefore more passes of the area may be needed, increasing flight time. Determining the most efficient method is important to achieving high quality results.

Each separate job will likely require a delicate balance between all these criteria, which this report aims to determine.

Other factors to consider, but not in this document, include legal requirements such as gaining permission to fly over a person's property, or a council's permission to fly within road corridors.

4.2. SOFTWARE EVALUATION CRITERIA

Evaluating the software packages is largely subjective as the testing proved that whilst each has its benefits or drawbacks, the outputs will be largely similar. Rather than deciding which should be used for all future projects, the nature of the packages and subscriptions allows them to be used interchangeably depending on the project, the outputs required, or person performing the work. The evaluation criteria for software are as follows:

Table 5: Software Evaluation Criteria

Criteria	Comment
Ease of Use	This will be scored based on personal testing and is the most subjective. It is likely that other people may feel differently but reasons for the score given to each will be outlined. Processing time is somewhat linked as more difficult to use software generally takes longer.
Processing Time	This is heavily dependent on the computer hardware used. Gains in processing time from one package to another are not necessarily true for all use cases but are indicative. The computer hardware that processing was performed on included an Intel i7 8700K processor and Nvidia GeForce GTX 1080 graphics card. This is not top-of-the-range hardware but is still very capable.
Customisability	The ability to change and alter settings to tweak outputs to suit.
Output Accuracy	This is arguably mostly to do with the flight process used, but output quality (such as point density) affects the accuracy too.
Output Utility	How useable the outputs are, and how many different output types.

Each package is able to do something that the others cannot or has perks that may make it more desirable to use in certain circumstances. In terms of real-world results, the packages had mostly comparable results thus, it is about deciding which feature(s) are most important.

4.3. SURVEY METHOD COMPARISON CRITERIA

To determine which method of collection is best suited to Lumen projects, we must first establish the evaluation criteria. It is important to note that the costs will only be briefly compared in this document and will be analysed in more detail later as they are specific to each job and estimations have to be made.

Table 6: Data Collection Method Comparison Criteria

Criteria	Description
Cost to client	The likely cost the client will see. This will be evaluated in the financial analysis report
Accuracy – Ground	The relative accuracy between any two ground points.
Accuracy – Other Features	The relative expected accuracy between any two points excluding ground
Point Density	The number of usable points created from each method.
Delivery Time	The estimate time it would take to deliver data from procurement. This would vary from project to project and be dependent on the survey length.

It is important to note that the value assigned for each is highly dependent on the specific survey being carried out, so generic values will be assigned and explained.

5. PHOTOGRAMMETRY PROCESS

The figure below shows the general process for a photogrammetry mission. It shows the minor steps within each main category. An in-depth guide/procedure is in development and will be provided at a later date. The current progress can be found in appendix A.

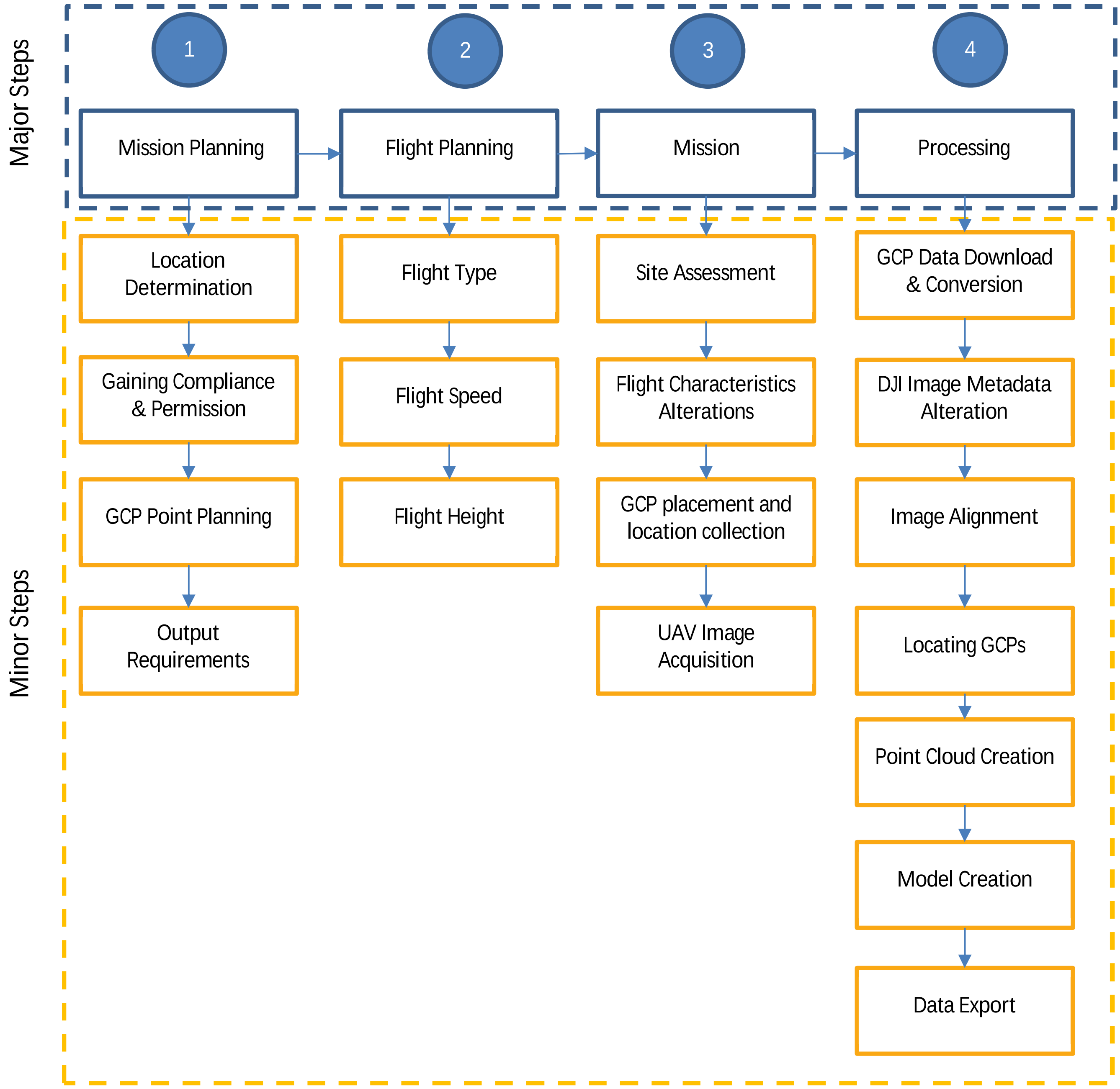

Figure 2: High-Level Photogrammetric Process

6. RESULTS

This section outlines the results generated from the photogrammetry process. Most of the testing was performed with the DJI Mavic Air due to availability. It is expected that the Mavic 2 Zoom would generate results comparable or better than the Mavic Air. When the Mavic 2 Zoom was used the results appeared as good, if not better. Measurements within the models were taken and the resulting measurements appeared very close to those from the Mavic Air, and with the addition of GCPs it is assumed that the results would be almost identical.

6.1. LUMEN DRONES

The results of the tests were generated in four different ways for each of the four flight plans. This allowed an assessment of the drone, the software package, and the flight plan to be carried out simultaneously. Accuracy results for each flight type were generated using the following criteria:

1. Using ground control points to align the model
2. Using no ground control points. Only the check points were used
3. Using ground control points to align the model. Rolling shutter correction was applied
4. Using no ground control points. Only the check points were used. Rolling shutter correction was applied

The resulting accuracy is found in the table below.

Table 7: Photogrammetry Accuracy Results Using Mavic Air

Photogrammetry Accuracy (m)								
Alignment Type	Flight Type 1		Flight Type 2		Flight Type 3		Flight Type 4	
	GCP	Check	GCP	Check	GCP	Check	GCP	Check
With GCP	0.081	0.295	0.069	0.107	0.063	0.101	0.064	0.108
Without GCP	N/A	2.07	N/A	2.0	N/A	1.32	N/A	1.58
With GCP, RS Correction	0.089	0.356	0.068	0.104	0.066	0.128	0.064	0.148
Without GCP, RS Correction	N/A	2.19	N/A	2.0	N/A	1.20	N/A	1.22

The results show that flight type 1 produced poor accuracy, with the check point average error at 0.295 m without RS correction, and 0.356 m with RS correction. This is an unacceptable result. The results also show that the RS correction increased error for three out of four flight types. These drones use perspective lenses and this result aligns with the results Pix4D published on the use of RS correction, that perspective lenses don't necessarily need RS correction to be applied (Pix4D, 2016a). Using RS correction also increased the processing time significantly. It can be seen that flight types 2, 3, and 4 had similar results, with flight type three producing the best results overall. It is unclear why type 4 had inferior results given that it had much more data. Whilst flight type 3 produced the highest accuracy, flight type 4 produced the least noise in the outputs, followed by 3, 2, then 1. Type 3 was also significantly quicker to process as well. It is unknown why type 1 produced such poor results.

It is shown that the check points had lower accuracy than the GCPs. This is likely because natural features were chosen, and it was difficult to determine their position in the photos, given the resolution. It is likely that if physical, easy to identify markers were used, the check point accuracy would be similar to that generated from the GCPs. It is therefore recommended that check points use physical markers.

As mentioned, the Mavic 2 Zoom was not available at all times due to other commitments and the first test using GCPs was performed incorrectly due to unfamiliarity with the processes. To determine its accuracy, the model was created using no GCPs, and relative measurements were taken and compared to those in the correct model. The measurement comparison results are as below.

Table 8: Mavic Air & Mavic 2 Zoom Measurement Comparison

Description	Mavic Air with GCP Measurement	Mavic 2 Zoom Measurement
Tower Leg C-D	11.2 m	11.2 m
Tower Leg D to Bike Ramp	121 m	121 m
Tower Leg D to Start Point Rock	115 m	115 m
Bike Ramp to Rock near start	49.9	49.8 m

The granularity with which Metashape allows measurements to be taken is only 0.1m. As seen, the results are very close and if GCPs were used with the Mavic 2 Zoom it is assumed that the results would be identical.

Each flight time took a significantly different amount of time to perform. In the field, this could have cost implications as over large sections battery swaps would be necessary. The approximate flight time for each is below.

Table 9: Test Survey Flight Time

	Flight Type 1	Flight Type 2	Flight Type 3	Flight Type 4
Flight Time	3:51	4:19	7:42	9:22

Whilst for this test all flights fell within the battery's useable range, a scaled-up survey would require more consideration over which type to use based on the time available and survey area required. When using the Mavic 2 Zoom it was determined that due to the battery constraints, the maximum corridor distance surveyed per flight is as follows:

Table 10: Approximate Maximum Survey Length Using Mavic 2 Zoom

	Flight Type 1	Flight Type 2	Flight Type 3	Flight Type 4
Flight Time	N/A	800 m	500 – 600 m	400 m

Flight type 1 was assumed inadequate due to the survey test results. Table 8 shows that each subsequent flight type has a lower surveyable distance than the previous. It is therefore important to note other factors that may affect the survey length. One of the legal requirements is that the drone must be in visual line of sight at all times, without visual aid (Civil Aviation Authority of New Zealand, 2021). This was determined to be approximately 350 m to 450 m. While the operator can move as the drone does, it would seem impractical to move as far as flight type 2 requires, and mistakes would likely be more common. It is recommended that flight type 3 or 4 is used as it will maximise the likelihood of high-quality outcomes.

Online literature often recommends the DJI Phantom 4 Pro as a low-cost survey drone (Jin, 2022). It has 20-megapixel resolution and much larger sensor size than the two drones currently available. It also has a flight time similar to the Mavic 2 Zoom. Whilst it may not produce better results, it would likely reduce the chance of results being inadequate. In addition, in late 2021 DJI released the DJI Mavic 3. It has all these features plus a bigger battery life. As of the time of writing it is not usable as 3rd party software is not yet compatible. To improve results further, Lumen could invest in higher-end equipment such as the WingtraOne. This is a fixed wing photogrammetry drone with a 42 megapixel resolution, better battery life, and higher flight speed (Wingtra, N.D.). Wingtra estimate that the accuracy could be as good as 20 – 30 mm, but this drone is expensive (Wingtra, 2021). On the other hand, TopoDrone offer equipment with high accuracy positioning systems where GCPs may not be required. These would offer a good middle ground in terms of both price and accuracy with price being approximately $6,700, and accuracy of 20 – 40 mm.

Some other possible alternatives are below.

Table 11: Potential Drone Upgrade Price Estimates

Drone	Price	Technology
DJI Phantom 4 Pro or Phantom 4 Pro V2.0	$2,899	Photogrammetry
DJI Mavic 3	$3,099	Photogrammetry
TopoDrone Phantom 4 PPK	$6,700	Photogrammetry
DJI Phantom 4 RTK	$13,999	Photogrammetry
DJI Matrice 300 RTK + Zenmuse P1 Module	$29,000	Photogrammetry
DJI Matrice 300 RTK + Zenmuse L1 Module	$45,000	LiDAR
WingtraOne	$30,000	Photogrammetry

6.2. SOFTWARE

There is a wide array of software packages available for photogrammetry but only three were selected to be analysed and tested, for various reasons. The prime reason for selecting only a few is time constraints. When considering how many to evaluate it was important to note user experience and time taken to learn each step of the process, the learning curve associated with each software package, the time taken to process – especially when factoring in non-default settings, program support (both 1st and 3rd party), and prevalence within the industry.

The three packages are:

- DroneDeploy
- Pix4D
- Agisoft Metashape Professional

DroneDeploy was selected because according to many online forums it is the "industry standard" for UAV flight planning and mapping, and is commonly one of the first programmes recommended when searching online literature. This package was also suggested by Lumen management.

Agisoft Metashape and Pix4D were selected as processing packages because during the literature review, they were seen as the most commonly used packages. They also have large amounts of support both from the developer, and from the community. In the literature they both consistently performed well.

The software comparisons are mostly subjective, although each software package does have benefits and weaknesses. This section will provide a brief overview each package used.

DroneDeploy is both an all-in-one solution and flight planning solution. As a flight planning software there are many other comparable applications such as Pix4D capture, 3Dsurvey Pilot, DJI GS Pro (iOS only), Litchi, and more. Of these packages, DroneDeploy was the only one to support both of the Lumen owned drones so only it was chosen. DroneDeploy is unique compared to the other two packages for various reasons. It has flight planning and automatic processing, which neither Pix4D nor Agisoft Metashape have, although the processes can be streamlined. The benefit of DroneDeploy is that the flight planning is free-to-use, whilst the processing is subscription based. The downside to DroneDeploy is that there is not much customisation available which means that output settings such as point density cannot be altered. For ground-only surveys this would be adequate, but it did not appear to reproduce poles, towers, or conductors well when compared to the other two packages.

Pix4D does not have any unique features when compared to the other two software packages. The benefits of Pix4D are mostly subjective as it is much more customisable that DroneDeploy and is more intuitive than Agisoft Metashape. It also appeared slightly faster to process results than Agisoft Metashape whilst its user interface is also nicer and easier to navigate.

Agisoft Metashape is also a processing only package. Its unique feature is that it has powerline detection. This means that it would be significantly more useful than the other two packages as it can be used to determine conductor and attachment point positions.

The scores applied to each package for the evaluation criteria are found in table 9.

Table 12: Software Evaluation Scores

Criteria	DroneDeploy	Pix4D	Agisoft Metashape
Ease of Use	10	8	7
Processing Time	7	7	7
Customisability	3	8	10
Output Accuracy	8	8	8
Output Utility	7	8	10

Whilst much of the criteria is subjective, the reasoning behind these scores is below.

DroneDeploy scored highest in "ease of use" because most of the processing is automatic. Pix4D was second as the menu context was easier to understand than Metashape, and GCP placement was simpler and quicker. All packages scored the same for processing time. This is not necessarily always true, but when adequate hardware is used and the outputs generated are similar (i.e. point cloud density), the processing time was largely similar.

DroneDeploy scored lowest on customisability as it has practically no settings that can be changed. This means that the point cloud is predetermined by the software and cannot be altered. In many cases it may not be necessary to produce the highest density point cloud, but it is a nice-to-have. On the other hand, Agisoft Metashape had an array of settings that could be changed and could easily overwhelm a new user.

The accuracies were approximately identical. The absolute accuracy of DroneDeploy was unknown as it was not performed with GCPs, but Pix4D and Metashape produced identical absolute accuracy.

Agisoft Metashape scored highest in utility as it has additional features that the other two do not. The addition of powerline detection and by extension, attachment point location could be incredibly useful to Lumen.

The outcome of this is that all software packages could be recommended, but for different use cases. DroneDeploy would be the recommended software of choice if only ground data was needed, or if a new user needed to perform the analysis as the other two packages have a steeper learning curve.

Pix4D would be recommended if buildings and ground were needed, or if a specific resolution of data needed to be generated. It would also be adequate for locating poles but may not be able to determine what kind of pole. It was able to produce conductor points but not reliably therefore, if conductor or attachment points were needed, this would not be recommended.

Agisoft Metashape would be the software package recommended if conductor points or attachment points needed to be generated. Whilst it did not directly generate attachment points, the way it generated conductor points meant that the attachment point could be inferred. For a capable user, this is the most powerful package.

6.3. SURVEY METHOD COMPARISON

Results of photogrammetry were paired against typical industry expectations or quotes from providers for both traditional survey and LiDAR surveys. The quoted values are generic and may not apply to all situations, but are a good indication for comparison's sake. Photogrammetry results have been determined in two ways: using Lumen's own drone, and from online literature.

Table 13: Survey Method Accuracy Comparison

Type	Accuracy	Comment
Traditional Survey	3 mm (but 20 mm for GPS)	Very sparse, functional accuracy lower, there can be some very inaccurate points provided
Manned LiDAR LINZ (specification)	200 mm vertical, 1000 mm horizontal (Land Information New Zealand, 2021)	This is the specified minimum requirement but from observing results and comparing them to other surveys they often appear within 30-50 of the expected location.
Manned LiDAR (From Survey)	150 mm specification (Beca, 2016) but 30-40 mm expected (Hosking, 2022)	The 150 mm accuracy for Transpower surveys is a requirement and it is much likely better than this. The quoted accuracy from a survey for Orion was 3 cm.
Unmanned LiDAR (Quoted)	30 mm (quoted) (Fox, 2021) 150 mm (guaranteed)	The provider quoted 30 mm accuracy, but only guaranteed 150 mm accuracy.
High-end photogrammetry	20 mm horizontal 30 mm vertical (Wingtra, 2021)	Hypothetical accuracy from Wingtra information booklet.
Lumen Photogrammetry at 60 m	60 – 100 mm	These are the results generated from the Lumen photogrammetry testing.

The table shows that Lumen's results are likely as good as those generated from LIDAR, for ground. It is noted that the test survey area was small so it is unknown how accuracy would alter for larger areas, but there is little reason to assume that it would be different.

Data density is also an important factor when determining which survey type to use. The survey area was approximately 1.65 hectares. The table below shows the number of survey points that could be expected for an area of this size.

Table 14: Survey Method Point Density

Type	Expected Number of Points	Comment
Survey	495	This can be altered based on the needs, and likely would not require this many points to be captured. If it did, however, the survey would take much longer that the equivalent UAV survey.
Manned LiDAR LINZ	350,000 -380,000	Determined from survey results,
Manned LiDAR TP	150,000-200,000	Determined from survey results.
Unmanned LiDAR	2,000,000-5,000,000	Approximation based on the expected point density.
Photogrammetry	5,000,000 - 10,000,000 Up to 30,000,000 if required	Point numbers generated from testing.

It can be seen that photogrammetry produces the densest point cloud. This means that it can detect smaller changes in altitude or position and should lead to better data overall. As noted earlier, photogrammetry cannot penetrate vegetation which means that the areas underneath tussock or scrubs will have to be approximated whereas with LiDAR it may be able to generate actual ground data. In areas with heavy vegetation or long grass, it may be best to used alternative solutions if ground is required.

Whilst it was endeavoured to evaluate each method based on the criteria, it is simply not possible from a generic, high-level perspective. This is because each survey has different advantages and disadvantages so criteria such as cost and delivery time are dependent on the specific project. It can largely be expected that manned LiDAR will be the most expensive for short surveys, and traditional surveying would be the cheapest for very short surveys. It is likely that photogrammetry or UAV LiDAR would have the fastest delivery time as the survey would be quick, and the processing is largely performed by a computer.

In addition to ground accuracy, Lumen wishes to know how the technology fares with conductors and attachment points. The figures below show the location differences between the LiDAR surveys and photogrammetry survey for wires close to the attachment points. It should be noted that the conductor positions generated from LiDAR were less uniform than from the photogrammetry. That is, if following the conductor's real position, the observed position varied between being above and below the actual conductor, which is displayed in figure 4.

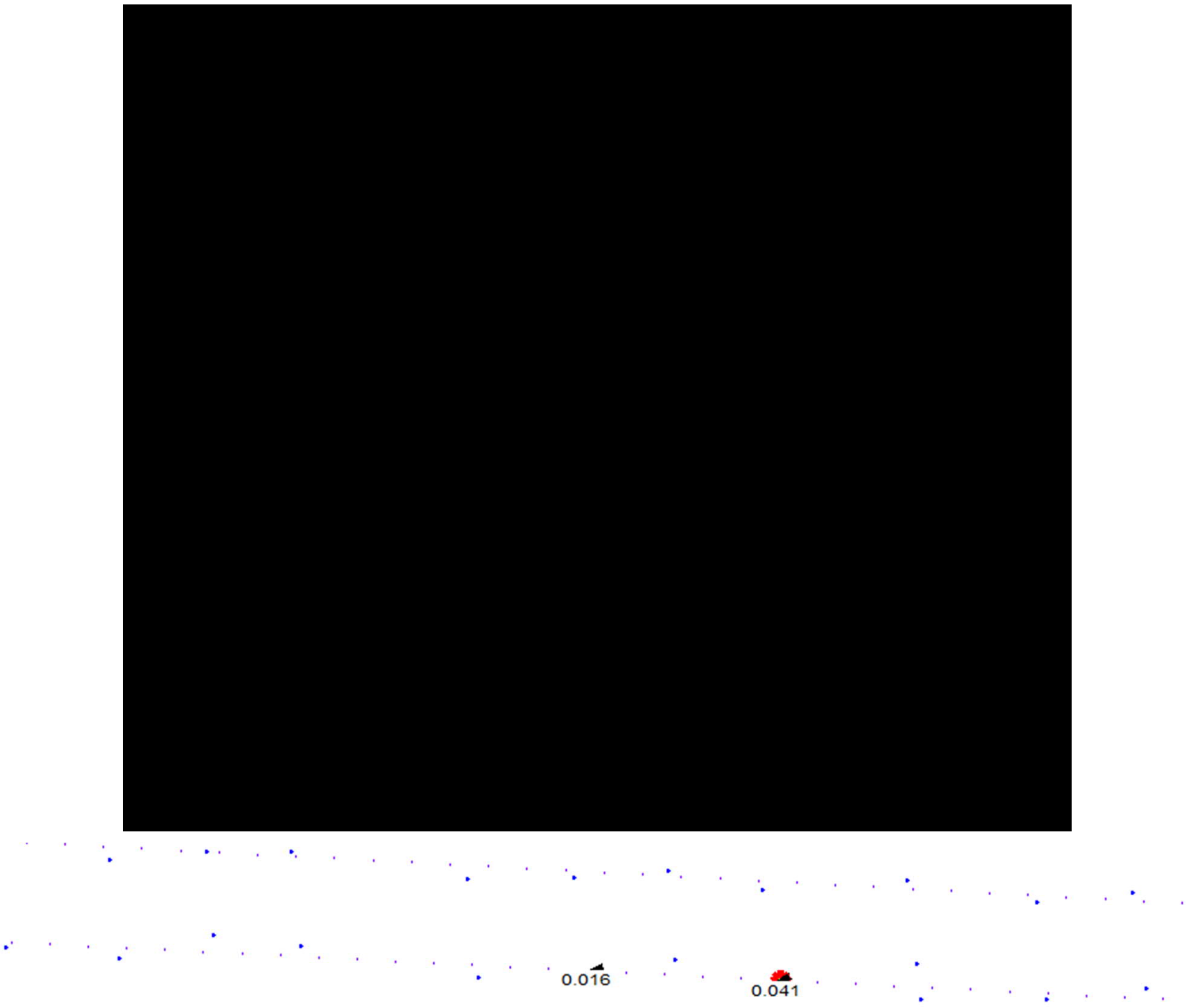

Figure 4: Conductor Location Deviation Between LiDAR and Photogrammetry

While the ground control points produced high accuracy, so too did the attachment points. All attachment points were within 54 mm of the expected location, which is consistent with the GCP accuracy. The difference is shown in figure 3.

Figure 4 shows that the expected wire positions generated from photogrammetry (small points) were similar to those generated from LiDAR (big points). There are other considerations to be made such as temperature on the day. Ideally the surveys would have been completed on the same day and this does mean that there are slight unknowns.

Nevertheless, these results prove adequate for Lumen's use cases. It was also difficult to measure as the points were not generated at the same position along the conductors. The results from LiDAR are actually interpolated from the raw points shown here.

6.4. DJI MAVIC AIR CONSIDERATIONS

This drone has a very short battery life and when accounting for the fact that stakeholders may require minimum battery percentage requirements for a mission, it only leaves 12-15 minutes of useable flight time per battery. This leads to a few different outcomes. In a hypothetical scenario where there is a specified area that needs to be surveyed the following scenarios arise:

1. Fly higher to survey more area for a given battery usage – this reduces accuracy and point density.
2. Fly at a faster speed – when flying at faster speeds the lighting conditions need to be even better as the shutter speed will need to be increased to reduce image blur. At the higher speed the drone does not track its predetermined flight path well.
3. Change batteries – this takes time, and means that the survey must start again from the pause point. Lumen sells its time so must be efficient.
4. The positioning system is poor, as is the georeferencing in the photos. The altitude georeferencing is particularly poor as the system 'zeroes' itself when it is turned on, and every photo is taken relative to this zero point. This means that the height of the model is incorrect by the height of that zero-point relative to a datum. In addition, when adding the ground control points, due to the large difference in the apparent altitudes, the model accuracy is low.
    a. This can be accounted for by measuring the altitude at the zero point and editing the EXIF data in the photos, but it is an extra step processing step that is easy to perform incorrectly.

6.5. DJI MAVIC 2 ZOOM VS MAVIC AIR

The Mavic 2 Zoom has a much better battery life than the Mavic Air so 50% more survey can be completed per battery. It is not without its drawbacks, though. Having zoom capabilities appears to be a substantial benefit as it allows you to achieve the same ground sample distance from a higher altitude, but this can be a drawback too. If the focal length of the camera changes mid-operation it is likely to cause issues as the photo alignment in the photos will be difficult. This is unlikely to cause issues but should be a consideration. Apart from this, the Mavic 2 Zoom is the better drone to use.

As the Mavic Air has poor battery life and may require additional processing steps to perform correctly, it is recommended that only Lumen's Mavic 2 Zoom is used to begin with.

6.6. OUTCOMES

Whilst the literature reviews indicated the importance of ground control points, with the equipment Lumen possesses it is even more clear that this is a requirement. If the drone had additional positioning systems this may not be the case as the camera locations will be more accurate.

The outcomes are that the Lumen drones are capable provided that specific processes are used. Ground control points are essential.

The software package used is largely dependent on the requirements of the survey or the user's capability. If only terrain is needed, DroneDeploy is the easiest solution and would therefore be recommended. If buildings or other assets are required in addition to terrain then Pix4D is likely the best solution as it is more powerful than DroneDeploy, but easier to use than Agisoft Metashape. Finally, if attachment points or line positions are needed then Agisoft Metashape should be used.

The recommended flight height would be 60 m to provide the best compromise of resolution and survey area per flight. The user must aware of how this factor can affect results.

Of the four survey types (traditional survey, manned LiDAR, UAV LiDAR, photogrammetry), none are catch-all solutions and will be applicable for different projects.

6.7. LIMITATIONS

This testing was not without limitations. The survey area was small do to numerous legal requirements. It is not expected that results would differ with a larger survey, but it is a consideration.

Due to unfamiliarity and lack of experience, it was difficult to determine the best processing settings to use. It is possible that with more experience, the user will determine the best settings.

Requiring GCPs makes the overall survey more difficult. The user must plan, set out, and measure their location. The user must take care to ensure this is performed correctly. During processing the user must then determine the location within the photos to allow the model to align. Overall this is a somewhat difficult process and takes significant time.

The comparison data was not captured on the same day and is a dynamic asset. This presents the opportunity for the data to be different but it is not expected that the difference would be substantial.

This test location was chosen as it had a good variety of sloping and complex terrain, along with multiple sets of powerlines and other desirable features that allowed adequate conclusions to be reached, but the tested area was quite small at approximately 120 m long by 80 m wide. [redacted]

The check points selected were natural or man-made features rather than typical ground control points or high contrast markers. This made the check points difficult to see in the photos and so it is possible that they were incorrectly located in the images. This is likely why their accuracy is lower when compared to the ground control points.

7. Conclusions and Recommendations

This phase of the project was about determining if Lumen's currently available UAVs can generate high quality, high accuracy results using photogrammetry and if so, how. It was also about comparing the outputs to outputs generated from other survey methods. This phase was necessary because of various characteristics of each drone.

One characteristic is that the on-board positioning systems are poor so it was important to determine how this would impact results, and how any errors could be mitigated. The second is that the battery life is short with only 12-14 useable minutes for the Mavic Air and 20 useable minutes for the Mavic 2 Zoom. Thirdly, are the camera characteristics. The cameras on these drones have small sensors, are only around 12-megapixel resolution, and have electronic rolling shutters (which can introduce artifacts and distortion into images) (Pix4D, 2016b). Due to these characteristics, the online literature, experts, and hobbyists appear to recommend either processes that would make it non-viable to use these drones (such as stopping to take each photo) or upgrading to different equipment.

The conclusion is that high quality results can be achieved using the current equipment available, although there as some considerations to be made in doing so.

Firstly, it is only possible to achieve adequate results if using ground control points and flight methods 2, 3, or 4 outlined in section 3. The use of ground control points overrides the on-board GPS information to update the model georeferencing and scaling. Without these, either the results were multiple metres from their actual position, or they were distorted – although the reason for this is unclear. If using flight method 1, regardless of whether ground control points are used or not, the results will be poor and the resulting model had an unsatisfactory accuracy. Flight methods 2, 3, and 4 all appear to have very similar accuracy

The low battery life means the maximum surveyable distance per flight are highly dependent on the flight method used. DroneDeploy does predict flight times which can be used to plan adequately. Alternatively, multiple different flights/missions could be used. This also means that the operator will have account for their number of available batteries when planning the flight. Due to battery constrains, only the Mavic 2 Zoom should be used.

Finally, while the camera characteristics do somewhat force specific methods to be used, they do not appear to have as much of an influence as first thought. Higher resolution and a larger sensor would improve the image quality, but altering the flight plan accordingly can mitigate these drawbacks. The rolling shutter on each drone appears to be inconsequential. Both of these drones use perspective lenses according to their camera model and Pix4D's literature has shown that the rolling shutter does not impact results at the similar flight speeds (Pix4D, 2016a), which matches the conclusion here.

Upgrading to the DJI Phantom 4 Pro or Phantom 4 Pro V2.0 would be a minimum recommendation as they are relatively cheap, have much larger sensors, a 67% higher resolution, and a mechanical global shutter. This would enable very good results without fear of photo artifacts and distortions due to rolling shutters. It also has the same battery life as the Mavic 2 Zoom so eliminates most of the drawbacks, except for the on-board positioning. Another alternative is the DJI Mavic 3 as it is also low-cost but has a 46 minute battery life and a 20-megapixel camera, significantly extending the usable time. Other alternatives are available, but they are expensive.

When comparing with other data collection methods, it is clear that using these drones can produce results on par with the other methods, although there are some caveats. For example, up to a few hundred metres it is likely the most cost-effective of all of the solutions, particularly if the flight can be performed without battery swaps. To survey a larger area on the same battery a higher flight may be required which may be detrimental to accuracy.

DroneDeploy is the recommended flight planning and mission software due to its ease of use and support for DJI drones. It is also the recommended software package for greenfield sites where no vegetation is present and no structures need to be captured as it is the easiest and quickest solution. It would also be a good solution for sites where ground-only features are needed. Whilst the flight planning software is mainly automated it is important that the user is able to determine the correct camera settings and that operations are carried out safely.

For brownfield sites both Pix4D and Agisoft Metashape Professional are good solutions, depending on the survey requirement. Agisoft Metashape is the only package with powerline detection so if wire or attachment point location is needed this is the software package that must be used. For sites where this information is not needed, it is largely down to personal preference. The Pix4D user interface is slightly easier to use, and ground control point placement is quicker, but Agisoft Metashape has more customisability and appears more powerful.

The recommendations from this section are as follows:

Table 15: Technology Recommendations

Recommendation	Person(s) Responsible	When by
Offer service using the Mavic 2 Zoom.	Team Managers	Immediately
Consider upgrading drone.	Team Managers	Monitor continuously
Use DroneDeploy for flight planning.	Operator	When a survey is performed
Use DroneDeploy if only ground data is needed, Metashape for sites requiring wires and attachment points.	Operator	Decide based on survey requirements
Determine which of the flight paths in section 3 is used primarily based on time (from 2-4). Each subsequent type should produce higher certainty of obtaining adequate results.	Operator	Decide based on survey requirements
Finalise photogrammetry procedure	Tom Savage	March 2022

Whilst it has been determined that using these drones for photogrammetry is appropriate, there are some additional considerations to take before performing a survey:

1. What is the survey length?
2. Where is the survey?
3. What outputs and accuracies are needed?

A flow chart in the final recommendations will be provided when considerations such as cost are accounted for.

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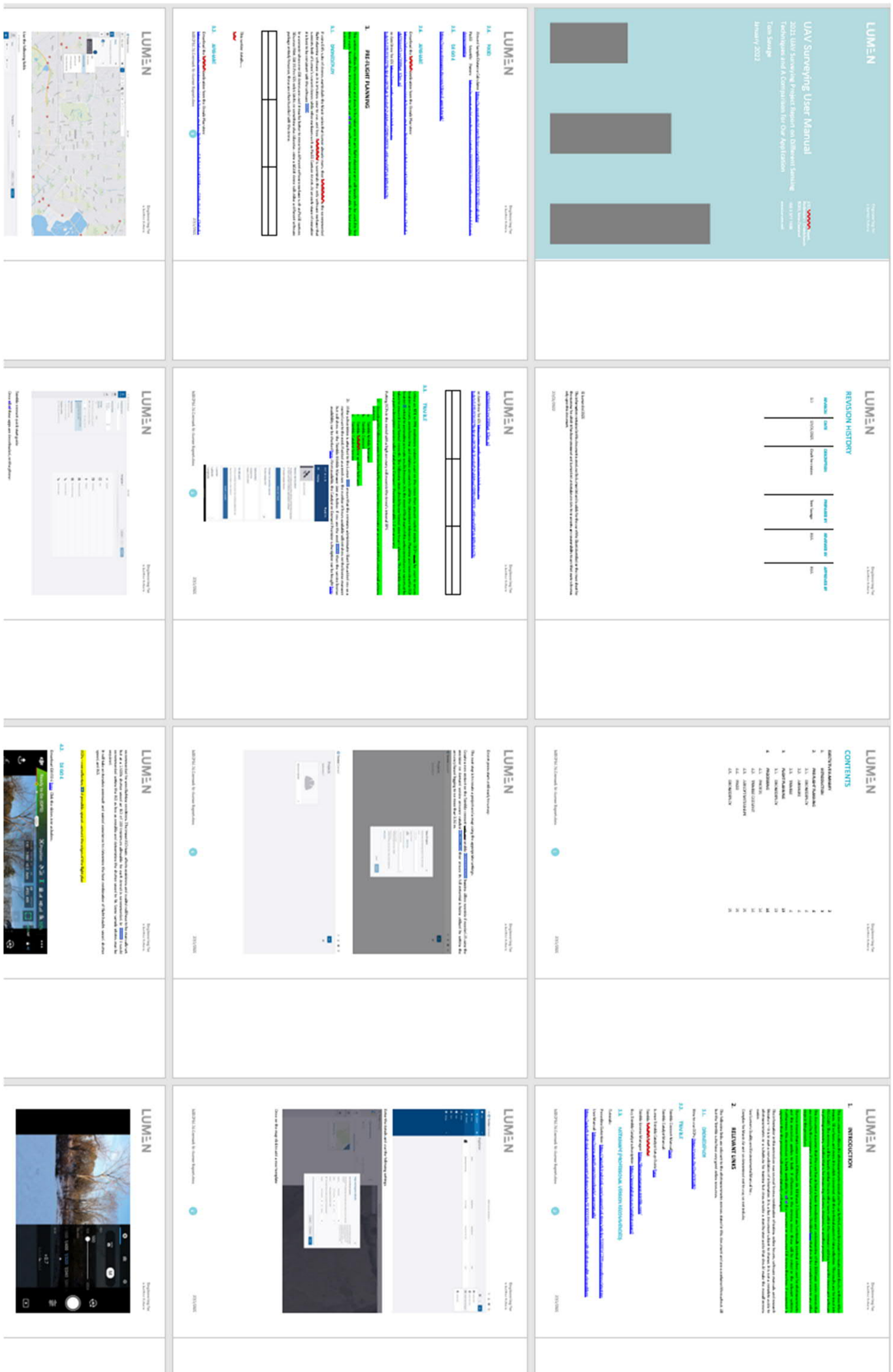
Appendix A – Current Progress of Procedure



4.2. CONCLUSION

The aim of this phase was to determine how Lumen could perform UAV surveys by answering the following questions:

- Can Lumen utilise its current drones for surveying via photogrammetry?
    - If so, how?
- Is there anything it can do to improve the outputs?
- How does it compare to the alternative survey methods?

The conclusion of this section is that Lumen can perform photogrammetry surveys with its UAVs and that they can generate adequate results, but specific processes must be followed. While both the Mavic Air and Mavic 2 Zoom are capable, neither are ideal.

It was found that the most efficient survey altitude was around 60-70 m above ground level. This altitude allowed for an ideal combination of survey speed for a given survey area, and accuracy. The altitude flown affects the survey speed because the image's footprint on the ground gets larger or smaller as the altitude increase or decreases.

It was determined that ground control points must be used to produce adequate accuracy. This is mostly a function of the poor on-board positioning systems of each drone. The 60-70 m altitude mentioned above is approximately the maximum that would allow the operator to see and locate the centre of the ground control point. Locating the centre is critical to allow the software to accurately move and scale the outputs, and the relatively low resolution of these drones mean that flying higher makes it difficult to see.

The Mavic Air battery life is incredibly short at only around 12-15 minutes of usable time. This severely limits the area that can be surveyed per flight. This would be both inconvenient and inefficient. It also requires extensive post-processing of the image metadata otherwise the expected results will have low accuracy, even with ground control points. For these reasons it is recommended that this drone is not used as it creates unnecessary difficulty and will add too much time.

Results comparable to those guaranteed for manned LiDAR were generated with a best-case accuracy of 0.063 m for the control points and 0.101 m for the check points. The check point accuracy was lower likely because of how the point positions were taken in real-life. Whilst LiDAR specifications generally guaranteed ±0.15 m accuracy, the real-world accuracy of the comparable datasets was estimated to be 0.03-0.04m.

Whilst there are many software packages available, the three tested did not seem to generate substantially different accuracies. They did, however, have different use cases. Agisoft Metashape Professional was the only one capable of generating power lines and attachment points. Clearly this package has the most utility for Lumen. DroneDeploy processing was all automatic and subjectively the easiest, but it had the least customisability. This could be used when ground only surveys are required.

There are numerous ways for Lumen to perform the survey better. It could upgrade drone to one with better battery life or camera such as the DJI Phantom 4 Pro or Mavic 3. The Phantom 4 Pro is often recommended for these purposes and its capabilities are well known. It has an adequate battery life and higher resolution camera. The Mavic 3 is the newer option and expected to be as good or better than the Phantom 4 Pro. It has a 46-minute battery life as opposed to the 31 minutes of the Phantom 4 Pro, 31 of the Mavic 2 Zoom, and 20 of the Mavic Air. It also has a 20-megapixel camera which is higher than the Air and Zoom. The issue with this drone is that it is not yet compatible with any flight planning software as it was only released in late 2021. There are many other alternative options that could provide the results needed, but they are all very expensive..

As such, the following recommendations are made:

Table 1: Technology Report Recommendations

Recommendation	Person(s) Responsible	When by
Offer service using the Mavic 2 Zoom.	Team Managers	Immediately
Consider upgrading drone.	Team Managers	Monitor continuously
Use DroneDeploy for flight planning.	Operator	When a survey is performed
Use DroneDeploy if only ground data is needed, Metashape for sites requiring wires and attachment points.	Operator	Decide based on survey requirements
Determine which of the flight paths in section 3 is used primarily based on time (from 2-4). Each subsequent type should produce higher certainty of obtaining adequate results.	Operator	Decide based on survey requirements
Finalise photogrammetry procedure	Tom Savage	March 2022

5. COMPLIANCE REPORT

5.1. INTRODUCTION

While the previous section determined that Lumen could perform the surveys from a technical perspective, Lumen must also determine how the UAV and other associated rules within New Zealand may affect its ability to provide a survey service. That is the purpose of this section.

To do this, Lumen must first be aware of the relevant rules and regulations, and then understand how their application may hinder the service. This is an important step of the overall project because while technically it can perform the survey, if it is difficult to perform the survey legally, it may not be worth the risk or the effort. It will also assist when determining the cost implications as it should help determine potential utilisation.

By providing a new service, Lumen already puts itself at risk. It is not currently competent in this discipline and there are many areas that it could go wrong, particularly with UAV flight and procedures. Providing adequate surveys at the risk of non-compliance could put additional strain on the company.

It must consider a variety of different rules and regulations that govern this type of technology's use within New Zealand.

Once it has recognised the how the rules may affect it, it can determine if there are any strategies it could take to negate the impacts. It can then determine the associated risks and available opportunities. Some are the opportunities that it may develop are: generating and elevating client relationships, increasing profitability, and increasing areas of competence. Potential risks are: legal risks, financial risks, environmental risks, reputational risks, operational risks, and more.

This section aims to determine the following:

- The legal constraints and how they affect an operation
  - If there are any mitigation strategies
- Requirements of other external stakeholders such as councils, clients, and landowners
- Lumen's own requirements and how it fits into overall the strategy
  - If there are any operational improvements or suggestions that Lumen could make
- How future shifts in legislation could benefit or harm the operation
- The risks and opportunities as a result

Understanding all of these will assist Lumen in forward planning and determine the financial implications.

LUMEN

Engineering for
a better future

UAV Legal Compliance Report and Risks

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Report to Understand the Compliance Considerations and Risks of Lumen Performed UAV Surveying

Tom Savage

January 2022

REVISION HISTORY

REVISION	DATE	DESCRIPTION	PREPARED BY	REVIEWED BY
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0.2	18/01/2022	Draft for Review	Tom Savage	DT, PG
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CONTENTS

EXECUTIVE SUMMARY

Lumen wishes to offer surveying services to some of its current or prospective clients as a means of obtaining ground information to assist in design or asset management activities. To do this, Lumen has proposed using its current drones to perform photogrammetry surveys. For analysis of the technical requirements and capabilities, see the Technology Report. This report aims to determine the constraints, risks, and opportunities that would arise as a result of Lumen performing photogrammetry surveys.

When using drones, there are many relevant stakeholders whose requirements must be accounted for. These stakeholders may be internal or external and range from the government and its agencies to private property landowners, or to Lumen's own employees.

The CAA creates the overarching rules surrounding drone use in New Zealand and the most relevant to Lumen are the Part 101 rules. These create numerous restrictions and effectively limit where Lumen could perform such surveys, although many of these restrictions could be negated by acquiring a Part 102 certification – as this provides more privileges.

The two rules that impact Lumen the most are the requirements to gain landowner permission, and the visual line-of-sight requirement. Power lines are often located alongside or within road corridors and requiring landowner permission means that councils are likely to decline the use of this service within these road corridors, particularly the Christchurch City Council (CCC). Both of these can be negated by acquiring a part 102 certification as it allows for notification only flying (i.e. no permission) and proves competence to stakeholders. It also allows extended line-of-sight flight, which would often reduce the required time in the field.

The CCC has very strict rules that effectively mean Lumen could not operate this service within the Christchurch City District. They do not allow uncertified pilots to fly within road corridors, with no exception. There are also numerous aerodromes and airports close-by, making it difficult or impossible to gain permission to fly a drone. Within the Christchurch City District, Lumen could likely only operate this service over very short areas, or rural sections. It is difficult to determine exactly how much impact this would have, but clearly it is a significant limitation.

Some councils are less restrictive and may allow flight within road corridors, but almost all grant permission on a case-by-case basis. It is likely that Lumen would have to demonstrate traffic and safety management plans, competence, or limit the service to rural areas over private property.

Lumen has recently gained ISO certification to a number of standards. To retain this certification it must endeavour to continue to meet the requirements of the standards. This means that Lumen must create procedures for the drone usage, management, data management, and create plans and contingencies surrounding the use of these systems. It must be constantly evaluating and trying to find areas for continuous improvement, whether that relates to the drone and survey performance, safety systems, quality systems, or environmental management systems.

In addition, the Ministry of Transport has proposed drone rule changes which are likely to positively impact the potential of this operation. The proposed changes provide more regulation but also more accountability to drone operators, meaning that safety incidents should decrease, and the industry as a whole is seen more positively. It also opens the door to future beyond line-of-sight flight which, if Lumen decided to upgrade to more capable equipment, would increase the range, and therefore, survey time dramatically. In the case where the rule changes negatively impact Lumen, there is the possibility that it is unable to recover its investment due to the changes.

Whilst Lumen can perform the survey within the part 101 rules, it will be highly limited in its scope. This is not necessarily an issue, as Lumen's appetite is to only offer this as an auxiliary service anyway, rather than offer it to a wider market. This approach may change in the future and Lumen can adopt a dynamic approach to monitor and enable this.

This report has generated the following recommendations:

Table 1: Recommendations Generated from Compliance Report

Recommendation	Person Responsible	By When
Engage Orion to develop relationship and offer service.	Overhead Lines Manager	As soon as possible
Develop a plan and checklist for drone footage and photo data management, using the Privacy Act CCTV checklist in Appendix A (Privacy Commissioner, 2009).	Operators, Manager	Before any operations
Undertake a Part 101 training course.	Operators	When the projects are decided upon
Create a landowner liaison form or register.	Admin/management	When first engaged for a project
Monitor MoT prospective rule changes.	Operators	Indefinitely
Create a high-level drone maintenance plan and log.	Operators	Immediately
Add drone battery contingency to allow mission completion to quality manual.	Management	Immediately
Engage other electricity network owners	Management	Upon completion of a successful project
Determine a company policy for visual line of sight distance.	Management	Immediately
Do not gain Part 102 certification unless appetite changes.	N/A	N/A

1. INTRODUCTION

This report pertains to the legal and compliance considerations, issues, and requirements regarding Lumen undertaking UAV surveying. It also aims to understand the risks involved, both externally and internally, and provide mitigations, as well as determining the opportunities that may be presented.

To be able to provide this new service, Lumen must be aware of all regulations and restrictions and how they can affect the proposed service. It must also determine how it wishes to act upon these restrictions and whether there are mitigation strategies that could reduce the potential impact.

If Lumen enters a new sector, it must understand both the risks and opportunities available. The opportunities involve generating and elevating client relationships, which could be leveraged to generate more income, increase profitability, and increase areas of competence. The risks involved pertain to both actual and perceived risk and may involve – legal risks, financial risks, environmental risks, reputational risks, operational risks, and more.

As a new opportunity presents new risks, Lumen must determine its risk appetite, policies surrounding the area of operation, how it can fit into the current strategy or how the strategy can be altered to fit it. Externally, Lumen must recognise the market competition and barriers to entry, future shifts in legislation, and events that may affect the company's image.

For information on the technical aspect of drone operation for photogrammetry, see either the Technology Report, or Photogrammetry Procedure for Lumen.

2. CONTEXT & GOVERNERNING RULES

In order to discuss the impacts that operational requirements may have, the context must first be defined, and the governing bodies and associated rules determined.

Lumen is an engineering consultancy and has determined that utilising UAV surveying and photogrammetry is an opportunity to engage and develop relationships with clients, increase its competencies and knowledge, show that it is a forward-thinking company, generate more income, and provide a better overall service. As engineers, its employees undertake highly detailed analysis and design, however, site data and data used by the engineers is often sourced by other organisations that may not fully understand the context of each individual project. This opportunity enables Lumen to provide a service where rapid mobilisation and engineering context can lead to higher quality results through better, and potentially faster, data collection.

As the governing body for all aviation matters, the Civil Aviation Authority of New Zealand (CAA) has provided rules for the use of UAVs. The rules by which operators must abide are CAA Part 101: Gyrogliders and Parasails, Unmanned Aircraft (Including Balloons), Kites, And Rockets Operating Rules (Civil Aviation Authority of New Zealand, 2021). If the organisation or operator needs to operate outside of the rules set by Part 101 then it must hold a certification as per CAA Part 102: Unmanned Aircraft Operator Certification (CAA, 2015).

The certifications under Part 102 provide extra privileges to persons and organisations such as: extended line-of-sight flight, night flight, and flying over people and property with notification (FlyUAV, N.D.). Any certified operation also displays competence to potential clients as the organisation and operators must prove their capabilities, plans, and safety protocols.

By extension of the CAA rules, Lumen must also comply with council and district rules, NZTA/Ministry of Transport rules, and Department of Conservation rules.

Furthermore, as this is a surveying operation, Lumen should be aware of the Cadastral Surveying Act 2002. Lumen does not intend to operate cadastral surveying services which pertain to the establishment or confirmation of legal boundaries. Lumen operators would be classed as unlicensed surveyors, and while it is unlikely that the company would be affected, it should be aware of the restrictions.

Finally, the Privacy Act 2020 is likely to have an impact as photogrammetry needs to capture images. It must be determined what data is being captured, and how this data is dealt with.

2.1. LUMEN'S APPETITE

Whilst Lumen wishes to offer the drone surveying service, it currently only wishes to offer it in limited capacity. It wants to augment the capability onto its current service, for its current clients, and does not wish to market this as a surveying operation to the wider market. It also wishes to offer the service within Canterbury to start, with an opportunity to expand later on.

The main drivers are not monetary. Rather, they are around developing client relationships and enabling Lumen to provide more efficient services with better outcomes.

Some of the restrictions discussed later on could have large impacts on the operation, but given Lumen's appetite, they are likely much less restrictive than initially thought.

3. COMPLIANCE CONSIDERATIONS

Within New Zealand, drone and UAV use is governed by the CAA. The two parts most relevant to Lumen are CAA Part 101: Gyrogliders and Parasails, Unmanned Aircraft (Including Balloons), Kites, And Rockets Operating Rules, and Part 102: Unmanned Aircraft Operator Certification.

Part 101 is largely aimed toward recreational flyers or hobbyists but does not restrict commercial operations, provided that they can be performed within the 101 requirements. It is for non-certified flyers and organisations, and provides absolute limits on many operating parameters. Whilst there are numerous limitations, in many cases, Lumen would be able to alter flight procedures to meet these requirements, although there are rules which may affect the operational potential.

Part 102 is a certification process that should be obtained if the intended flights and operations cannot be performed within the part 101 limits. The organisation must meet various operational requirements and display UAV competence under a variety of settings. It must also be able to display that it has adequate safety plans and procedures, hazard identification, operational procedures, maintenance plans, and more (Land Information New Zealand, N.D.).

In addition to legal requirements, Lumen must also understand client requirements, its own internal requirements, and other external stakeholder requirements such as nearby people.

3.1. CADASTRAL SURVEYING

Cadastral surveying is a surveying field that specialises in the establishment and confirmation of legal property boundaries. The Cadastral Surveying Act 2002 sets the regulations surrounding this.

Lumen engineers and current employees are not Cadastral Surveyors. They would be classified as unlicensed surveyors, therefore, under no circumstances can they undertake work to determine the position of a legal boundary, or place marks that could be considered boundary marks.

Lumen should notify clients that they are not qualified or permitted to determine boundary positions. They must also not place a mark that could be considered to be a boundary mark. An example of this is a boundary peg, as below.

Figure 1: Boundary Peg Example (Boundary Consultants, N.D.)

This is unlikely to cause an issue. The only time it possibly could is when using ground control points. Lumen should use standard ground control points that are distinct from survey pegs. They are typically 12" x 12" (Aerotas, N.D.) squares with a checkerboard pattern or other patterns that make visibility from the air easy.

Clients must understand that that this surveying would operate for the sole purpose of obtaining ground and asset information and elevations, and not for Cadastral Surveying.

This is the only area of the Act that would possibly affect Lumen. For more information see the Cadastral Survey Act 2002, Rules for Cadastral Survey 2010, and "restrictions on unlicensed surveyors undertaking redefinition surveys" here. If Lumen breached these rules, it would be subject to fines. These vary depending on the area of noncompliance (New Zealand Government, 2002).

Because of these requirements, Lumen would likely need to engage other surveyors if unsure of the boundary positions provided by LINZ or if placing objects near boundaries.

3.2. CAA PART 101 LIMITATIONS

Initially Lumen would need to operate to the CAA Part 101 requirements. Part 101 is the area in which all UAV pilots must operate unless they have acquired a CAA Part 102 certification. A certification is not needed to fly drones under CAA Part 101, but it does create numerous restrictions. Flying outside of these boundaries without a Part 102 certification could lead the operators and business to fines or prosecution.

In terms of the Part 101 restrictions, Lumen must first understand what they mean, and then determine how they could affect the drone photogrammetry.

A summary from AC101-1 is as follows (Civil Aviation Authority, 2015):

You must—

1. not operate an aircraft that is more than 25 kg and always ensure that it is safe to operate; and
2. at all times, take all practicable steps to minimise hazards to persons, property and other aircraft (i.e. don't do anything hazardous); and
3. fly only in daylight; and
4. give way to all crewed aircraft; and
5. be able to see the aircraft with your own eyes (e.g., not through binoculars, a monitor, or smartphone), to ensure separation from other aircraft (or use an observer to do this in certain cases); and
6. not fly your aircraft higher than 120 metres (400 feet) above ground level (unless certain conditions are met); and
7. have knowledge of airspace restrictions that apply in the area you want to operate; and
8. not fly closer than four kilometres from any aerodrome (unless certain conditions are met); and
9. when flying in controlled airspace, obtain an air traffic control clearance issued by Airways Corporation of New Zealand; and
10. not fly in special-use airspace without the permission of the administering authority of the area (e.g. restricted or military operating areas); and
11. have consent from anyone you want to fly above; and
12. have the consent of the property owner or person in charge of the area you want to fly above.

Some of these do not affect Lumen as it would not be able to, or not intend to, fly outside of these requirements. For example, night flight is irrelevant as the camera needs daylight to function as intended.

It is unlikely that Lumen would need to operate within 4 km of an aerodrome however, this would mean that large portions of Christchurch could not be flown. On the west there is the West Melton Airfield and Christchurch International Airport whilst in central and north-eastern Christchurch there are the Christchurch and Burwood Hospitals. In addition to the Christchurch City Council rules mentioned in section 5.2, this renders much of the Christchurch District unflyable.

The technology report determined that the drones should be flown at approximately 60 – 70 m to achieve the required accuracy, so point 6 is also largely irrelevant. The recommended drone would also not be affected by this however, the high-end photogrammetry drones such as the WingtraOne, would likely be able to provide the adequate accuracy at or above the 120 m limit. If Lumen ever decided to upgrade to a more capable drone in the future, it must be aware of this requirement. This is a somewhat circular argument as Lumen would likely not upgrade to this type of drone without a Part 102 certification, but may not obtain a Part 102 certification without making the necessary upgrades. It could be the case that it is not intended to fly close or beyond this limit, but that it could occur by accident. [redacted] Lumen must be aware of the ground and how it undulates. The issue here is that the drone can follow the terrain profile, but it may not be able to accurately from this height. It will attempt to, but this generates significant risk.

Points 11 and 12 produce the biggest impact and limit operations the most. It may be difficult to acquire permission from the general public as people can be apprehensive to drones. In addition, obtaining permission from councils may be subject to strict requirements that Lumen cannot currently meet. The wording means that the permission is needed only from the property and persons that will be flown above. Discussion with the CAA has indicated that these two rules are explicit. That is, permission is not required if flying near other properties or people. Obtaining permission from nearby landowners may be a good idea to avoid confrontation, but is not absolutely necessary.

Point 9 can be achieved by using the Airshare or Airmap apps for iOS and Android. They have sections where permission can be applied for and it is a straightforward process.

Point 5 arguably has the second biggest operational impact. The technology report determined that certain flight methods could perform flights up to 800 m however, during testing it was determined that visual line of sight for these drones is likely somewhere between 350 m and 450 m. An 800 m survey could still be performed but the operator would either need to move as the drone completes the survey or stand at approximately the survey midpoint. This would likely be the maximum length surveyable per flight. This makes the shorter but more complex flights the most likely solution as they provide less risk in terms of data capability, but also compliance with this rule. Beyond 450 m it became increasingly difficult to see the drone so this should be an upper limit. When the drone was this distance away it also became difficult to relocate it after looking away briefly.

It is recommended that the user undertake a drone training programme to familiarise themselves with the rules and requirements of CAA Part 101. The completion of some Part 101 training courses also grants the recipient the ability to fly within 4 km of an aerodrome. This enables Lumen to track its pilot's competencies and currency.

3.3. CAA PART 102 CERTIFICATION AND BENEFITS

Many of the restrictions imposed by CAA Part 101 can be alleviated by acquiring a CAA Part 102 certification, with one notable exception – beyond line-of-sight flight (BLOS) (Ministry of Transport, 2021). Numerous drone training providers have confirmed that acquiring certification for BLOS flight is difficult under the current regulations and unlikely to be granted.

The operating range of the drone far exceeds visual line-of-sight, so a method of extending the usage distance could prove valuable, especially if upgrading to drones that can perform the operation faster, or have higher battery capacity, both of which mean the technical limit would be greater. Whilst clearance for beyond line-of-sight flight may not be granted, it is possible to acquire permission for extended line-of-sight (ELOS) flight. ELOS utilises spotters or trained observers that communicate the UAV's flight information to the operator when it is out of VLOS range. From the testing, it was possible to observe the drone up to 450 m away, but it was difficult. Therefore, the maximum recommended range from the operator would be 350 – 400 m. The use of observers could extend the distance up to the maximum operating range of the drone. The figure below illustrates this concept.

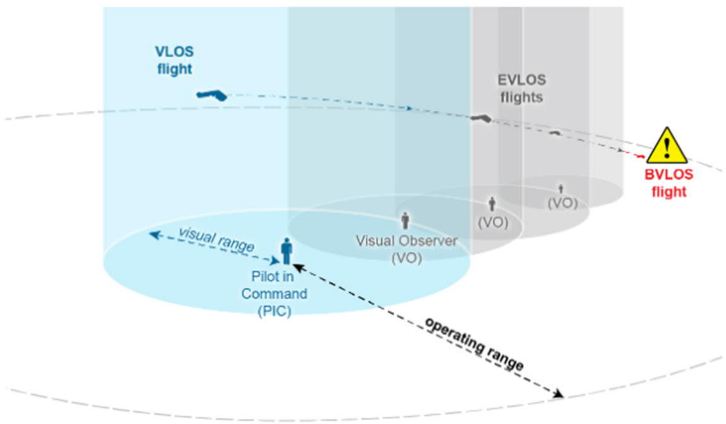

Figure 2: VLOS, ELOS, BLOS Diagram (Jeziorska, 2019)

It has been noted by numerous parties that the CAA is currently in consultation surrounding drone usage and rules (Ministry of Transport, 2021) (Allen, 2021). This is discussed further in section 3.6 but appears that it could be positive for Lumen.

Other Part 102 privileges, although not ones that provide any benefit to Lumen, are the ability to fly at night unshielded, flying within 4 km of an aerodrome, and the ability to fly in low fly zones (Dolman & Adventure Helicopters, 2021) (Aviation Safety Management Systems, 2021). The other privilege that would benefit Lumen is the ability to fly over people or property with notification, but not requiring permission. This would allow them to perform a survey even in the event that a person or landowner was non-compliant with Lumen, although they might not wish to.

Various external stakeholders require that operators have Part 102 certification to allow them permission to fly. This certification would provide clarity to clients and external stakeholders that Lumen is proficient in the use of drones and has adequate safety and risk management processes, but it does also have some drawbacks.

The issues surrounding Part 102 certification are that it is relatively expensive – approximately $9,000 initially, and then $350 per pilot per year for the annual Operational Competency Assessment (Dolman & Adventure Helicopters, 2021) (Aviation Safety Management Systems, 2021). It is also likely to take a year or more to gain the certification. This means that even if Lumen committed to it immediately, it would not reap the benefits for at least a year, possibly longer. This makes the decision to commit to it difficult, especially given Lumen's experience in this area, and its intended application.

Certification can be gained from a variety of training providers such as ASMS and FlyUAV. These companies provide training and work with the company to develop an exposition for CAA approval. The privileges granted are not blanket privileges and only those applied for will be granted. Lumen would have to determine which aspects of the part 101 hinder it the most and work from there.

Gaining this certification requires additional safety procedures and well-defined processes, but Lumen's ISO compliance requires these anyway. This is unlikely to be a barrier as Lumen has experience developing and producing these procedures.

For an idea of what an exposition looks like, see the sample exposition at aviationtraining.co.nz here or in Appendix B. It does not provide much information but shows the template and the information required. The drone training organisations provide assistance in the development of the exposition. A quote was provided to Lumen outlining the benefits, privileges, and costs.

3.4. ISO COMPLIANCE

Lumen was granted ISO accreditation for three separate standards in 2021:

- ISO 9001 – Quality Management Systems
- ISO 14001 – Environmental Management Systems
- ISO 45001 – Occupational Health and Safety Management Systems

Accreditation to these three standards shows clients that Lumen is focussed on providing high quality outputs, committed to health and safety and the environment, and engages in practices that will allow it to minimise waste, hold each other accountable, provide a high-quality service, and more.

For some clients this is a prerequisite whilst for others it is a nice-to-have. Regardless, it allows Lumen to demonstrate competence and attract new customers. Due to this, it is incredibly important that Lumen has systems to manage its operations, and this UAV surveying would be no different. Lumen currently has a section in its Quality and Environmental Manual for UAV usage, but for this operation there are additions that could be made. A consent form should be created so that Lumen has a record of compliance and communications with landowners. The additions that could be made are discussed in section 4.4.

3.5. PRIVACY

Lumen will be collecting images during the drone survey. Whilst it must gain permission if flying above a person or property, the image footprint may be up to 90 m wide and so it will inadvertently capture other people and property.

A company is an agency and must therefore comply with the Privacy Act 2020. There are no specific rules surrounding drone use, but guidance is pointed to the CCTV section of the Privacy Act. As there are no specific guidelines, this is a grey area of the operation (Privacy Commissioner, N.D.). The CCTV guidelines and checklist appear to be largely applicable. For example, Lumen needs to clearly identify the need for obtaining the images, the purpose, the outcomes, how it will be operated and impacts minimised, as well as storage and retention of this data.

Lumen should modify and use the checklist in Appendix A to show how it will comply (Privacy Commissioner, 2009). In reality, privacy should not be of much concern as the drone will be a long way from people. This data would also be of no use to Lumen. Regardless, Lumen should utilise this resource to ensure that it meets compliance requirements.

The risk here is from external public perception and their lack of knowledge, but this risk is minimal. In essence, this is a procedural duty that is likely to have little impact, but would be good to implement.

3.6. FUTURE RULES AND CHANGES

In 2021 the New Zealand Ministry of Transport published a discussion document "Enabling Drone Integration". This was published as drone operations and recreational use has increased dramatically over the past few years. It was estimated that the global drone market would increase by 8.45% annually from 2019-2029 (BIS Research, 2019), so there is need for change.

The proposal is for a rule overhaul that will require basic pilot qualification, drone registration, remote identification and geo-awareness. The figure below explains these in more detail.

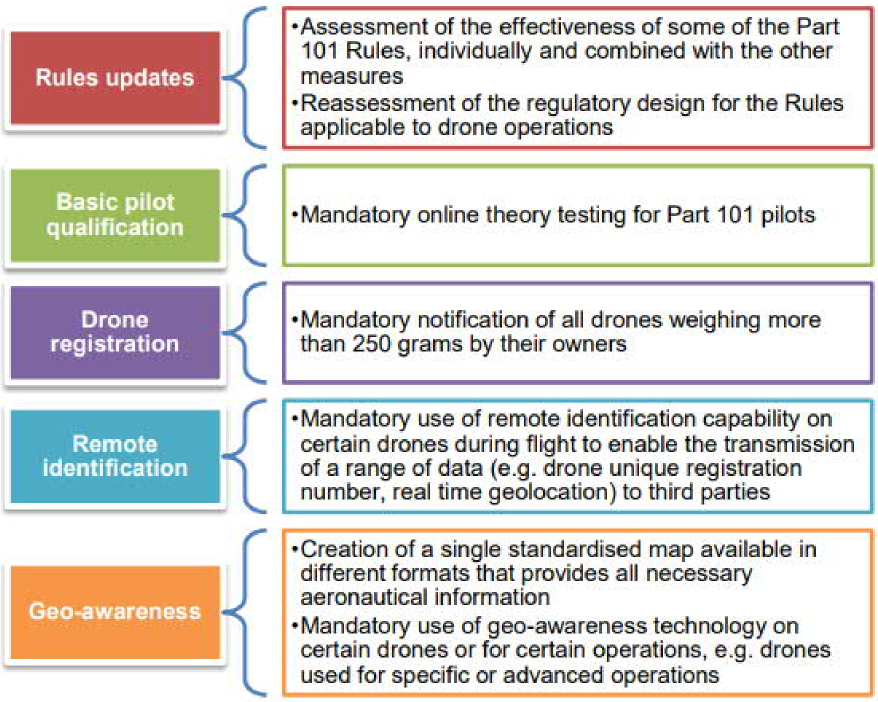

Figure 3: Future Update Explanation from Enabling Drone Integration (Ministry of Transport, 2021)

The rules development process is stated to take place in 2022-2023 with an aim to integrate some of these systems within 1-3 years, and a UAV traffic management system in 5+ years.

The reasoning is because any member of public is currently permitted to fly a drone, and no vetting is required. It relies on self-teaching and a willingness to learn the requirements. This leads to safety incidents that could be avoided and a general lack of compliance.

Whilst it appears to be a tightening of regulations, it could also provide opportunities. Some drone operators feel that the 4 km restriction around aerodromes may prohibit legitimate use and growth of the sector. It also commits to enabling beyond-line-of-sight flight in the future and the CAA is considering a pathway to authorise this.

The document is largely focussed around creating safer operational environments via regulation but does consider relaxing the rules in numerous areas. There is consideration to relax the consent requirements around flying over people and property as the realistic risks are minimal, and it is difficult or impossible to regulate and enforce. Whilst a company such as Lumen would endeavour to meet the current requirements, this would provide an opportunity for the proposed survey operation to develop further and operate more freely if the need to apply to all people and property was removed or reduced.

They wish to implement mandatory testing of anyone that wishes to use a drone, regardless of which Part is being operated under. This would have little material impact on Lumen.

It also wishes to formally define what visual line of sight means. This is likely to be in the form of official guidance for a distance. They desire mandatory drone registration to increase responsibility and accountability, as well as provide assurance to the public that drone operators are accountable.

Remote identification would allow near real-time data from the drone to be transmitted to relevant parties such as the CAA without physical access to the drone. This could mean that the drones would be identifiable to other aircraft or authorities, and pave the way for BLOS flights to become more common as they could track operations.

The full document can be found here (Ministry of Transport, 2021) and is one that the Lumen management team should be aware of, particularly from page 26 down. Table 6, 7, 8, 9, and 10 provide overviews of the benefits of the overhauls. It wishes to bring New Zealand's drone rules closer to those of countries such as Australia, Canada, UK, EU, and the United States and overall appears that it would be an adequate update and provide Lumen more opportunities.

It appears that none of the areas where restrictions may tighten would negatively impact Lumen, but most of the areas where restrictions could be loosened may positively impact the company.

In addition to these rules by MoT, Lumen should be aware of other possible changes. In 2021 DJI was added to the US governments investment blocklist which means that US investors and organisations can no longer invest in DJI and US companies cannot sell components to them unless licensed. This does not mean that Americans are banned from buying and operating DJI drones however, if this did eventuate, it may have far-reaching consequences and could eventually impact use in New Zealand. This is unlikely to cause an issue in the near future, however.

4. STAKEHOLDER REQUIREMENTS

When considering providing a new service, there are many stakeholders that must be considered to ensure that all parties remain satisfied, or at least have the knowledge required of the operation. These stakeholders may be internal or external, public or private, or regulatory.

Examples include the government and its organisations, councils and council bodies, Lumen's clients, Lumen employees, the general public, and landowners. This section discusses some of the requirements of these stakeholders and the unknowns.

4.1. GOVERNMENT

The government requirements are largely set out by Civil Aviation Authority (CAA) Part 101: Gyrogliders and Parasails, Unmanned Aircraft (Including Balloons), Kites, And Rockets Operating Rules and Part 102 Unmanned Aircraft Operator Certification – these rules are set out in section 3.1. In addition to CAA rules, the operators must comply with the relevant council authority, Department of Conservation, and NZTA rules.

To fly over DOC land, users require a concession. There is an application fee for this and in some DOC areas it is recommended that operators do not apply as applications are likely to be declined (Conservation, N.D.). These are as follows:

- Abel Tasman National Park
- Arthur's Pass National Park
- Egmont National Park
- Fiordland National Park
- Mount Aspiring National Park
- Nelson Lakes National Park
- Paparoa National Park
- Tongariro National Park

Being unable to fly in these areas is unlikely to affect Lumen as it intends to operate within Canterbury initially.

In addition, NZTA will not permit non-certified or recreational operators to fly within their road corridors, regardless of highway status and traffic volume (Airshare, 2016). Even Part 102 certified organisations must apply for permission, and it is not guaranteed that it will be granted. Permission is granted on a case-by-case basis subject to an agreed safety plan to manage risks (Airshare, 2016). If part 102 is obtained and flight is needed near or within a state highway corridor, applications should be passed to the regional performance manager. Flying near state highways would be a safety risk and unless Lumen gains Part 102 certification, it must not fly within these areas. It should engage external operators for this.

4.2. COUNCILS

The Christchurch City Council have well documented rules surrounding flights on their land, and over and within road corridors. Part 102 certification must be held to fly over council roads. Discussion with the traffic engineer involved has indicated that there is no exception (CCC Traffic Engineer, 2021). More information and a map of areas where permission may be required is shown here (Christchurch City Council, N.d.). It must be stated that even if the drone can be flown according to CCC rules, it may not be able to meet CAA requirements, and vice versa. This means that it would be incredibly difficult to offer this service within the Christchurch City District to Part 101 rules unless it was performed rurally. In tandem with the 4 km aerodrome rule, this makes the opportunities within the Christchurch District highly limited and probably unlikely to occur.

Lumen also performs much of its work within the Selwyn District. Selwyn District rules are less defined but do state that aircraft cannot be flown over council-controlled land without permission. Discussion has determined that it is generally their policy not to allow drone flying over formed carriageways (Johnson, 2021), but permission is granted on a case-by-case basis. This means that it is unlikely that Lumen would be granted permission to fly over high-traffic areas, but in low volume areas it may be able to. It is likely that permission would be granted over paper roads where the corridor exists but there is no formed road in place. Providing or generating adequate traffic management plans and safety plans will give Lumen the best opportunity to operate in these areas, but the likelihood is uncertain.

Other councils like Upper Hutt do permit flight over roads provided that road use is not impeded (Upper Hutt City Council, N.D), and users are not put at risk. With the proposed changes in section 3.6, this may develop further.

The Canterbury region is likely to be the initial primary focus. [redacted]

Most councils have vague rules and only state that permission is required. This will need to be managed on a case-by-case basis, particularly as Lumen can only currently perform to Part 101 requirements. These rules appear to make the most likely operating solution in rural areas where there are no or few roads nearby, and large, consecutive sections of private property. As this is more likely aimed at the distribution or sub-transmission market, it appears that the scope is limited.

4.3. CLIENTS

If using drones for external use, Lumen must adhere to client requirements to ensure that their assets are protected.

As the network operator, Transpower is regarded as the industry standard. Meeting Transpower requirements and demonstrating competency will mean that Lumen is likely to ensure other clients' needs are maintained and they can work from this basis.

As UAVs are still considered an emerging technology, potential clients may not have well defined guidelines and demonstrating use for Transpower will increase the likelihood that a client trusts Lumen for this operation. Potential clients are any lines companies and distributors. The initial primary target may be a company such as Orion as Lumen performs many jobs for them each year.

It is highly unlikely that this would be used for Transpower projects as they already utilise aerial laser surveying, however, it is not impossible. It could be used for Transpower work such as as-building replacement poles and structures, or vegetation management.

4.3.1. Transpower

As Transpower's position in the market is critical, they have highly defined specifications regarding drone use for their work. This enables them to reduce the likelihood of safety or performance events occurring and ensures any downtime is not caused by UAV intervention.

[redacted]

- [redacted]
- [redacted]
- [redacted]
- [redacted]

[redacted]

[redacted]. This is not an issue for Lumen's Mavic 2 Zoom as it can still obtain the required photo detail whilst maintaining the distances required. For the Mavic Air however, the lack of zoom renders it functionally useless. Having two drones means that Lumen has redundancy in the case where one is out for maintenance, or allows multiple jobs to be performed at the same time.

[redacted]

[redacted]

Transpower also require flight logs, flight planning, hazard identification, and ensures safety is a primary concern. With the visual inspection work Lumen performs for Transpower, the company already knows what it must do to meet the requirements. It would be recommended that regardless of other client requirements, Lumen aims to adopt similar processes to those used on Transpower jobs for all drone clients.

4.3.2. Orion

[redacted]

Orion do use drones in-house for various inspections regarding their lines and substations. Peter Allen, Orion's specialist noted that Orion would not be against service providers using drones near their lines but would require them to undertake a course to prove competence and show that it has the safety systems in place to ensure a smooth workflow. [redacted]

[redacted]

Lumen should engage further with Orion to develop a plan surrounding this drone procedure.

As mentioned in section 4.2, Selwyn District Council may allow drone use over their land and road corridors depending on various factors. [redacted]

4.3.3. Other

Multiple other lines' companies were contacted. Their requirements are aimed at the general public [redacted] For example, Mainpower require that UAVs maintain 20 m distance to their assets, and that flights are not carried out above lines or structures (Mainpower Services Representative, 2021). If these requirements were not adjusted for specific projects, Lumen would not be able to perform photogrammetry for an existing line project, although it may be able to use it for greenfield work.

[redacted]

[redacted]

4.4. INTERNAL

Lumen's Quality and Environmental Manual lists Lumen specific requirements for flights as follows (Lumen, 2021):

1. No UAV flights permitted outside NZ (Due to limitations in our aviation insurance policy).
2. Manager approval required prior to any personal use. The user will be financially responsible for any damage while being used personally, including traveling.
3. No personal flights while on company business.
4. No flights in urban areas unless approved by the Managing Director and the Client.

These requirements are reasonable but to meet its ISO compliances there are various factors that could be added.

Lumen could add or create a maintenance checklist and log. There is no official recommendation for how long parts such as propellers should last but it would be good to record that Lumen checks and cleans them after a set amount of flight time or flights. Lumen should check and document that components such as propellers, the battery, and the camera system/gimbal are airworthy, free from damage and debris, and note if or when replacements are used.

Lumen also has a competency assessment that must be completed prior to drone use but there is no register of each pilot's experience. Creating a competency register would allow Lumen to remain vigilant in ensuring that the operators skills remain current and relevant, allow them to pick the right person for a particular project, and allow them to log the experience of each person in one large dataset, as well as maintain a record of training.

[redacted] Drones like the DJI Mavic 3 have a 46-minute flight time and it could be argued that a time reserve requirement is more relevant. Nonetheless, Lumen should implement an official battery reserve requirement [redacted]

It should also determine a company policy for visual line-of-sight. The drones are small and easy to lose sight of, particularly if looking away briefly. Whilst there is no official definition as everyone's eyesight differs, Lumen can minimise its compliance risk by making a company policy for distance from the operator. The drone heads up display shows approximate distance to the operator, so it is easy to track.

5. STAKEHOLDER REQUIREMENT IMPACT

This section outlines how stakeholder requirements may impact operations and what could be done to mitigate their impact, and if the mitigation strategies are realistic.

5.1. RESTRICTIONS

Some of the current restrictions, especially those caused by council road corridors mean that the range in which Lumen could operate is limited. It is unlikely that the service could be provided in urban areas with the current restrictions (and without a Part 102 certification), particularly within the Christchurch City District.

Drone use near road corridors within CCC boundaries will not be granted permission (Christchurch City Council, N.d.). Given that most powerlines are installed alongside roads, and when combined with the number of airports and aerodromes within the Christchurch District, it is highly unlikely that Lumen could use this service in the foreseeable future. [redacted] Alternatively, if the rule changes proposed by the Ministry of Transport are passed, this is likely to open opportunities to Lumen.

The visual line of sight requirement was initially thought to provide considerable restriction, but given the drone capability, it does not hinder the operation significantly. The recommended flight type was type 3 or 4 in the technology report. These only have the ability to capture around 400-600m corridors under ideal conditions, whilst providing the security required to produce good data outputs. With an estimated 350-450m VLOS range, the operator could move along the survey corridor to ensure compliance is met.

No definitive answer was given regarding drones use near roads in the Selwyn District, but their policy is no drones over formed carriageways (Johnson, 2021). It is likely dependent on the specific road, when, and what Lumen's processes would be to ensure it can be carried out safely, which may include a traffic management plan.

Overall, these restrictions will impact the proposed operation slightly, but even if Lumen decides to upgrade to one of the recommended drones, it should not create much financial burden on the company. Once it is confident and has shown competence, it can reassess the CAA Part 102 certification process.

5.2. RESTRICTION MITIGATIONS

In large, the mitigations to these restrictions can be summarised in two ways. Lumen must either accept them, thus accepting that there will only be limited scope for engagement, or obtain a CAA Part 102 certification. Obtaining a Part 102 certification also brings risks, although they are mainly financial. It would allow the company to demonstrate competence, although their current work with Transpower is an indicator of this anyway.

[redacted]

6. RISKS & OPPORTUNITIES

Risks are an inherent part of doing business and are therefore important considerations when operating or wishing to operate in new markets. The risk response strategy as well as the company's risk appetite will determine the future action(s) taken regarding any current or new ventures.

This section aims to determine the risks generated by Lumen operating this service.

6.1. RISK REGISTER

The following risk register identifies both internal and external risk factors in numerous impact areas including safety, performance, reputational, compliance risks, as well as mitigation factors.

Table 2: Risk Matrix Scoring

			Insignificant	Minor	Moderate	Significant	Major
			1	2	3	4	5
Likelihood	Very likely	5	5	10	15	20	25
	Likely	4	4	8	12	16	20
	Possible	3	3	6	9	12	15
	Unlikely	2	2	4	6	8	10
	Very unlikely	1	1	2	3	4	5

Table 3: Risk Matrix & Mitigations

Hazard	Impact Description	Likelihood	Consequence	Risk Score	Mitigation
Business Risks					
Poor survey performance	Poor design, leading to loss of revenue or reputation, rework at Lumen's cost, insurance claims	2	4	8	Use a detailed and approved procedure. Work within competencies. Transfer survey risk depending on the project via things such as insurance or engaging other providers. Ensure adequate training.
Lack of trust	No clients, poor investments	2	1	2	Demonstrate competence via use on Transpower work, or gain certifications.

Camera failure	No survey data	3	2	6	Check onboard storage before flight and after flight to ensure photos are legible. Take a sample photo prior to survey. Ensure settings are in the recommended range.
Poor forecasting	Revenue loss	2	2	4	Engage and work with potential clients early.
Drone utilisation	Unable to perform job because the drone is in use somewhere else	1	2	2	Create a drone booking system similar to that used by the vehicles.
Rule change	The proposed rules changes could affect the way this operates and mean Lumen doesn't recover its investment	2	3	6	
Hazard	**Impact Description**	**Likelihood**	**Consequence**	**Risk Score**	**Mitigation**
H&S Risks					
Loss of control	Injury to persons, mission completion	2	4	8	Monitor in-flight information and transmission. Ensure return to home function is enabled.
Collision with other aircraft	Collision or safety events with other aircraft could lead endangering other people's hearth and would lead to prosecution. It could have dramatic impacts on the finances of the company.	1	5	5	Ensure part 101 rules are followed, no flight over 120 m,
Powerline or asset strikes	Damage to the power lines causing loss of power or financial repercussions	3	3	9	Stay as far as reasonably possible from assets. Perform a pre-flight inspection and create a hazard register. Ensure return to home flight height is adequate. Ensure pre-flight check accounts for the terrain variability.
Weather	Weather disrupts drone flight, causes poor results	3	1	3	Check and monitor weather reports, ensure windspeed is within the drone's useable wind range.

Loss of power	Drone loss, damage to persons or property	2	3	6	Ensure batteries are fully charged prior to mission inception. Ensure return to home is set at least 20% battery. Check battery health periodically. Ensure drone is in working order, propellers are free from debris and cracks before and after each flight. Create a Lumen policy on battery limit. E.g. complete mission with 4 minutes remaining.
Transmission Failure	Drone loss	2	3	6	Ensure all users have completed the Lumen drone training procedure. Stay as far as reasonably possible from objects that may cause interference
Hazard	**Impact Description**	**Likelihood**	**Consequence**	**Risk Score**	**Mitigation**
Environmental Risks					
Noise	Scared animals Irritated landowners or neighbours	3	2	6	Ensure permission is granted to fly over people or property. Record interactions and agreements.
Collisions or scaring of animals	Destruction of habitat, injuring animals	2	4	8	
Collision with flora	Damage to native or protected species	1	3	3	
Air pollution from driving	Minimal individual impact	3	1	3	Offset using carbon credits
Hazard	**Impact Description**	**Likelihood**	**Consequence**	**Risk Score**	**Mitigation**
Compliance Risks					
Non-compliance with CAA Part 101	Fines for pilot and business Reputational damage	2	4	8	Ensure training performed, ensure up-to date, undertake regular re-assessing of operators. Create a drone competency register.
Flying above 120 m AGL Limit	Fines to the business and operator	1	4	4	Ensure the operator is aware of the surrounding terrain. Set a suitably low maximum height in the DJI application
Flying outside of VLOS range	Fines to the business and operator, loss of the drone	3	3	9	Determine a company policy regarding a maximum permissible distance

Data management	Not meeting requirements leads to reputational damage or ISO non-compliance	2	3	6	Ensure all data is backed up and stored in an appropriate manner, utilise the CCTV checklist to manage this
Landowners and external people	People become annoyed at the operation, hassle Lumen employees, try to hinder the operation	2	4	8	Ensure landowner permission is sought, create an action plan for if peripheral people become irate or bothersome

Whilst some of the risk scores are relatively high, undertaking the mitigations provided should allow these risks to be minimised or removed entirely. Overall, the risk profile of this operation is quite small, provided that Lumen creates and manages some processes around it.

6.2. MITIGATIONS

In addition to the risk mitigations listed above, the following mitigating actions should take place.

Ensure a well-defined, up-to-date procedure on the data capture and processing is defined. Ensure regular process reviews occur.

In addition, insurances can minimise potential losses. Lumen currently has public liability insurance for drone use, with each pilot specified. New pilots must be added to the policy. Lumen also has professional indemnity insurance which should minimise any design implications of errors made. It is currently unlikely that anything beyond the current coverage would be needed. The drone is light and reliable so risks to people and property are minimal provided standard procedures are followed. Lumen's current coverage is $10,000,000 public liability, and $2,000,000 professional indemnity. This should be adequate coverage for the use of these small drones.

Finally, Lumen's drones are not currently insured for loss or damage. Under current circumstances, this is appropriate as they are low cost. Loss of a drone (due to damage or otherwise) would not have a material impact and is not worth the additional cost, given the risk. It was recommended that Lumen upgrade to the DJI Phantom 4 Pro series or Mavic 3. These are still relatively inexpensive drones so insurance would likely not be needed for the drone itself. If, however, Lumen decides to upgrade to any of the following then the cost of insurance would likely be outweighed by the risk of loss: a high-end photogrammetry drone and equipment, an RTK or PPK embedded drone, or LiDAR drone and sensor.

Annual competency checks of the Lumen pilots can ensure that each pilot is up-to-date and able to fulfil the requirements of the job.

6.3. OPPORTUNITIES

As the rules are restrictive, and Lumen' does not currently wish to provide this service to the wider market, the opportunities provided are relatively small and most likely regard the development of relationships or partnerships with clients. Because of this, the opportunities are largely intangible as the main driver is not financial gain.

7. Conclusions and Recommendations

Overall, the residual risks are relatively low, but so are the opportunities in which this could operate. Whilst some of the rules surrounding drone use within New Zealand do mean that there are significant restrictions, it quickly became apparent that Lumen's appetite was not to offer this service to the wider market anyway. It only wishes to offer this service to its current overhead line clients to begin with. This means that it is most likely to be used in the lines team to provide supplementary data in the case of rework, or greenfield line design. It is possible that it could be used for brown field design provided that permission can be gained, although this is highly situational.

If Lumen wished to market this as a service to the wider market, operating under part 101 rules would be highly restrictive, primarily due to permission requirements. It would be almost impossible to offer this service in the Christchurch City District as they require CAA Part 102 certification to fly within or across road corridors. The vast majority of urban power lines travel alongside or within road corridors. With the extra consideration of distance to aerodromes, there are likely to be very few opportunities for use within the Christchurch City District without gaining extra certification.

Gaining a Part 102 certification is the best way to navigate around some of the rules set by Part 101. Given the time it takes to acquire it, and the costs involved, it is hard to recommended applying for a Part 102 certification. The financial implications are discussed later. Whilst it would create more opportunities, Lumen does not currently want to act upon these opportunities. Even with Part 102, access to some areas Lumen may wish to operate in would still be difficult, if not impossible. It is recommended to re-evaluate this stance after performing at least 5 drone surveys.

There are a variety of proposed rule changes by the Ministry of Transport, which appear to offer more opportunity for Lumen regardless of which CAA Part is being operated under. The caveat is that they are not likely to take effect for a number of years. This does, however, give Lumen time to perform some projects, and re-assess its appetite at a later date. If all went well, it could expand in the future as a result of the proposed rule changes. Conversely, if the changes negatively impact Lumen it may mean that it is unable to recover some of its investment.

Some of the restrictions imposed mean that there are likely to be many times where the best solution would be to engage someone else. For example, any project within the Christchurch District. Whilst it is possible Lumen could perform here, it would almost certainly need to be over private property.

Based on the findings of this report, the following recommendations are made:

Table 4: Compliance Recommendations

Recommendation	Person Responsible	By When
Engage Orion to develop relationship and offer service.	Overhead Lines Manager	As soon as possible
Develop a plan and checklist for drone footage and photo data management, using the Privacy Act CCTV checklist in Appendix A (Privacy Commissioner, 2009).	Operators, Manager	Before any operations
Undertake a Part 101 training course.	Operators	When the projects are decided upon
Create a landowner liaison form or register.	Admin/manageme nt	When first engaged for a project
Monitor MoT prospective rule changes.	Operators	Indefinitely
Create a high-level drone maintenance plan and log.	Operators	Immediately
Add drone battery contingency to allow mission completion to quality manual.	Management	Immediately
Engage other electricity network owners	Management	Upon completion of a successful project
Determine a company policy for visual line of sight distance.	Management	Immediately
Do <u>not</u> gain Part 102 certification unless appetite changes.	N/A	N/A

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Appendix A – CCTV Checklist

CCTV checklist for small businesses

This checklist is for small businesses that operate or intend to operate small CCTV systems of a low number of cameras. **You should review the checklist regularly**.

Before you start, you need to have identified a clear reason for having a CCTV system. This is your purpose – see Section 1 and Guideline 1.1 for more details.

Purpose				
Relevant guidelines	***Actions and practices***	***Date checked***	***By***	***Date of next review***
Section 2 Guideline 2.3	**Responsibility:** There is a named individual who is responsible for the operation of the system.			
Section 3 Guideline 3.1	**Equipment:** You have chosen CCTV cameras and other equipment that are suitable for your purpose (outlined above) and they are operating properly.			
Section 3 Guideline 3.3	**Unintrusive camera locations:** The CCTV cameras are not located in places that intrude on the privacy of individuals (such as bathrooms, backyards, through windows etc).			
Section 4 Guideline 4.2 and 4.3	**Signage:** There are visible signs showing that CCTV is in operation. Where it is not obvious who is responsible for the system, your name and contact details are displayed on the signs.			
Section 5 Guideline 5.1	**Limits to time when cameras operate:** CCTV cameras only operate when necessary, such as during opening hours or days and times of the week when crime peaks.			
Section 6 Guideline 6.2	**Use and disclosure of CCTV images:** You only use or disclose CCTV footage for the purpose outlined above and not for any other reason.			
Section 7 Guideline 7.1	**Security of CCTV images:** Images are transmitted and stored securely.			
Section 7 Guideline 7.2	**Limited retention periods:** Recorded CCTV images are kept for a specified time. This time period must not be longer than is necessary to achieve your purpose outlined above.			
Section 8 Guideline 8.2	**Access to CCTV images by individuals:** Individuals can access CCTV images of themselves, but you also protect the privacy of others in the footage.			
Section 8 Guideline 8.4	**Log of access:** You keep a log of who has accessed your CCTV footage, including access by individuals and the Police.			
Section 9 Guideline 9.3	**Regular review:** You do regular checks to ensure the system is working properly.			

Appendix B – Sample Exposition

Insert Organisations name

ORGANISATIONS NAME

Sample Exposition

CAR Part 102 Unmanned Aircraft Operators Certificate

Document Version 0

29 July 2015

NOTE TO READERS:

This outline sample exposition has been prepared to assist applicants in the development of an exposition that will help them meet the requirements of a Part 102 Unmanned Aircraft Operator exposition.

Further assistance can be found in Advisory Circular 102-1 Unmanned Aircraft – Operator Certification.

It consists mainly of headings and subject titles with little details as to the types of operation and equipment since this detail is so diverse we could not always give a good example to act as guidance.

In developing your exposition you will need to expand on each section, as appropriate to your operation.

When complete you will need to delete all CAA guidance notes which in most cases are easily identified by the red italic text.

Copy 1

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5.2. CONCLUSION

The main conclusion of this section is that there are many restrictions to what Lumen is able to do if operating to CAA Part 101 requirements. The easiest solution to most of the restrictions is to obtain a Part 102 certification, but this does not mean it is simple.

The primary driver that limits Lumen's operating window is the requirement to obtain permission of landowners whose property is being flown over. For the most part, power lines are located alongside or within road corridors. The road corridors are generally controlled by the local council or NZTA for state highways. This means that the operator must acquire permission from these organisations to fly within these areas. UAVs are often seen as a safety risk. Because of this, councils like the Christchurch City Council require that operators flying in these corridors have a Part 102 certification (Christchurch City Council, N.d.) to be granted permission. Some councils, such as Upper Hutt Council, are relatively relaxed and allow flight to part 101 rules (Upper Hutt City Council, N.D). It is most common that councils take a conservative approach where drone flight is concerned, and it is not typically allowed. This is highly situational.

The combination of these factors creates unknowns that make it difficult to accurately determine when or where the service could be operated, without the additional certification.

The secondary driver is the visual line of sight requirement (Civil Aviation Authority of New Zealand, 2021). In the technology report it was determined that under ideal conditions, the drone could be seen up to approximately 350-450 m away. When the operator can no longer see it, it is beyond visual line of sight, and therefore breaks the rules. This is not as limiting as first thought as the current drone can only perform a survey up to a maximum of approximately 800 m. In theory, the operator could stand at the halfway point of the survey, but this would then be approaching the limits of what is allowed.

Gaining a CAA Part 102 certification would allow numerous benefits such as extended line-of-sight flight and flying with notification only (i.e. not needing permission in many cases) (Dolman & Adventure Helicopters, 2021). Obtaining this is a lengthy, expensive process (Aviation Safety Management Systems, 2021). Lumen could expect to commit to the certification a year before it is granted, and even longer before any benefits materialise. In combination with Lumen's current appetite, it is difficult to recommend that the company invests this certification.

Furthermore, there are numerous ways in which Lumen can ensure that its ISO compliance obligations continue to be met.

The Ministry of Transport is proposing that some of the rules surrounding UAV use in New Zealand are changed (Ministry of Transport, 2021). The changes have potential to increase Lumen's ability to provide these services, rather than hinder it. In addition, it will attempt to form a path by which beyond line-of-sight flight can be achieved. If beyond line-of-sight flight is allowed in future this may dramatically increase the available opportunities. Whilst it is not currently recommended that Lumen obtain a Part 102 certification, if the rule changes are enacted Lumen should reconsider its stance on this, especially after gaining some experience. Combined with a longer-range drone, it could increase the number of opportunities dramatically.

It has also been determined that Lumen's current appetite is to not offer this service to a wide market, which creates self-imposed restrictions.

Overall, it appears that the risk profile of this service is relatively low, but so are the opportunities. The recommendations from this report are as follows:

Table 2: Compliance Report Recommendations

Recommendation	Person Responsible	By When
Engage Orion to develop relationship and offer service.	Overhead Lines Manager	As soon as possible
Develop a plan and checklist for drone footage and photo data management, using the Privacy Act CCTV checklist in Appendix A (Privacy Commissioner, 2009).	Operators, Manager	Before any operations
Undertake a Part 101 training course.	Operators	When the projects are decided upon
Create a landowner liaison form or register.	Admin/manageme nt	When first engaged for a project
Monitor MoT prospective rule changes.	Operators	Indefinitely
Create a high-level drone maintenance plan and log.	Operators	Immediately
Add drone battery contingency to allow mission completion to quality manual.	Management	Immediately
Engage other electricity network owners	Management	Upon completion of a successful project
Determine a company policy for visual line of sight distance.	Management	Immediately
Do <u>not</u> gain Part 102 certification unless appetite changes.	N/A	N/A

6. FINANCIAL ANALYSIS

6.1. INTRODUCTION

The technology and compliance sections have determined that Lumen can provide this service with adequate results but that there are limited opportunities available – whether that is because of the rules surrounding UAV use, or Lumen's appetite.

The purpose of this section is to determine financial viability of Lumen providing this service. To do this Lumen must determine its expected income or profit, the costs associated with this operation, and the pricing structure of a job.

As a profit generating company, Lumen would endeavour to generate a profit from this type of operation, but it is not the most critical aspect. Its strategic values mean that this is not necessarily required given that other benefits may outweigh it. Namely, the ability to provide industry leading service. Lumen is a nimble company that is always moving forward and adapting to new situations and this service enables it to adapt to client needs. This is an opportunity for the company and should provide both tangible and intangible benefits. This means that Lumen may offer the service even if it was cost neutral over the life of the product.

To determine Lumen's expected return a net present value and sensitivity analysis has been performed. To determine how the service would perform relative its current performance, the opportunity cost of the service has been determined.

Assuming that permissions are granted, a consideration must be made for the expected cost to a client. Realistically Lumen must be price competitive with the other methods, otherwise a client may not use the service despite the other apparent benefits. To understand this, a survey situation that is likely typical has been assumed and priced. This has then been compared to the expected price of other survey methods.

This section aims to answer the following questions:

1. What are the financial implications to Lumen?
2. How much income would Lumen generate?
3. What would be the likely cost to a client?

Determining the financial implications will allow each part of the project to combine to provide overall recommendations for how Lumen should proceed.

LUMEN

Engineering for
a better future

Financial Analysis Report

Financial Analysis of Lumen Providing UAV Surveying Services

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January 2022

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REVISION HISTORY

REVISION	DATE	DESCRIPTION	PREPARED BY	REVIEWED BY
0.1	28/12/2021	First draft	Tom Savage	N/A
0.2	20/01/2022	Draft for Review	Tom Savage	DT, PG
1.0	27/01/2022	Version 1	Tom Savage	

CONTENTS

EXECTUTIVE SUMMARY

To make an informed decision on how Lumen should approach providing photogrammetry survey services, it must understand the financial implications and determine an expected return.

Lumen must consider its potential utilisation, hardware or software costs, certification costs, expected survey length, and more. It must also determine how competitive its pricing is, as if the costs differ substantially from the status quo a client is unlikely to use the service.

To determine the expected return, an NPV analysis was performed, and its sensitivity tested. In addition to this, the opportunity cost of investment was determined. The NPV analysis was performed based on the number of usage days per year, with the use of a DJI Mavic 3 as this was previously recommended. In addition, Lumen has a duty to be able to perform aerial inspections for some clients and after it was deemed that the Mavic Air can no longer be used, the Mavic 3 provides the best utility to Lumen.

The NPV analysis determined that Lumen's expected return over the four-year life of the drone is positive, provided that it uses the drone ten times per year or more. In addition to this, the opportunity cost was determined on the same basis but showed that for Lumen to generate a better outcome than it would by giving the survey to another provider, it would need to charge the drone at a higher rate than usual - $400.

The costs to clients were determined for corridor lengths up to 8 km and compared with other survey methods. It was found that Lumen's UAV survey would be cost competitive with traditional surveys for shorter lengths and cost beneficial for larger lengths. It is likely more cost effective than UAV LiDAR for corridors up to 4-5 km and then relative parity beyond this.

This shows that Lumen can provide a service to the client at a competitive rate. The report also shows that the while the costs to Lumen are not significant, neither are the opportunities.

Due to the findings of this report, the following recommendations are made:

Table 1: Financial Recommendations

Recommendations	Person Responsible	By When
Purchase new drone (Mavic 3)	Software & IT consultant	When the API for the Mavic 3 is released, allowing more utility and compatibility with the flight planning software
Allow the drone to be used elsewhere in the business	Team managers	N/A
Monitor use, missed opportunities and then decide on Part 102 certification	Team managers	1 Year from first survey
Increase drone day rate to $400 for Mavic 3	Team managers	Commencement of survey
Finish Pricing Spreadsheet	Tom Savage	March 2022

1. INTRODUCTION

This report provides information on and detail about the financial implications of Lumen performing UAV surveying operations. In particular, it will focus on the cost of investment using a net-present-value analysis and summarises expected cost to clients across all survey methods discussed previously.

Whilst Lumen is currently capable of performing the UAV surveys from a technical and compliance perspective (albeit with some limitations). It must understand the financial risks and implications that it could incur. For Lumen, while it endeavours to make money out of this type of operation, its strategic values mean that this is not necessarily required given that other benefits may outweigh it.

It could allow the company to achieve some of its strategic goals and values to a higher standard. Lumen aims to adopt a nimble strategic approach enabling them to adapt to meet client needs. This is one of those opportunities. This business opportunity provides both tangible and intangible benefits to the company. This means that Lumen may offer the service even if it aimed to be cost neutral over the life of the product.

One of Lumen's current drones, the DJI Mavic Air, has been deemed unsuitable due to battery life capability [redacted] Lumen's other drone, the DJI Mavic 2 Zoom is usable but often in-use elsewhere. This means that Lumen will likely need to buy a new drone if it decides to offer this service.

Whilst it may undertake an operation if it is cost neutral, it is unlikely to be worth undertaking a new venture if it will not provide other benefits. The benefits for Lumen are control over a design process and better client outcomes - due to speed and ease of mobilisation.

This report aims to answer the following questions:

1. What are the financial implications to Lumen?
2. How much income would Lumen generate?
3. What would be the likely cost to a client?

2. INTERNAL COSTS

This section outlines the expected cost of investment Lumen would incur if it decided to pursue UAV survey operations for its intended market. Whilst Lumen has an appetite to perform these surveying operations, it does not currently have the appetite to expand into the wider surveying market, particularly as it has no experience in this sector. It wishes to provide a niche service to some of its core customers that could allow their projects to be performed more quickly and efficiently. It is therefore unlikely that this would add significant revenue but could allow them to build on relationships, show its competence, and expand in the future.

Forecasting for future use is difficult given that Lumen has no experience in this field. Numerous scenarios will be performed to allow a broad overview to be determined. The caveat is that costs have potential to vary considerably, from minimal to extreme, depending on choices made and the outcomes generated. In addition, due to the likely low utilisation, this analysis is subject to high sensitivity in relative terms, but low in absolute terms. It is, however, possible to perform these projects and make this investment with minimal financial risk.

Lumen's core objective with this operation is to provide a service that will help meet its client's needs, rather than significantly boost income however, it may not be willing to perform the job at a loss.

An analysis will be performed under a number of scenarios. It was determined that Lumen's Mavic Air is functionally useless and that upgrading to a new low-cost drone would allow them provide this service while also allowing use in other areas of the business. The drone chosen based is the DJI Mavic 3. It has been assumed that this drone has been used in all of the following analyses.

2.1. OUTRIGHT COSTS

The outright costs are those that Lumen should or must incur to undertake the drone operations. This includes any software, drone upgrades, subscription services, certifications, and more.

As noted in the technology report, various factors are required to provide adequate results. The use of Ground Control Points (GCPs) is overwhelmingly recommended. This requires both GCP markers and a position measurement system. Lumen already has a Trimble DA1 GPS receiver which is capable of accuracy to 1 cm horizontal and 2 cm vertical, which is perfectly adequate to utilise ground control points. Lumen therefore only needs:

- GCP markers, at least 10 recommended. DroneDeploy recommends 8 over a 50-acre area, and 1 extra per 10 acres after that (DroneDeploy, 2021). For Lumen, this should be sufficient an entire survey.
- Trimble Catalyst Service subscription. The Precision service is highly recommended and can be bought either on demand for 10 hours, using 1 hour at a time, or monthly where there is unlimited use during the subscription period. The precision on demand is recommended at an early stage, which would cost $218.50 including GST.

In addition, a drone upgrade is recommended, primarily due to battery concerns. The recommended options were the $3,100 DJI Mavic 3 because of the overall utility it has, or $2,900 Phantom 4 Pro because it is specifically recommended as a photogrammetry drone. These drones were recommended as they solve most of the primary issues with the Mavic Air, whilst being relatively cost-effective solutions. There are other options available such as the Phantom 4 Pro RTK (accurate positioning), WingtraOne (fixed wing, fast, large range), Matrice 300 RTK with Zenmuse P1 (drone with swappable payloads) or Zenmuse L1 (LiDAR module). All of these solutions will produce results better than the recommended drones in some way, but cost from 4-15 times as much ($14,000 to $45,000) so require significantly more investment.

Software must also be acquired. There are multiple options for this and the three packages considered are Agisoft Metashape Professional, DroneDeploy, and Pix4Dmapper. Agisoft Metashape can be bought either as a perpetual, node-locked licence, or with cloud processing services (SAAS). The DroneDeploy pricing has been updated during the course of this project and has been assessed based on the old pricing. As it is likely that only one person would be using the software, it was assumed that the old "business" plan is used, which appears similar to the current "individual" plan. The subscriptions are either monthly or annual. Pix4D can be purchased as either a perpetual licence, monthly subscription, or annual subscription.

It is thought that utilisation will be low, so only the monthly subscriptions or the cloud processing services will be considered.

In addition to software, a computer may be required depending on the chosen processing method. DroneDeploy and Agisoft Metashape cloud processing do not require PC upgrades or high-end hardware, but Pix4D does, as the processing is performed locally. Even if a PC was required, Lumen currently has spare computers that would be capable, so it is unlikely that additional costs would be required.

There is the cost of certifications and qualifications. The Part 101 certificate is cheap and will provide an opportunity for pilots to gain experience and prove their competency. The Part 102 certification is expensive, will require extensive training and time, but will allow Lumen to meet many of the client or Council requirements, and will provide additional privileges.

Finally, there are training costs. It will also require at least one person to be familiar with the processing techniques involved. Using both the photogrammetry procedure and a formal course, it is likely to take 2-4 days per person to grasp a level of competence likely to be required by the client. This could amount to $6,000-$11,000 in lost revenue. It is assumed that the actual cost to Lumen is half of the lost revenue, which is not insignificant. The Part 102 certification cost is approximately known, but it is not known what level of competence is required to begin.

The potential costs are summarised in table 1:

Table 2: Potential Outright Costs Lumen Could Expect to Incur

Item	Cost Range
GCP Markers (at least 10)	$150-$200
Trimble Catalyst Subscription (10 hours on-demand precision service)	$218.50 Per 10 Hours (recommended) Or $640 Per Month (annual subscription)
Drone	Nil if using current drones $2,500 - $3,500 if upgrading to other low-cost drones $8,000-34,000 High-end photogrammetry and survey drones $45,000+ For LiDAR Drones
Software	DroneDeploy $660 per month + $75 for GCP usage Pix4D $515 per month, or $5145 annually Agisoft Metashape Professional $4-$15 per hour cloud-based processing, or $5,000 per perpetual license
PC Upgrade	$0 Due to already owning adequate computers
Training	$3,000-$5,500
101 Certificate	$500

Many of these costs depend on which outcome is chosen and some are grouped together. For Lumen it will be about balancing the costs with financial risk, potential utilisation, and expected outcomes.

2.2. COST RECOVERY

To ensure that Lumen can generate a profit it must charge its time and services to clients with a rate high enough to offset the costs. For the proceeding analysis it is assumed that:

- An engineer charge-out rate is $150, with an expected profit of 20%
- A junior engineer charge-out rate is $135, with an expected profit of 20%
- A mark-up on services procured by Lumen of 10%. i.e. the drone cost is passed directly to the client + 10%

- The drone is charged at $250 per day usage as this is typical

These values are currently typical for Lumen.

2.3. NPV ANALYSIS

A NPV analysis has been used to determine the optimum scenario and to help understand if any options can provide positive financial return. For all the scenarios, it is assumed that the survey service is a separate entity to the overarching design project, and that Lumen would likely be given the design project regardless of whether this service is performed. This is a reasonable assumption. Offering this service is unlikely to materially improve the likelihood of winning a design project. Financially this is the most conservative assumption.

For Lumen, these projects would be low volume and would only be performed under ideal operating conditions, which includes gaining all the necessary permissions from clients, councils, and landowners. It is unknown how much difference obtaining a Part 102 certification would make to the utilisation so obtaining a Part 102 certification has been excluded, as have any associated benefits.

Lumen has two options once its competence is proven. It could upgrade and expand the markets served, or it could continue with the status quo. For Lumen it is not necessarily about additional revenue that could be generated, but control over the design process and serving the client. This is an intangible benefit but one that must be considered.

All the analyses have been performed over a 4-year period as this is the IRD's estimated operating life (Inland Revenue, 2021). A 10% discount rate was used for the initial NPV analysis. As Lumen has little debt, the weighted cost of capital plus inflation is around 20%. Due to the current wider financial outlook, a discount rate of 10% was chosen, but 5% and 15% are used to test the sensitivity

The NPV analysis was split across three usage scenarios. As mentioned, this is likely to be low volume for Lumen so usage days of 5, 10, and 15 per year were selected.

2.3.1. NPV Scenarios

The NPV analysis has been performed with scenarios assuming that they are used just 5, 10, or 15 days per year. It is currently unknown but when factoring additional use cases, 10 or 15 days per year are the most appropriate.

In addition to these scenarios, the NPV sensitivity was considered by factoring in the following:

- 5% discount rate
- 15% Discount rate
- Upgrade to a high-end photogrammetry drone (Phantom 4 RTK with base station, costing $13,999)

The table below shows the results of the NPV analysis with the sensitivity analysis included.

Table 3: NPV & Sensitivity Analysis

Number of Usage Days Per Year	NPV (Base)	5% Discount Rate	15% Discount Rate	RTK Drone
5	-$2,813	-$2,166	-$3,355	-$13,713
10	$8,409	$10,387	$6,752	-$2,491
15	$19,630	$22,940	$16,859	$8,730

The table shows that the NPV is relatively small for all scenarios but that some will generate a loss over the drone's life. The small value is due to the low volume, so is to be expected.

Clearly using the drone more often will generate better results for the company. Even using it just five more days per year generates a significantly different value and as 10-15 days is expected, Lumen can expect a positive NPV. Upgrading to the RTK drone has a significant impact and only provides a positive result if being used more than 10 days per year. Due to the uncertainty around this, this drone should not be acquired.

The change in discount rate does not significantly affect the expected outcomes. This shows that it is likely valuable to Lumen to invest in the low cost drone, but not the higher cost drones.

2.3.2. Opportunity Costs

The opportunity cost for Lumen has been determined using the above assumptions and by comparing it to Lumen engaging other service providers to do the work. It assumes that the Lumen engineer has equal utilisation in both the case where Lumen provides this service, and the case where an external service provider is engaged. As in the NPV analysis, the volume of work is unknown, so it has been performed over a number of use cases.

When charging the drone to the client at $250 per day the follow opportunity costs arise:

Table 4: Opportunity Cost of Investment Over Drone Lifecycle

Number of Usage Days Per Year	Opportunity Cost vs Engaging Others
5	-$9,279
10	-$4,524
15	$230

A positive value means that Lumen can expect to generate more profit over the expected life of the drone when compared to how it currently performs a project. A negative value does not necessarily mean that a loss will be incurred, but that the overall profit will be less. The 10 day per year average is the most likely, especially when considering other use cases. With the standard charge out rate it will generate less profit than it would by simply engaging another service provider.

As this provided a loss compared to the status quo, the same analysis was performed with a $400 per day rate. This is still seen as a reasonable price and would be unlikely to dissuade clients from using the service. The results are as below:

Table 5: Opportunity Cost for Drone Charge Rate of $400 per Day

Number of Usage Days Per Year	Opportunity Cost vs Engaging Others
5	-$6,901
10	$230
15	$7,362

This shows that the with a day rate for the drone of $400, and an expected usage of 10 days per year, Lumen can expect to generate slightly more profit that it otherwise may have.

The recommendation from this is that Lumen should charge the drone out at a higher rate to guarantee a higher profit than they otherwise would.

Another consideration to take is that Lumen may not charge their engineers at engineering rates if providing these services. This would negatively affect effect the company as their overhead costs would likely remain the same. In this case it would make less profit per person per hour. It would likely need to provide the service more often or increase the drone rate even more to obtain a net positive benefit.

2.3.3. Discussion

None of the options are likely to provide significant revenue or income and to ensure a positive return Lumen should ensure they are used for at least 10 days per year and increase the day rate for the drone. This will ensure that the drone pays itself back over its life and should add some extra profit, albeit negligible.

These are relatively simple solutions and show that the Mavic 3 would be a suitable purchase, without introducing too much financial risk.

It is clear that upgrading to one of the more expensive drones is unlikely to return a profit and is not worth obtaining unless its purchase will guarantee additional work. It is unlikely to be used on additional work unless a Part 102 certification was acquired.

In addition, a Part 102 certification would not be acquired unless it will generate additional work. Whilst it has potential to, Lumen does not fully understand how much extra work it could facilitate. This was left out of the analysis because the upfront costs are significant and there would also be additional training costs. Lumen could re-evaluate this stance when it has more experience and better understands the expected utilisation.

3. CLIENT COSTS

It is unlikely that a client would choose to engage Lumen if its services were substantially more expensive than other alternatives. It is therefore important to understand the costs Lumen could charge a client as well as costs of alternative survey options which a client might engage. Price estimates were created based on the testing involved in the technology report, and assumptions generated from it. In addition to charging its time, Lumen would pass some costs directly to the client, such as software costs for one-off jobs.

Even though this service may be intended to operate within a larger project, it will be priced separately on the assumption that the overarching project was provided to Lumen anyway, as the line design market is quite small. It will be assumed that the service is performed for a lines project. This will also allow for greater clarity on the impact that this could have on Lumen's finances. If Lumen decides to operate these services, then it may wish to re-analyse the financial impacts when it better understands how much capacity it has to perform these services. It may then be able to operate in different areas and use it to provide a service to the wider engineering or survey markets.

Costing considerations are as follows:

1. Who will be performing the survey and processing?
2. How long will client or stakeholder liaison take?
3. Travel costs – car hire or flights, distance to a site, time to mobilise
4. Time taken on site which includes factors such as
    a. Survey length
    b. The goal of the survey
    c. Survey terrain - steeper, less accessible terrain will take more time
5. Time taken to process, and the method used
6. Effective financial recovery of the equipment to the client (i.e. how much to charge the client for 1 day's use of the drone)
    a. Dependent on the drone cost, depreciation, accident/damage rate, insurance costs, and projected utilisation
7. How other costs (such as software) may be included in the final price
8. The intended financial return

These factors will vary from project to project which makes it difficult to provide a general overview of cost. In this document, the costs for Lumen to perform a survey will be based on the following assumptions: survey performed within 1 hour driving of Lumen's office, flat terrain that is easy to access, survey performed by a standard engineer, processing performed by a junior engineer, drone priced at $250 per day, software purchased for the job only and the costs are passed directly to the client, and the time used to liaise with the client and to gain consent is approximately four hours.

The pricing in this document will be estimated for survey lengths from 1 km to 8 km. Factors such as flight time, down time, and time to set up and measure ground control point locations will be factored into each survey length. It is also assumed that the Mavic 2 Zoom is used as it has better battery life. The costs would not vary much if a drone such as the Mavic 3. It would likely be slightly more efficient, but the $400 charged would offset any time savings.

Whilst the software chosen would depend on the specific project, and Agisoft Metashape is recommended for its utility, this programme is not available on a monthly subscription. It is available via online processing services where it is purchased per hour of use or by credits. It is likely that this method would be the cheapest solution as it costs only $4-$15 per hour and uses very powerful hardware. It should process quickly. As Lumen currently has little experience, using the price of a DroneDeploy monthly subscription is conservative and likely to provide an upper limit on expected cost.

The results will be compared against other survey methods to perform approximately the same survey. The prices for these were determined from a combination of past projects, provider quotes, and literature information.

From a technical perspective, there is no maximum survey length that can be performed using UAV photogrammetry and Lumen's drones however, there is likely to be a survey distance where it is no longer feasible due to pricing or legal constraints.

Three flight types were recommended to be used by Lumen when performing photogrammetry with the current drones. Each flight type has advantages and disadvantages both technically, and financially. It was determined that each flight type generated approximately equal accuracy however, because of the differences in flight path taken, each took a significantly different amount of time to perform – this means that for a given corridor length, one method may only take one flight, whilst another might take multiple. Each type also took a significantly different amount of time to process. As Lumen sells its time, it must consider these factors, although processing time can largely be neglected as only the initial and post processing need user engagement.

Comparisons are made between the following survey methods:

1. Traditional surveying
2. UAV LiDAR
3. Manned LiDAR
4. LINZ LiDAR
5. UAV Photogrammetry for each of flight type 2, 3, and 4 as explained in the technology report

The comparisons will be based on the following criteria:

1. Survey cost for a given corridor length
    a. In addition to comparing all methods, Lumen's available flight types will also be compared to each other separately, both with and without processing time as processing time may be automated depending on the system used
2. Cost per kilometre for a given corridor length

It is important to see the following cost implications in conjunction with the technological restrictions mentioned in the technology report as well as the legal constraints.

3.1. COST FOR A GIVEN CORRIDOR LENGTH

The following graph shows the approximate cost that a client could expect for a range of survey types, when performed over corridor lengths up to 8 km. These prices are likely to differ depending on the requirements however, it should be indicative of the expected relationships.

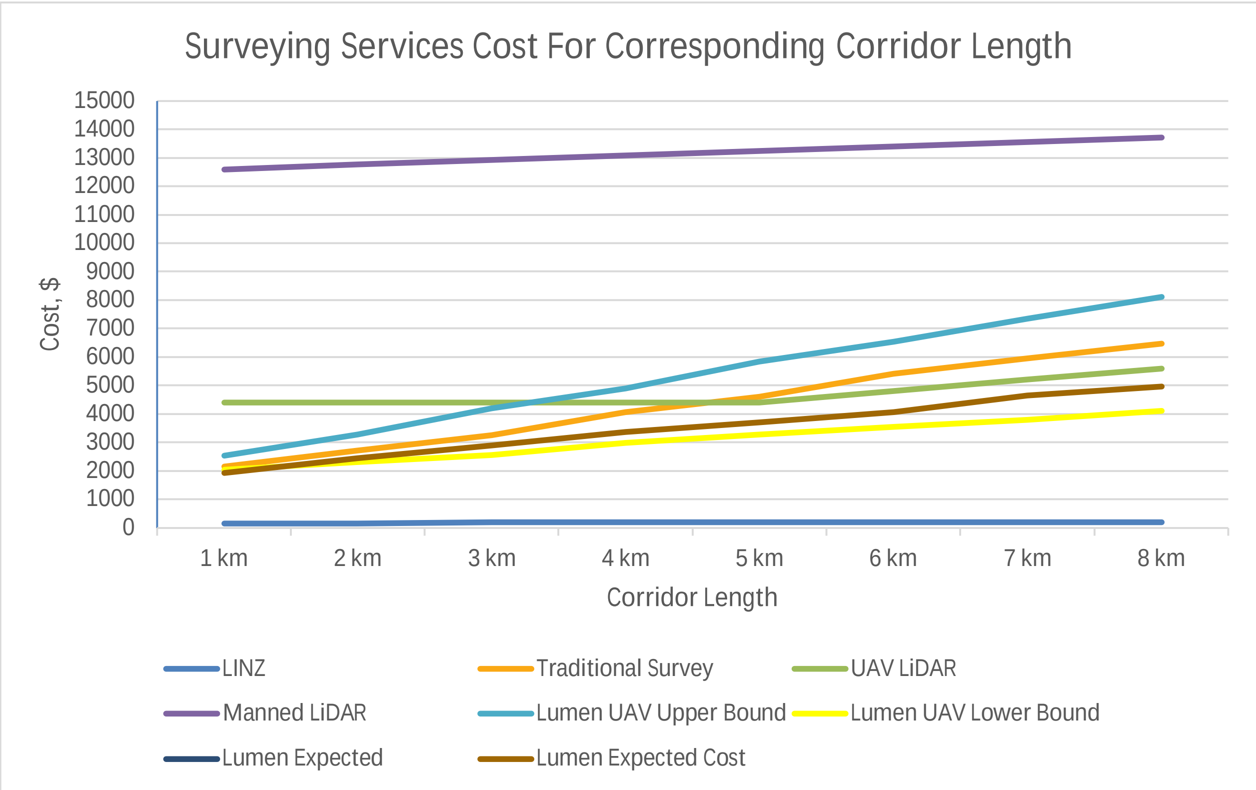

Figure 1: Different Survey Methods Pricing for Corridor Length Up To 8 km

The graph shows that the manned LiDAR is the most expensive option for corridors of these lengths and can largely be discarded. It is widely accepted that manned LiDAR become feasible for larger areas and benefit from economies of scale. As such, this result is largely expected.

It shows that UAV LiDAR is quite expensive for short corridors but as the length increases it becomes more competitive and cost efficient, becoming more cost effective than a traditional survey between 4 and 5 km. When the additional benefit of UAV LiDAR is considered, it may be a better solution than traditional survey even for corridors of only 2-3 km, although this depends on the area and if the provider can obtain flying permission.

It also shows that the cost of Lumen's UAV photogrammetry can vary substantially, and the true cost is likely unknown until more experience has been gained. Nevertheless, it is expected that its price is largely in line with traditional surveying up to around 3 km, and then becomes a more cost-effective solution. It is also likely to be cheaper than UAV LiDAR, although this is probably specific to each job. For highly variable terrain it is likely that Lumen's service cost would vary substantially, so it may be less cost efficient in these scenarios.

LINZ data is the cheapest by far as it only requires the user to find and download the data, and then perform some processing. It must be noted that the quality is not controlled in anyway by Lumen or the client as they cannot specify requirements.

UAV LiDAR cost was provided for a 50 m corridor width for corridors up to 10 km long. The price is fixed up to a corridor length of 5 km and then increases at $400 per extra kilometre. These providers have two key advantages over Lumen. They have CAA Part 102 certification and are able to perform a survey quicker than Lumen over a given length, although they are unlikely to mobilise as quickly as Lumen can.

The cost of the traditional survey was estimated based on time taken on similar projects previously (Resonant Surveyors, 2021) (Resonant Surveyors, 2020). The cost of manned LiDAR was provided [redacted], and then altered according to some online literature (Marshall et al., 2012).

The final issue here is that there may not be many areas where Lumen could perform a survey with a corridor up to these lengths, without the addition of Part 102 certification. A couple of projects performed in the last year likely would have been granted permission based on their location, but others prior to that may not have.

Overall, it is expected that the service would be at least price competitive.

3.2. COST PER KILOMETRE

The following graph uses the information in section 2.1 to determine the expected cost per kilometre, for a given corridor length. Manned LiDAR was excluded as for projects of this length, the results would skew the graph heavily.

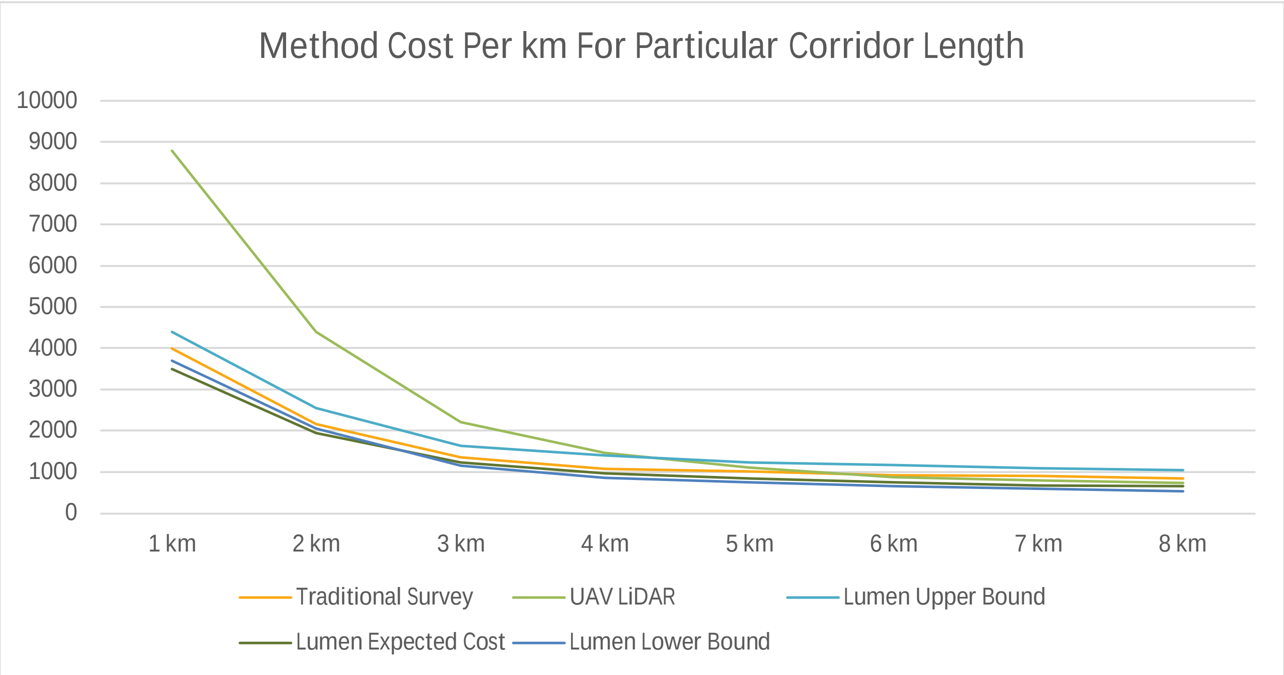

Figure 2: Survey Method Cost Per km Up to 8 km Corridors

Manned LiDAR was excluded as section 2.1 showed that it is extremely expensive for sections of these lengths. This means that over the chosen corridor lengths, Lumen would have to compete against traditional surveyors and UAV LiDAR surveyors. While Lumen has 6 options in terms of flight and processing, three are shown here – the expected value, the cheapest, and the most expensive option. The client could expect to see costs between these, which shows that it is likely price competitive with traditional surveying whilst UAV LiDAR is not competitive up to 3-4 km but then becomes financially viable after this.

Whilst the true factors are unknown, the reason that UAV LiDAR is so expensive to begin with is due to the price of the equipment and certification being factored in to allow the provider a guaranteed minimum return each time. Their equipment likely cost $50,000+, and it is expected that they would need to maximise return for it to be worth their time. On the other hand, Lumen does not need to operate this way and can charge a day-rate as its equipment is relatively inexpensive. The pricing would likely change if Lumen were to invest in expensive equipment.

There are numerous reasons why the UAV photogrammetry is competitive with traditional surveying. Factors such as processing, drone rate, and software cost contribute significantly to the cost however, the survey itself can be performed much more quickly for a given area which is why the costs are in line with each other.

3.3. LUMEN METHOD COST COMPARISON

The following graph shows the expected cost for a given survey length for all methods available to Lumen. This graph compares the three flight types recommended in the technology report and applies the costing both with and without additional processing time.

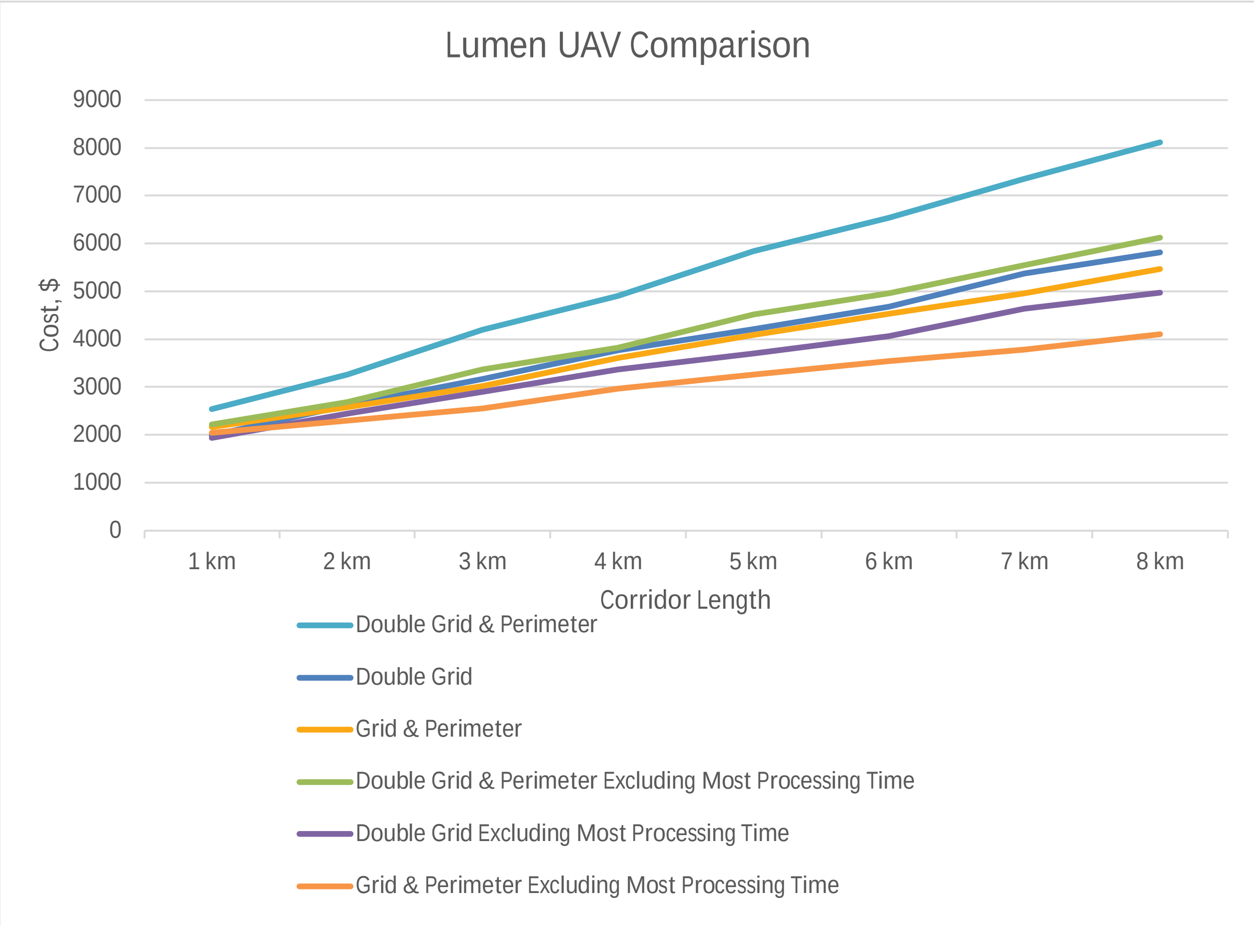

Figure 3: Comparison of Corridor Survey Cost for Each Available Lumen Method

The different methods are considered because each flight type provides benefits that another may not such as speed, security, or a combination of these. It is therefore important to acknowledge the range of prices that could be expected. As seen, the prices diverge. This occurs because even though the price per km decreases as the survey length increases, the more complex cases still retain a higher cost per km.

The four middle datasets are all relatively close pricewise, so the expected cost would be around this region.

With more experience, Lumen may wish to implement a fixed cost for small projects to increase return on investment, but this may leave it exposed to the cost of rework if required.

3.4. RAPID MOBILISATION

All of the pricing above assumes that mobilisation and delivery time is non-critical. As discussed in both the technology report and compliance report, one of Lumen's key advantages is its ability to understand the engineering context of a project and therefore its ability to mobilise rapidly. A typical surveyor is unlikely to have this ability, and even if they did, a Lumen engineer may still need to accompany them.

Lumen has two main client bases. One for whom it provides regular services that generate significant income for the company, and one for small clients where it performs one-off jobs or generates very little revenue. This type of operation would be aimed at the first base, and as these are Lumen's core clients it must look after them. Lumen is therefore likely to prioritise these types of projects in the event of a rapid survey without the need for extra financial incentive whereas other providers may not.

If another surveyor was engaged, it may take half-a-day to a day to explain the context, determine deliverables, discuss contracts, and estimate pricing. They may also need Lumen's guidance on site to be able to gather all the relevant information. This would add cost and complexity. Lumen would not have this issue.

The difficulty with rapid mobilisation is that unless on private ground owned by the lines company or in secluded areas, it may be difficult to gain permission quickly.

3.5. LIMITATIONS

Whilst the analysis should provide a general overview, it is impossible to account for all situations. For example, in areas outside of Canterbury it may be best to outsource to a surveyor or someone else, as the mobilisation cost would be a minimum of 1 FTE day's work. Whilst Lumen believe that there is added benefit to the client, the client might value the cost saving over the better data.

Data for traditional surveying was sourced from previous surveys performed for Lumen. This is the service that is likely to vary the most in cost, partially because it is the slowest, but also because it is the service most tailored to the needs of the client. For example, a ground-only survey may be able to be performed faster or as fast as UAV photogrammetry and LiDAR depending on numerous factors. If only sparse ground points along a centre line are needed and not at exceptional accuracy, the surveyor could attach a GPS unit to a vehicle and drive the route, collecting points at specified time or distances.

Data for manned LiDAR was sourced from a client and combined with literature information to provide an overview at this level. It is widely regarded to be not financially viable for small surveys and benefits greatly from economies of scale therefore, only a general picture is required.

Lumen estimates were based on testing with the Mavic 2 Zoom drone. It is possible that if an upgrade was performed, it would be more efficient, so the cost may be cheaper, although this may be offset by additional day rates. It is probable that using the Mavic Air would make Lumen performing a survey more expensive (up to 50%) unless some compromises were made.

The cost pricing is based on using part 101 requirements and current or relatively cheap drone upgrades, assuming no extensive marketing. Part 102 was discarded as the ability to perform extra work is impossible to determine, and it has significant initial outlay required. Lumen would also not gain any of the benefits for at least a year after starting the application process.

It does not include additional services such as boundary verification. This is something that Lumen cannot do and if it was required, a surveyor would need to be engaged.

These analyses were created using a base assumption. An in-depth pricing spreadsheet is still in development Current Progress can be seen in appendix A.

The costs must be observed in conjunction with technical capability and compliance issues.

4. Conclusions and Recommendations

This report has determined the cost implications of Lumen providing UAV services to both Lumen and potential clients.

To determine the cost implications to Lumen an NPV analysis has been performed using numerous scenarios. It is currently difficult to determine the projected utilisation that this service would have, however, the NPV was performed assuming there were either 5, 10, or 15 usage days per year. This is low volume but it is expected that 10 would be the minimum, especially if the drone was used elsewhere in the business.

In addition, a sensitivity analysis was performed to help determine how variations would affect the expected return. To do this alternative discount rates were used, and one situation assumed a more expensive drone upgrade. The analysis did not appear to be overly sensitive, but the values achieved are minor anyway. It showed that Lumen could expect a positive return on investment over the life of a new, low-cost drone such as the DJI Mavic 3.

The opportunity cost of investment was determined by comparing the drone usage to the equivalent situation where Lumen had to engage a surveyor, and assumed that the employees had equivalent utilisation in each scenario. It was determined that to gain a larger profit than it otherwise might, Lumen should increase the drone charge-out rate from $250 per day to $400 per day. This is unlikely to have any material impact on a client engaging Lumen for this service but the benefits over the life of the drone are minimal.

To determine the costs a client could expect, a mock survey example has been assumed. As the intended market is in Canterbury, it has been assumed that the survey is performed within a 60-minute drive of the Lumen office, has flat terrain, and is performed by one of Lumen's engineers. It has been performed this way as these are typical of Lumen's projects for Orion. There are a number of limitations from the analysis, but it determined that Lumen could expect to be cost competitive with both traditional surveyors and UAV LiDAR, depending on the survey length. It is clear, however, that there is a large amount of variability to be expected, although the survey can be tailored to meet the specific needs of the client.

An area of weakness is that it is difficult to determine utilisation as past performance is not necessarily an indicator of future results. While the overhead lines design market is small, and Lumen can expect to obtain a fair share of the available projects, it is difficult to determine usage as Lumen currently only has the ability to perform to CAA Part 101 rules. Whilst some of the recent projects would likely have been granted permission, it is not guaranteed, and others would not have gained permission.

Lumen has other use cases for the drone which would help should help offset most of the cost and garner a return on the initial investment.

The associated costs to Lumen are not minor but are not significant either. The initial cost to Lumen would be around $8,300 and is made up of GCP cost, training costs, and drone costs.

As such, this report shows that the financial risks are relatively small, but so are the opportunities.

Lumen could drastically improve the opportunities by obtaining a Part 102 certification and providing the service to a wider market, but it does not currently wish to do this. It is noted that the Part 102 certification is expensive and may take up to a year to obtain. As Lumen only wishes to provide the service to a small number of clients, this makes it difficult to recommend as it is expensive.

Lumen could consider the use for its civil and structural team, particularly in suburban and rural areas where disturbances would be less likely and permission easier to grant, but the added opportunities from this are small.

The following recommendations were generated from this part of the project:

Table 6: Financial Analysis Recommendations

Recommendations	Person Responsible	By When
Purchase new drone (Mavic 3)	Software & IT consultant	When the API for the Mavic 3 is released, allowing more utility and compatibility with the flight planning software
Allow the drone to be used elsewhere in the business	Team managers	N/A
Monitor use, missed opportunities and then decide on Part 102 certification	Team managers	1 Year from first survey
Increase drone day rate to $400 for Mavic 3	Team managers	Commencement of survey
Finish Pricing Spreadsheet	Tom Savage	March 2022

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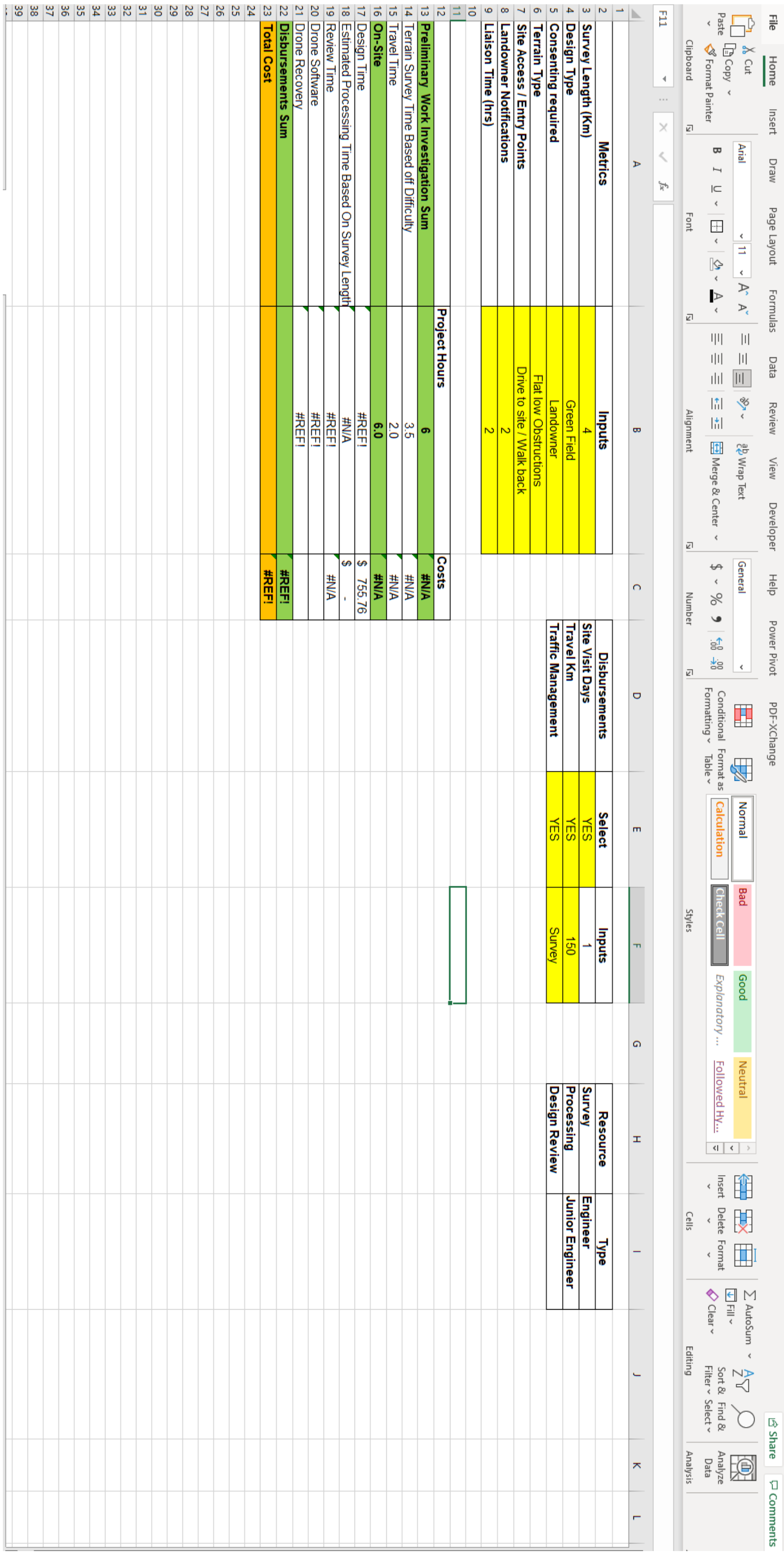
Appendix A – Pricing Spreadsheet



Metrics	Inputs
Survey Length (Km)	4
Design Type	Green Field
Consenting required	Landowner
Terrain Type	Flat low Obstructions
Site Access / Entry Points	Drive to site / Walk back
Landowner Notifications	2
Liaison Time (hrs)	2

	Project Hours	Costs
Preliminary Work Investigation Sum	6	#N/A
Terrain Survey Time Based off Difficulty	3.5	#N/A
Travel Time	2.0	#N/A
On-Site	6.0	#N/A
Design Time	#REF!	$ 755.76
Estimated Processing Time Based On Survey Length	#N/A	$ -
Review Time	#REF!	#N/A
Drone Software	#REF!	
Drone Recovery	#REF!	
Disbursements Sum		#REF!
Total Cost		#REF!

Disbursements	Select	Inputs
Site Visit Days	YES	1
Travel Km	YES	150
Traffic Management	YES	Survey

Resource	Type
Survey	Engineer
Processing	Junior Engineer
Design Review	

119		Flight Lines			
120	80% Side over Lap 20m corridor	2			
121	80% Side over Lap 30m corridor	2			
122	80% Side over Lap 40m corridor	3			
123	80% Side over Lap 50m corridor	3			((survey length / (image width -(image width * overlap %))) * corridor width + survey length)
124	Approximate Image Width at 40m	58			
125	Approximate Image Width at 50m	72			
126	Approximate Image Width at 60m	87			
127	Approximate Image Width at 70m	101			
128	Approximate Image Width at 80m	115			
129					
130	Survey Length				
131	Altitude				
132	Survey Speed				
133	Approximate Survey Distance (Grid)	Logic	(Survey distance * no. flight lines) + (image width -(image width * overlap %))*(no. flight lines -1)		
134	Approximate Survey Distance (Double Grid)	Logic	((Survey distance * no. flight lines) + (image width -(image width * overlap %))*(no. flight lines -1)) + **((survey length / (image width -(image width * overlap %))) * corridor width + survey length)**		
135	Approximate Survey Distance (Grid + Perimeter)		(Survey distance * no. flight lines) + (image width -(image width * overlap %))*(no. flight lines -1) + (corridor width * 2) + (Survey length*2)		
136	Approximate Survey Distance (Double Grid + Perimeter)		((Survey distance * no. flight lines) + (image width -(image width * overlap %))*(no. flight lines -1)) + **((survey length / (image width -(image width * overlap %))) * corridor width + survey length)**+ (corridor width * 2) + (Survey le		
137					
138	Downtime between battery swap	10			
139	Maximum Flight time	22			
140	GCP Placement time per 100m of survey	15		Multiplier for terrain	
141					
142					
143					
144	**Terrain Type (Time)**		For Drone Time		
145	Flat low Obstructions	0.9	1		
146	Flat High Obstructions	0.6	1.1		
147	Undulating Low Obstructions	0.6	1.3		
148	Undulating High Obstructions	0.4	1.43		
149	Mountainous Low Obstructions	0.3	2		
150	Mountainous High Obstructions	0.1	2.2		
151	Flat and Undulating Low Obstructions	0.75	1.1		
152	Flat and Undulating High Obstructions	0.5	1.21		
153	Mountainous and Undulating Low Obstructions	0.45	1.65		
154	Mountainous and Undulating High Obstructions	0.25	1.815		
155					

6.2. CONCLUSION

This section has determined the financial implications of Lumen providing this service. To do this, an NPV analysis was performed, the opportunity cost was determined, and a baseline survey was priced.

The overall conclusion is that with the low-cost drone upgrade recommended in the technology report (DJI Mavic 3), the financial risk is generally low. Unfortunately, due to the restrictions caused by CAA Part 101 and Lumen itself, so are the opportunities.

From this operation Lumen can expect only marginal improvements in overall profitability, at best. It is expected that Lumen would use the drones around 10-15 times per year. With a discount rate of 10%, the net present value over the four-year life of the drone is only $8,400. This takes into account costs associated such as training, certification, and equipment, as well as the survey itself. The survey accounts to drone recovery charge-out rate, survey time and usage, expected processing, and insurances. This section also determined that given the expected use, Lumen should not upgrade to one of the more expensive but more capable drones. It has determined that the Mavic 3 suggested is ideal. Whilst the Mavic 3 should be adequate, it is not yet usable for this purpose. It is expected that it will be within 6 months.

It was also determined that when compared to Lumen's general utilisation, the opportunity cost using its current drone recovery rate of $250 per day is -$4,500. This means that the company would be less profitable than if it engaged other provides to do the job, assuming similar employee utilisation. To generate a positive opportunity cost, Lumen must either use the drone at least 15 times per year, or increase the drone recovery rate to approximately $400 per day.

Either way, the money involved is not substantial and Lumen could not expect significant financial gains as a result. This is partially expected as its current appetite for this is conservative and when combined with the Part 101 restrictions, the opportunities are severely limited.

Even with a Part 102 certification there is not expected to be significant increase. So it has been decided that Lumen should not pursue this avenue until it better understands the operating environment. Currently, Lumen only wishes to offer the photogrammetry to a small number of clients rather than the larger market.

The costs to a client were determined and compared against other survey methods. Lumen can expect to be price competitive with traditional survey, and cheaper than UAV LiDAR survey for corridor lengths up to 4-5 km. This is significant as it dramatically increases the likelihood that Lumen would be engaged for this stage of a project. A pricing spreadsheet is currently still under development

Overall, the financial risks are low but so are the opportunities for growth. The following recommendations have been generated from this section:

Table 3: Financial Analysis Recommendations

Recommendations	**Person Responsible**	**By When**
Purchase new drone (Mavic 3)	Software & IT consultant	When the API for the Mavic 3 is released, allowing more utility and compatibility with the flight planning software
Allow the drone to be used elsewhere in the business	Team managers	N/A
Monitor use, missed opportunities and then decide on Part 102 certification	Team managers	1 Year from first survey
Increase drone day rate to $400 for Mavic 3	Team managers	Commencement of survey
Finish Pricing Spreadsheet	Tom Savage	March 2022

7. PROJECT CONCLUSIONS

Lumen primarily wanted to determine if, or how, it could perform photogrammetry surveys using low-cost UAVs. These surveys would be used primarily in its overhead lines team to augment its existing services. This could allow Lumen to provide better engineering outcomes and services. It is also potential area for revenue growth.

It is clear that under ideal conditions and using a specific operating procedure, Lumen can produce adequate survey results using both of the current drones. The caveat is that neither are ideal and there are better, low-cost, options available such as the DJI Mavic 3 and Phantom 4 Pro.

The DJI Mavic Air that Lumen has is now functionally useless as various factors (battery life and GPS positioning) mean that it is not good enough for photogrammetry surveying and it cannot be used for other work within the company. The DJI Mavic 2 Zoom is often in use which could mean that one of Lumen's core advantages, time to mobilise, is negated. To counter this, Lumen can invest in one of the mentioned low-cost drones as it will allow it to provide this service as well as provide redundancy in the even that the Mavic 2 Zoom fails or cannot be used. In the meantime, Lumen can perform the service with the Mavic 2 Zoom provided that it is available.

The issue with the Mavic 3 drone is that it is not yet usable with 3rd party flight planning applications and it might take 6 months before it is. When it can be used, it should provide the best combination of price, battery life, camera quality, and usability within Lumen.

UAV rules within New Zealand are incredibly restrictive. The operating environment is severely limited by some of the CAA Part 101 requirements. While it is possible to overcome some of these by obtaining a Part 102 certification, at this stage it appears that the risks of obtaining this outweigh the potential benefits. This is due to two main reasons.

In its initial stages this venture would be low volume, primarily due to the size of the market wishing to be served. Lumen currently only wishes to offer this as an auxiliary service to its existing overhead power line clients. Projects where this data could be used are often performed over long periods of time rather than having high project volumes. Coupled with the fact that permission may not be granted for a number of these projects due to the Part 101 requirements, the opportunity for growth is minimal.

It is expected that a survey would take 1-2 days and is therefore only a small part of a much larger project and that the overarching project would be assigned to Lumen anyway. It is unlikely that the addition of this service would entice clients to provide the job to Lumen. In addition, the operational restrictions may mean that Lumen can only provide this service for a fraction of the available projects.

The service is expected to be cost competitive for clients when compared with other survey methods.

While there is not significant opportunity for growth, making the right investments means that Lumen can still offer these services, but with minimal risk. It may then be able to grow and improve its client relationship, establish a new area of competence, and can reassess some of the operational restrictions later. If it wishes, it can expand this service later and offer it to a wider market.

Overall, it can be expected that if Lumen provides these services it can generate adequate results at a competitive rate, and be able to make a small amount of additional profit. The overall risks are relatively low, but so are the opportunities available.

8. PROJECT RECOMMENDATIONS

The project has generated a number of recommendations across the deliverables. Many of them relate to procedural actions but some relate to future work. The recommendations are formed from the project are compiled below:

Table 4: Overall Project Recommendations

Recommendation	**Person(s) Responsible**	**When by**
Offer service using the Mavic 2 Zoom.	Team Managers	Immediately
Purchase new drone (Mavic 3)	Software & IT consultant	When the API for the Mavic 3 is released, allowing more utility and compatibility with the flight planning software
Finalise photogrammetry procedure	Tom Savage	March 2022
Engage Orion to develop relationship and offer service.	Overhead Lines Manager	As soon as possible
Develop a plan and checklist for drone footage and photo data management, using the Privacy Act CCTV checklist in Appendix A (Privacy Commissioner, 2009).	Operators, Manager	Before any operations
Undertake a Part 101 training course.	Operators	When the projects are decided upon
Create a landowner liaison form or register.	Admin/management	When first engaged for a project
Monitor MoT prospective rule changes.	Operators	Indefinitely
Create a high-level drone maintenance plan and log.	Operators	Immediately
Add drone battery contingency to allow mission completion to quality manual.	Management	Immediately
Engage other electricity network owners	Management	Upon completion of a successful project
Determine a company policy for visual line of sight distance.	Management	Immediately
Do <u>not</u> gain Part 102 certification unless appetite changes.	N/A	N/A
Allow the drone to be used elsewhere in the business	Team managers	N/A
Monitor use, missed opportunities and then decide on Part 102 certification	Team managers	1 Year from first survey
Increase drone day rate to $400 for Mavic 3	Team managers	Commencement of survey
Finish Pricing Spreadsheet	Tom Savage	March 2022

In addition to these recommendations, the following flow chart is provided as a guide for when Lumen should offer these services. It has been developed by combining the relevant information from each stage of the project.

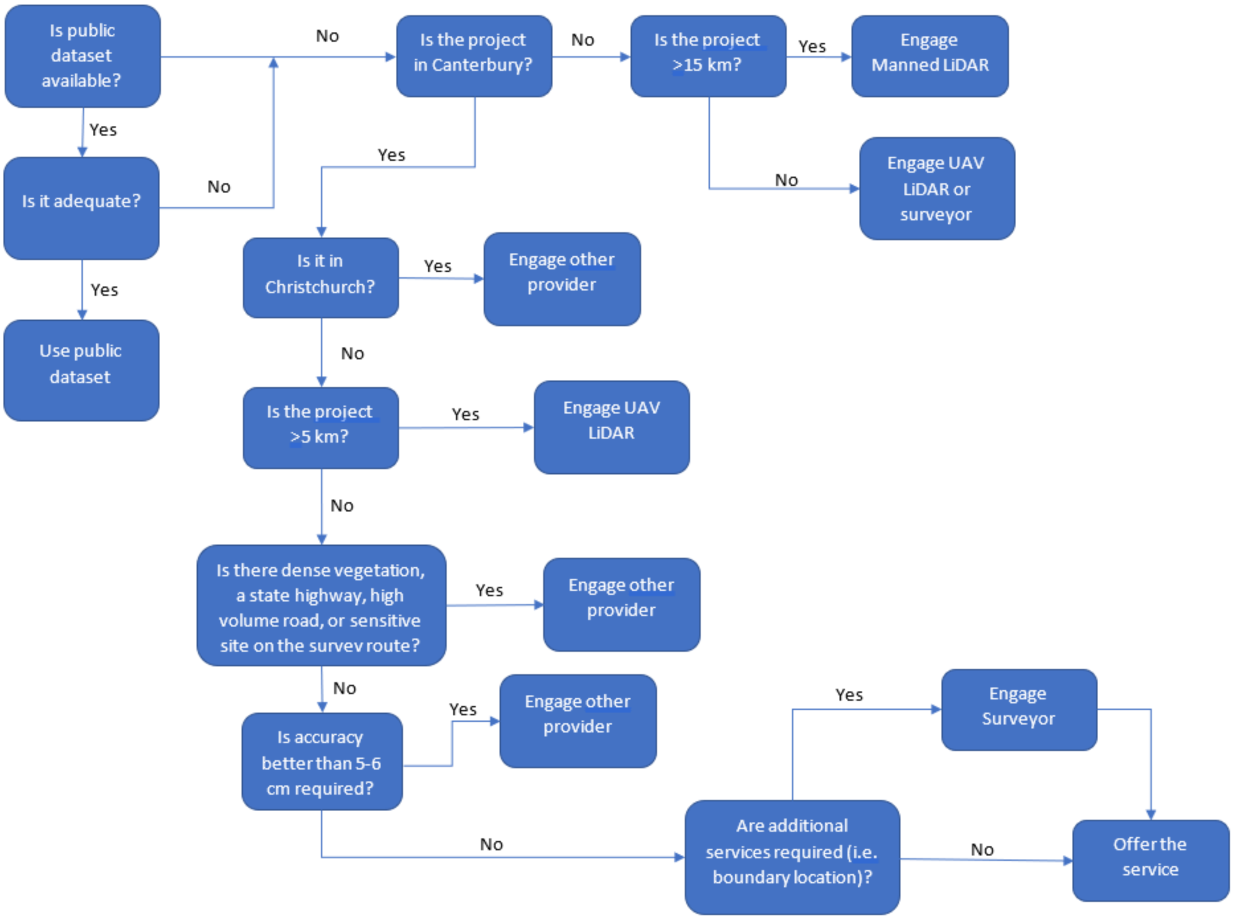


Figure 1: Flow Chart for Providing Photogrammetry Services

9. PROJECT LIMITATIONS

The project, the conclusions, and the recommendations are deemed adequate but there are numerous limitations.

For example, a limitation of recommending the DJI Mavic 3 is that at the time of writing it has been available for less than three months and so it has also not been tested by anyone in this capacity. Not all features of the drone are currently available as DJI has not yet released the API allowing it to work with third party applications.

Other limitations relate to the CAA Part 101 requirements for permission. Many councils do not offer broad guidelines other than permission is granted on a case-by-case basis. This makes it incredibly difficult to determine approximate utilisation, which is why blanket assumptions had to be made.

While it was endeavoured to provide defensible arguments, it is possible that there were some biases in the way that data was collected and assessed. At every stage of testing an idea was thought about the potential outcome. To overcome this, the idea was attempted to be disproved or proved unequivocally to allow satisfaction that the right results were generated.

Whilst the test site was likely a good option, given the conditions there. There was no opportunity to test other sites. This means that while many tests were performed at this site, and they seemed to generally agree, there is only one large dataset to make conclusions from.

Some providers did not want to engage to assist with pricing. This could be due to the way they were approached, or other factors.

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