Economic Benefits to New Zealand from Beyond-Line-of-Sight Operation of UAVs

FINAL REPORT

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ABBREVIATIONS

ATV	All-Terrain Vehicle (also known as a “Quad Bike”)
BLOS	Beyond Line of Sight
CAA	Civil Aviation Authority
CPZ	(Cook Strait) Cable Protection Zone
DNZES	Dairy NZ Economic Survey
FSC	Forest Stewardship Council
GPS	Global Positioning System
ICP	Installation Control Point
kgMS	kilograms of milk solids
LOS	Line of Sight
MBIE	Ministry of Business, Innovation & Employment
MS	Milk Solids
NZIER	New Zealand Institute of Economic Research
MPI	Ministry of Primary Industries
N,P, K	Nitrogen, Phosphorous, and Potassium
PGP	Primary Growth Partnership
PNB	Physiological Needle Blight
RNC	Red Needle Cast
RPA	Remotely Piloted Aircraft
RPM	Rising Plate Meter
SAIDI	System Average Interruption Duration Index
SLD	Straight Line Distance
UAV	Unmanned Aerial Vehicle
UAS	Unmanned Aerial System
VOLL	Value of Lost Load

1. EXECUTIVE SUMMARY

Unmanned Aerial Vehicles (UAVs) are aircraft that do not carry a pilot on board.[1] Instead, the pilot is remotely located and controls the aircraft from afar. In many instances the degree of control by the pilot may be nominal, with the aircraft essentially flying autonomously.

The Civil Aviation regulatory framework in New Zealand currently requires the pilot of a UAV to maintain visual contact with the aircraft at all times, or otherwise to have an observer who maintains visual contact.

Andrew Shelley Economic Consulting Ltd and Aviation Safety Management Systems Ltd were retained by Callaghan Innovation to quantify the economic benefits of operating UAVs beyond line-of-sight (BLOS) in the following sectors:

- Pasture measurement and monitoring;
- Forestry; and
- Electricity Lines and Transformer Inspection.

1.1. LINE OF SIGHT

Current Civil Aviation Rules governing UAVs do not specifically require the aircraft to remain within line of sight of the pilot, but instead required that:

> *101.213 Right of Way*
> *Each person operating a model aircraft shall ensure it gives way to, and remains clear of, all manned aircraft on the ground and in flight.*

There are no automated systems that can currently ensure that manned aircraft are given right-of-way to a level of safety which is considered to be equivalent to that which occurs with conflicting manned aircraft, so the only way that this Rule can currently be satisfied is if the aircraft remains within unaided line of sight of the pilot. This requirement is further clarified under the proposed new "visual line of sight" Rule 101.209, which requires that a person operating an aircraft under the Model Aircraft Rules "must at all times maintain visual line of sight with the aircraft".

There is no explicit requirement under the proposed new Part 102 to remain within line of sight, providing the opportunity for CAA to authorise BLOS operations if they are satisfied that the operator can operate to an equivalent level of safety as line-of-sight operations.

Research and practical experience suggest that line of sight is restricted to a distance of from 500m to approximately 1.4km. Assuming that UAV operators take measures to enhance the visibility of their aircraft, we assume that a distance of 1km can reliably be seen. With a visibility threshold of 1km, a UAV can survey a square area of approximately 200ha.

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[1] UAVs may also be referred to as "Remotely Piloted Aircraft".

1.2. PASTURE MEASUREMENT AND MONITORING

Researchers estimate that active pasture management can provide a productivity gain of at least 17% to farms of all types. Although this gain is estimated to exist, a relatively small proportion of farmers employ active pasture management techniques. The techniques are employed almost exclusively on dairy farms, and even then the take-up rate is relatively low. One reason for this is the time and effort necessary to take regular pasture readings and to keep equipment calibrated.

The use of UAVs operated beyond line of sight would enable farm consultants to regularly obtain relevant imagery for a set of farms and provide the farmer with the information needed to optimise use of pasture (via a feed wedge and associated recommendations). Current methods typically only measure a transect of each paddock, whereas UAV-borne sensors would be able to measure the entire paddock, providing a more accurate estimate of total pasture cover.

The benefits from greater uptake of active pasture management to NZ as a whole is estimated to be over $1 billion per year. In the dairy sector alone, the use of UAVs in this manner could result in direct gains of $857 million per year in export revenue. An additional $72m per year could be achieved from a more limited take-up rate in the sheep and beef sector. The ability to fly BLOS results in lower cost UAV surveys. At the assumed take-up rates it is estimated that BLOS operation could provide additional benefits of $29.0m per year from the dairy sector and $37.6m per year from the sheep and beef sector over and above the benefits that might arise with line-of-sight operation.

1.3. FORESTRY

Within the forestry sector UAVs could be used for any task currently undertaken by manned aircraft. They could provide more accurate estimates of pre-harvest inventory, although there would need to be additional sensor and software development to fully replace manual sampling. The actual cutting of trees into logs of highest value appears to be best performed by computer-controlled harvest machinery. The selling of logs into higher value uses relies on the pre-harvest assessment of log quality, but it is not obvious that UAVs will be able to contribute to that assessment.

While harvesting is underway, UAVs provide a significantly cheaper alternative than manned aircraft for cut-over mapping. However, if performed regularly it is not obvious that beyond-line-of-sight operations are necessarily required, with an operator potentially able to fly LOS over recent changes to the cut-over line.

UAVs also have applications in the monitoring of forest health, particularly in identifying a range of forest diseases, pests, and weeds. As trees grow in height it becomes more and more difficult to find locations within a forest that enable UAVs to be flown within line-of-sight, so forest health applications are necessarily beyond-line-of-sight. The lower cost of UAVs compared to conventional aircraft allows more regular surveys to be flown, enabling earlier identification of disease.

It is estimated that losses from two common diseases, *Dothistroma* and *Cyclaneusma*, could cause an annual reduction in growth costing in order of $115m per year. It is unclear whether early detection would necessarily reduce this value loss, but it could allow for alteration of pruning and thinning regimes, potentially avoiding the need for copper sprays. Copper sprays are used when fungal infections become severe, but there are some concerns around the effect of copper sprays on the wider environment and particularly aquatic life.

Once disease has been detected, the confirmation of which disease (and strain) requires samples to be collected from affected trees. This currently requires forestry personnel to walk to the relevant trees, and a shotgun may be used to shoot down a branch to obtain samples. A multi-copter with a robotic arm could be flown from the nearest access road, with the arm used to obtain samples. For this to be a practical solution it would also need to be able to be operated beyond line of sight.

Similarly, aerial surveys can be conducted to identify pests and weeds. Image analysis software may even be able to automatically identify any areas of significant weeds.

Following identification of disease, pests, or weeds, a UAV with a spray system could be flown to the tree(s) concerned and deliver spray to control the problem. Although trials would need to be conducted to establish the level of control possible, it seems reasonable to assume that the gross benefits from control of *Dothistroma* alone could be in the order of \$46m-\$69m per year.

New Zealand currently imports approximately \$30m of sawn hardwood per year. Despite this, hardwoods comprise only 2% of New Zealand’s forest estate, at least partly because pest infestations can have a significant negative impact on the economics of a plantation. Control of pests such as the eucalyptus tortoise beetle could potentially result in displacement of the imports, generating a further net benefit in the order of \$26m per year if all sawn hardwood imports could be displaced.

The potential benefits from controlling other diseases and pests have not been quantified, and nor have the benefits from using UAVs for weed control. Total benefits may, therefore, exceed the aggregate benefits of \$72m-\$95m.

1.4. ELECTRICITY LINES AND TRANSFORMER INSPECTION

Transpower, the owner and operator of the national electricity transmission network, and Unison Networks, the owner and operator of the electricity distribution networks in Hawkes Bay, Rotorua, and Taupo, have both conducted trials with UAV for inspection of overhead power lines and the associated transformers and switchgear. Both companies have determined that there is a significant difference in benefits between LOS and BLOS operations as they may be utilised with regard to transmission and distribution system assets. While LOS operations are possible, they do not create significant additional value over and above existing inspection methods, and in some cases may cost more than a traditional linesman.

The major benefits for overhead power line inspection derive from the ability to operate beyond line of sight. Benefits are derived from:

- Information about the network;
- Reduced reactive maintenance (better information allows better planning and better targeted proactive maintenance so less reactive is required);
- Reduced outage times – the UAV can identify the location of the outage so that the crews can travel directly to the affected location. Unison Networks estimated that the average outage duration per year for their customers could reduce by 10 minutes per year from the current 90 minutes; and
- Reduced routine maintenance – the lower cost of UAS relative to helicopters means that inspections can be conducted more frequently and routine maintenance can be better targeted.

A significant proportion of gains for both transmission and distribution were related to vegetation encroachment, with more frequent inspections being more likely to detect issues with vegetation. Transpower may also be able to substitute a UAV for the helicopters currently used for patrolling the Cook Strait Cable Protection Zone.

Transpower estimates that it may be able to achieve gains of $1m per annum once suitable systems are available. Building on Unison Networks' estimates of the benefit that they could achieve from deploying UAVs, it is estimated that the benefits in electricity distribution range from $1.85m per year for UAVs that were centrally located and had to be booked in advance by a distribution company, through to $6.62m if distribution companies had their own UAV(s) that could be deployed at short notice to identify the cause of outages, monitor storm damage, etc. We estimate additional economic benefits of $4.46m to $19.26m per year to consumers of electricity from the reduced cost of outages (both number and duration) originating on electricity distribution systems, depending on the value attributed to unserved load. We have not quantified the benefits from the reduced cost of outages originating on the electricity transmission system.

1.5. SUMMARY

Table 1 summarises the various estimates of the economic gain from BLOS operations over and above the benefits that might arise with line-of-sight operation. In all cases there are additional unquantified gains from having more timely access to more accurate information. The potential gains from enhanced disease control in forestry require confirmation by trials, and the value of reduced electricity outages from enhanced electricity transmission monitoring has not been quantified. Taking those qualifications into account, the economic gain from BLOS operations is estimated to be in the order of $151m to $189m per year.

Table 1: Estimates of Annual Economic Gain from BLOS Operations

Sector	**Economic Gain**
Dairy	$29.0m
Sheep & Beef	$37.6m
Forestry	$72m-$95m
Electricity Transmission	$1.0m+
Electricity Distribution	
- **Cost Reduction**	$6.6m+
- **Reduced Outage Duration**	$4.5m-$19.3m
Total	$151m-$189m

2. INTRODUCTION

Unmanned Aerial Vehicles (UAVs) are aircraft that do not carry a pilot on board.[2] Instead, the pilot is remotely located and controls the aircraft from afar. In many instances the degree of control by the pilot may be nominal, with the aircraft essentially flying autonomously.

The Civil Aviation regulatory framework in New Zealand currently requires the pilot of a UAV to maintain visual contact with the aircraft at all times, or otherwise to have an observer who maintains visual contact.

Andrew Shelley Economic Consulting Ltd and Aviation Safety Management Systems Ltd were retained by Callaghan Innovation to quantify the incremental economic benefits of operating UAVs beyond line-of-sight in the following sectors, when compared to line-of-sight operations or alternative methods:

- Pasture measurement and monitoring;
- Forestry; and
- Electricity Lines and Transformer Inspection.

This report is intended to provide information on the economic impact of BLOS operations, for the development of future government policy and regulations concern UAV operation.

2.1. PROCESS

The initial step in conducting this study was to talk to a selection of relevant people in the fields reviewed. For pasture management, interviews were first conducted with Massey University researchers to obtain a picture of what might be possible. We then interviewed Agrioptics personnel to obtain the views of a commercial leader in the practical use of precision agriculture. Interviews were also held with staff from LIC (Livestock Improvement Corporation), which gave valuable insight into farmer behaviour around the take-up of sophisticated measuring and monitoring technologies.

For forestry, an interview was conducted with Scion personnel to obtain an understanding of what might be possible. Interviews with personnel from PF Olsen and Timberlands then provided a practical perspective. A follow up interview was conducted with Dr Katrin Webb of Scion to obtain more information on diseases of plantation forests.

For electricity power lines and transformer inspection, interviews were held with: Transpower, the owner of the national transmission grid; and with Unison Networks Ltd, an electricity distribution company. Project personnel also attended the UAV demonstration hosted by Transpower in September 2013.

Further interviews were held with a small number of commercial UAV operators to identify whether the economic model provided a reasonable estimate of potential UAV operating costs.

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[2] UAVs may also be referred to as “Remotely Piloted Aircraft”.

2.2. STRUCTURE OF REPORT

This report is structured as follows:

- Section 3 describes the current regulatory environment for UAVs. Estimates are derived for the distance that might be considered "line of sight". We then consider how changing the current requirement for UAVs to be used within line of sight might affect the patterns and broad economics of UAV use. Potential barriers to BLOS operation are briefly presented.
- Section 4 estimates the potential economic gains from the use of UAVs for pasture management;
- Section 5 evaluates the potential for the use of UAVs in forestry;
- Section 6 estimates the potential economic gains from the use of UAVs for overhead power line inspection;
- Appendix A provides a very brief survey of selected UAV that might be suitable for pasture measurement and monitoring and some forestry applications; and
- Appendix B presents the assumptions used to derive estimates of the cost of LOS and BLOS operations for pasture measurement and monitoring.

3. REGULATORY ENVIRONMENT

The economics of unmanned equivalents to a manned aircraft depends on the regulation in place. This section briefly reviews the current regulatory environment and then discusses the changes in UAV operation that might occur with BLOS regulation.

3.1. Current Regulations

Currently there is little in the way of formal regulation for UAVs, with most operating under the Model Aircraft Rules contained in Rule Part 101. Large UAVs with a weight greater than 25kg require authorisation under Rule 19.105, but UAVs lighter than 25kg are able to operate without specific authorisation. An urgent rule development programme is aiming to have a new Rule Part 102 *Unmanned Aircraft – Operator Certification* signed by the Minister of Transport by the end of the first quarter of 2015 so that a wider range of UAV operations may be authorised.[3]

Under the existing "Right of Way" Rule 101.213,

> *Each person operating a model aircraft shall ensure it gives way to, and remains clear of, all manned aircraft on the ground and in flight.*

There are no automated systems that can currently ensure that manned aircraft are given right-of-way, so the only way that this Rule can currently be satisfied is if the aircraft remains within "line of sight" of the pilot. The pilot can "see and avoid" other aircraft, a general principle that applies to all aircraft. This requirement is further clarified under the proposed new "visual line of sight" Rule 101.209, which requires that a person operating an aircraft under the Model Aircraft Rules "must at all times maintain visual line of sight with the aircraft".

There is no explicit requirement under Part 102 to remain within line of sight, providing the opportunity for CAA to authorise BLOS operations if they are satisfied that the operator can operate to an equivalent level of safety as line-of-sight operations.

The interpretation of the "see and avoid" principle is more restrictive for unmanned aircraft than it is for manned aircraft. A manned aircraft is permitted to have a single pilot, who will of necessity have his attention directed at specific targets in the operational environment (e.g. scanning for wires, attention on the terrain) and may not be focussed on the potential for other aircraft. Even if the pilot is aware of the potential for other aircraft in the area, it is highly likely that he will be unable to spend significant periods of time visually scanning for the aircraft's presence.

In contrast, current CAA policy is to interpret the requirement to see-and-avoid such that an operator of unmanned aircraft must maintain eye contact with the UAV at all times. Due to the risk that the pilot will not be able to immediately refocus on the UAV when looking back up, and may therefore lose sight of it at a critical moment, the pilot is unable to look down from the UAV to his controls unless a second crew member has the UAV in sight. Under CAA's current policy, it is generally not possible to operate the UAV with less than two crew.

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[3] For details of the proposed new Part 102, as well as proposed changes to Part 101, see Civil Aviation Authority of New Zealand (2014) *Notice of Proposed Rule Making: Part 102 Unmanned Aircraft Operator Certification*, NPRM 14-01, Docket 15/CAR/1 Unmanned Aircraft Operator Certification.

3.2. HOW FAR IS LINE OF SIGHT?

To understand the effect of the current regulations it is necessary to have an estimate of how far away might be "line of sight". In the analysis that follows, we estimate of the threshold distance at which the UAV is just visible. By definition, operation beyond that range would be beyond line-of-sight. We also consider the effect of trees on visibility, specifically the "shelter belts" that are found on many farms, and the effect of hills.

3.2.1. Visibility Threshold

Watson *et al* (2009) summarise results obtained by Howell in 1957 for the ability of a person to detect an oncoming DC3 aircraft:[4,5]

> *Howell … carried out a field study in which pilots attempted to detect another aircraft (DC-3) approaching on a collision course. Over various conditions, the average distance at which detection by the pilot occurred ("detection distance") was from 5.5 to 8.7 km. Of greater relevance to this study, the subject aircraft also carried an experimenter who knew exactly the approach angle of the target aircraft, and "kept constant vigil with his naked eye" until he detected the intruder aircraft. This "threshold distance", over the same conditions, averaged from 17.3 to 23 km…*

The experimenter who knew where to look for the target aircraft provides a reasonable approximation to the UAV pilot who knows where the unmanned aircraft should be in the sky.

Results from Watson *et al* clearly indicate that aircraft visibility is dependent on lighting conditions and contrast with the background. Repeating Howell's experiments using a modern modelling approach, Watson et al find that a well-lit DC3 aircraft (providing little contrast against the sky) may not be visible until 7-9km distant, whereas a dark silhouette may be visible from about 19-27km distant.

A DC3 is a relatively large aircraft. The standard dimensions of a DC3 aircraft are:[6]

Wingspan:	95'0" = 28.96m
Length:	63'9" = 19.43m

In contrast, the standard dimensions of the AeroVironment Puma are:[7]

Wingspan:	9.2' = 2.8m
Length:	4.6' = 1.4m

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[4] Watson, Andrew, Cesar V Ramirez, Ellen Salud (2009) "Predicting Visibility of Aircraft", *PLoS ONE* 4(5): e5594. doi:10.1371/journal.pone.0005594.

[5] Howell W.D. (1957) "Determination of daytime conspicuity of transport aircraft", Civil Aeronautics Administration Technical Development Center, Indianapolis Indiana: 304.

[6] Flight 2000 Ltd, *Technical Manual*, Amendment TE-32, 30 June 2006.

[7] AeroVironment (2013) "Puma AE Data Sheet", http://www.avinc.com/downloads/DS_Puma_Online_10112013.pdf. See also section Appendix A of this report for further information on the AeroVironment Puma.

The length of the Puma is thus only 7.2% of the length of the DC3, and the side-on view is likely to be approximately the same percentage. All else being equal, the threshold distance of visibility is proportional to the size of the aircraft, which leads to the estimates of visible distance shown in Table 2.

Table 2: Estimates of Visual Range for UAV Aircraft

Source	**Visibility Threshold (km)**		**side of square[b] (km)**	**Area[c] (ha)**
	DC3	**UAV[a]**		
Howell	17.3 – 23	1.25 – 1.66	1.77 – 2.35	313 – 552
Watson – well-lit	7 – 9	0.50 – 0.65	0.71 – 0.92	50 – 85
Watson – dark silhouette	19 – 27	1.37 – 1.94	1.94 – 2.74	376 – 751

Notes: (a) The visibility threshold for the UAV is calculated as 7.2% of the visibility threshold for the DC3. (b) The "side of square" is the maximum size of a square (km) that fits inside the circle with radius equal to the visibility threshold of the UAV. (c) The Area (ha) is the area of the square with sides of the indicated length. An area of 1km x 1km is 100 ha in area.

Under poor contrast conditions (a well-lit aircraft against a clear sky) visibility may be as little as 500m. However, in ideal high contrast conditions a range of up to 1.94km may be possible.

Massey University researchers suggested that, based on their trials to date, depending on the size and layout of the farm it may be possible for an area of perhaps 4km^2 (i.e. 400ha) to be surveyed in a single flight under LOS restrictions, whether one crew member or two is required. The 400ha area implies a square of 2km x 2km, which in turn implies a visibility threshold of 1.414km.[8] This is consistent with our estimates of visibility obtained from both Howell and Watson *et al*'s dark silhouette case.

However, commercial UAV operators indicated that while 1.4km might be possible under ideal conditions, 500m was often a more realistic threshold when meteorological conditions and visual background were taken into account. For example, a dark UAV may be visible against the sky but disappear against a patterned background created by trees, whereas for a light coloured UAV the reverse is likely. A 500m visibility threshold is at the bottom end of the range derived from the literature, but is the same as the maximum distance allowed for line-of-sight operations in the UK.[9]

We assume that UAV operators would "paint" their aircraft in colours that enhance visibility, and would use other features such as high lumen LED lights to ensure visibility. If this occurs then a visibility threshold of approximately 1.0km might be reasonable (being approximately the mid-point of 0.5km and 1.4km). A visibility threshold of 1.0km implies a circular area of 314ha, or a square area of 200ha.

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[8] The maximum potential area covered by a UAV is described by the circle with radius equal to the visibility threshold. However, we note that a farm or series of paddocks is more likely to be square or rectangular in shape, so the area surveyed by the UAV is better approximated by the maximum square that fits inside the circle. The sides of the square will be 1.414 times the visibility threshold.

[9] UK Civil Aviation Authority (2012) *Unmanned Aircraft System Operations in UK Airspace – Guidance*, CAP722, 10 August 2012, Section 2, Chapter 1, page 3, para. 6.7.

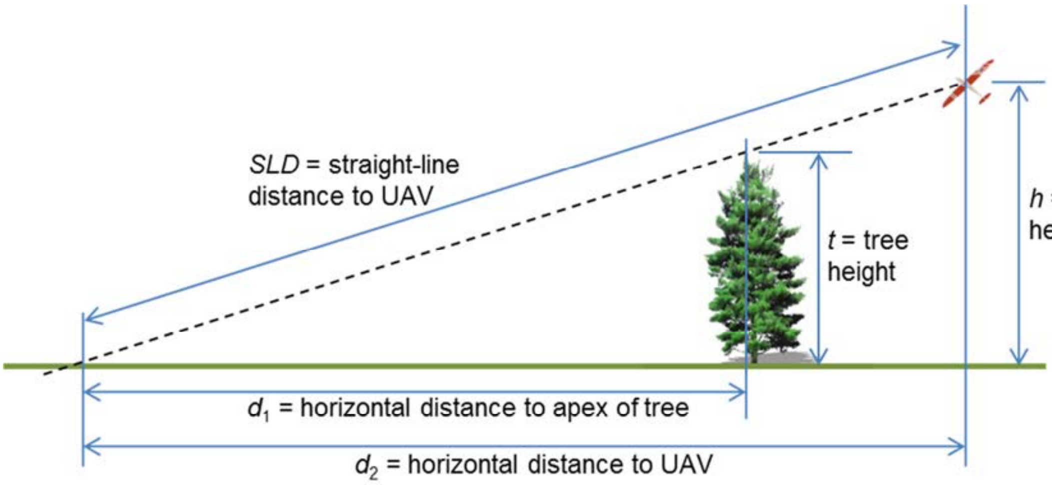
We therefore use 200ha as a standard estimate of the land that can be surveyed by a UAV under line-of-sight conditions. Larger areas would require the pilot to move to a new location, which could involve significant travel time, as well as the need for additional set-up time for the UAV.

3.2.2. Effect of Shelter Belts

Flatland farms may have rows of trees planted as shelter belts, with distances of approximately 800m to 1,000m between shelter belts. When mature, the trees could be up to 30m high. An UAV can fly beyond a shelter belt, but must remain within line-of-sight of the pilot. The obstruction provided by the shelter belt trees might therefore prevent a UAV flying to the full extent of its range.

Our model for calculating the maximum distance that can be covered by the UAV is summarised in Figure 1 below. A tree (or row of trees) of height *t* is located a distance d_1 from the pilot. The pilot can see over the top of the trees to the UAV, which is flying at a height *h* above ground level at a horizontal distance d_2 from the pilot. Distance d_2 is constrained by the maximum allowable height *h* and the straight line distance *SLD* at which the pilot can see the aircraft.

Figure 1: Model for Calculating Maximum UAV Distance from Pilot on a Farm with Shelter Belts



Note first that:

$$\frac{d_1}{t} = \frac{d_2}{h} \Rightarrow d_2 = h\frac{d_1}{t}$$

For any given tree height and distance we can then calculate the horizontal distance to the UAV. The most constrained situation is given by closely spaced shelter belts (800m) and tall trees (30m). If the pilot is situated mid-way between the shelter belts then d_1 = 400m, and *t* = 30m. The UAV is assumed to be at the maximum permissible altitude of 400ft AGL, so *h* = 121.92m. Given the formula above the maximum distance of the RPA from the pilot is 1,625.6m. If the UAV was lower than 121.92m elevation at this distance it would disappear behind the trees, and if the UAV was further than 1,625.6m horizontal distance from the pilot then it would need to be higher than 121.92m (400ft) in order to be seen by the pilot.

The straight-line distance to the UAV is given by:

$$SLD^2 = h^2 + d_2^2 \Rightarrow SLD = 1{,}630\text{m}.$$

The straight line distance to the UAV is greater than the maximum visibility threshold of 1.0km. This means that the maximum distance of the UAV is constrained by the visibility threshold rather than the presence of shelter belts, and on flat farms with shelter belts 200ha remains a reasonable estimate of the land that can be surveyed by a UAV under line-of-sight conditions.

3.2.3. Effect of Hills

Much of New Zealand farmland (although only a small proportion of dairy land) is characterised by hills. It may be possible to launch a UAV from on top of a hill, thereby having a commanding view over the surrounding landscape, but that may not always be possible or desirable.

The same model that was applied for trees can also be applied for hills. It should be noted, however, that the far side of the hill may not be at the same elevation as the pilot. The land may drop away at a relatively gentle slope from the apex of the hill, which means that 400ft AGL may be higher than 400ft above the pilot's elevation, allowing the UAV to potentially be able to be operated at a greater distance from the pilot than suggested by the basic model. Alternatively, the hill may drop away steeply, in which case the basic model will be relatively accurate. The two limiting cases are (a) that the land beyond the apex of the hill is at the same elevation as the apex of the hill, and (b) that the land beyond the apex of the hill is at the same elevation as the pilot.

For the example with the shelter belt, the tree is only 30m high, and it is a relatively long distance from the pilot. At 400m, the pilot is looking at an angle of just 4.3° above horizontal to view the tops of the trees. If instead we assume a small hill with height 30m and slope of 15°, then the apex of the hill is 112.0m from the base (horizontal distance), and if the pilot is 50m from the base then the horizontal distance from the pilot to the apex of the hill is just 162.0m. The pilot must now look an angle of 10.5° to see the top of the hill. We test the two limiting cases:

- In the first case, the hill is assumed to drop sharply away so that the land on the far side of the hill is the same as the elevation of the pilot, which means that the UAV will be at 400ft (121.92m) above the pilot. Applying the formula, the maximum horizontal distance is $d_2 = 121.92 \times (162/30) = 658.2$m (differences due to rounding), and the straight-line distance is $SLD = 669.4$m. The straight-line distance is much shorter than the visibility threshold and restricts the area that can be surveyed to 140.8ha (circular) or 89.6ha (square).
- In the second case, the land beyond the hill is assumed to be level with the apex of the hill, which means that the UAV will be operated at 121.92m + 30m = 151.92m above the pilot. Applying the formula, the maximum horizontal distance is $d_2 = 151.92 \times (162/30) = 820.2$m (differences due to rounding), and the straight-line distance is $SLD = 834.1$m. The straight-line distance is much shorter than the visibility threshold and restricts the area that can be surveyed to 218.6ha (circular) or 139.2ha (square).

Both cases represent a significant reduction from the 200ha that can be surveyed with unrestricted line-of-sight.

An important difference between the analysis for hills and the analysis for trees is the height of the obstruction. By definition, hill country has slopes greater than 15°, and slopes could be as steep as 60°. Hills could also be 400m or higher, although perhaps more generally in the 200m-300m range.

To illustrate the effect of higher and steeper hills we assume the following:

- The hill has a height of 250m, so t = 250m.
- The hill has a slope of 30°, so the apex of the hill is a horizontal distance of 433m from the base of the hill.
- The distance from the pilot to the foot of the hill is 50m, so d_1 = 50m + 433m = 483m.
- The far side of the hill is level with the top of the hill, so we can assume that h = 121.92m (400 ft) + 250m = 371.92m.

Applying the formula for the ratio of distances to heights we have d_2 = 371.92 × (483/250) = 718.55m, and the straight-line distance SLD = 809.1m. Unsurprisingly, the maximum distance from the pilot is reduced from the maximum with a smaller hill. The circular distance covered is 206ha, and the square with maximum distance of 809.1m from the pilot has an area of 131ha.

Table 3 and Table 4 below summarise the area surveyed (in ha) given hills of indicated heights and slopes, for the two limiting cases. Table 3 shows the case where the land behind the hill is level with the top of the hill, and Table 4 shows the case where the land behind the hill is level with the pilot. The shaded blue area in Table 3 is the combination of height and slope that results in the survey area being unaffected.

Table 3: Area Surveyed (ha) with hills of indicated height and slope angle, land behind hill level with top of hill

Height of Hill	Slope Angle							
	15	20	25	30	35	40	45	50
30	139.2	94.6	71.7	57.9	48.8	42.3	37.4	33.6
50	138.3	88.9	64.4	50.0	40.8	34.3	29.6	25.9
100	186.3	113.7	78.7	58.9	46.5	38.0	32.0	27.5
110.52 (*)	200.0	121.4	83.7	62.4	49.0	40.0	33.6	28.8
150	200.0	155.1	105.6	77.9	60.7	49.2	41.1	35.1
193.79 (*)	200.0	200.0	135.0	98.9	76.6	61.8	51.5	43.9
272.80 (*)	200.0	200.0	200.0	145.5	112.1	90.1	74.8	63.7
348.58 (*)	200.0	200.0	200.0	200.0	153.6	123.2	102.2	87.0
420.97 (*)	200.0	200.0	200.0	200.0	200.0	160.2	132.7	113.0
489.60 (*)	200.0	200.0	200.0	200.0	200.0	200.0	165.6	141.0
554.03 (*)	200.0	200.0	200.0	200.0	200.0	200.0	200.0	170.3

* These heights are the minimum at which the height of the hill no longer affects the area surveyed. 110.52m for 15° slope; 193.79m for 20° slope, 272.80m for 25° slope, 348.58m for 30° slope, 420.97m for 35° slope, 489.60m for 40° slope, and 554.03m for 45° slope.

Table 4: Area Surveyed (ha) with hills of indicated height and slope angle, land behind hill level with Pilot

Height of Hill	Slope Angle							
	15	20	25	30	35	45	45	50
30	114.4	77.7	58.9	47.6	40.1	33.2	30.8	27.6
50	103.9	66.8	48.4	37.6	30.6	24.6	22.2	19.5
100	121.2	74.0	51.2	38.4	30.2	23.9	20.8	17.9
110.52	127.5	77.4	53.4	39.8	31.3	24.6	21.4	18.4
150	126.1	93.2	63.4	46.8	36.4	28.7	24.7	21.1
193.79	125.2	114.9	77.6	56.8	44.0	34.8	29.6	25.2
272.80	124.3	114.3	109.5	79.7	61.4	48.6	41.0	34.9
348.58	123.8	113.9	109.3	106.7	82.0	65.0	54.5	46.4
420.97	123.5	113.7	109.1	106.6	105.0	83.4	69.7	59.4
489.60	123.3	113.6	109.0	106.5	105.0	103.3	86.1	73.3
554.03	123.2	113.5	108.9	106.4	104.9	103.3	103.3	87.9

Absent a detailed map of a representative sample of farms, it is not possible to derive concrete conclusions from this analysis. For those farms where it is possible to fly from the top of a hill then the presence of hills will make no difference to the area that can be surveyed by an UAV in a single flight. However, for those farms where it is impractical to fly from a high point, the presence of hills could severely restrict the area that may be covered in a single flight to perhaps something in the order of 30-60ha, i.e. as little as 15%-30% of the area covered with unobstructed line-of-sight.

3.3. THE IMPACT OF REVISED REGULATIONS ON UAV OWNERSHIP AND OPERATION

Existing Civil Aviation line-of-sight regulations are based on the reasonable premise that this rule is required for the safety of manned aircraft. The requirement to see and avoid other traffic, and to give way to certain classes of aircraft, could be revised in certain cases for unmanned aircraft where a safety case demonstrates that there is no appreciable reduction in safety. Such cases would focus on areas where there is very low risk of conflict with other air traffic, or where the UAVs are operating close to known hazards (such as power lines).

There are alternative views on the model of UAV ownership and operation that BLOS operation would allow. Moving to BLOS operations would lower costs and allow large areas to be surveyed in a single flight. In many instances it may also be feasible to survey multiple farms in a single flight. One school of thought, advanced by the Massey University researchers, was that cheaper UAV operation would make UAVs and their benefits accessible to even small farms. In essence, their vision of the future was one where each farm would have its own UAV, and the farmer could be undertaking other activities while the UAV was flying (whether that was farm maintenance or administrative tasks).

The alternative view held by farm consultants was premised on the observation that farmers are generally time-poor, they need and want information rather than data, and time spent keeping abreast of new developments and trends is better spent focussed directly on farming than on a particular technology. BLOS operations would allow a farm consultant to operate a UAV remotely, flying over multiple farms. The farm consultant would process the data and deliver the management information (e.g. feed wedges) to the farmer on a regular basis (7-10 days).

Transpower and Unison both noted that they would prefer not to own the UAVs but instead have the service provided by a third party and simply receive the data. The same point was made in the forestry industry by Timberlands. Similarly, LIC considered that this was the preferable model for the agricultural industry.

LIC personnel suggested that an unintended consequence of current regulations could be the mass proliferation of small UAVs used by under-trained operators with a poor knowledge of aviation and limited access to new technology as it becomes available. A corollary could be drawn to in-line milk sensors in the dairy industry. These sensors are not yet developed to the point where they meet the regulatory standards required to allow their use for milk quality monitoring. This is one of the factors that have slowed adoption of in-line milk meters. Furthermore, since the regulations are so technically demanding there is little incentive for companies to invest in the research and development necessary to fully develop the technology to a point where it does meet the required standard. In this example, an unintended consequence of the regulations appears to be a barrier to technology research and development.

It was further noted that UAVs and UAV control systems are a rapidly-evolving area of technology, and an operator focussed on a different business (whether farming, forestry, or electric power) will not necessarily have the resources (time or money) to keep abreast of technological changes. Enabling BLOS operations will provide the environment where specialist contractors are able to invest in advanced control systems and sensors as they become available.

3.4. BARRIERS TO BLOS OPERATION

During interviews the following issues were raised by industry participants as potential barriers to BLOS operations:

- The accuracy of autopilots – will the UAV fly where it has been programmed to fly? This is relevant both to general survey flights for farms and forestry, where it may be important to fly within defined boundaries, and for forestry applications requiring a UAV to fly to specific tree. It is also a critical issue for electricity transmission and distribution power line inspection, as failure to hold the correct position could result in the UAV coming too close to the line, flash-over occurring, with serious unrecoverable damage occurring to the UAV. Furthermore, height control may be even more challenging than horizontal positioning, and craft may require laser or radar altimeters coupled with an accurate digital elevation model of the underlying terrain.
- The reliability of flight controllers was raised as a separate issue to accuracy (above). High reliability controllers may require a high reliability software engineering approach. This could push UAV costs considerably higher than current low cost models, perhaps to somewhere in the order of the Boeing Scan Eagle (Appendix A); however some mid-ground might be appropriate.

- The necessity for a communications link for control of the UAV if it departs from its pre-programmed path or it is otherwise necessary to abort the flight or regain manual control. This is particularly problematic for long-range BLOS operations, where a direct line from the base radio to the UAV may no longer be possible.
- Navigation in areas where GPS coverage may be denied or unreliable (such as in valleys), necessitating the use of alternative or supplemental navigation systems such as inertial navigation.
- The potential dangers of interaction with other aircraft such as low-level agricultural aircraft operators and other low-level aircraft such as rescue helicopters.
- Dynamics of technology development are high up-front development costs, but then the technology rapidly becomes a commodity product. This means that there are high risks for a small entity seeking to develop the technology. Research might only occur if it is publicly-funded, or funded by those who will benefit from the technology (such as Transpower and Unison funding research on UAS in the electricity transmission and distribution industries). For this concern to be true also implies that the technology in question is readily replicable with intellectual property that is difficult to protect.
- Cost and expertise to develop a safety case for BLOS operations which demonstrates an equivalent level of safety to line-of-sight operations.

This report does not seek to solve or suggest approaches to address these barriers. Instead, the report is focussed on quantifying the benefits that could arise if these barriers could be overcome.

4. PASTURE MEASUREMENT AND MONITORING

Regular monitoring of pasture enables maximum use to be made of pasture, both in terms of better utilising the quantity of pasture and in terms of making the best use of high quality pasture. When there is a pending surplus, allowing the grass to continue to grow will result in low quality older pasture with a high lignin and low glucose content. When stock are then rotated to this area of the farm they may lose condition. Identifying a surplus situation early enables decisions to be made about the most effective areas of the farm to graze stock, and for high levels of surplus to be put to use making silage or baleage. Regular monitoring also enables pasture to be grazed to the optimal minima, beyond which excessive plant damage and death causes long pasture recovery times.

These concepts have been put to use on many flat country farms, particularly in dairying. Dairy NZ states that

> *Pasture management is the cornerstone of profit for* ***every*** *New Zealand dairy farm.*[10]

4.1. THE FEED WEDGE

A feed wedge gives a visual picture of the current level of pasture cover by ranking the paddocks based average pasture cover in table or diagrammatic form (see Figure 2 overleaf). By adding a target line the feed wedge becomes a tool for making pro-active farm decisions.

Dairy NZ notes that the benefits of using a feed wedge include:

- *Able to quantify average pasture cover (APC) on farm;*
- *Have targets for both pre and post grazing residuals* [i.e., the level of pasture cover before and after grazing];
- *Help identify surpluses / deficits early;*
- *Decide the grazing order for the next week's grazing;*
- *Reduce stress with pasture management decisions; [and]*
- *Improve the timeliness of pasture management decisions.*

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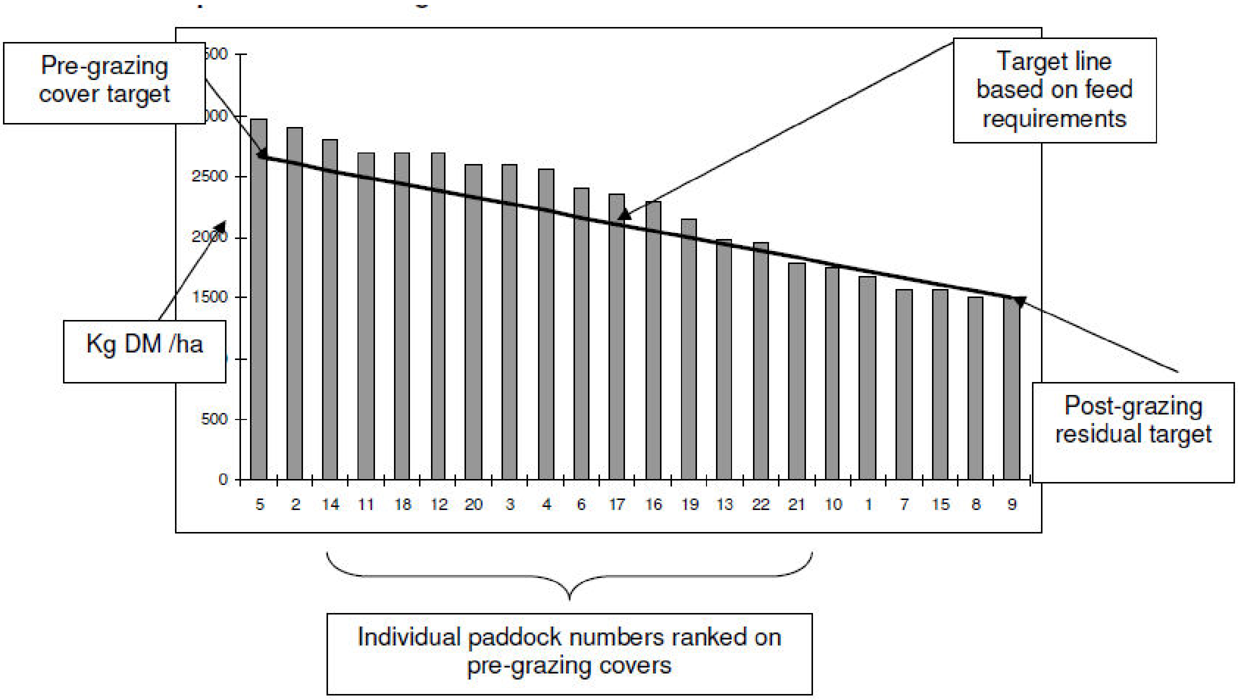
[10] Dairy NZ (2010) *Feed Wedges*, Farm Fact, October. Available for download from http://www.dairynz.co.nz/feed/feed-management-tools/pasture-feed-wedges/

Figure 2: An Example Feed Wedge



Source: Dairy NZ, *supra*. note 10.

The ability to use techniques such as the feed wedge depends critically on the existence of data on pasture cover. On flat country a pasture meter can be used to conduct measurements of the quantity of feed in each paddock. Traditionally a rising plate meter (RPM) was used as the farmer physically walked around the farm to take measurements in every paddock. Development of more advanced measurement technology means that devices such as the C-Dax pasture meter can be easily towed behind an ATV, taking 200 measurements per second at speeds up to 20km/h.[11] The ease of use means that measurements can be taken every 7-10 days. Software then converts the GPS-tagged measurements into a calculation of average pasture quantity per paddock, and a feed wedge can be prepared.

However, the C-Dax story is not one of runaway success and overwhelming market participation that changes the way that farming is conducted. Massey University researchers estimated that perhaps 2,500 C-Dax meters have been sold in New Zealand, primarily to dairy farmers. New Zealand Dairy Statistics report that there were 11,891 dairy herds for the 2012/13 year.[12] While the number of dairy farms and herds will not necessarily be an exact match, this suggests that approximately 20% of dairy farmers may have a C-Dax meter. LIC personnel noted that perhaps 80% of dairy farmers understand the benefits of metering using technology such as C-Dax, so if 20% of farmers own a C-Dax meter with perhaps half that number using the meters regularly, then technology adoption rates have been moderate. In the view of LIC personnel, successful uptake would be indicated by 60%-70% of farmers regularly using the technology.

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[11] http://www.pasturemeter.co.nz/view.php?main=benefits

[12] Dairy NZ and LIC (2013) *New Zealand Dairy Statistics 2012-13*, p. 7.

4.2. AERIAL ASSESSMENT OF PASTURE COVER

Data for generating feed wedges and making other pasture management decisions (such as the quantity of fertiliser to apply) is generally limited to flat country due to the difficulty and danger of taking measurements on hill country. Amongst other objectives, the "Transforming Hill Country Farming" PGP project[13] is aiming to develop technology that can be used in agricultural aircraft to measure pasture by flying overhead. While the research equipment is large and heavy, this should ultimately lead to the development of smaller sensors that are suitable for mounting on UAVs.

The frequency of use of the technology depends on the cost of use, including opportunity costs such as time. The C-Dax pasture meter can be towed around a farm in 1-2 hours, with the opportunity also taken for a visual inspection of paddocks and infrastructure. As such, the pasture meter is relatively cheap to use and can be used on a regular basis. However, the farmer towing a C-Dax meter around the farm is unlikely to drive back-and-forth across paddocks, but is much more likely to take a simple transect. Data gained from a UAV will cover the entire paddock and may therefore provide a more accurate estimate of pasture cover. A sensor mounted on a manned aircraft is expensive to use, and may only be used once or twice a year, particularly to assess fertiliser requirements.

4.3. NUTRIENT MONITORING AND APPLICATION

Spectral imaging can be used to determine nutrient stresses in plants (i.e., N, P, and K deficiencies), although this requires knowledge of plant water status.[14] When coupled with knowledge of water status, required nutrient application rates can be accurately determined. Water content of plant cells may itself be detected by reflectance in the far infrared wavelengths. Studies have shown that variable rate application of fertiliser, targeted to the more nutrient-deficient areas, can both reduce fertiliser cost and increase dry matter production.[15]

In the current PGP project, Massey University researchers estimate that the gains in fertiliser productivity for an average hill country farm may be as much as 17%.[16]

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[13] This seven-year research project is being conducted by Massey University and AgResearch, with funding from MPI and Ravensdown.

[14] Christensen, Lene K., Shrinivasa K. Upadhyaya, Bernie Jahn, David C. Slaughter, Eunice Tan, and David Hills , "Determining the Influence of Water Deficiency on NPK Stress Discrimination in Maize using Spectral and Spatial Information" (2005) *Precision Agriculture*, December, 6(6):539-50. For access to this paper see http://link.springer.com/article/10.1007%2Fs11119-005-5643-7

[15] Lawrence, Hayden (2013) "A Precision Fertiliser Plan: Real Measurements, Real Costs, Real Results", In: *Accurate and efficient use of nutrients on farms* (Eds L.D. Currie and C L. Christensen). http://flrc.massey.ac.nz/publications.html . Occasional Report No. 26. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand.

[16] Personal communication, Prof. Ian Yule and Dr Miles Grafton.

4.4. SCENARIOS

In this model of farm-level ownership, flights would be undertaken as regularly on hill country properties as pasture meters are currently used on flat farms. Regular pasture measurement should lead to further efficiency gains beyond the 17% suggested by Massey University researchers. Anecdotal evidence from flat farms suggests that some farms may be able to increase productivity by as much as 25%.[17] It is unclear at this point whether the same productivity gains could be expected from hill country farms that have been largely unmeasured in the past, or whether the gains would be higher or lower.

The *ANZ Agri Focus* for December 2014 presents detailed analysis from the Red Meat Profit Partnership.[18] That analysis identifies that the top 20% of red meat (i.e. sheep and beef) farmers have rates of profitability two to three times that of the average.[19] ANZ also identifies that “Mid-tier farmers relish the way of life that farming provides, but for them profit is not necessarily a key driver,”[20] whereas “Top farmers have a much keener focus on making good profits and they know which aspects of their operations make the best returns.”[21] This analysis is consistent with the view that UAV use on hill country farms might be undertaken as often as pasture measurement is currently performed on flatland dairy farms: there will be a proportion of farmers who are motivated to improve productivity to the extent that they are able, and will seek to use the latest technology to do so. Others will be aware of the potential benefits but not adopt the technology.

Based on the discussion above, the following scenarios will be analysed:

- Dairy: increasing use of active pasture management techniques from 15% of herds to 60% of herds; and
- Sheep and beef: adopting active pasture management by 25% of finishing farms and 15% of other farms, giving a weighted average of 19% of farms.

The primary aim of this analysis is to establish the gain from using UAVs beyond line of sight. To do this the following cases will be analysed:

- UAV operated LOS on-farm;
- UAV operated BLOS from on-farm; and
- UAV operated BLOS from off-farm.

The difference between LOS and the least cost BLOS option provides the gain from BLOS operation.

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[17] http://www.pasturemeter.co.nz/view.php?main=testimonials

[18] Bagrie, C., C. Williams, and D. Croy (2014) “Feature Article: The Secrets of Top-Performing Red Meat Farmers”, *ANZ Agri Focus*, ANZ Research, December.

[19] *Op. cit.*, p. 4.

[20] *Op. cit.*, p. 5.

[21] *Op. cit.*, p. 6.

4.5. PRODUCTIVITY GAINS

4.5.1. Productivity Growth

Let x denote the rate of production from a farm that does not use active pasture management techniques, and π denote the proportional increase in production from using active pasture management. If p is the proportion of farms using active pasture management then average observed productivity is:

$$(1-p).x + p.x.(1+\pi)$$

Let the proportion of farms using active pasture management increase to $p+\delta$. Average observed productivity increases to:

$$(1-p-\delta).x + (p+\delta).x.(1+\pi)$$

The proportional growth in productivity, g, is:

$$g = [(1-p-\delta).x + (p+\delta).x.(1+\pi)]/[(1-p).x + p.x.(1+\pi)] - 1 = \delta.\ \pi/[(1-p).x + p.x.(1+\pi)]$$

Table 5 shows the estimated productivity growth for dairy farms is 6.6% (middle row, bold), ranging between 5.1% and 8.1%. Table 6 shows the estimated productivity growth for hill country farms is 3.0%, ranging from 2.3% to 3.8%. The key driver of productivity growth is the assumed rate of take-up for the UAV-based pasture measurement.

Table 5: Estimated Productivity Growth, Dairy Farms

p	δ	$p+\delta$	π	g
0.10	0.45	0.55	0.15	0.067
0.10	0.50	0.60	0.15	0.074
0.10	0.55	0.65	0.15	0.081
0.15	0.40	0.55	0.15	0.059
0.15	**0.45**	**0.60**	**0.15**	**0.066**
0.15	0.50	0.65	0.15	0.073
0.20	0.35	0.55	0.15	0.051
0.20	0.40	0.60	0.15	0.058
0.20	0.45	0.65	0.15	0.066

Table 6: Estimated Productivity Growth, Hill Country Farms

p	δ	$p+\delta$	π	G
0.00	0.15	0.15	0.15	0.023
0.00	**0.20**	**0.20**	**0.15**	**0.030**
0.00	0.25	0.25	0.15	0.038

Converting Productivity Gain to Income

Productivity gain can be assessed as either using the same inputs to produce a greater output (e.g. better utilisation of existing pasture means that more stock can be carried), or using less inputs to produce the same output (e.g. better targeted application of fertiliser requires less fertiliser to achieve the same level of production). The two measures are potentially quite different, as one captures the value of additional stock units, while the other captures the reduction in one component of on-farm costs. For this analysis, we assume that productivity is measured as the additional carrying capacity of the farm.

4.5.2. Dairy

For the purpose of calculating the value of additional livestock, we make the following assumptions:

- All additional cows have average milk productivity reported in the most recent three years of available data (2010/11, 2011/12, 2012/13); and
- All additional milk is supplied to Fonterra and paid the Farmgate milk payout. The MBIE Food & Beverage Information Project estimates that Fonterra controls 88% of the New Zealand milk supply (i.e. 88% of milk is produced by Fonterra-contracted suppliers).[22] Prices for other processers are closely correlated to the price set by Fonterra.

We have not estimated the impact of the higher stocking rate on the production of calves or trading of stock. In the initial years of growing productivity, additional calves would be retained to build up herds, reducing the supply of stock available for sale. This is typically a relatively small component of farm income.

Milk Payout

Fonterra suppliers receive two components of return: the primary return is a milk payout expressed in $/kg of milk solids ($/kgMS); the second is a dividend which may also be expressed as a $/kgMS. The vast majority of the return to dairy farmers is via the milk payout, which has averaged $6.784/kg MS over the 5 years 2010/11 to 2014/15 (forecast). Over the same period the dividend has averaged just $0.253/kgMS.

The milk payout is volatile and directly depends on the global price of milk. In the year to September 2014, the international price fell 45%.[23] As with all markets, the international price depends on the balance of demand and supply. While New Zealand is dominant in the international dairy trade, New Zealand only produces a small proportion of the global milk supply. A modest increase in world dairy production could therefore result in significant increases in available milk supply and prices and returns being depressed. Balanced against this, rising incomes in some countries (particularly China) is significantly increasing the demand for milk products. A reduction in the NZ exchange rate will increase the available payout to NZ dairy farmers. Given these complexities it is difficult to forecast the milk payout for future years. We therefore estimate the payout as the average payout over the most recent 5 years, being $7.037/kg MS.

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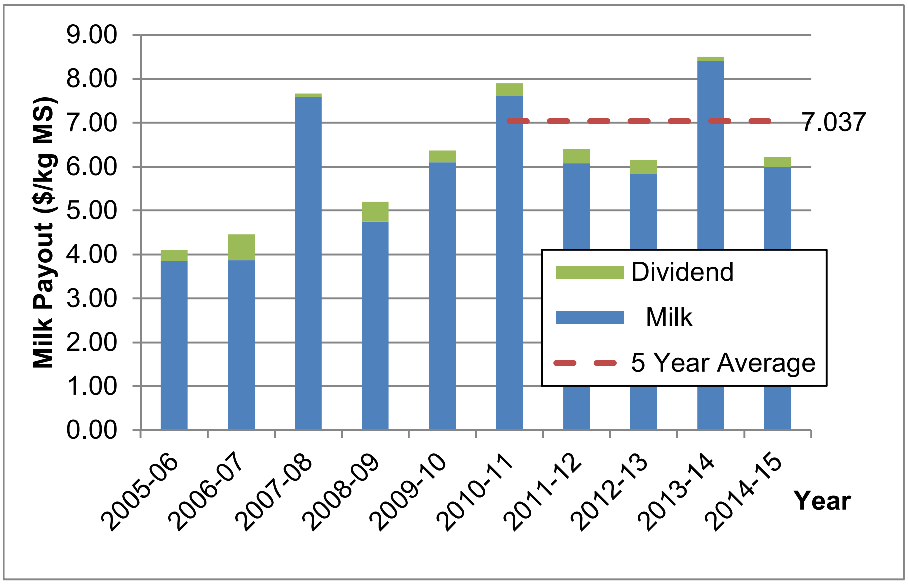
[22] Fonterra (2013) *The Milk Price Statement 2013: for the season ended on 31 May 2013*, p. 3.

[23] Kloeten, N. (2014) “Dairy auction prices drop again”, http://www.stuff.co.nz/business/farming/dairy/10454115/Dairy-auction-prices-drop-again, 3 September 2014.

Figure 3: Historical Milk Payout



Source: http://www.interest.co.nz/rural-data/dairy-industry-payout-history, accessed 1 September 2014

Export / International Price

Fonterra sets the milk payout with reference to the Farm Milk Price, a theoretical value calculated as the international price of commodity milk products less (a) the cost of transport from the farm to the dairy factory, and (b) the efficient cost of processing the milk. It is the international price that is relevant, rather than just the payout to the farmer. The value to “NZ Inc” is export revenue less import costs. Import costs will include imported fuel costs (noting that road user charges, taxes, and levies are collected by the government), equipment not manufactured in New Zealand such as trucks, and imported feed such as palm kernel.

Fonterra reports that the capital and cash costs of transport and processing were $1.88/kgMS for 2013, $1.78/kgMS for 2012, and $1.91/kgMS for 2011.[24] The average costs of transport and processing are $1.857/kgMS. Adding this to the average milk payout gives an average international price of $8.89/kgMS.

Cost of Imports

A 2010 report from the NZIER estimates that 8% of the raw milk payout to farmers was spent on imported inputs such as fertilizer, pharmaceuticals, feed, and agricultural equipment.[25] The same report estimates that 6% of dairy processor revenue is spent on imported inputs.[26] These figures imply that the cost of imported intermediates is $0.56/kgMS for milk production and $0.53/kgMS for milk processing, giving a total imported cost of $1.10/kgMS (differences due to rounding).

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[24] Fonterra, *The Milk Price Statement 2013: for the season ended on 31 May 2013*, p. 6.

[25] NZIER (2010) *Dairy’s role in sustaining New Zealand – the sector’s contribution to the economy*, Report to Fonterra and Dairy NZ, December, pp. 6,7.

[26] Op. cit., p. 7.

Gross Benefit to NZ Inc

The net "NZ Inc" portion of the international dairy price is the estimated international price less the estimated import costs, giving a value of $7.80/kgMS (differences due to rounding). Table 7 shows that the application of this value to the estimated total increase in milk solids production results in a gain to New Zealand of $857m per annum.

Table 7: Value of Increasing Active Pasture Management in Dairy from 15% to 60% of Farms

	litres	kg milkfat	kg protein	kg milk solids
2010/11	3,829	190	144	334
2011/12	4,128	206	158	364
2012/13	3,947	196	150	346
Average	3,968	197	151	348
Increase (%)	6.6%	6.6%	6.6%	6.6%
Increase per cow	262	13	10	23
Total Cows (2012/13)	4,784,250	4,784,250	4,784,250	4,784,250
Total Increase (000)	1,253,216	62,324	47,585	109,909
5 Year Avg Price ($/kgMS)				7.80
Value annual production ($m)				857

Per-Farm Gains

The purpose of this part of the analysis is to determine whether the gains to individual farms are sufficient that there is a reasonable prospect of the "NZ Inc" gains being achieved.

To establish the gains per farm from use of UAVs for pasture management we calculate the gross increase in farm income and then deduct an estimate of the cost of operating a UAV. We have not included an estimate of the costs of transforming the digital imagery into feed wedge information – a service that we would expect would be provided by a farm management consultant in conjunction with the UAV operator.

The returns available from using active pasture management depend on the farm ownership structure. Two common structures are owner-operated and a 50:50 sharemilking arrangement. Under a 50:50 sharemilking arrangement one party provides the land and the other provides the stock. The income from production of milk solids (i.e. the payout) is shared on a 50:50 basis between the land owner and the sharemilker.

In Figure 4 overleaf we estimate the gross increase in dairy farm income from active pasture management is in the order of $81,690 per year for an owner-operated farm and $30,691 per year for a sharemilker ins a 50:50 sharemilking arrangement.

The production of a feed wedge from aerial imagery is a sophisticated task requiring ongoing recalibration of sensors, sophisticated image processing, and translation of the data into useful management information for the farmer (e.g. a feed wedge). We assume that this is best performed by specialist agricultural consultants. Consistent with the industry model envisaged by LIC, we assume that the farm consultant is the operator of the UAV and is able to undertake a high volume of flying hours per year.

We estimate that for LOS operations the cost of UAV aerial surveys is $7,103 per annum,[27] considerably less than the increase in farm income. These costs do not include the cost of administrative overheads for the farm consultant or the costs associated with processing the data captured and presenting it in a meaningful format. Nevertheless, it is likely that the use of UAVs and active pasture management will be profitable for both forms of farming.

We also estimate that the cost of BLOS UAV operations would be $3,043 per annum, a reduction of $4,060 per annum over the LOS case.[28] If the 11,891 dairy herds are assumed to equate to farms, 60% take-up suggests a gain of $29.0m per annum from BLOS operations.

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[27] Appendix B, Table 21, column [A].

[28] Op. cit.

Figure 4: Net Increase in Dairy Farm Income, LOS Operations

	Owner-Operator	50:50 Sharemilker
Average cows / ha	2.82	2.86
Average Farm Area (ha)	141	137.9
Average Cows	397	394
Average Production per Cow (kgMS/cow)	360	361
Average Production (kgMS)	143,052	142,234
Increase (%)	15%	15%
Total Increase (kgMS)	21,458	21,335
Farmgate Payout (S/kgMS)	7.037	3.5185
less		
Operating Costs ($/kgMS)		
Reported ($/kgMS)	4.13	2.35
less costs unchanged		
Fertiliser ($/kgMS)	0.58	0.16
Irrigation ($/kgMS)	0.04	0.01
Regrassing ($/kgMS)	0.06	0.02
Weed & Pest ($/kgMS)	0.03	0.01
Insurance ($/kgMS)	0.06	0.03
ACC ($/kgMS)	0.03	0.03
Rates ($/kgMS)	0.1	0.01
Incremental Operating Costs ($/kgMS)	3.23	2.08
Incremental Profit ($/kgMS)	3.807	1.4385
Gross Increase in Income ($)	81,690	30,691
Cost of Farm Surveys ($ pa)	7,103	7,103
Net Increase in Income ($ pa)	74,587	23,588

Sources: (a) *New Zealand Dairy Statistics*, Table 2.2, p.7, most recent year; (b) DNZES, most recent year, tables listed below; (c) DNZES, average most recent three years, tables listed below; (d) DNZES, most recent year.

DNZES data from *Dairy NZ Economic Survey 2012-13*. Owner-operator data from “Table 7.4: Cash Operating Surplus and Operating Profit - $ per milk solids sold”, p. 54. 50:50 Sharemilker data from “Table 8.4: Cash Operating Surplus and Operating Profit - $ per milk solids sold”, p. 61.

4.5.3. Sheep & Beef

Dairy farms are relatively homogenous, but Beef + Lamb New Zealand defines eight different types of sheep and beef farm, differentiated by location (North Island or South Island) and type of farming system. The eight farm types are summarised in Table 8. Beef + Lamb New Zealand provides benchmark economic models for each farm type.

Table 8: Sheep and Beef Farm Types

Farm Type	Average Area (ha)	Number of Farms
NI Hard Hill Country	834	1,155
NI Hill Country	418	4,020
NI Intensive Finishing	289	1,490
SI High Country	7,672	220
SI Hill Country	1,477	850
SI Finishing-Breeding	481	2,657
SI Intensive Finishing	220	1,306
SI Mixed Finishing	409	592

Source: Beef + Lamb New Zealand

A breeding farm is primarily used for breeding stock. A finishing farm is a farm primarily used to get stock into prime condition ready for slaughter. A mixed finishing farm also derives a significant proportion of revenue from cropping.

Most sheep and beef farms are much larger in area than an average dairy farm. This means that more flying time is required to survey the farm, and the cost of UAV surveys is commensurately greater.

In Table 9 below we provide an estimate of the value to an individual farm and the value to "NZ Inc" of the gains from using UAVs and active pasture management for sheep and beef farms when restricted to LOS operations. For each class of farm we report Beef + Lamb's forecast model farm profit for the 2014/15 year, and the increase in profit that would be possible if 15% more stock could be carried. We then estimate the cost of UAV surveys based on the average size of farm and calculate the net increase in farm profits. Note that for all farm types except South Island High Country we assume that aerial surveys are conducted fortnightly on a year-round basis; for the South Island High Country stations we assume that aerial surveys are conducted 4-weekly for only 8 months of the year.

We estimate that South Island High Country stations experience only a small net gain in income from using line-of-sight UAVs: UAV costs equal almost 90% of the gross increase in income, leaving a net increase in income of just 5%. Given the uncertainty around UAV costs, such a small increase in net income could easily be eliminated by only a small increase in UAV costs or a small decrease in incremental productivity. We therefore assume that South Island High Country stations do not adopt line-of-sight UAVs for pasture management.

South Island Mixed Finishing farms are the only class of farm where line-of-sight UAVs appear to cost more than the value that they might create. The gross increase in farm profit is $16,201 per year ($39.61/ha), but UAV costs are $28,277 per year ($69.14/ha), giving a net *reduction* in income of $12,076 per year. The costs per hectare for UAV surveys are broadly similar to those for North Island Hill Country, South Island Finishing-Breeding, and South Island Intensive Finishing Farms (all in the $59/ha-$68/ha range). However, this is one of the least profitable forms of farming (on a $/ha basis the only farms less profitable are the High Country stations), so incremental profit does not support the incremental cost of line-of-sight UAV operations. Farm consultant costs would potentially further reduce farm income. We therefore assume that South Island Mixed Finishing farms would not use UAVs for pasture management under LOS restrictions.

For all other classes of sheep and beef farm there is an increase of between 12% and 24% in net farm profits, before any allowance for farm consultant costs.

Notwithstanding the potential increase in net income, we note the comments from ANZ on the differing motivations for top- and mid-tier farmers, and assume that only 25% of finishing farms and 15% of other farms that could profitably adopt the technology do so. The potential gain to “NZ Inc” is the product of the gross increase in per-farm profit for the relevant farms and the number of farms. Given the assumed take-up the estimated gain to NZ Inc from LOS operations is $44.5m per year.

We estimate that the cost of BLOS operations from a home base is less than the cost of LOS operations for all farm types. Furthermore, the cost of BLOS operations is sufficiently low that both South Island High Country stations and South Island Mixed Finishing farms can profitably use UAVs for pasture management. Given the assumed take-up rates, the estimated gain from BLOS operations is $37.6m per annum (Table 10): this gain is derived from the decrease in cost for farm types that employed UAVs under LOS operations, plus the net increase in income for South Island High Country stations and South Island Mixed Finishing farms.

The estimated gain is based on the average profitability of sheep and beef farms. If the top 20% of most profitable farms is over-represented in the farms that utilise UAVs, as seems likely, then the estimated economic gains from LOS operations would be greater than estimated in Table 9. However, the gains from BLOS operations would be much the same, as those gains primarily arise from the reduction in cost relative to LOS operations.

Table 9: Per-Farm and NZ Inc Value from Adoption of UAVs for Active Pasture Management in Sheep & Beef Farms, LOS Operations

		North Island			South Island					
		Hard Hill Country	**Hill Country**	**Intensive Finishing**	**High Country**	**Hill Country**	**Finishing-Breeding**	**Intensive Finishing**	**Mixed Finishing**	**Total**
B+LNZ Forecast 2014-15	[a]	133,935	97,341	86,071	151,749	148,497	136,496	85,992	89,104	
Gross Increase in per-farm profit	[b]	61,618	45,628	33,245	87,938	63,982	49,882	33,764	16,201	
Annual UAV Costs ($)	[c]	28,855	28,355	14,264	69,241	57,144	28,359	14,183	28,277	
Net Increase in Farm Profits ($)	[d]=[b]-[c]	32,763	17,274	18,981	18,697	6,839	21,523	19,582	-12,076	
% Increase in Farm Profits	[d]/[a]	24%	18%	22%	12%	5%	16%	23%	-14%	
Likely to Adopt?		Y	Y	Y	Y	N	Y	Y	N	
Number of Farms	[e]	1,155	4,020	1,490	220	850	2,657	1,306	592	
Max Gain to NZ ($m)	[f]=[d]x[e]	37.8	69.4	28.3	4.1	-	57.2	25.6	-	222.4
Take-up Rate	[g]	15%	15%	25%	15%	15%	25%	25%	25%	20%
Net NZ Inc Gain ($m)	[h]=[f]x[g]	5.7	10.4	7.1	0.6	-	14.3	6.4	-	44.5

Table 10: Per-Farm and NZ Inc Incremental Value from use of BLOS UAVs for Pasture Management

		North Island			South Island					
		Hard Hill Country	**Hill Country**	**Intensive Finishing**	**High Country**	**Hill Country**	**Finishing-Breeding**	**Intensive Finishing**	**Mixed Finishing**	**Total**
Gross Increase in per-farm profit	[b]	61,618	45,628	33,245	87,938	63,982	49,882	33,764	16,201	
Annual UAV Costs ($)	[c]	20,972	10,488	5,424	53,686	22,419	10,630	4,314	7,285	
Net Increase in Farm Profits ($)	[d]=[b]-[c]	40,646	35,140	27,821	34,252	41,563	39,252	29,450	8,916	
% Increase in Farm Profits	[d]/[a]	30%	36%	32%	23%	28%	29%	34%	10%	
Likely to Adopt?		Y	Y	Y	Y	Y	Y	Y	Y	
Net Increase over LOS	[e]	7,883	17,866	8,840	15,555	41,563	17,729	9,869	8,916	
Number of Farms	[f]	1,155	4,020	1,490	220	850	2,657	1,306	592	
Max Gain to NZ ($m)	[g]=[e]x[f]	9.1	71.8	13.2	3.4	35.3	47.1	12.9	5.3	198.1
Take-up Rate	[h]	15%	15%	25%	15%	15%	25%	25%	25%	19%
Net NZ Inc Gain ($m)	[i]=[g]x[h]	1.4	10.8	3.3	0.5	5.3	11.8	3.2	1.3	37.6

5. FORESTRY

Aerial imaging from conventional aircraft is already used for tree growth assessment and aerial mapping, with appropriate software used for applications such as automated tree counts and ground surface mapping (i.e. creating a three-dimensional map of the ground surface beneath the forest).

UAVs provide two benefits over conventional aircraft. First, the lower cost of UAVs means that flights can be conducted more regularly, allowing more accurate and timely assessment of forest growth, and allowing more timely identification of damage after storm events. Second, the lower flight level of UAVs enables images with a higher level of detail and precision to be obtained, improving the accuracy of estimates of tree counts, forest height, and tree volume.

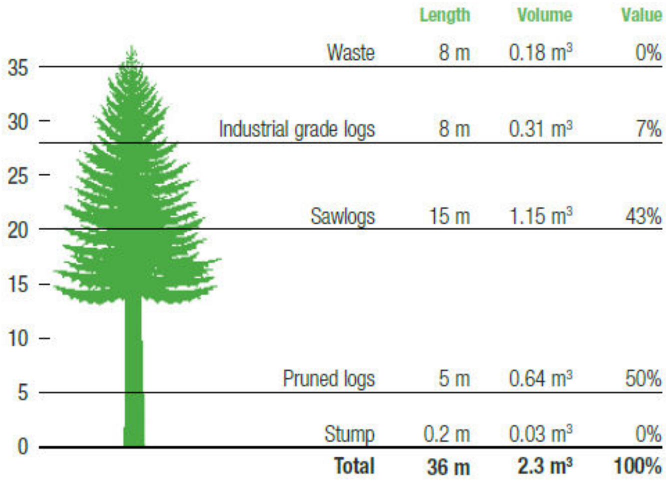
Estimates of tree volume are particularly important at and around harvest time. A pre-harvest inventory is used to pre-sell the logs that will be harvested, and harvesting companies bid for the right to harvest the forest block based on the same information. During harvest cut-over mapping may be used to confirm the area already logged and the area remaining to be logged, with payments to contractors made accordingly. Reconciliation of actual area logged and timber volume with the expected volume can also identify if there are any opportunities for additional sales.

UAVs also provide a tool for real-time monitoring of the health of forests. Aerial surveys can identify the tell-tale signs of a range of diseases, and then action can be taken to reduce the spread of that disease.

5.1. PRE-HARVEST INVENTORY AND IDENTIFICATION OF HIGH-QUALITY TREES

An individual tree will typically not be used for a single wood product, but will instead be cut into a variety of log products at the point of harvest. Figure 5 shows the typical out-turn of a pruned tree under a “direct sawlog” regime. The logs themselves will be of different grades, such as those shown in Table 11 (export) and Table 12 (domestic).

Figure 5: Typical Log Products from a Direct Sawlog Regime



	Length	Volume	Value
Waste	8 m	0.18 m³	0%
Industrial grade logs	8 m	0.31 m³	7%
Sawlogs	15 m	1.15 m³	43%
Pruned logs	5 m	0.64 m³	50%
Stump	0.2 m	0.03 m³	0%
Total	**36 m**	**2.3 m³**	**100%**

Source: New Zealand Forest Owners Association, *New Zealand Plantation Forest Industry Facts & Figures*, 2011/2012, p. 14.

A pre-harvest inventory is typically conducted by way of a "timber cruise", conducted by crews on the ground. The objective of the pre-harvest inventory is to develop a harvest plan and sell the logs into their highest value use. A 100% cruise may be conducted, in which all the trees in a stand are measured, but sampling is more cost effective. UAVs provide the opportunity to cost-effectively overfly an entire forest to conduct the equivalent of a 100% cruise.

Image processing technology is at the point where individual trees can be identified with reasonable accuracy, and the height of trees can be established. More difficult is the use of UAVs to establish other parameters such as straightness (or sweep), pruned height, tree condition, and overall wood volume. These later parameters may possibly be able to be established by side-scan from a UAV, but may be better conducted by ground surveys. This alone means that UAVs might be able to complement, but not replace, ground-based timber cruises. UAVs may therefore provide a more accurate tree count, but it is difficult to quantify whether this adds any significant value.

Scion staff suggested that a UAV may be able to identify individual high-value trees within a stand, which could then be extracted at harvest time and cut and routed to processors who can best utilise the logs. In support of this strategy, Scion staff referred to studies showing 20% of logs might be sold into lower-value uses than what they could be graded at, and that the additional value for those logs could be anywhere from 10% to 25%. Timberlands staff suggested that this was not an economically viable strategy, which would increase harvest costs at a time that timber companies internationally are striving to reduce cost. Reducing cost at harvest time relies on high volume cutting and processing rather than individually picking trees.

The literature recognises that regardless of the pre-determined cutting plan, the harvesting crews are the ones who determine the actual logs cut from harvested trees. This process is subject to human error and the limited ability of humans to optimise the cutting of multiple trees of differing quality.

Modern harvesting technology is able to overcome human limitations by automatically assessing trees and cutting them to their highest value use. An Australian trial using a harvester with an onboard computer system in radiata pine plantations demonstrated a 9.3% increase in harvester productivity and a 3.2% increase in log value.[29] The New Zealand-designed "Logmeister" system:

> *consists of a scanner cab that runs parallel to a delimbed stem, creating a stem profile that is virtually cut up (bucked) by the Logmeister optimiser algorithm. A secondary machine with a processing head mounted on an excavator base takes the scanned solution (wirelessly) and cuts the log sorts as prescribed by the Logmeister scanner. Cutting strategies and log grade prices are relayed from company offices wirelessly and all production data is uploaded, instantly, to a remote server…*[30]

The Logmeister has been shown in operational trials to generate between 11.9% and 39.0% more value than traditional logging crews using a grapple processor.[31]

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[29] Walsh, Damian (2012) "Quantifying the value recovery improvement using a harvester optimiser", Bulletin 26, CRC for Forestry, May.

[30] http://www.logjiztix.co.nz/Logmeister.php

[31] Dick, Andy (2012) "Value recovery results from two Logmeister operational trials" Logjistix Ltd. http://www.logjiztix.co.nz/media/Value_recovery_results_from_two_Logmeister_operational_trials.pdf

Even with the harvesting machinery able to optimise the cutting of each log, the value on which the cutting decisions are made may depend on the contracts that the forestry company has in place. Those contracts will in turn depend on the pre-harvest inventory, but as discussed above, while UAVs may be able to contribute to an accurate tree count given current research it is not obvious that UAVs are able to significantly contribute to the assessment of tree quality.

Table 11:Export Log Grade Specification[32]

Log Grade	Small end Diameter (mm)	Maximum Large end Diameter (mm)	Maximum Knot size (mm)	Length (m)	Percentage allowed	Sweep[33]
Pruned peelers	300+	No limit	0	4.0, 6.0	Shippers option	d/4
Japan A	200-340	800	d/3 up to 150 mm max Excessive number of large knots not permitted	4.0 8.0 12.0	10% max balance 50% min	d/4 d/2 d
Japan J	200-260	No limit	d/3 up to 150 mm max Excessive number of large knots not permitted	4.0 8.0 12.0	10% max balance 50% min	d/4 d/2 d
Korea K	200-260	No limit	d/3 up to 150 mm max Excessive number of large knots not permitted	3.6 5.4 7.3 11.0	balance 10% max balance 40% min	d/4 d/4 d/2 d
Pulp (Japan)	100+	No limit	No limit	4.0, 6.0, 8.0	Shipper's option	No limit

Note: d = small end diameter. For export grades, small end diameter is measured at the wharf under the Japanese Agricultural Standard (JAS) convention, i.e., rounded down to the nearest even two-centimetre interval.

Table 12: Domestic Log Grades (Forest Research Specification)[32]

Log Grade	Log status	Small end Diameter (mm)	Maximum Knot (mm)	Sweep class
P1	Pruned	400+	0	1
P2	Pruned	300-399	0	1
S1	Unpruned	400+	60	1
S2	Unpruned	300-399	60	1
S3	Pruned or unpruned	200-299	60	1
L1	Unpruned	400+	140	1
L2	Unpruned	300-399	140	1
L3	Unpruned	200-299	140	1
Pulp	Unpruned	100	n/a	2

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[32] http://www.mpi.govt.nz/news-resources/statistics-forecasting/forestry/log-grade-specification

[33] Sweep is the maximum deviation from straightness along the length of the log. For definition of the “sweep class” for domestic logs see the MPI website in note 32 supra.

5.2. CUT-OVER MAPPING

As a forest stand is being harvested the area that has been cut will need to be mapped (this process is known as “cut-over mapping”). Cut-over mapping is primarily used to reconcile the volumes expected from the cut area against the actual volumes cut, and hence refine prediction models, adjust contracts, and make payments to the contracted harvesting crews.

Initial cut-over mapping may be conducted on the ground with GPS, with further refinement conducted aerially. The forestry companies suggested that aerial mapping had greater precision. The use of aerial cut-over mapping varied significantly between companies, from annually to every two months. Timberlands also noted that any inaccuracy is only a temporary phenomenon, with all inaccuracy resolved once the stand has been completely cut.

Using UAVs for aerial cut-over mapping may allow more frequent mapping, improving the accuracy and cut-over estimates and therefore alter the timing of cash flows to contractors, but this in itself is likely to have minimal economic benefit.

The primary benefit of using UAVs for cut-over mapping would be to reduce the cost of cut-over surveys conducted using conventional aircraft. Given that cut-over mapping primarily requires over-flying the areas cut and accurately mapping the cut line, it is likely that substantial cut-over mapping could be conducted line-of-sight from different positions along forest access roads or elevated skid sites.[34] Figure 6 shows an example of a cut-over line: while it would be difficult to fly line-of-sight for any appreciable distance over the trees, the cut-over line itself could readily be flown from the position of the photographer.

Figure 6: Example Cut-Over Line

Source: Andrew Shelley

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[34] A skid site is an area of land in the forest where logs or tree lengths extracted from the forest are accumulated, cut into logs, and loaded onto trucks for removal.

5.3. DISEASE DETECTION AND CONTROL

Table 13 (p. 35) describes four diseases that can adversely affect the needles of *Pinus radiata* (commonly known as “radiata pine”). Two of the diseases involve needle “cast”, where needles die and detach from the tree; the other two involve needle “blight”, where needles die but remain attached to the tree. The photograph in Figure 7 overleaf shows trees affected by Red Needle Cast and Physiological Needle Blight. While both diseases result in needles turning a brownish shade there are differences in presentation that can be detected from high aerial imagery (although probably not from the photo provided).

5.3.1. Value Loss from Disease

New (1989) estimated that *Dothistroma* in New Zealand resulted in losses of 225,000m^3 per annum from a forest estate of 450,000ha.[35] As at 1 April 2013 there was an estimated 658,225ha of radiata pine forest aged from 1 to 15 years. [36] Applying the same proportional rate of losses implies annual losses from *Dothistroma* of 329,113m^3.

Bulman and Gadgil (2001) report the results of a study that estimated that *Cyclaneusma* caused growth losses of 6.6% per annum for the radiata pine estate aged between 6 and 20 years.[37] Estimates for individual regions were higher or lower than this New Zealand-wide average. In calculating this loss, an average annual growth increment of 20m^3/ha was assumed.[38] As at 1 April 2013 there was an estimated 923,112ha of radiata pine forest aged from 6 to 20 years.[39] Applying the estimates of 20m^3/ha annual growth and 6.6% growth losses suggests annual losses from *Cyclaneusma* of 822,508m^3.

New (1989) based his calculation of economic losses on a stumpage rate of \$20/m^3. More recently, Watt et al (2011) use a stumpage rate of \$55/m^3. [40] In our view, neither of these values is correct, as stumpage is simply the apportionment of *part* of the value of the tree. Economically, the value of these losses are related to the sale price of the logs. Figure 8 (p. 36) shows the PF Olsen log price index, which reflects weighted average prices for a broad average of log products produced from a typical pruned forest. Although the index fluctuates, it is reasonable to assume a weighted average price of \$100/tonne.

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[35] New, David (1989) “Forest Health – An Industry Perspective of the Risks to New Zealand’s Plantations”, *New Zealand Journal of Forestry Science*, 19(2/3):155-158, p. 157.

[36] Ministry for Primary Industries (2013) *National Exotic Forest Description*, as at 1 April 2013, Table 9.8.

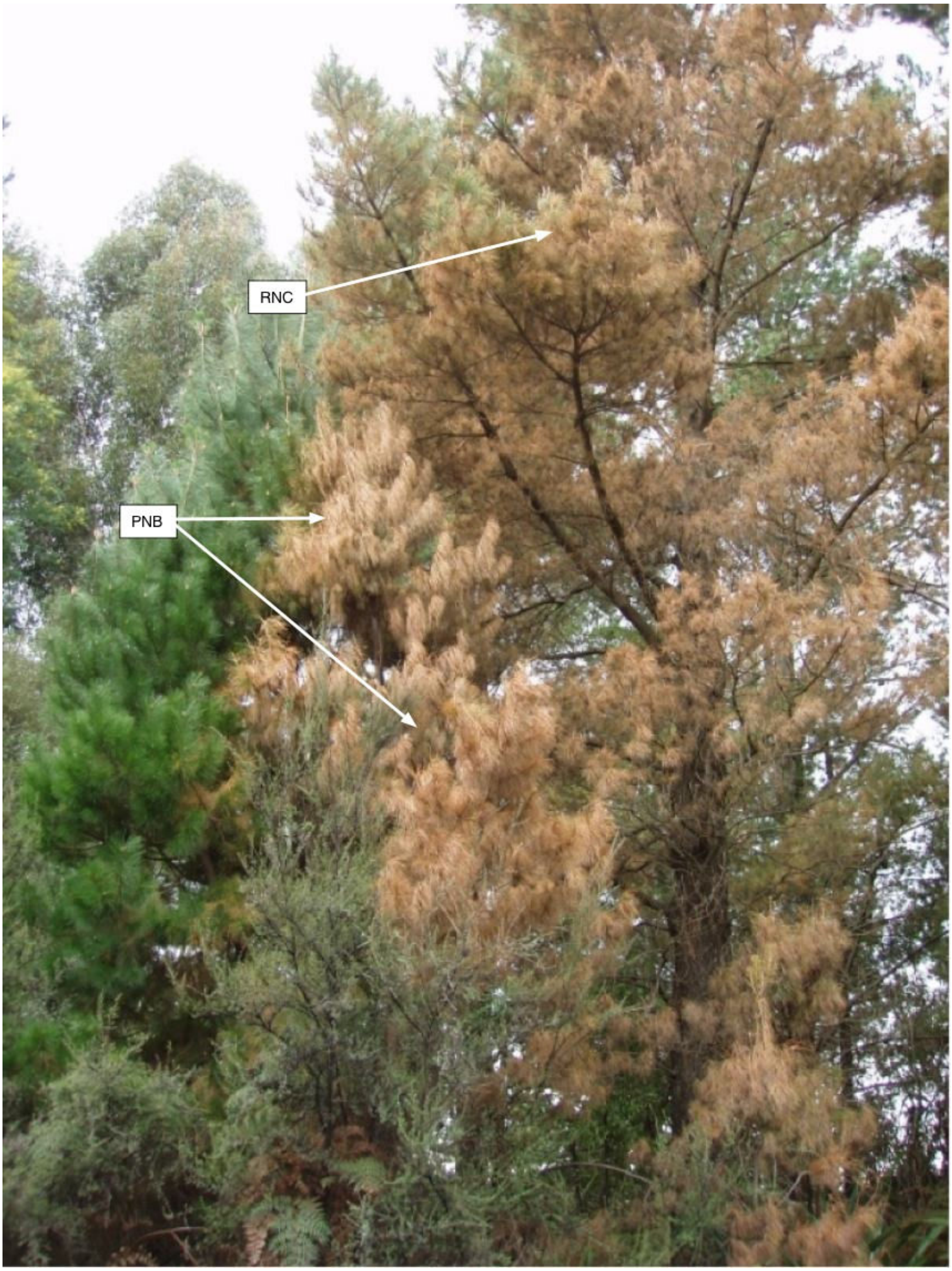
[37] Bulman, Lindsay and Peter Gadgil (ed) (2001) *Cyclaneusma Needle-Cast in New Zealand*, Forest Research Bulletin No. 222, Forest Research.

[38] *Ibid*.

[39] Ministry for Primary Industries (2013) *National Exotic Forest Description*, as at 1 April 2013, Table 9.8.

[40] Watt, Michael, Lindsay Bulman and David Palmer (2011) “The economic cost of Dothistroma needle blight to the New Zealand forest industry”, *New Zealand Journal of Forestry*, 56(1):20-22, May.

Figure 7: Pine Trees showing Red Needle Cast (RNC) and Physiological Needle Blight (PNB)



PNB on tree in foreground showing wilted foliage in front of a larger tree affected by RNC.

Source: http://www.nzffa.org.nz/farm-forestry-model/the-essentials/forest-health-pests-and-diseases/diseases/Needle-diseases/Physiological-needle-blight/

Table 13: Needle Diseases for *Pinus radiata*

Symptom	*Cyclaneusma* Needle Cast	Physiological Needle Blight (PNB)	Red Needle Cast	*Dothistroma* Needle Blight
Time of year expressed	September to November	June to November	April to October	All year, first appears on current foliage about December
Incidence and severity	Scattered individuals, up to 90% severity on very susceptible trees	Localised distribution, very high incidence in affected parts of a stand	Localised/general distribution, almost every tree in affected parts of a stand	General distribution, almost every tree in affected parts, but tree to tree variation is apparent
Needle colour	Yellow, then gold, then brown	Red, then red-brown, then grey	Oily green band, then yellow, then red	Brick red bands on green needles with black spots usually seen within the bands
Needle wilt	No wilt	Wilt common at late stage of disease development	No wilt	Needles may wilt, but usually wither and turn brown/grey
Needle retention	Needles detach very readily	Needles retained	Needles detach readily	Needles die completely and are retained
Cambium and bark	No damage, no lesions, no resin	No damage, lesions, or resin	No damage, no lesions, resin blobs sometimes seen at needle base	No damage, no lesions, no resin
Tree age	Six to 20 years	Generally over 15 years	All ages, but generally over 3 years	From planting up to about 15 years

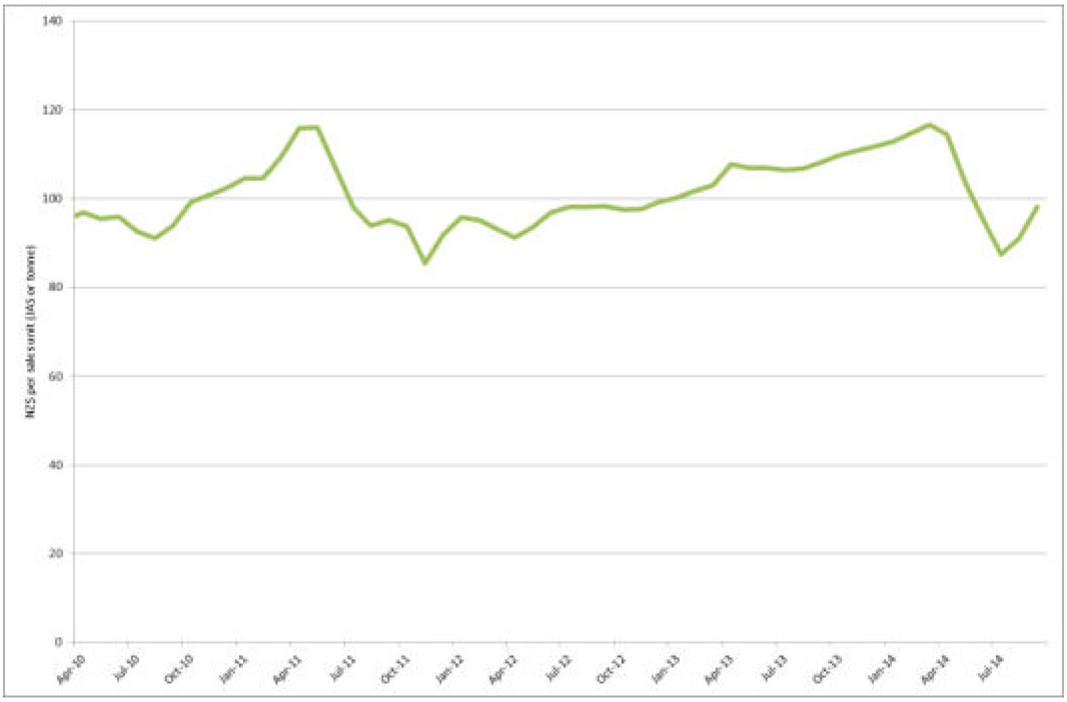
Source: Bulman, Lindsay and Judy Gardner (2014), "Needle Diseases of Radiata Pine in New Zealand", NZ Farm Forestry Association website, June, http://www.nzffa.org.nz/farm-forestry-model/the-essentials/forest-health-pests-and-diseases/diseases/Needle-diseases/

Prices are in $/tonne, but timber production is quoted in units of m^3. The MPI radiata pine log prices webpage states:[41]

> *Export log grades are typically measured in Japanese Agricultural Standard (JAS) cubic metres. A JAS measures logs according to prescribed formulae. Domestic logs are typically measured in cubic metres or tonnes. Conversion factors between all three measurements vary owing to a number of variables including wood age, log size and taper, but are mostly within 90 percent of a 1:1 relationship. Conversion factors are assumed to be 1:1 on this website.*

Employing a 1:1 conversion factor, we therefore assume that a reasonable indicative estimate of the value of radiata pine is $100/m^3. The aggregate annual losses from *Dothistroma* and *Cyclaneusma* of 1,151,621m^3 per annum equates to economic losses of $115m per year.

Figure 8: PF Olsen Log Price Index



Note: Index is based on weighted prices for log grades P40, S30, S20, Export A, Export K, Export KI, and Pulp. Weights represent a broad average of log grades produced from a typical pruned forest with a mix of domestic/export log supply.

Source: PF Olsen (2014) *Wood Matters*, Issue 68, September.

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[41] Ministry for Primary Industries (2014) "Indicative New Zealand Radiata Pine Log Prices", http://www.mpi.govt.nz/news-resources/statistics-forecasting/forestry/indicative-new-zealand-radiata-pine-log-prices.aspx, accessed 1 October 2014.

5.3.2. Control of Dothistroma

Dothistroma is controlled by various means, including pruning, thinning, and spraying of either cuprous oxide or copper oxychloride. The New Zealand Farm Forestry Association advises the pruning regime in Box 1, with up to five rounds of pruning and each round within an age range. Spraying with copper is generally reserved until the level of infection reaches approximately 15% of trees.[42]

There are concerns over the toxicity of copper to aquatic life. High concentrations of copper have been detected in streams an hour after spraying where young trees were present and there was no riparian vegetation. However, mature trees and riparian vegetation resulted in little copper being detected.[43]

The pruning regime in Box 1 provides flexibility, and modification of the pruning regime can therefore be used to prevent the need for relatively expensive aerial spraying, as well as preventing potential adverse environmental effects of copper sprays.

Box 1: Clearwood Pruning Regime[44]

A typical clearwood pruning regime is as follows:

1. Age 2-3 years. Do sail pruning if toppling is a threat. Removal of double leaders is optional.
2. Age 3-4 years. When trees are about 5 metres high, clear lift prune to a trunk diameter of about 10cm, rather than a constant height. Leaving about 2.5 to 3 metres of green crown. Note that trunk diameter correlates strongly with the crown height above. A 10cm caliper can be used as a guide. Prune with loppers or saw flush with the bark collar at the base of the branch. Remove double leaders in the crown and possibly cut large branches back to less than half their length.
3. Aged 4-6 years. (between 8 to 18 months after the first lift, depending on growth rate). When the tree height is about 8 metres, prune to a trunk diameter of 10 to 11cm leaving 3 to 4 metres of green growth. Use a trunk diameter of 11cm or more on more stressed or disease-prone sites and 10cm on less stressed sites. Remove any double leaders in the crown. Maximum DOS should be less than 20cm preferably averaging 16 to 18cm. Average pruned height should be about 4 metres.
4. Aged 6-8 years (between 8 to 18 months after second lift, depending on growth rates). Prune to a 6.5 metre target height. Prune to 10-11cm trunk diameter. Leaving 3-4 metres of green crown. On stressed or disease-prone sites do not prune below a trunk diameter of 11-12cm.
5. If necessary, return in about 12 months to prune smaller trees to 6.5 metres target height.

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[42] Watt, Michael, Lindsay Bulman and David Palmer (2011) "The economic cost of Dothistroma needle blight to the New Zealand forest industry", *New Zealand Journal of Forestry*, 56(1):20-22, May.

[43] Bulman, Lindsay, Rebecca Ganley and Margaret Dick (2008) *Needle Diseases of Radiata Pine in New* Zealand, Client Report No. 13010, Scion, August, p. 39.

[44] New Zealand Farm Forestry Association (2005) *Guide Sheet No. 1: An Introduction to Growing Radiata Pine*, 3 June, http://www.nzffa.org.nz/farm-forestry-model/resource-centre/farm-forestry-association-leaflet-series/nzffa-guide-sheet-no-1/

5.3.3. UAVs for Sampling

When diseased trees have been detected, ground-based personnel obtain a sample of the needles for diagnostic tests to confirm the specific disease involved. For needle blight diseases this involves personnel walking through the forest to the affected trees and using a shot gun to shoot down a branch. It was suggested that specially adapted multi-rotor UAVs equipped with some form of robotic arm with a pincer grip could be a safe and practical alternative for obtaining samples. The UAV could be launched from an access road and pre-programmed with the co-ordinates of a tree of interest. The UAV could then fly to those co-ordinates, and descend to a height where a trained operator could use the robotic arm to retrieve a sample. Once the sample had been obtained the UAV would be able to return to the launch location. This use of UAVs could reduce the time taken to obtain samples in hard to reach locations, and would reduce the hazards faced by personnel obtaining those samples. However, these benefits are difficult to quantify.

We note that this application is necessarily beyond line-of-sight. For juvenile trees, the tree(s) of interest may be some distance from an access road, making line-of-sight flight difficult. For mature trees, the tree(s) of interest will often be hidden by other trees closer to the pilot. A typical scenario may be that shown in Figure 9, where the UAV will be required to ascend above the mature trees and fly out of sight of the pilot to the relevant trees.

Figure 9: Tarawera Forest Access Road

Source: Andrew Shelley

5.3.4. Quantification of Benefits

Watt *et al* (2011) divide the cost of *Dothistroma* into three components: the cost of spraying; losses in value from sprayed stands; and losses in value from unsprayed stands. They specifically note that lowering the threshold at which *Dothistroma* is controlled will increase spray costs but reduce the cost of volume losses. UAVs provide the opportunity to identify potentially diseased trees from aerial imagery, sampling the affected trees to determine the exact disease, and then spraying individual trees. UAVs suitable for spraying range from commercial models such as the Yamaha R-Max (Figure 10 below) to custom-built machines. The R-Max can spray 2 acres of crops in as little as 6 minutes, although the area of trees covered will depend on their age and height.

Figure 10: Yamaha R-Max Helicopter Spraying Vegetation

Source: McFarland, Matt (2014) "America's clumsy regulation of drones stirs up frustration, confusion", *Washington Post*, 9 December. Photo Rich Pedroncelli/AP. http://www.washingtonpost.com/blogs/innovations/wp/2014/12/09/americas-clumsy-regulation-of-drones-stirs-up-frustration-confusion/

Absent specific trials to measure costs and control rates, we can only broadly estimate the benefits from using UAVs for disease monitoring and control. It seems reasonable to assume that the combined effectiveness of aerial monitoring and spraying is in the order of 40%-60%, i.e. that somewhere between 40% and 60% of existing losses are avoided. This means that the gross benefits from monitoring and control of *Dothistroma* and *Cyclaneusma* of could be in the order of $46m - $69m per year.

5.4. PESTS CONTROL

5.4.1. Value of Hardwood Imports

Over the 5 years to 30 June 2013 New Zealand has imported an average of 20,000m^3 of sawn hardwood per year, with a nominal average value of $28m per year.[45] In the most recent year sawn hardwood imports were 22,000m^3,[46] equivalent to approximately 45,100m^3 of roundwood.[47]

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[45] Ministry for Primary Industries, "Imports by forestry product: Year ended 30 June 1981 to most recent", downloaded 6 January 2015.

[46] *ibid*.

[47] A conversion factor of 2.05 has been applied.

The value of sawn hardwood imports in the most recent year was $30.638m,[48] equating to $679/m^3 of roundwood equivalent. To enable a direct comparison with radiata pine processing costs would need to be added to the assumed average radiata pine price of $100/m^3, although it should be noted that the entire $679/m^3 is value that can be captured by New Zealand.

A June 2010 study estimates that cold-climate eucalypt plantations in New Zealand could earn an internal rate of return of 16.8%.[49] Despite this potentially high return to growers, and the high value to New Zealand of displacing imports, hardwoods comprise only 2.0% of the national forest estate.[50]

5.4.2. The Eucalyptus Tortoise Beetle

Eucalypts are the predominant hardwood species grown commercially in New Zealand, comprising over 63% of the hardwood forest area. However, many Eucalypt subspecies grown in New Zealand are susceptible to the eucalyptus tortoise beetle, *Paropsis charybdis*.

Adult *P. charybdis* beetles over-winter either under bark or in forest litter on the ground. Adult beetles are capable of eating mature Eucalyptus foliage, but will not oviposit (lay eggs) until they have eaten new leaf growth. Larvae progress through four stages ("instars") before dropping to the ground to pupate in the ground. After pupating the adults emerge and, in New Zealand, feed vigorously in preparation for over-wintering. The full time from egg to adult takes approximately seven to nine weeks, and is dependent on temperature.[51]

The tortoise beetle has been reported as killing or rendering woodlots "totally moribund".[52] McGregor (1989) reports significant defoliation of Eucalyptus nitens in late summer (February and March), although foliage had apparently recovered by April.[53] Elsewhere it has been shown that defoliation of Eucalypts can significantly reduce growth. Elliot *et al* (1993) reported growth reductions one-year-old and six-year old *Eucalyptus regnans* in Tasmania of 39%-52% from defoliation due to the *Chrysophtharta bimaculata* leaf beetle.[54] Lundquist (1987) summarises the loss of growth for 4-year-old *Eucalyptus nitens* that occurs at differing levels of defoliation from leaf-infecting fungi. While less than 38% defoliation appears to result in no loss of growth, greater than 75% defoliation results in a complete loss of volume growth. It would be

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[48] *ibid*.

[49] Satchell, D. and J. Turner (2010) "Solid Timber Recovery and Economics of Short-rotation Small-diameter Eucalypt Forestry Using Novel Sawmilling Strategy Applied to *Eucalyptus regnans*", Report FFR-DS028, June.

[50] As at 1 April 2013, the area planted in Eucalyptus species comprises 22,000 ha and "other hardwoods" is 12,600 ha. Given net stocked area of 1,728,500 ha, this means that hardwoods (including Eucalyptus) comprise 2.0% of the national forest estate. Source: Ministry for Primary Industries (2013) *National Exotic Forest Description*, as at 1 April 2013, Table 2.1, p.3.

[51] For a detailed description of the *P. charybdis* lifecycle see P.G. McGregor (1989) "Ecology of *Paropsis charybdis* Stål (Coleoptera: Chrysomelidae): A *Eucalyptus* defoliator in New Zealand", A thesis presented in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Zoology at Massey University.

[52] Fry, G. (1983) "Eucalypts in New Zealand: a position report", *N.Z. Journal of Forestry*, 28(3):394-411, p. 397.

[53] *Supra*., note 51.

[54] Elliot, H.J., R. Bashford, and A. Greener (1993) "Effects of defoliation by the leaf beetle, *Chrysophtharta bimaculata*, on growth of *Eucalyptus regnans* plantations in Tasmania", Australian Forestry, 56(1):22-26.

reasonable to assume that the same loss of growth would occur with defoliation due to insect pests.[55]

The tortoise beetle is currently controlled through aerial spraying of a broad-spectrum synthetic pyrethroid insecticide.[56] While this is effective against the tortoise beetle, it also has the effect of killing other insects in the spray zone, including native insects. The most commonly used insecticide is alpha-cypermethrin, which is generally not acceptable for plantations certified by the Forest Stewardship Council (FSC). The FSC promotes biological control agents over the use of hazardous chemicals. Ongoing research is attempting to identify biological control agents (e.g. parasites and fungal diseases that will attack the tortoise beetle) and alternative sprays.[57]

UAVs could be used to identify whether a plantation required spraying, potentially reducing the need to spray, and through regular monitoring both enable spraying to occur early in the beetle lifecycle when spraying is most effective, and monitor the effectiveness throughout the season. The same UAVs that are suitable for spraying disease would be appropriate for spraying pests.

5.4.3. Quantification of Benefits from BLOS use of UAVs

As with applications in radiata pine plantations, UAV applications in eucalyptus plantations are necessarily BLOS. UAVs are required to inspect the forest canopy when trees are too high to be visually inspected from the ground, and even with younger trees the terrain and topography may make it necessary to fly BLOS. Application of sprays or other control agents would similarly often need to be conducted BLOS.

Effective control of the tortoise beetle could allow eucalypts to be more commercially viable, enabling larger quantities of eucalypts to be planted and harvested. Conceptually it would be possible for all sawn hardwood imports to be displaced, which would give a gross value of approximately $30.64m to New Zealand.

Satchell and Turner quote two studies providing volumes from sample stands: 303.2m^3/ha (unspecified age) and 417.6m^3/ha at age 19. Assuming the mid-point of 360 m^3/ha, displacing the 45,100m^3 of roundwood equivalent requires 125.3ha to be logged each year. Assuming a 19 year rotation, 2,380ha would need to be planted in eucalypts to displace sawn hardwood imports on an ongoing basis. Planting this area in hardwoods would presumably displace radiata pine plantings. The 2013 National Exotic Forest Description provides an average yield of 559m^3/ha for radiata pine, felled at an average age of 28.8 years.[58] If the 2,380ha was planted in radiata pine then an average of 82.64ha would be harvested each year, yielding 46,195m^3 of logs with a value of $4.62m. The net benefit to New Zealand from effective control of eucalyptus pests could, therefore, be in the order of $26m per year if all sawn hardwood imports could be displaced.

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[55] Lundquist 1987, cited in G.S. Ridley and M.A. Dick (2001) “An Introduction to the Diseases of Forest and Amenity Trees in New Zealand”, *Forest Research Bulletin 220*.

[56] Withers, T.M., M.C. Watson, M.S. Watt, T.L. Nelson, L.A. Harper and M.R.H. Hurst (2013) “Laboratory bioassays of new synthetic and microbial insecticides to control Eucalyptus tortoise beetle *Paropsis charybdis*”, *New Zealand Plant Protection* 66:138-147.

[57] Withers *et al* (2013).

[58] Ministry for Primary Industries (2013), Table 2.1.

5.5. WEED CONTROL

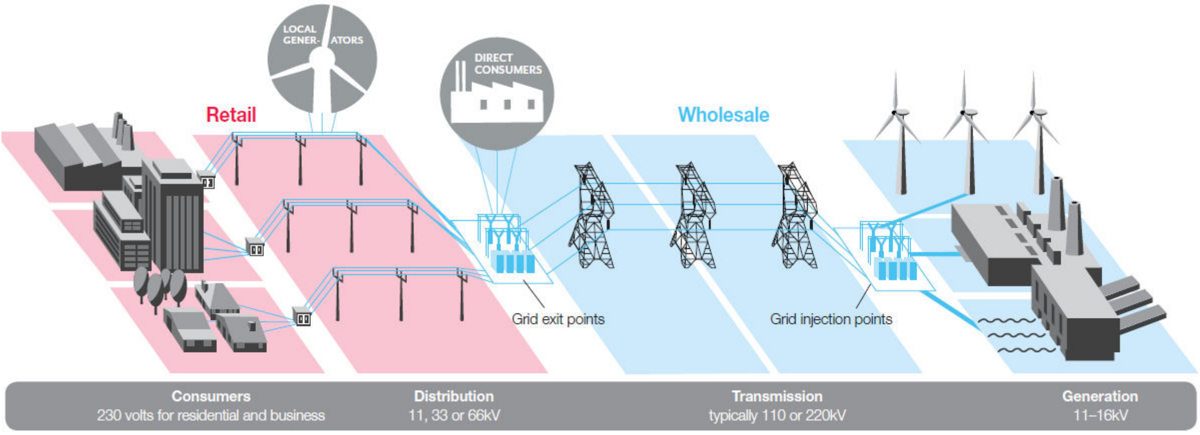
Weeds can have a significant effect on the growth of young trees, reducing the trees access to light, and generally resulting in a lower rate of growth. While young plantations can be observed on foot, doing so is time consuming and relatively slow. A UAV provides a faster way of surveying the young plantations, and image-analysis software may even provide automated weed identification. A UAV can then spot-spray weeds rather than a blanket spray across the entire area, or the weeds can be manually removed. Follow-up aerial surveys by a UAV can be used to monitor the success of weed control.

The same issues apply to the use of UAVs for weed control as for disease control: the hilly nature of the terrain on which plantations are established and the potential distance of juvenile trees from an access road means that BLOS operations may be necessary.

6. ELECTRICITY LINES AND TRANSFORMER INSPECTION

The physical structure of New Zealand's electricity industry can be summarised as shown in Figure 11. Electricity is primarily generated at large remote generators (right hand side) and then transmitted at high voltage via the transmission network to "grid exit points". The substations at the grid exit points transform the power to a lower voltage, and it is then conveyed via a distribution network to the electricity consumer (left hand side).

Figure 11: The Physical Structure of the Electricity Industry in New Zealand



Source: Electricity Authority (2011) *Electricity in New Zealand*.

Most transmission and distribution power lines in New Zealand are overhead lines rather than underground cables. Condition assessment of overhead power lines generally takes one of several forms:

- Linesmen patrolling the line on foot or vehicle and climbing a ladder or using a 'cherry picker' to directly visually observe the condition of transmission and distribution structure (towers and poles) and attachments; and
- Helicopter patrols of lines using direct visual observation and imaging to detect 'hot spots' and corona discharges.[59]

6.1. SAFETY BENEFITS

Working from a height always carries risks, and despite the best safety systems there is always the potential that a linesman may fall or will inadvertently contact a live power line, resulting in injury or death. In addition, Helicopter patrols are dangerous, with three crashes and five fatalities reported globally so far for 2014.[60] UAVs offer the potential for long range patrols to be conducted without risk to on-board crew.

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[59] Pagnano, A., M. Höpf, R. Teti (2013) "A roadmap for automated power line inspection, maintenance and repair", 8th CIRP Conference on Intelligent Computation in Manufacturing Engineering, *Procedia CIRP* 12:234 – 239.

[60] On 9 January 2014 a helicopter conducting a power line patrol crashed in Rögla, Sweden with no fatalities; on 27 January 2014 a Bell 206L3 helicopter performing a routine power line inspection crashed in Silt, Colorado, killing all 3 occupants. On 19 August 2014, an MD500 helicopter crashed on power line patrol, killing both occupants. See reports on http://helihub.com/tag/powerline-patrol/ and http://helihub.com/tag/fatal+accidents/ .

6.2. INDUSTRY TRIALS

The two potential applications for UAVs in monitoring electricity transmission and distribution infrastructure are: inspecting an individual pole or tower rather than having a linesman climb a ladder (up the pole) or up the tower; and surveying along overhead lines. Both Transpower and Unison Networks have conducted field trials to assess the commercial viability of both applications, [61] and have concluded that there are little or no gains to be obtained from inspecting individual poles or towers because there is no reduction in required manpower and often no gain in capability compared to existing methods of inspection.

Unison Networks Ltd conducted their trials using a quadcopter developed in-house specifically for research purposes. Unison Networks established that small UAVs have a high marginal cost per km of network, and are typically more costly than a linesman climbing a pole. Except for niche situations where poles are difficult to access – such as on steep slopes, there are trees impeding access, or the pole is on the other side of a gully or river – LOS operations do not provide any significant value for overhead power line inspection, and may add to cost. Rather, the value is derived from being able to fly beyond line of sight along power lines, and being able to stop and inspect any features of interest.

Transpower's trials of LOS and BLOS operations were conducted in 2012 with their contractor Linetech and their Raptor quadcopter, and in 2013 using a Schiebel Camcopter S-100. Standing approximately 3.5 feet tall, the Camcopter has an Empty Weight of approximately 110kg, and a Maximum Take-Off Weight of 200kg.[62] It has a rotary engine that can be fuelled by 95 Octane, 98 Octane, Avgas, or Diesel. Capable of operating in most weather conditions, the Camcopter can withstand a downpour of up to 50mm per hour.

The Camcopter was fitted with the FLIR Systems Corona 350 Airborne Sensor package, specifically designed for power line inspections. The sensor is described as:[63]

The Corona 350 is a four axis gyro-stabilized gimbal containing four different cameras including an ultraviolet camera for corona detection, a thermal imaging camera for detecting hot-spots in power lines, a visual light camera and a digital frame camera. [The Corona 350 overlays] its ultraviolet and color TV video data to create a combined image that allows operators to detect and identify coronal discharges – areas of ionized air – that are known to damage power line insulators and other electrical components.

Figure 12: The Corona 350 Airborne Sensor Package

Photo: Aviation Safety Management Systems Ltd

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[61] Transpower is the owner and operator of the national electricity transmission network. Unison Networks Ltd is the owner and operator of the electricity distribution networks in Hawkes Bay, Rotorua, and Taupo.

[62] Technical specifications for the Camcopter are summarised on the Schiebel Camcopter S-100 page on Wikipedia http://en.wikipedia.org/wiki/Schiebel_Camcopter_S-100.

[63] Schiebel (2013) "Schiebel integrates Camcopter with FLIR Systems Corona 350 sensor", HeliHub, 11 September, http://helihub.com/2013/09/11/schiebel-integrates-camcopter-with-flir-systems-corona-350-sensor/.

After conducting a number of trials, Transpower provided a demonstration to members of industry (with separate sessions for aviation and electricity industry members).

UAVs will not be used in urban areas, where it is more efficient to conduct inspections by manned patrols and there are heightened concerns over privacy (where overhead power lines are close to houses). The economics of overhead power line inspection favour using UAVs for rural power line inspection. This effectively means that UAVs are likely to be used in exactly the same geographic locations that helicopters are currently used, and not used in the geographic locations where helicopters are not currently used.

Figure 13: Pilot Screen, Schiebel Camcopter Demonstration, Auckland, September 2013

Source: Bradley, Grant (2013) “Transpower’s Spy in the Sky”, *NZ Herald*, 19 September. http://www.nzherald.co.nz/business/news/article.cfm?c_id=3&objectid=11126707.

6.3. BENEFITS

6.3.1. Distribution

Financial Cost of Inspecting Overhead Distribution Power Lines

Unison Networks advised that they had conducted an analysis of the costs and benefits of using UAS for overhead power line inspections. While the details of that analysis were commercially sensitive, and therefore not disclosed, Unison did advise that they considered two scenarios for the use of UAS:

- Scenario 1: In the first scenario a UAV would be based in a central location, and a distribution company would be able to “book” use of that UAV. Bookings would need to be made at least several days in advance. It is likely that distribution companies would pre-book an entire annual survey programme, which may limit the ability of a UAV to be available at short notice to respond to developing situations or storm events, outages, etc.

- Scenario 2: In the second scenario a distribution company would have a UAV based at a convenient location for that company. The UAV would be used on an annual survey programme, but could also be used at short notice to look for the source of an outage, survey the extent of storm damage, etc.

Unison estimated that the net benefit to Unison in the first scenario could be in the order of $150,000 per year, while the net benefit in the second scenario could be in the order of $100,000 to $700,000 per year with a best estimate of $350,000 per year. The gains are achieved across a range of categories, rather than a single area:

- Information about the network;
- Reduced reactive maintenance (better information allows better planning and better targeted proactive maintenance so less reactive is required);
- Reduced outage times – the UAV can identify the location of the outage so that the crews can travel directly to the affected location; and
- Reduced routine maintenance – the lower cost of UAS relative to helicopters means that inspections can be conducted more frequently and routine maintenance can be better targeted.

A significant proportion of gains were related to vegetation encroachment, with more frequent inspections being more likely to detect issues with vegetation.

The benefits derive solely from surveys conducted on rural lines, so these benefits can be extrapolated across New Zealand by using published data on rural lines for each distribution company. Table 14 summarises the length of overhead power lines in urban and rural areas by electricity distribution company. In total there is 104,419km of overhead distribution power lines in New Zealand, of which 85,915km (82%) is in non-urban areas.

Table 15 applies Unison's estimates of benefit to the rural lines length of each company. The columns headed "Gross Benefit" assume that every distribution company would utilise a UAV, even if the benefit were small. However, it is likely that there is a *de minimis* level below which it is unlikely that the distribution company would utilise the technology. We assume that the *de minimis* level is $20,000 and recalculate the benefits accordingly. Electricity Invercargill and Nelson Electricity have such a small length of rural overhead lines (3km and 2km, respectively), that neither scenario delivers sufficient benefits to exceed the *de minimis* level. Buller Electricity, Network Waitaki, and Wellington Electricity Lines exceed the *de minimis* for Scenario 2 (dedicated UAV based at convenient location), but not for Scenario 1. Total benefits are calculated at $1.85m per year for Scenario 1, and $6.62m per year for Scenario 2. As the benefit from LOS operations is effectively zero, the incremental value of BLOS operations is the calculated total.

Table 14: Overhead Line Length by Urban/Rural Classification by Distribution Company

Electricity Distribution Company Name	Urban (km)	Rural (km)	Total (km)
Alpine Energy Ltd	315	3,174	3,489
Aurora Energy Ltd	1,463	2,435	3,898
Buller Electricity	98	492	590
Centralines Ltd	111	1,530	1,641
Counties Power Ltd	69	2,330	2,399
EA Networks	76	2,415	2,491
Eastland Network Ltd	192	3,067	3,259
Electra Ltd	451	1,094	1,545
Electricity Invercargill Ltd	51	3	54
Horizon Energy Distribution Ltd	221	1,696	1,917
MainPower NZ Ltd	38	3,938	3,975
Marlborough Lines Ltd	362	2,496	2,857
Nelson Electricity Ltd	37	2	39
Network Tasman Ltd	195	2,352	2,547
Network Waitaki Ltd	827	825	1,652
Northpower Ltd	656	4,260	4,916
Orion NZ Ltd	2,009	3,787	5,796
Powerco Ltd	2,697	19,578	22,276
Scanpower Ltd	45	921	966
The Lines Company Ltd	527	3,514	4,041
The Power Company Ltd	469	7,878	8,347
Top Energy Ltd	176	2,938	3,114
Unison Networks Ltd	958	4,542	5,500
Vector Ltd	4,160	4,272	8,432
Waipa Networks Ltd	215	1,510	1,725
WEL Networks Ltd	585	2,624	3,209
Wellington Electricity Lines Ltd	1,356	395	1,751
Westpower Ltd	143	1,850	1,993
Total	18,504	85,915	104,419

Source: *Electricity Information Disclosure Requirements, Compendium of completed EDB Schedules 1-10 templates, Disclosure Year 31 March 2013*, NZ Commerce Commission.

Table 15: Overhead Line Length by Urban/Rural Classification by Distribution Company

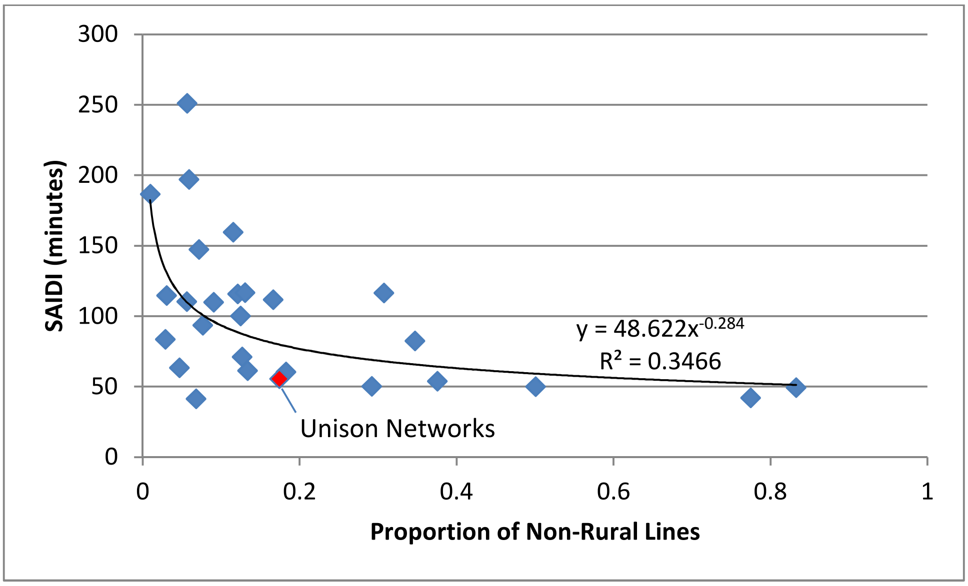
Distribution Company Name	Overhead Rural Lines (km)	Gross Benefit		Benefit > $20k	
		Scenario 1	Scenario 2	Scenario 1	Scenario 2
Alpine Energy Ltd	3,174	69,884	244,595	69,884	244,595
Aurora Energy Ltd	2,435	53,612	187,642	53,612	187,642
Buller Electricity	492	10,835	37,921	-	37,921
Centralines Ltd	1,530	33,687	117,905	33,687	117,905
Counties Power Ltd	2,330	51,297	179,540	51,297	179,540
EA Networks	2,415	53,171	186,097	53,171	186,097
Eastland Network Ltd	3,067	67,528	236,349	67,528	236,349
Electra Ltd	1,094	24,087	84,306	24,087	84,306
Electricity Invercargill Ltd	3	61	213	-	-
Horizon Energy Distribution Ltd	1,696	37,333	130,665	37,333	130,665
MainPower NZ Ltd	3,938	86,699	303,447	86,699	303,447
Marlborough Lines Ltd	2,496	54,947	192,314	54,947	192,314
Nelson Electricity Ltd	2	41	143	-	-
Network Tasman Ltd	2,352	51,786	181,250	51,786	181,250
Network Waitaki Ltd	825	18,165	63,576	-	63,576
Northpower Ltd	4,260	93,800	328,299	93,800	328,299
Orion NZ Ltd	3,787	83,376	291,814	83,376	291,814
Powerco Ltd	19,578	431,071	1,508,747	431,071	1,508,747
Scanpower Ltd	921	20,278	70,974	20,278	70,974
The Lines Company Ltd	3,514	77,361	270,764	77,361	270,764
The Power Company Ltd	7,878	173,447	607,064	173,447	607,064
Top Energy Ltd	2,938	64,685	226,398	64,685	226,398
Unison Networks Ltd	4,542	100,000	350,000	100,000	350,000
Vector Ltd	4,272	94,068	329,237	94,068	329,237
Waipa Networks Ltd	1,510	33,236	116,326	33,236	116,326
WEL Networks Ltd	2,624	57,774	202,208	57,774	202,208
Wellington Electricity Lines Ltd	395	8,687	30,405	-	30,405
Westpower Ltd	1,850	40,733	142,565	40,733	142,565
Total	85,915	1,891,646	6,620,762	1,853,858	6,620,407

Gains from Reduction in Distribution SAIDI

In addition to the financial benefits, there was also an estimated improvement in outage duration. One key outage statistic within the electricity industry is the “System Average Interruption Duration Index” (SAIDI), the average outage duration for each customer served. Unison’s current normalised SAIDI is approximately 90 minutes per year, which means that on average a customer will experience 90 minutes of supply outage per year. Unison estimated that the use of UAS could reduce this by approximately 10 minutes per year, primarily as a result of improved proactive routine maintenance.

Figure 14 below shows the relationship between SAIDI and the proportion of non-rural lines across electricity distribution networks for the year to 31 March 2013. Approximately one-third of the variation is explained by a best-fit negative exponential curve. The greater the proportion of rural lines, the higher the expected SAIDI.

Figure 14: Relationship between SAIDI and Proportion of Non-Rural Lines, Class C (Unplanned Interruptions originating on the network)



Source: *Electricity Information Disclosure Requirements, Compendium of completed EDB Schedules 1-10 templates, Disclosure Year 31 March 2013*, NZ Commerce Commission.

We use the best-fit curve to estimate the reduction in SAIDI for each network that adopts UAVs for surveying rural lines. While Unison reports 55.52 minutes of SAIDI from Class C interruptions (unplanned interruptions originating on the network), the best-fit curve predicts 79.87 SAIDI minutes.[64] Unison’s expected 10 minute reduction in SAIDI is 12.5% of the 79.87 SAIDI minutes. We assume that the same proportional improvement can be achieved on the other networks. Across all affected networks we estimate that a total of 19,678,155 ICP-minutes of interruptions could be avoided each year.[65]

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[64] The difference between the 90 minutes of normalised SAIDI and the 55 minutes of Class C SAIDI is accounted for by planned interruptions (i.e. for maintenance), unplanned interruptions on the Transpower network, and storm events that are subject to the normalisation process.

[65] An ICP or “installation control point” is a connection to the distribution network. We assume that an ICP is equivalent to the measure of consumer used in the calculation of SAIDI.

The electricity information disclosure for the year ended 31 March 2013 reveals that the distribution networks of interest supplied 30,264,524 MWh of electricity to an average of 2,050,196 ICPs for the year.[66] Dividing the MWh by the number of ICPs and the number of minutes in the year (525,600), and then multiplying by the ICP-minutes of avoided interruptions suggests that an average of 552.67MWh of lost electricity consumption could be avoided each year.

The Value of Lost Load (VOLL) is the economic value of the electricity that is not delivered to consumers (i.e. is “lost”) as a result of an outage. In a study of the VOLL for New Zealand, results from a mail-out survey suggested a weighted average VOLL of $15,631/MWh for an 8 hour outage at the worst possible time for consumers, whereas a face-to-face survey of large electricity consumers suggested a weighted average VOLL of $8,063/MWh for those consumers connected to the distribution rather than transmission network.[67] The study suggest a mean load-weighted VOLL of $50,031/MWh for an 8 hour outage at the worst possible time for consumers. However, this estimate will be heavily influenced by large transmission-connected consumers who have a significantly higher VOLL than other consumers. On the other hand, survey results from the respondents not connected to the transmission system indicated that VOLL is higher with shorter duration outages, with a 1 hour outage having a mean VOLL 2.23 times higher than that for an 8 hour outage.[68] Given these estimates, we calculate the value of reduced outage durations at estimated VOLLs of $8,063/MWh, $15,631/MWh, and $34,857/MWh (being 2.23 x $15,631/MWh).

These three VOLL values provide estimates of the annual economic value of reduction in outages and/or outage duration of $4.46m, $8.64m, and $19.26m respectively. As with the direct financial benefits of reduced line patrol costs, these benefits only arise if UAVs can be used beyond line of sight.

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[66] *Electricity Information Disclosure Requirements, Compendium of completed EDB Schedules 1-10 templates, Disclosure Year 31 March 2013*, NZ Commerce Commission, data summed from disclosures of relevant electricity distribution businesses.

[67] Electricity Authority (2013), *Investigation into the Value of Lost Load in New Zealand: Report on methodology and key findings,* 23 July, p. 56.

[68] Op. cit., table at top of p. 38.

6.3.2. Transmission

While Transpower viewed line-of-sight operations as having some value, as it might eliminate the need for a linesman to climb a tower and thereby improve both safety and productivity, as with distribution the major value is derived from BLOS operations. A key difference between transmission and distribution is the height of the structures: a distribution pole may be 6-7m high, easily climbed by a linesman with a ladder; but transmission pylons may be 20-50m tall, or higher, depending on voltage, topography, and any buildings or structures under the line.[69]

Transpower estimates that to patrol 11,800km of line annual costs would reduce from $3.5m with manned helicopters to $2.5m with a suitable UAV, i.e. a saving of approximately $1m per year on current costs.[70]

In addition to lower costs per survey, UAVs offer a number of other advantages over traditional helicopters. For transmission line work a UAV must have an accurate position monitoring system, and from that it will be able to identify the exact position of a transmission line in space, at an accurately determined time. The current flowing through a transmission line heats the conductor, causing it to expand, and the line to sag closer to the ground. The maximum current that can be transmitted is dependent in part on the clearance available to objects on the ground below the transmission line.[71] Regular UAV surveys will be able to establish the position of a transmission line relative to known current flow, and also establish the proximity of objects on the ground (trees, buildings, etc). This information will have two benefits: in some instances it may enable Transpower to use higher peak loads on particular lines, deferring the need for network upgrades; and it will also enable Transpower to identify trees and (new) buildings that could be a hazard to the fault-free and safe operation of the network before they become a hazard.

As with distribution, vegetation is a major concern for transmission. However, while vegetation problems at distribution level are most likely a result of contact between vegetation and the distribution lines, at the transmission level faults can arise simply because vegetation grows within the flashover range of the line. The information collected from regular surveys could enable Transpower to model the vegetation in the vicinity of a transmission line as a 3-dimensional surface, with growth rates applied to predict when vegetation will grow to close to the line. Vegetation control can then be scheduled to ensure that vegetation is trimmed before it becomes a problem.

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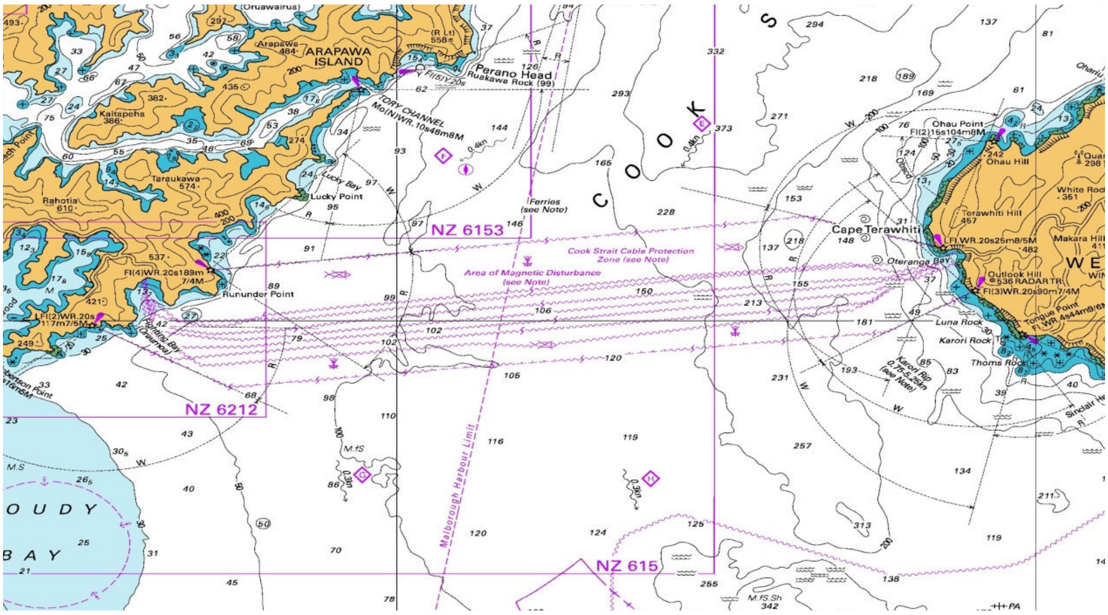
[69] For indicative line heights see https://www.sa.gov.au/topics/water-energy-and-environment/electrical-gas-and-plumbing-safety-and-technical-regulation/building-industry/powerline-safety/identifying-powerlines#132. The voltages used differ from those in New Zealand, but the indicative pole heights are still applicable. For example, the distribution voltage in New Zealand is 400V rather than 415V in South Australia, but the indicative pole height of 6-7m is reasonable for New Zealand. Similarly, transmission voltages in New Zealand are 110kV and 220KV rather than 132kV and 275kV, but the indicated transmission tower heights are within a similar range.

[70] Renton, Andrew (2013) “Transmission Applications Utilising Remotely Piloted Aerial Systems”, presentation, Transpower.

[71] At 110kV the minimum clearance is 6.5m, and at 220kV the minimum clearance is 7.5m.

A further use of UAVs for Transpower is to monitor the Cook Strait Cable Protection Zone (CPZ). While the submarine telecommunications and power cables are designed to withstand tidal and seabed conditions, any vessel mooring, anchoring, trawling, crayfishing or line fishing is likely to cause damage to the cables if the equipment used contacts the cables.[72] Transpower already conducts helicopter and sea patrols of the CPZ, but the use of a UAV could enable this activity to be conducted at lower cost. The Schiebel Camcopter could be directly deployed to this role in its current configuration, as maritime surveillance is one of the key roles in which it has been tested and deployed.

Figure 15: Cook Strait Cable Protection Zone



Source: Part of Chart NZ 46 Cook Strait, Land Information New Zealand. Used under license: Creative Commons Attribution 3.0 New Zealand, https://data.linz.govt.nz/license/attribution-3-0-new-zealand/.

6.4. FURTHER DEVELOPMENTS

Pagano et al (2013) proposed the following three areas of further research to develop UAV systems that are capable of completely autonomous live power line inspection:[73]

> *Visual servoing for power line tracking (just a GPS system is not sufficient for an autonomous navigation capable to follow the lines, but must be complemented with other systems).*
>
> *Obstacle detection and avoidance (considering the consequence of a crash in a live line, this become an essential aspect for a reliable autonomous inspection system).*
>
> *Robust control algorithms for flight dynamics, ensuring a very high stability and positioning capability for close and precise inspections in particular in case of adverse weather conditions like strong lateral wind (noting that the British Columbia Transmission Corporation identifies as requirement for a power line inspection UAV the capability to operate in 60 km/h wind).*

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[72] Transpower (2013) *Cook Strait Cable Protection Zone*, Version 11.

[73] Pagano, A., M. Höpf, and R. Teti, “A roadmap for automated power line inspection”, *Procedia CIRP*, 12 (2013):234-239.

Transpower echoed this research agenda, expressing particularly the importance of position holding accuracy and the ability to navigate with the absence of GPS. The minimum approach distance at 220kV is 4m and a UAV that "strays" within this range risks a flashover – this could cause a catastrophic failure of the UAV, potentially resulting in 100kg of aircraft falling out of the sky. Unison estimated that perhaps another 2-3 years of work would be required to develop flight controllers to the point where sufficient accuracy is available.

UAVs suitable for long-distance overhead line surveys are require the ability to hover in place while the pilot inspects features of interest. The Schiebel Camcopter trialled by Transpower is an obvious option, but a hybrid aircraft that can hover but also takes advantage of the superior endurance of fixed wing aircraft may also be appropriate.

Unison Networks views electricity as an obvious source of power for UAVs, with electricity networks potentially able to build automated recharging facilities at substations. However, for electrical power to be a realistic option for long range operation there will need to be further development of storage technology (batteries).

Transpower viewed a liquid fuel engine was viewed as likely to be necessary to achieve the necessary endurance, but there were concerns over lack of redundancy. In a manned helicopter redundancy can be achieved by way of dual engines, manual controls that still work if electronic systems fail, and the ability to conduct an auto-rotative landing. The size and unmanned nature of UAV aircraft mean that many of these systems are not possible. As an alternative, it was suggested that the rotor could be driven by an electric motor, with a liquid fuel engine providing the primary power source. If the liquid fuel engine failed then LiPo batteries could be used to provide sufficient back-up power to land.

6.5. REGULATORY ENVIRONMENT

There would appear to be little in the way of regulatory barriers to establishing BLOS operations for monitoring electricity transmission and distribution overhead lines. Authorisation for UAV with a weight greater than 25kg can currently be obtained under Civil Aviation Rule 19.105. The proposed Civil Aviation Rule Part 102 will also provide specific authority for CAA to approve UAV operations for a UAV of any weight.

It is understood that CAA have indicated to Transpower and Unison that they would consider favourably any proposal to establish a "shielded" operation, with the UAV operating within close proximity to power lines, in exactly the area that a normal manned aircraft would be seeking to avoid. The major requirement will be to demonstrate that the aircraft does, in fact, remain in close proximity to the power line, even with adverse weather conditions and extended flights.[74] Transpower indicated that they would consider it appropriate for the UAV to carry a transponder, which should further reduce the risk to manned aircraft when the UAV is operating in controlled airspace.

While some risk still remains of collision with agricultural aircraft, agricultural operators that operate close to power lines are already choosing to operate in a manner that has a high risk of wire strike.

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[74] Personal communication, Edwin Hayes, Unison Networks Ltd.

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APPENDIX A: SELECTED FIXED-WING UAV

Pasture measurement and forestry monitoring applications are likely to be more suited to fixed wing UAVs with long endurance and relatively high efficiency.

At one extreme there is the mass-produced small UAV with programmable GPS controller that can have a flight path programmed by clicking on a map on a laptop. Such laptop-based software lacks the ability to take control of the UAV when BLOS, and the associated machines may not be sufficiently robust for high volume or low failure rate use.

It is difficult to estimate with any accuracy the cost of UAV platforms suitable for BLOS use. Airframes are considerably cheaper than conventional airframes, but many existing UAVs may be a poor guide to the true cost of UAVs designed for BLOS. It is likely that UAVs for BLOS will need to be type design acceptance, as occurs with microlight category aircraft. This in turn will require a standardised and documented design. Possibly more significant for agriculture and forestry is that to be truly useful for the applications reviewed, UAVs will need to be able to operate in a range of weather conditions: perhaps not “all weather”, but certainly able to operate with reasonable levels of wind and a degree of precipitation. Aircraft will also need to be robust, and not easily damaged during transportation or on landing. Communication and navigation systems will need to be able to operate over long distances and in GPS-denied areas.

As such, we assume that microlights are likely a more reasonable point of price comparison than some current UAVs. The Hawkes Bay Microlight club provides a broad range of prices from $5,000 for a second-hand “Bantam” to $250,000 for a top of the range aircraft direct from the manufacturer.[75] (The British Microlight Association cites £16,000 to £80,000 for a new microlight, which equates to approximately $30,000 to $160,000.[76])

Two fixed-wing UAS systems have received limited certification by the FAA for use in civilian aerospace: the Boeing Insitu Scan Eagle X200 and the AeroVironment Puma.[77] The Scan Eagle is cost-prohibitive for commercial applications, reportedly costing US$3.2 mllion for four aircraft and one launcher.[78] The AeroVironment Puma costs approximately costs around US$250,000 for a system consisting of the Ground Control Station and three aircraft.[79] Another source cites the Puma at $300,000 each,[80] but this may be referring to a “unit” being

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[75] Hawke’s Bay Microlight Club, “Microlight myths and realities”, http://microlight.org.nz/microlight-myths-and-realities/ .

[76] British Microlight Aircraft Association, “Fixed Wing” page, http://www.microlightflying.org.uk/tim/fixed-wing/ . Conversion to NZD assumes an exchange rate of £0.50 per NZ$.

[77] Bellamy III, Woodrow (2013) “FAA Issues First Commercial UAS Type Certificates”, *Avionics Today*, 29 July, http://www.aviationtoday.com/av/unmanned-aircraft-systems/FAA-Issues-First-Commercial-UAS-Type-Certificates_79815.html.

[78] Wolf, Harrison (2013) “The Scan Eagle and Why it Matters for Safety Management Systems”, Wolf Unmanned Air Systems blog, 18 June, http://wolfuas.com/2013/06/18/the-scan-eagle-why-it-matters-for-safety-manegement-systems/

[79] Mary Landers, “Drone hunts atlantic fish”, *Savannah Morning News*, 2 April 2014. http://savannahnow.com/news/2014-04-01/drone-hunts-atlantic-fish.

[80] http://diydrones.com/profiles/blogs/faa-certifies-first-two-drones-for-commercial-use, comment by Gary Mortimer.

the three aircraft and control station. While the total cost for the system is in the order of a “top of the range” microlight, the cost of each aircraft is well within the range for microlight aircraft.

Figure 16: The AeroVironment Puma

RQ20A-130304-M-DE426-001 crop by Sgt. Bobby Yarbrough - http://www.marines.mil/Photos.aspx?igphoto=2000010661 Crop of 130304-M-DE426-001.JPG. Licensed under Public domain via Wikimedia Commons.

Two smaller scale systems are the Xerospace Light Intelligence LI-1 and the Aeromapper EV-2. The Xerospace LI-1 is priced in Australia from $19,000 AUD,[81] which at an exchange rate of AUD:NZD 0.90 this equates to $21,111 NZD. The Aeromapper EV-2 is priced at $13,700 CAD,[82] which at an exchange rate of CAD:NZD 0.90 equates to $15,222 NZD. These prices are likely to be for base-level models, and additional expenditure may be required for specialist software or additional equipment (for example, the Aeromapper requires the addition of a laptop computer).

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[81] Xerospace (2014) “Xerospace Lite Mapping Aircraft”, *sUAS News*, 15 October, http://www.suasnews.com/2014/10/31843/xerospace-lite-mapping-aircraft/ , accessed 1 November 2014.

[82] http://www.aeromao.com/aeromapper_uav, accessed 1 November 2014.

Figure 17: Xerospace LI-1

Source: Xerospace website, http://xerospace.co/, accessed 1 November 2014.

New Zealand manufacturers such as Hawkeye UAV and Skycam UAV offer comparable systems (although flight endurance appears to be more limited), but details on costs are not publicly available. Operational data on the six commercial UAVs mentioned is listed in Table 16.

Table 16: Selected Commercial UAVs

Manufacturer & Model	Weight	Range	Duration	Cruise Speed	Fuel/Power Source
Boeing Insitu Scan Eagle X200	MTOW 18kg, empty weight 12kg		15 hrs	49 knots	petrol, max 5.4kg/11.9lb
AeroVironment Puma	6.1kg	15km (comms)	3.5 hrs+	37-83km/h (20-45knots)	LiPo
Hawkeye UAV RQ-84Z Aerohawk	5.5kg MAUW		60-90 mins	50-60km/h	LiPo
Skycam UAVKahu	3.9kg	25km	2 hrs	60km/h	4 Cell LiPo (16.8 V, 8.4 Ahrs)
Xerospace LI-1	7kg MTOW	53km, 2800ha	92 minutes on single battery	70km/h	12000mAh LiPo
Aeromapper EV2	4.5kg	20km, 800ha	60 mins	50-60km/h	2 x 4000mAh LiPo

Figure 18: RQ-84Z Aerohawk shortly after launch

Source: Hawkeye UAV website, http://www.hawkeyeuav.com/resources/hawk-gallery.html, accessed 1 November 2014.

Figure 19: Aeromapper EV-2

Source: Aeromao, Aeromapper webpage, http://www.aeromao.com/aeromapper_uav, accessed 1 November 2014.

APPENDIX B: PASTURE MONITORING UAV COST MODEL

Appendix B.1 sets out the assumptions employed for calculating the potential cost of UAV operations for pasture measurement and monitoring. Appendix B.3 then presents the cost estimates for LOS and BLOS operations for each farm type.

B.1 ASSUMPTIONS

B.1.1 Capital Costs

For line-of-sight operations an aircraft similar to the Xerospace LI-1 or Aeromapper EV-2 would be suitable. Taking the mid-point of the two cost estimates and adding $5,000 for specialist software and additional equipment gives an estimated capital cost of $23,167.

For BLOS operations we assume that the UAV must be built to a higher standard of airworthiness, and have more advanced communications abilities. The USD$250,000 for the AeroVironment Puma system is probably more costly than necessary for the civil environment, and we would expect the price to reduce as more manufacturers build suitable systems (increased volume will drive down unit costs, and competition will both lower profit margins and drive a search for cheaper components). At an exchange rate of USD:NZD 0.80 the AeroVironment Puma system (ground station and three aircraft) equates to NZD $312,500, or $104,167 per aircraft including an allocation of the ground station). We assume that prices for commercial BLOS systems settle at the mid-point between the $104,167 and the assumed cost for the LOS system, i.e. $63,667.

All UAVs in Table 16 except for the Boeing Scan Eagle use LiPo batteries. LiPo batteries are assumed to have very low running costs- in the order of 10c per hour – but have significant capital costs. High quality LiPo batteries and associated chargers are estimated to cost a total of $500 and have the same life as the UAV and ground station.

Further assumptions for the development of an estimate of annualised capital costs are:

- Post-tax weighted average cost of capital of 15%;
- The expected life of the aircraft and ground station is 3 years – as assumed by the IRD for microlight aircraft; and
- The tax depreciation rate is 67% DV – the same as for microlight aircraft.

Given these assumptions, the annualised capital cost is $20,421 for each BLOS aircraft and $7,482 for each LOS three aircraft. These annualised costs include the ground station, batteries, and charger. The cost of specialised sensors may be in addition to these figures, but such costs should generally be constant between LOS and BLOS operations.

B.1.2 Other Annual Costs

Other assumed annual costs are:

- Annual inspection costs of $80 per aircraft;
- CAA costs $5,000 per year for the operation, regardless of the number of UAV; and
- Insurance costs of 10% of the initial capital cost of the aircraft and ground station.

In New Zealand, microlight aircraft are required to undergo an inspection every 12 months. It seems likely that the same requirements would apply to UAVs. The Sport Aviation Corporation publishes general advice that an annual inspection takes approximately 1-2 hours,[83] and we expect an inspection for a UAV would take about 0.5-1 hours each due to the relatively small size of the aircraft.

B.1.3 Manpower

For LOS operation we assume that the UAV is piloted by two crew at a cost of $100,000 per year regardless of the frequency of flying or annual flying hours. For BLOS operation we assume that the UAV is piloted by a single remote pilot.

B.1.4 Maintenance Costs

UAVs used for forestry may be able to be operated solely over unpopulated areas, but UAVs for farming may need to fly over roads and some areas with low population density. As such, we assume that regular maintenance inspections will be required as for standard category aircraft. We assume that inspections will be required at intervals of 50 hours flying time, i.e. once every 7-10 days for UAVs deployed in high volume commercial applications. We also assume that each year or 500 hours of flying time, whichever comes first, requires a maintenance cost equal to 10% of the initial capital cost of the UAV platform.

B.1.5 Travel Costs (Mileage)

We analyse the following scenarios:

- Strict LOS, with the pilot driving from base to the first launch location of the day, and then from one launch location to the next. In the case of a large farm requiring multiple days of flying (e.g. South Island High Country), we assume that the pilot stays overnight in accommodation available on the farm.
- BLOS on the farm, using a LOS aircraft beyond visual range. Again the pilot drives from base to the first launch location of the day, and from there drives from farm-to-farm. Savings are made in driving distance (no extra on-farm driving) and consequent reductions in time per farm.
- BLOS on the farm, using an aircraft properly designed for BLOS operations. This is more costly than the previous scenario, as the aircraft is designed to higher specifications and therefore costs more.
- BLOS from “home base”. All flights are conducted from home base and the aircraft may fly a considerable distance to the first farm of the day. While the aircraft is more costly than the aircraft for LOS operations, there are no regular travel/mileage costs involved.

We adopt the AA’s 2012 vehicle mileage calculator for annual mileage costs, which broadly calculates an annual fixed cost of $6,305 excluding GST for medium sized vehicles with running costs of 23.74 c/km excluding GST.

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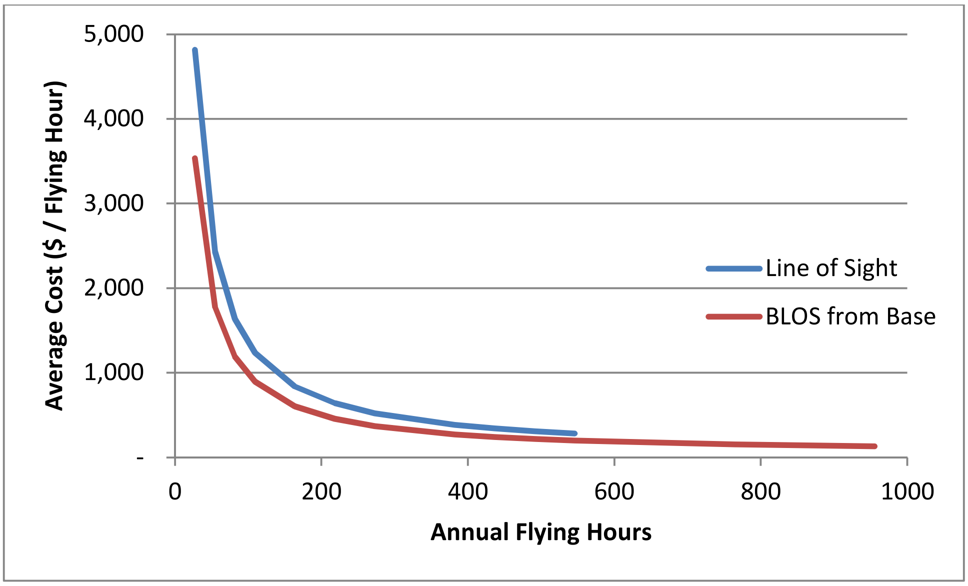
[83] Sport Aviation Corp Ltd, *Aircraft Owner Obligations for Annual Inspections*, http://www.sportflying.co.nz/Forms/Aircraft%20Owners%20Obligations%20for%20Annual%20Inspections.pdf.

B.2 COST CURVES

Figure 20 below shows the estimated average cost per flying hour for the two extreme cases: strict LOS and BLOS from a home base. While the curves appear close together, it is the vertical distance between curves that provides the difference in average cost at any given level of annual flying hours; at low flying hours the difference can be very significant.

The shape of the cost curves reflects the high fixed costs and low variable costs of the UAV. The UAV has a relatively high capital cost, and there is a significant annual wage cost.

Figure 20: Average Cost per Flying Hour, LOS and BLOS from Home Base



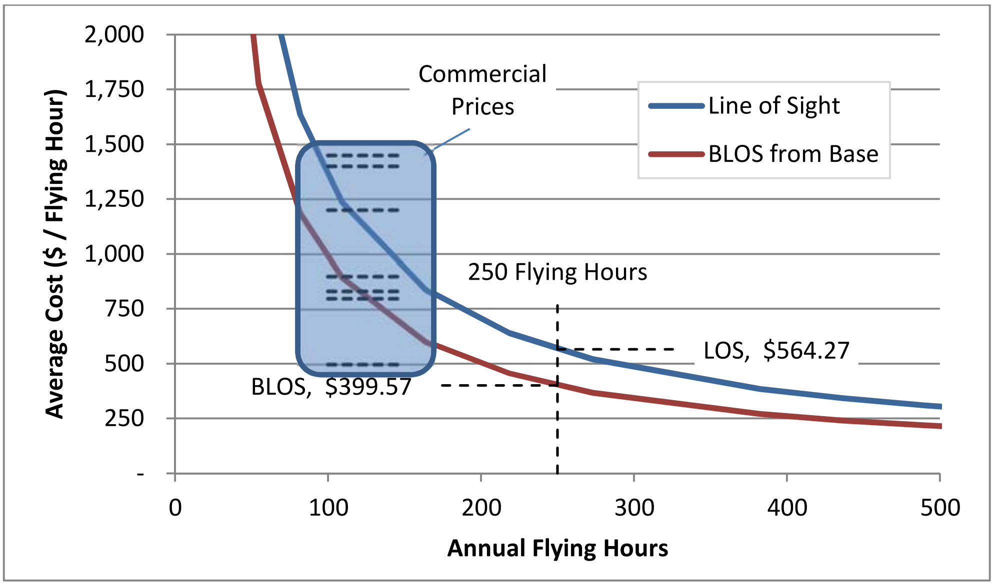
The validity of the cost curves was tested by comparing prices from commercial operators with the predicted curves. Existing operators can only fly LOS, so the appropriate comparison is with the “Line of Sight” curve.

Commercial operators interviewed do not charge by flying hour; instead they may charge for a project or job, or have a day rate or half-day rate, and may have a minimum charge. This sort of charging structure recognises that the UAV is just a component of the cost of the job, and it has a relatively low variable cost.

A typical job might include a half day preparation, a day on site that includes flying, and a day of processing the imagery into the end product. The day on site may only include 3 hours flying in the entire day, with on-site planning, hazard review, UAV set up, and reviewing footage all taking up considerable time. With this sort of job structure a maximum of around 230-250 hours of flying per year is possible, but 100 to 150 hours is more likely when weather and availability is factored in.

Figure 21 shows the comparison of operator prices with predicted cost curves. The two curves are for LOS and BLOS as before (Figure 20). The shaded area encompasses a number of dashed lines, each of which represents a price point. A single operator may have multiple price points, each corresponding to a different type of job (or day rate, half-day rate, etc). All prices are shown corresponding to the 100-150 hour range.

Figure 21: Comparison of Operator Prices with Predicted Cost Curves



When questioned the operators did not know how their pricing would change with BLOS operation, but they did acknowledge that it would reduce the time and cost for some jobs (particularly involving surveying significant areas), which would also make some jobs economically feasible that currently are not. BLOS would also resolve practical issues associated with flying in areas that have few suitable take-off and landing areas (e.g. some coastal areas).

The absence of knowledge of expected price changes with BLOS operation is not unexpected: commercial UAV operators operate in a competitive market and price to what the market will bear. If the market price is not sufficient to make a reasonable return then commercial operators will exit the market, and in this respect there will be some relationship between prices and the predictions from a cost model. However, there is little point in operators spending any significant amount of time considering how their prices might change in the event of a technology that regulations currently prohibit.

B.3 APPLICATION TO FARMS

Summary statistics for each farm type are provided in Table 17 below. All farms are assumed to have fortnightly surveys conducted year-round, with the exception of South Island High Country stations which are assumed to have a survey conducted once every four weeks for 8 months of the year. High Country and Hill Country farms are assumed to reach 15% penetration (i.e. 15% of farms utilise UAV technology), while breeding and finishing farms are assumed to reach 25% penetration. The weighted average penetration across non-dairy farms is 20%.

Table 18, Table 19, and Table 20 below present the annual per-farm cost estimates for aerial surveys conducted using LOS and BLOS aircraft. We then present the annual per-farm gain from using BLOS aircraft.

Table 17: Summary Farm Statistics

Farm Type	Average Area (ha)	Number of Farms	Frequency of Surveys (weeks)	% of year surveys conducted	Penetration
NI Hard Hill Country	834	1,155	2	100%	15%
NI Hill Country	418	4,020	2	100%	15%
NI Intensive Finishing	289	1,490	2	100%	25%
SI High Country	7,672	220	4	75%	15%
SI Hill Country	1,477	850	2	100%	15%
SI Finishing-Breeding	481	2,657	2	100%	25%
SI Intensive Finishing	220	1,306	2	100%	25%
SI Mixed Finishing	409	592	2	100%	25%
Dairy	140	11,891	2	100%	50%

B.3.1 Cost Estimates

Table 18 below shows the estimated annual per-farm cost of conducting farm surveys using LOS aircraft on the farm. Cost estimates are provided for a range of survey areas. A survey area of 200ha is consistent with a farm where line-of-sight is obstructed by hills and trees. On farms where obstructions reduce line-of-sight so that areas less than 200ha are flown then costs may be higher than shown.

We also note that LOS aircraft may have the capabilities to fly beyond line of sight, perhaps by way of programmable GPS co-ordinates, and that some farmers and/or operators may be tempted to do this even the aircraft does not meet other requirements for legal BLOS operations. We therefore have extended the analysis to include much greater areas than could be covered in a single LOS flight.

It is notable that for several farm types there is no significant gain from using the LOS aircraft beyond line of sight. However, being able to fly BLOS provides a significant reduction in cost (approximately 50%) for North Island Hill Country farms and all forms of Finishing farm in the South Island.

Table 18: Annual Per-Farm Cost of Farm Surveys using LOS UAV

Farm Type	Maximum Survey Area (ha)						
	200 (LOS)	400 (BLOS)	600 (BLOS)	800 (BLOS)	1,000 (BLOS)	1,500 (BLOS)	2,000 (BLOS)
NI Hard Hill Country	**28,855**	28,845	28,833	28,833	28,798	28,798	28,798
NI Hill Country	**28,355**	28,346	14,455	14,455	14,455	14,455	14,455
NI Intensive Finishing	**14,264**	14,243	14,243	14,243	14,243	14,243	14,243
SI High Country	**69,241**	69,239	69,237	69,235	69,233	69,229	69,222
SI Hill Country	**57,144**	57,132	57,124	57,108	57,108	57,061	57,061
SI Finishing-Breeding	**28,359**	28,350	14,457	14,457	14,457	14,457	14,457
SI Intensive Finishing	**14,183**	9,542	9,542	9,542	9,542	9,542	9,542
SI Mixed Finishing	**28,277**	14,402	14,378	14,378	14,378	14,378	14,378
Dairy	**7,103**	7,103	7,103	7,103	7,103	7,103	7,103

Table 19 shows the estimated annual per-farm cost of conducting farm surveys using BLOS aircraft on farm. The cost is dependent on the number of flights that need to be conducted, which is in turn dependent on the maximum area that could be covered by a UAV. We show costs for 2,000ha, which is less than the Xerospace LI-1 range of 2,800ha, and 8,000ha, which is large enough to encompass the average South Island High Country station. The only farm type with an average area greater than 2,000ha is the South Island High Country station, so this is the only farm type that has lower annual UAV costs when the UAV can cover 8,000ha rather than 2,000ha. This model assumes that whilst the UAV can fly beyond line of sight, the mission is restricted to the current farm, i.e. it does not fly on over and survey another farm other than the one where the pilot is located.

Table 19: Annual Per-Farm Cost of Farm Surveys using BLOS UAV On-Farm

Farm Type	Maximum Survey Area (ha)	
	2,000	8,000
NI Hard Hill Country	23,211	**23,211**
NI Hill Country	11,661	**11,661**
NI Intensive Finishing	11,450	**11,450**
SI High Country	55,542	**55,479**
SI Hill Country	45,887	**45,887**
SI Finishing-Breeding	11,663	**11,663**
SI Intensive Finishing	7,680	**7,680**
SI Mixed Finishing	11,584	**11,584**
Dairy	5,706	**5,706**

Table 20: Annual Per-Farm Cost of Farm Surveys using BLOS UAV from "Home Base"

Farm Type	Maximum Survey Area (ha)
	8,000
NI Hard Hill Country	**20,972**
NI Hill Country	**10,488**
NI Intensive Finishing	**5,424**
SI High Country	**53,686**
SI Hill Country	**22,419**
SI Finishing-Breeding	**10,630**
SI Intensive Finishing	**4,314**
SI Mixed Finishing	**7,285**
Dairy	**3,043**

Table 20 shows the estimated annual per-farm cost of conducting farm surveys using BLOS aircraft from a home base. Mileage costs are no longer incurred, but there is additional flying time flying to/from the home base. We assume that aircraft for these operations must be capable of extended range and limited by the number of available flying hours in a day rather than area, so present only the costs for the maximum 8,000ha survey area. Note that this model assumes that the UAV flies from farm-to-farm during the day and only returns to base at the end of the day.

B.3.2 Gains from BLOS

Table 21 summarises the calculation of the annual per-farm reduction in cost from using BLOS aircraft. The various costs are as follows:

- Column [A] has the minimum LOS cost from Table 18, i.e. the cost with a 400ha survey area;
- Column [B] presents the BLOS cost from the 2,000ha column of Table 18;
- Column [C] presents the minimum cost from Table 19 for conducting BLOS operations on-farm with a BLOS aircraft;
- Column [D] presents the cost of BLOS operations conducted from a home base (Table 20).

Due to the difference in the cost of the aircraft, flying BLOS on-farm is generally cheaper with a LOS aircraft than a BLOS aircraft. However, once a long-range BLOS capable aircraft is available it is cheaper to fly from the remote home base than to drive to each farm and fly BLOS on the farm.

Table 21: Annual Per-Farm Reduction in Cost from Using BLOS Aircraft

	LOS Minimum Cost [A]	BLOS using LOS [B]	BLOS On Farm [C]	BLOS From Base [D]	Min Legal BLOS [C] or [D]	Least Cost BLOS Option	Gain from BLOS
NI Hard Hill Country	28,855	28,798	23,211	20,972	20,972	From Base	7,883
NI Hill Country	28,355	14,455	11,661	10,488	10,488	From Base	17,866
NI Intensive Finishing	14,264	14,243	11,450	5,424	5,424	From Base	8,840
SI High Country	69,241	69,222	55,479	53,686	53,686	From Base	15,555
SI Hill Country	57,144	57,061	45,887	22,419	22,419	From Base	34,725
SI Finishing-Breeding	28,359	14,457	11,663	10,630	10,630	From Base	17,729
SI Intensive Finishing	14,183	9,542	7,680	4,314	4,314	From Base	9,869
SI Mixed Finishing	28,277	14,378	11,584	7,285	7,285	From Base	20,991
Dairy	7,103	7,103	5,706	3,043	3,043	From Base	4,060

All farm types experience a reduction in farm survey costs from using BLOS aircraft operated from a home base rather than LOS operations.