Drones: Benefits study

High level findings

m.e consulting

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Contact person: Lawrence McIlrath

lawrence@me.co.nz

DDI: 09 915 5523

Mob: 021 042 1957

www.me.co.nz

Executive Summary

Drones will provide unprecedented levels of access to airspace, which has been prohibitively costly and difficult to access for a majority of businesses to date. This new access could lead to fundamental changes in the way New Zealanders conduct business, move goods, and travel.

Commercial demand will account for most of the growth in drone use over the next 25 years. New Zealand, and most other countries, are in the early stages of developing and fostering commercial uses for drones. This means it is both difficult and vitally important to understand the potential benefits of drones, and what is needed to enable and support those benefits.

This study looks at the potential economic value that drone use could provide New Zealand over the next 25 years. It also attempts to define a "drone sector" by identifying those sectors of the economy which could make direct use of drones, or improve their own operations through drone use.

Modelling the potential economic value of drone use considered both how the market understands drones today, including how businesses already use drones as an input or part of a business process, and stakeholder input and expectations around how drones could best be used in the economy. Modelling was not undertaken around the potential social impacts of drones, or the impact of drones on employment in New Zealand. While the findings of the study are indicative only, the key outtakes include:

- Drones could assist in lifting productivity across large parts of the economy
- Drones have the potential to transform existing industries and create new industries, particularly in the areas of commercial deliveries and inter-regional passenger transport.
- With moderate commercial uptake rates, the potential value to the economy of increasing line of sight (LOS) drone use over the next 25 years, ranges between $2.5 billion and $3.9 billion, with dairying contributing between $1.3 billion and $1.5 billion
- Drones flights beyond the visual line of sight (BLOS) could increase these figures to between $3.2 billion and $5.0 billion to the economy per year
- Using aspirational figures for uptake rates, appetite to shift towards drone technologies and the number of potential uses, the potential value to the economy increases to between $4.6 billion and $7.9 billion.
- New and innovative uses for drones, that have not yet been conceived, could provide even further benefits and value to the economy.

The study also highlights the challenges around drone uptake and use. As with any new and transformative technology, a key challenge lies in the limited track-record of drones to demonstrate their commercial value. In addition, social acceptance, scale of production, and the regulatory environment will all influence uptake. Uptake will be particularly impacted in sectors with low margins, and in areas where alternative innovative technologies may compete with drones, or they are not perceived to add value.

The findings from this study will inform the wider work programmes of the New Zealand Ministry of Transport and the Ministry of Business, Innovation, and Employment around the value of drone use to the New Zealand economy. It will also inform the approach to regulation and supporting technological innovation in the drone space. The paper confirms that due to the potential scope of the benefits, a do-nothing regulatory approach is not appropriate.

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1 Introduction

Globally, there has been strong growth in research and development of new unmanned aerial systems and the commercialisation of unmanned aerial vehicle (or drones) applications. Some drones are semi- or fully autonomous and can operate independently of direct (immediate) human control. Drones can be equipped with sensors and cameras enabling a wide range of uses. It is these wider uses that can deliver the economic benefits. In effect, it is only when drones are connected with other technologies, that their true economic value can be realised. Drones offer aerial mobility that allows the controller to remotely access areas that were previously difficult, or dangerous, to access in a cost-effective, timely and safe manner. Advances in sensing, measuring and optical technologies, combined with gains in drone capabilities have driven great interest in using drones in new ways. However, there are still practical limitations, like payload, battery life (range) and safety concerns that are inhibiting widespread uptake of drones.

Intuitively, widespread uptake of drone in the mainstream economy will deliver a range of new benefits to New Zealanders. These benefits will arise through lifting productivity and other social effects like seeing new/better imaging of remote natural landscapes. Increased drone usage could cause issues with privacy, disruption of aviation services, and airspace management. These issues may require appropriate technological and/or regulatory interventions to be put in place.

Drones come in different sizes and styles. They range from small handheld devices to large devices capable of carrying large payloads. Drones can be rotary wing (helicopter or multicopter), fixed wing (airplane) or a combination.

Users generally fall into one of two categories:

- Commercial – where a drone is used in a business context, with some form of revenue or business purpose, or
- Recreational – where flying is performed as a pastime, hobby, leisure or in a sporting capacity (i.e. non-commercial).

Emerging technologies and advances in drone equipment are presenting businesses with ways to change how they work, do business and lift productivity.

1.1 Project aim

It is our understanding that this project sits within a wider work stream and that it will inform other project pieces. Ultimately, this project is concerned with understanding the potential benefits of drones to New Zealand. This research adds to the understanding by using a scenario approach to assess the potential economic shifts that could occur under different growth assumptions. The scenarios focus on different economic sectors and consider the potential gains to those sectors. There are many unknowns around the use of drones and the supporting technologies since they develop in parallel to other technologies and compete with (or substitute) other applications. It is not possible to forecast the future; this work makes assumptions around uptake rates and the potential outcomes. The assumptions are based on a mix of available literature, feedback and information from the industry, and our own judgement.

The aim must be viewed in the context of a wider research agenda i.e. what the potential benefits could be to New Zealand of establishing itself as a 'world leader in the testing and development of UA?' This question has several layers. Looking at it from an UA-sector level suggests that the benefits could arise through lifting 'internal industry practice[1]' and 'developing the technology and know-how and exporting it (independently of local industry)'. Both approaches have merits, but one focuses on 'using UA and developing the applications' and the other is about 'developing the technical systems'. Dealing with the real-life challenges, are often addressed by developing the applications and systems in parallel. Nevertheless, it is important to understand the attributes of the different parts – individually and collectively so that it can inform policy processes of Ministry of Transport (MoT) and the Ministry of Business, Innovation and Employment (MBIE).

1.2 Approach

The project was delivered using a staged approach with four steps as summarised below:

1. **Review past studies and international literature:** The project started by reviewing the existing knowledge base with a view to develop a set of baseline metrics. In parallel with this, the drone sector was mapped, showing important linkages and relationships between users and providers. Next, international trends and developments were reviewed. This forms a wider context within which to view the sector. Most of the available literature focused on sector level applications. We worked with the Ministries[2] to identify relevant sources and datasets that they held, and a general information gap was identified.
2. **Engagements:** Most of the available information covering drones is international, specifically the United States of America and Europe. There is very little primary research about drones and their use in NZ. The literature was supplemented with sector engagements. Interviews were conducted with several role-players and stakeholders covering different parts of the drone landscape, including:
    a. Businesses that use drones as an 'input' or part of the business process,
    b. Businesses that provide drone-based services,
    c. Businesses that supply the drone sector covering, hardware, software and supporting/complementary technologies, and
    d. Government agencies and regulators.

    Semi-structured interviews were used to canvas the following aspects:
    a. Scope of current activities, e.g. distribution across New Zealand, key clients (sectors), type of service being delivered, industry dynamics[3], growth strategies and sector outlook,
    b. Development challenges and opportunities,
    c. Regulatory issues, constraints and safeguards as well as emerging priorities,
    d. Applications and market uptake of new approaches,
    e. Impacts of drones on business practices, advantages and trade-offs associated with drones,
    f. Interactions and cross-over with other technologies (e.g. the Internet of Things or IoT),
    g. Views on the future of drones and the applications.

    Appendix 1 lists the parties that were interviewed.
3. **Scenarios and modelling:** Insights from the engagements were combined with New Zealand specific information and international literature to define different growth pathways (scenarios). The pathways reflect different assumptions around the growth drivers, sector uptake rates and outcomes. Several scenarios are modelled to assess the potential economic effects of drone-technology and to show the relative sensitivities.

[1] E.g. exporting the know-how developed in the dairy-pasture management vs developing it in-house.
[2] Ministry of Transport and Ministry of Business, Innovation and Employment.
[3] This includes matters like the sources of inputs (imports vs exports), suppliers, users and market development.

4. **Effects and implications:** Based on the modelling work, the effects and implications of the different growth pathways are explored.

It is worth noting that it is beyond the scope of this assessment to quantify all effects[4], across the entire economy. Instead, a high-level commentary on the mechanisms through which drones interact with other sectors is provided.

1.3 Limitations and caveats

The drone sector is complex and constantly evolving. This assessment attempts to develop a high-level picture of how drones could be used in key sectors and what the potential benefits could look like. The very nature of drones, and the uncertainties around future uses, means that the results are speculative. Our assessment relies on available information and there are caveats underlying the assessment. The following limitations and caveats apply:

- The scenarios reflect assumptions around how drones interact with the rest of the economy. There is little official information about drones, their applications, the direct costs and so forth. The results are not forecasting, or projections of the future – they are simply scenarios reflecting different growth outlooks. In addition, we assume that the overall business models (e.g. input structures and cost structures) would remain constant. This project does not adjust for, or attempt to estimate, the new business structures arising from new (drone) technology.
- While we comment on the potential economic effects (or contribution), the potential costs and benefits, undertaking a full economic impact assessment[5] or a cost-benefit analysis of drones is outside the scope of this work. The focus is on the benefit-side but where possible we net out the costs. In addition, increased drone use will see a lift in risks (e.g. an operator losing contact with a drone and causing an accident). Valuing these risks is a complex task and it would be useful to understand the drivers and potential outcomes of these risks. The risk assessment is beyond the scope of this report. Once they are better understood, the benefits should be compared against the risks.
- A large portion of the international literature covers military applications of drones. Military applications are beyond the scope of this research. Nevertheless, military-focused R&D and innovations are often commercialised and applied in a civil context. That is, developments in the military arena often end up in civil applications.
- It is beyond the scope of this study to explore the technical considerations, issues and their implications. Examples include how to manage shared airspace, ethical considerations of drones, human technical-interface issues, interoperability between systems and issues associated with guidance, navigation and control (GNC) and so forth. It is assumed that the technical considerations are addressed, and that drone-technologies/applications can be used.
- The sector mapping and definitions presented in the report are based on international literature with adaptations to reflect New Zealand conditions. These are working definitions and they will change over time. The sector definitions are not official government policy positions.
- Accessing business-specific data is often challenging with confidentiality constraints. We relied on published information as far as possible. We did not peer review the published information, and in most cases, the low or conservative positions are used in this work. We did not undertake primary (survey) research but we did engage with a selection of industry stakeholders. This implies that

[4] Like the employment and labour market shifts arising from new technologies associated with drones and the effects they unlock.
[5] If the economic impacts are assessed, then Multi-regional Input-Output (MRIO) or Computable General Equilibrium (CGE) models could be used.

the 'sample' was relatively small and so the biases (conscious or unconscious) of those interviewed are reflected.

- The project did not use the Longitudinal Business Database (LBD). The LBD contains micro-data that researchers can access to investigate different business features. Using the LBD for this project was not possible but it would be valuable to include the LDB in future assessments.
- How an industry responds to new technologies, the uptake rates and effects are not always known because they are often 'future' outcomes. Similarly, if the decision to replace one technology with another is made, there may be other flow on effects in other parts of the economy. For example, shifting from diesel power to electric power causes changes in those businesses associated with providing diesel. Similarly, if one sector grows it could attract resources (like labour) away from other sectors. These flow-on effects are beyond the scope of this report.
- Incorporating drones in normal, day-to-day operation of business could lead to short term costs, like sunk costs associated with historic investments. The values of such losses are not included in this assessment.
- This assessment's main focus is on the benefits of drones. However, where possible, we illustrate the net benefits i.e. the benefits excluding the direct costs associated with delivering the improvements.
- There are several unknowns and uncertainties around drone uses and the direct costs (initial investment and ongoing expenses) associated with drones. We did not undertake a full cost-benefit analysis of drones. Aspects like the cost to refurbish, or renew, drones are not reflected. Similarly, the environmental costs and risks of drones are beyond the scope of this work.
- The assessment contains several forward-looking parts. It was not the intention to undertake an economic forecast of the New Zealand economy. Where we use sector specific outlooks, we rely on official forecasts, but these datasets do not align with the timeframes used to look at the longer time (25 years). We use basic projections that align with historic trends to inform the sector outlooks, but they are tempered (lowered) to take a conservative position.
- The work does not include an assessment or analysis of the durability of drones – this point has several dimensions:
  - The replacement cost of drones at the end of their useful lives and the average useful live (i.e. how many flying hours could be expected from drones),
  - The ecological costs associated with manufacturing or disposing drones. This relates to components like the batteries, airframe and electronics. We anticipate that most parts would be recyclable but there are costs associated with recycling and disposal. The assessment considers the potential benefits of using drones. We did not undertake a 'whole-of-life' assessment of all the costs (associated with drones)[6]. Including these costs would reduce the net benefits outlined in the report.

1.4 Report structure

The report is structured as follows:

Section 2 provides a basic context of drones by defining 'drones' (for this study), highlighting recent global trends and summarising the known New Zealand landscape.

[6] Such an assessment was beyond the scope of this report.

Section 3 summarises the key points and themes that emerged from the sector engagements. This section sheds light on the issues and challenges that can be expected when rolling out drones.

Section 4 presents the potential benefits that drones could deliver. The discussion focuses on selected sectors, presents the assumptions, results and sensitivities. The section concludes with a summary of the findings and illustrates the scale of benefits under aspirational settings.

Section 5 presents a short discussion of two futuristic scenarios.

The report ends with some concluding remarks regarding drones and the key points.

2 Drones in context

Drones can be traced back to the late 1910s when they were applied in a military context. Recently, drones have entered the mainstream and are being used to support a range of applications across the economy. There is a general perception that drones are mostly used for leisure activities. This perception is somewhat misplaced because different technologies[7] are being combined and these new applications are disrupting traditional business models. But, as this section will show, in terms of numbers, the leisure market still dominates the drone landscape. Further, the same technology combination (e.g. drone and camera) can be used across different sectors, in positive and negative ways.

This section starts with a brief summary of international trends to set the scene. Next a high-level description of the New Zealand drone market is presented.

Drones are described using many different names, including:

- Unmanned Aerial Vehicle (UAV),
- Remote Piloted Aircraft (RPA),
- Remote Piloted Aircraft System (RPAS),
- Remote Piloted Vehicle (RPV),
- Unmanned Aerial System (UAS),
- And others.

Each name has a specific, technical meaning, referring to different technologies and human involvement. Appendix 2 presents a brief description and overview of drones, some specific meanings and general categories. In this report, we use the term 'drones' loosely, referring to 'unmanned aerial vehicles' in a broad sense.

2.1 Global context

There are several, high level estimates of the drone market's value and its outlook. These estimates are based on numerous assumptions and caveats[8]. The estimates have been prepared by global consulting firms and concentrate on individual regions (e.g. Europe) or countries (e.g. United Kingdom, UK). The estimates paint a very positive picture showing strong growth in the short and medium term. The estimates show:

- Globally, the total addressable value of drones is estimated at US$127bn (2015-value),
- A European valuation estimates that the value of drones will reach EUR10bn, by 2035 and over EUR15bn (annually) by 2050[9].
- In the UK[10]:
    - Productivity gains across UK industries could deliver net cost savings of up to £16bn[11] by 2030.
- In the USA:

[7] For example, a high-resolution camera is combined with the flying platform the drone provides.
[8] As is this study.
[9] SESAR. November 2016. European Drones Outlook Study – Unlocking the value for Europe.
[10] (PWC, 2018)
[11] PricewaterhouseCoopers. 2018. Skies without limits: Drones – taking the UKs economy to new heights.

- The economic impact of integrating drones into their National Airspace System is estimated to total more than $13.6bn in the first three years and expected to grow to $82.1bn between 2015 and 2025.[12]
- Consumer Technology Association estimated that 2.8m commercial drones were sold in the USA (in 2016/17) and that the total revenue came to $953m. BI Intelligence expects drone sales to top $12bn by 2021 with an important part of sales coming from personal drones (used for film-making, recording, still photography and gaming). The uptake profile for personal drones is expected to match that of GoPro. (Meola, 2017)

Some of the studies were performed as part of thought leadership and insights work without a clear indication of who the commissioning party was. And, some appear to the 'marketing-type work'. This makes it difficult to identify the purpose (research question), methodology(ies), limitations and assumptions and so forth. Similarly, in some instances, the reports were prepared by sector/industry associations, and could be seen as presenting a 'best case' scenario for the purpose of lobbying and industry marketing activities. Some reports were prepared for government entities (e.g. the European Commission) and apply scenario approaches to show the range of potential impacts. These government reports are more transparent and appear to use less bullish assumptions. **These reports offer some insights into the anticipated growth and distribution of drones across the different economies. They tend to be more conservative and claim lower benefits. Regardless of the sources used, the key takeaway is that the global outlook for drones is very positive.**

Even if the more pessimistic values are used, the potential impacts of drones are substantial. Drones are seen as a potential driver of productivity and growth. Therefore, a do-nothing regulatory approach is inappropriate.

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In terms of the sectoral distribution of effects, the benefits <u>generally</u> fall across the same/similar sectors, regardless of region. The reports show:

- Infrastructure, construction and manufacturing activity will gain from drones. Globally, infrastructure will see around 36% of the realisable benefits. In the UK, construction and manufacturing will see a quarter of the cost savings (25%).
- Agriculture and primary sectors (including mining, gas and electricity) will see a large portion of the effects. Globally, agriculture is expected to capture 26% of the value.
- Transport will capture around 10% of the global benefits and in the UK, 21% of the costs savings will accrue to transport and logistics.
- Public security will account for 8% of global benefits and in the UK, it is estimated that 'public and defence, health and other services' will see around 17% of the cost savings that drone could deliver.

Using the SESAR work (European Union, 2016), a drone-population ratio can be estimated. Such a ratio gives a useful benchmark to compare New Zealand data against. Using EU research and combining it with population data[13] and projections return the following ratios (note the different timeframes):

[12] Based on a 2013 report by the Association for Unmanned Vehicle Systems International.
[13] (Eurostat, 2018)

- Government and commercial drones:
    - 3.8/10,000 people by 2025,
    - 7.9/10,000 people by 2035.
- Leisure drones:
    - 98.3/10,000 people by 2015,
    - 134.5/10,000 people by 2025.

These ratios show that the leisure market is expected to remain a large part of the drone-fleet. Over time, the density of drones (relative to the population) is expected to increase. It is also this part of the market that has the highest propensity to use drones in a rogue manner (as seen in the airport disruptions in London around Christmas 2018 and January 2019).

2.2 New Zealand situation

There is no official information about the number of drones, commercial or leisure users, in New Zealand. Using the findings of the 2017 report by Colmar Brunton for the Civil Aviation Authority (CAA) and combining it with recent population projections suggests that there are 308,000[14] drone users in New Zealand. However, this figure has been disputed. Applying the information in the Colmar Brunton report differently, presents an entirely different picture with the number of drones estimated at 77,600 (in 2017). This is considerably lower than the Colmar Brunton figure but, when expressing the estimated on a per capita basis, the lower figures are better aligned with the European ratios. This estimate suggests that there are 106 drones per 10,000 New Zealanders. This is broadly consistent with the rates identified in the EU.

The 2018 Drone Tracker report (based on a survey of the 7,000 members on the Airshare database) paints a clear picture of the spread of commercial operators across New Zealand. Some of the key points shown and suggested in the Drone Tracker report are:

- Leisure/recreation users:
    - Leisure/recreation users spend $1,000-$2,000 on drones and do most of their flying in their backyards, local parks or beaches. This suggests that they use drones as a form or relaxation and often combine it with photography equipment to capture land/cityscapes.
    - The distribution of recreational users is broadly in line with New Zealand's population distribution.
    - More than half (57%) of recreational users fly between one and three times a month. And, one in five (19%) recreational users operate their drones less than once per month.
- Commercial operators:
    - Tend to use drones to supplement their existing business activities (54% of respondents).
    - Offer drone services as part of the overall business but drone services are not the 'core business' (30% of the respondents).
    - A relatively small proportion (14%) of commercial operators provide drone services as part of the core business.

> Drones are used to lift service levels, and only a small share of operators have drones at the centre of their businesses. Drones operators are based in the main, urban centres.

[14] Applying the ratios in the Colmar Brunton report differently, considering the margin of errors, restricting the age profile, and adjusting the population to households (not people), return the substantially lower estimate.

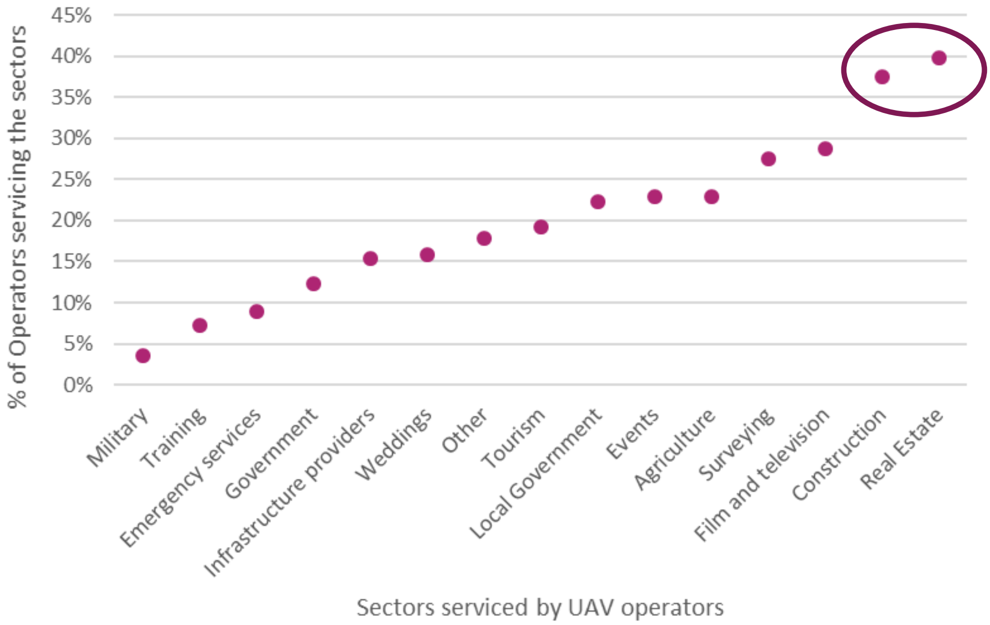
- Almost a third (27%) of drone operators are located in Auckland and 17% are based in Canterbury. Apart from some minor imbalances, there appears to be a reasonably good alignment between where drone operators are located and where most flying takes place, with Auckland the exception. The data suggests that some operators are based in Auckland but 'export' their services to the rest of NZ.

There is another segment of drone user – international tourists that use drones while they are visiting. Colmar Brunton asserts that 6 in every 100 overseas visitors (over 15-years old) had flown a drone while they were in New Zealand. This suggests that in 2018 (YE June) there were around 204,250 tourists that used drones while they were in NZ. This estimate is based on tourist departures. In light of the anticipated ongoing growth in New Zealand's tourism sector, this figure will grow. It is however not known from the research if these tourists came to New Zealand for the sole purpose of operating their drones or if this was simply incidental. This means it is difficult to put a value on drones in the context of tourist spend.

2.2.1 Sectoral applications

There is little official information on commercial operators in New Zealand. The Airshare database (held by Airways) provides useful information about the sector. In 2018, a survey was circulated amongst members to generate a user profile. Figure 2-1 shows the sectors/industries that use drones (as a service)

Figure 2-1: Industries that operators service and the % of NZ employment in those sectors



Note: Figures do not add to 100% because an operator can service. Based on Airways (2018).

The figure shows that currently, most commercial operators focus on the real estate and construction sectors with between 40% and 38% of operators servicing these two sectors. This is followed by:

- Film/television (29%),
- Surveying (28%),
- Agriculture (23%),

- Events (23%),
- Local government (22%),
- Other sectors (18%) and
- Infrastructure providers (15%).

It is worth noting that the NZ experience (i.e. sectoral distribution) broadly mirrors the international experience[15] (see Section 2.1) with infrastructure, construction and manufacturing activity seeing a large share of drone use. This is also the case if services related to the wider construction sector, like surveying, are considered. Agricultural applications feature relatively high – again consistent with international experience. This is followed by public security. Combining public security and associated sectors, as reported in the Airways report, again confirms a similar pattern for New Zealand. Military, emergency services, government and local government users returns a total share of 47% suggesting that almost half of the drone service providers engage with public services.

Drone service providers interact with the wider economy in a way that broadly mirrors international experiences. That is, they tend to service the same type of sectors.

Comparing the sectors currently receiving drone services against the employment levels show a mismatch. Around 40% of operators service construction and real estate but these two sectors are small in the NZ context with 1.2% and 1.6% of employment[16] each. Half (47%) of service providers work with public security and services but this sector accounts for five per cent of employment. This mismatch also shows up in the spatial distribution of commercial service providers. Drone operators are located in urban areas. A large portion of New Zealand's economy takes place in rural areas.

2.2.2 High level estimates of current values

As illustrated above, there is little existing data on drones, their use and the link to economic value that they create. The Drone Tracker report (Airways, 2018) is based on the responses of 579 commercial operators and there are over 7,000 registered operators. This includes both recreational and commercial users. Assuming that the responses are representative of the number of drones as estimated using the Colmar Brunton data, we estimate that there are between 1,500 and 1,800 commercial drones in New Zealand. That means that the commercial survey covered between 32% and 39% of commercial operators.

The potential benefits are estimated at between $154m and $216m. These figures reflect a very low growth outlook and should be seen as the minimum values (i.e. without any real further uptake of new opportunities, the drone industry maturing, or new applications being developed).

Based on the Drone Tracker report, drone-based company revenues[17] are estimated to be in the order of $162m - $194m. Looking forward, more than half of drone operators expect strong growth. Including this

[15] As explained by the envisaged benefits (not users).
[16] Based on 6D ANZSIC classification.
[17] Applying the ratios to the response returns a turnover estimate of $69m i.e. using only the returned sample.

growth lifts the turnover to $178m - $213m. Over a ten-year period, the drone sector's potential turnover[18] is estimated at between $1.3bn and $1.8bn – using a conservative 2% annual growth. Taking the turnover estimates and adjusting for the cost of goods sold, employment and taxes, provide a rough proxy for the benefits drones will deliver[19] if the current conditions (and sectoral use rates) do not change. **The potential benefits are estimated at between $154m and $216m. These figures reflect a very low growth outlook and should be seen as the minimum values (i.e. without any real further uptake of new opportunities, the drone industry maturing, or new applications being developed).**

Drone operators are actively engaging in R&D, with 36% of the respondents indicating that they will be increasing their R&D spend. Based on the data in Drone Tracker, the sector spends between $15m and 18m on R&D, and the sector indicated a strong lift in R&D spending. Based on the feedback, R&D is expected to grow to $21m - $25m over short term.

2.2.3 Wider landscape

Undertaking R&D and commercialising the outcomes are key parts of building productivity. Innovation focused businesses tend to grow faster, pay higher salaries and wages and are more competitive on the global stage. Many of New Zealand's universities, Crown Research Institutes and companies engage in R&D. Some of the R&D is privately funded and other workstreams are funded through research funding like the Endeavour Investment Fund. The New Zealand Government is also working directly with international companies to undertake their research in New Zealand. For example, Airbus is seeking out opportunities to support the development and adoption of new and innovative space data technologies. This includes the use of drones (NZ Government, 2018). Another example of private sector research and development taking place in New Zealand is Zephyr Airworks[20]. Unfortunately, information on the economic investment flowing to New Zealand to undertake the R&D is confidential so it is not possible to quantify the benefits. The main benefit flowing to New Zealand is in the form of the foreign direct investment. But, considering the media releases following (non-FDI) benefits are identified:

- **Labour market benefits from knowledge dissemination and sharing**: Zephyr is working with New Zealand universities to develop the skills it needs. Media releases suggest that most of the direct employment is based in the USA and three direct employees in New Zealand. It is not known how many of these positions are actually filled. The labour market benefits include the direct employment opportunities that are created. It also includes a lift in the technical knowledge and capability. The opportunities are also high(er) quality jobs paying premium salaries. At the time of writing, the following positions were being recruited for (to be in New Zealand): aircraft technicians and flight test engineers.
- **Building New Zealand's profile on the international stage**: hosting innovative companies to test new products in real life conditions is consistent with the government's work to attract future-focussed technologies to develop their products in New Zealand. In turn, this will assist in diversifying the economy and lifting resilience. Ultimately, by working with international companies (like Kitty-Hawk via Zephyr Airworks) one of the weaknesses of the NZ innovation system is addressed, specifically the drawing on connections to multinationals (Crone, 2018).

[18] While turnover is not a 'benefit', it is easy to see the sector's potential contribution.
[19] The adjustments are based on the information published in Annual Enterprise Survey.
[20] Zephyr Airworks is Kitty Hawk's New Zealand operator.

- **Contribution toward clean energy transport options**: New Zealand has a strong position on environmental values. Supporting innovation and R&D that contributes towards lifting environmental outcomes is consistent with these values
- **Developing the wider airspace management landscape:** Airways has announced that it is piloting future technologies needed to support the arrival of autonomous flying vehicles in New Zealand airspace. Airways also intends to test the capability of New Zealand's existing telecommunications network to track the likes of Zephyr Airwork's autonomous vehicle Cora and drones in uncontrolled airspace and enable better telemetry for drone pilots. A by-product of the increase in drones is that non-drone businesses are investing in infrastructure that support drones. This is because drones are stimulating demand for other services, like 5G.

> The Spark 5G Lab has a dual purpose. It's primarily designed to be a collaboration space for New Zealand innovators, entrepreneurs and companies like Emirates Team New Zealand to have early access to 5G, so they can test and develop products and experiences that will define the future. The lab will also host technologies that showcase some of the possibilities and benefits of 5G such as robotics, virtual reality, facial recognition, Internet of Things (IoT), smart cities, emergency services drones and driverless cars. (Emirates Team New Zealand, 2018)

In addition to the potential benefits of attracting and hosting drone R&D in New Zealand, drones can also unlock other technologies and opportunities like 'intelligent transport systems'. Recent research for the Intelligent Transport Advisory Group (Deloitte Access Economics, 2018) put the local market for drones at $725m with exports in excess of $520m.

Drones are also being used as part of active research. A review of the 2018 Endeavour Round Successful Projects identified two projects with direct links to drones. The first project has a $1m contract value and the second project has a budget of $999,000. Both projects have three-year timeframes. The projects cover[21]:

- **Drone flow: Aerial monitoring system for better river management**: Drone flow is a research project developing methods for measuring river flows from the air. It provides an efficient and cost-effective way to collect high resolution data of water depths, velocities, and volumetric flow rate. Using drones enables measurement of flows where existing methods are inadequate or dangerous, such as during floods. River flows are measured to manage rivers, quantify floods and evaluate physical habitat. This information is used to set minimum flows and limits on water take (e.g., regional council regulation of hydro-power and irrigation industries), and by central government to monitor the state of New Zealand's waterways. Existing methods of measuring river flows struggle in shallow channels (e.g., summer low flows, braided rivers), or during large floods due to floating debris, safety risks, and rivers overtopping their banks. These problems result in missing or inaccurate data, particularly at low and peak flows. It is critical to improve flow measurement capabilities now, since flow variability is expected to increase with climate change. The drone flow system uses a pair of drones flying in formation. An upstream drone releases biodegradable tracer particle, while a downstream drone records particle motion to resolve river surface velocities. Depth is then calculated from surface waves, turbulence, through-water imagery, and spectral attenuation. Physical habitat maps are generated by combining information on river velocity, depth

[21] (Ministry of Business, Innovation and Employment, 2018)

and substrate. Development of the drone flow system positions New Zealand as a world leader in river remote sensing and provides a valuable tool for river managers tasked with maintaining or improving the health of New Zealand's river ecosystems.

- Reducing the impact of LED streetlights conversions on cultural and ecological values: Most of the nearly 400,000 streetlights in New Zealand will be converted from largely high-pressure sodium lamps (HPS) to more energy efficient light-emitting diodes (LEDs) by mid-2021. This conversion is estimated to save $10 million/year and improve road user safety. However, LEDs emit more blue light than HPS lamps, which reduces night-sky visibility and has adverse effects on marine, terrestrial and freshwater ecosystems. There has been minimal research effort focused on understanding and mitigating impacts of such widespread streetlighting changes, particularly in New Zealand. This research project develops two tools that can be used to visualise different streetlighting scenarios, from the fine-scale (Tool 1: drone-mounted sensors) to the city-scale (Tool 2: interactive lightscape maps). The research will use experimental tests of operational streetlight types in the Christchurch Residential Red Zone to identify options that minimise impacts on cultural (night-sky visibility) and ecological (freshwater insects) values. Experimental results will populate an interactive map depicting lighting scenarios across Christchurch City, overlaid with areas of cultural importance identified by the Ngāi Tahu Cultural Mapping Project (Kā Huru Manu), to determine the impacts of LED streetlights on night-sky visibility and freshwater insects. Interactive maps will allow councils and developers to identify areas of cultural importance and areas where lighting impacts on ecological and cultural values are likely to be highest. These areas can be prioritised for assessment for the more appropriate lighting scenarios identified in the experiments. Together the tools will allow lighting project developers to realise economic and safety benefits associated with LED conversions while minimising impacts on important cultural or ecological values. We will trial the Christchurch Residential Red Zone, but our methods will be transferable both nationally and globally.

The above shows that drones offer direct benefits to the R&D landscape by opening up new ways to collect data and information. The role of drones is limited to transporting equipment, delivering research media and/or collecting data. Nevertheless, it is important to realise that without the aerial platform, the work would be delivered in other ways that might not be cost or process efficient.

The link between drones and other parts of the economy is clear. While the direct sales relationship is relatively small (i.e. small number of local firms buying the goods), the links to the R&D community should not be understated. Drones have links to areas like:

- Robotics,
- Advanced manufacturing,
- Engineering (mechanical, computer science, electrical and software engineering, and so forth),
- Wireless communications research,

These sectors make valuable contributions to the NZ economy.

2.3 Economy-drone interface

The conventional view that drones are only used for leisure or military applications is misplaced. There is a growing number of business/commercial applications and the commercial sector is showing interest in using the aerial capabilities that drone offer. Businesses are using other equipment and technologies to make the most of these capabilities. Drone-technologies have developed a great deal over the past few years and now include multiple uses, including:

- Aerial photography,
- Gathering information in a post-disaster context,
- Thermal sensor for search and rescue operations, and firefighting,
- Geographic mapping of inaccessible terrain and locations,
- Building safety inspections,
- Precision crop monitoring,
- Law enforcement and border control surveillance,
- Storm tracking and forecasting, and so forth.

Most applications are associated with surveillance and optical measurement of some sort. But some applications go beyond basic surveillance, photography or video. Drones are being rolled out to monitor crops and collect pasture/soil data. New and recently developed uses that are being trialled, include:

- Retailers testing drones as a delivery option. Amazon has been testing Prime Air for several years, and in 2017 it conducted the first public demonstration of the delivery system. While still in the early stages, Walmart recently filed for a patent that included in-store drones (Stribling, 2018). Pizza delivery was trialled by Dominos in Australia in2016 and 2017, respectively. In November 2016, a drone delivered a Domino's pizza order to a customer in Whangaparaoa (north of Auckland)[22].
- Targeted delivery of rodenticide in conservation areas. On the Galapagos Island of Seymour Norte, Drones have been used to fly autonomously along predetermined routes, dropping rodenticide with precision, down to half a metre accuracy.
- The New York Police Department[23] announced that it had acquired 14 drones to assist with policing efforts. The drones will be used to police/monitor large events (e.g. concerts), in hostage situations and in crime scene investigations. The NYPD indicated that it does not plan to use the technology to enforce traffic laws or survey citizens. In the announcement, the NYPD said that there are 29 officers who are trained to use the drones.
- Lifeguards are testing new drone technology in Australia and have recently saved two people stranded off the New South Wales coast[24]. The drones show a birds-eye view of the ocean before ejecting a floatation device, which inflates when it hits the water. Other surf-life rescue applications that are being trialled include pods designed to deploy automatic external defibrillators (AEDs), flotation devices, electromagnetic shark repel devices, and personal survival kits (that include water, a thermal blanket, a radio, and a first aid kit).
- Drone delivery service, Flirtey is partnering with a Reno-based ambulance service REMSA (Regional Emergency Medical Services Authority), to send out defibrillators by air in response to cardiac arrest-related emergencies[25].

Ultimately, drones provide a platform from which different applications can be delivered. Figure 2-2 shows the five general categories that applications fall in[26].

[22] (Domino's, 2016)
[23] https://www.theverge.com/2018/12/4/18125725/nypd-drones-police-new-york-city-advocacy-groups. The NYPD has 36,000 officers and 19,000 civilian employees. The NYPD services 8.5m people.
[24] January 2018. Website: https://qz.com/1182580/lifeguards-in-australia-make-history-by-using-a-drone-to-rescue-swimmers/. Date accessed 20/02/2019.
[25] https://www.rgj.com/story/money/business/2017/10/10/flirtey-launches-first-drone-defibrillator-service-america/750868001/
[26] Adopted from McKinsey & Company (2017).

Figure 2-2: Drone Applications – General Categories

Category	Uses	Description of uses	Impact
1 Surveillance	1a Short-range surveillance	Conducting short-range surveillance, image capture, and analytics	High
	1b Long-range surveillance	Conducing long-range surveillance, image capture, and analytics	High
	1c Photo/video	Using photo and video applications without analytics	Low
2 Operations		Facilitating labour-intensive or difficult tasks	Medium
3 Entertainment/advertising		Leveraging drones to entertain or advertise	Low
4 Signal emission		Proving multimedia bandwidth by emitting signal/video/sound	Low
5 Movement	5a Transportation	Moving people	High
	5b Delivery	Moving objects	High

High Medium Low

Adopted from McKinsey & Company (2017).

The five categories are:

1. Surveillance,
2. Operations,
3. Entertainment/advertising,
4. Signal emission, and
5. Movement.

Using these five categories as a guide, it is possible to identify economic sectors that could use drones (if the supporting technology was available). Appendix 3 lists the economic sectors that could use drones based on their current business processes. Crucially, we are not suggesting that these sectors are already using drone or that the eventual use of drones is guaranteed. Uptake is subject to a range of factors such as the cost competitiveness of drone-based solutions relative to other technologies, the degree to which the drones improve current processes or addresses a current issue, social acceptance, the regulatory environment and so on.

The five categories reflect the applications (how drones are used) but a sector can have a non-use connection to drones. These connections include:

- Delivering services using drones (i.e. use it as part of its own service),
- Technology partners and complementary services – businesses providing inputs, components and inputs to the drone eco-system,
- Regulators.

Interviewees highlighted that a significant portion of hardware and software solutions needed for drones was procured from overseas. The drone eco-system in New Zealand is still in its early stages of growth, with start-ups like Dotterel Technologies[27] coming to the fore. There is possibility for local suppliers to begin servicing the drone sector, especially as the sector expands.

It is evident that drones could touch a large part of the economy. At a very high level, almost two thirds (65%) of employees work in sectors that could use drones in some way or form. This is more than half of the businesses (55%) in New Zealand. Therefore, the potential gains could be substantial. But, it is very important to remember that there are other technologies and solutions that could provide the same (or better) outcomes for businesses. Further, businesses could engage with drones in different ways. Some might keep drone services in-house and others could contract the services in on an as needed basis.

2.4 Outlook

International literature paints a picture of increasing drone deployment across the wider economy, especially in areas that use data that can be collected via aerial means. Looking forward, most of the demand growth is anticipated to be in the lower level airspace (<150m)[28]. The growth profile for government and commercial entities is expected to be rapid in high potential areas out to 2035 (European Union, 2016). The rate of growth is then expected to flatten off as drone-technology matures. This suggests an overall timeframe covering some 35 years. The growth is expected to be driven by technology solutions that address the practical limitations of using drones. In terms of the leisure market, the number

[27] Dotterel Technologies offer proprietary solutions encompassing passive noise reduction and active audio recording technologies for drones.
[28] (Gent, E, 2016)

of drones is expected to increase rapidly over the next 2-5years adding over one million units per year to be in excess of five million by 2020-2023 before tapering off.

Using drone per capita ratio (drones/10,000 population as introduced in section 2.1) shows that, in the EU, an intensification of drones is expected with the number of commercial drone relative to population more than doubling. Leisure drone use will also intensify but indications are that the growth will flatten off over the medium term. Applying the relative changes underlying the European ratios to the New Zealand situation (and population trends), helps to gauge the outlook for New Zealand:

- Government and commercial drones:
  - 2025 2,020,
  - 2035 4,460.
- Leisure drones:
  - 2025 70,650,
  - 2035 75,310.

The strong growth in drone use will have positive effects. But with the lift in drone numbers comes an increase in risks. So, the growth needs to be managed in a way that enables the uptake of opportunities while limiting, or reducing, the risks.

We note that the starting points differ from the Colmar Brunton estimates, but the estimates are still informed by the Colmar Brunton work.[29]

The outlook suggests that the drone market will see an increase in the share of commercial operators relative to leisure users. Commercial drones are expected to account for around 3% of total users by 2025, growing to 6% of the fleet by 2035. Commercial demand will account for most of the growth in advanced drone users. This growth is indicative only and subject to many external factors, such as:

- Industry acceptance of the technology and the cost competitiveness of drone-based solutions relative to other technologies,
- Community and social acceptance,
- The regulatory environment,
- Availability of suitably qualified operators (and employees) and their ability to operate financially sustainable business models, and
- Reliable solutions for low-altitude air traffic control.

Other factors that would lift the growth even higher include the ongoing developments in emerging technologies like Artificial Intelligence (AI) and the Internet of Things (IoT). Combining drones with these technologies could unlock new innovations and opportunities. This includes the use of drones for parcel deliveries by retailers (e.g. Amazon and New Zealand retailers like Rebel Sport, Briscoes, Farmers and so forth). When this happens, the number of commercial drones operating is likely to be considerably greater than the 4,460 estimated above.

There are many technical and regulatory considerations that would impact on how drones are rolled out across the economy. Some argue that the principal barriers to development of the sector are regulatory in nature, but this oversimplifies the development challenges. The Department for Business, Energy & Industrial Strategy and the Goverment Office for Science (UK, 2017) identifed three distinct areas as significant potential barriers to the ongoing development of drone applications. These areas are:

- Technical challenges: Key technological challenges remain in relation to securing improvements in navigational performance, verification, connectivity and security issues. This relates specifically to

[29] If the growth rates are applied to the Colmar Brunton data, then the estimated number of drones come to 2025 – 454,600 and 2035 – 499,000.

BLOS operations. Further progress is needed in the areas of IT/data processing, power drives and sensors[30].

- Regulatory hurdles: The existing regulatory environment for drones was identified in the evidence base as directly holding back several areas of drone application, specifically for BLOS operations. This point was highlighted across several different studies[31]. (Note: This does not suggest that this is an issue in New Zealand, but it is worth noting that some interviewees mentioned regulations as a constraining factor).
- Public perception: Concerns about the privacy implications of drones, their association with military use, concerns about dangerous uses of drones, safety concerns, and public dissatisfaction with drone technologies. This has potential to hold back the commercial use of drones and slow the pace of regulatory reform on the one hand and industry uptake[32] on the other.

One of the key challenges that will influence the successful growth of drones relates to airspace integration. This is a central issue that many countries are grappling with. To achieve the full potential of drones, all parts of the aviation/airport and airspace management systems must operate seamlessly across the domains of air, ground, and maritime. This includes drones that are controlled, semi or fully autonomous. Currently, drones have a high degree of human interaction, but this is expected to decrease over the long term.

Regardless of these challenges, there will continue to be a push towards enabling drones to grow in areas where they can deliver the benefits like:

- Cost savings compared to the use of piloted aircraft or satellite systems, due to their reduced scale, complexity and lesser infrastructure requirements.
- Greater flexibility, predominantly due to their reduced scale which allows an increased range of uses.
- More precise control of devices due to the greater availability and affordability of autopilot systems.

The next section summarises the findings of the industry interviews.

[30] Literature suggests that Chinese competitors enjoy considerable cost advantages in these areas. During the sector engagement, it was mentioned that equipment is 'simply purchased from China' because it is easy and relatively fast.
[31] (European Union, 2016), (Jones, 2017), (PWC, 2016).
[32] Due to aspects like reputation risk (real or perceived).

3 Industry Engagement

Drones can be used in many different ways and in combinations with other technologies. How industries respond to the opportunities drone present is influenced by many factors including historic development pathways, cost factors and industry considerations. As part of this assessment, industry role-players were interviewed to get their views on drones, likely uptake rates and sectoral factors that will influence the success (or failure) of drones.

The interviews covered different parts of the drone landscape. A synthesis of the interviews follows, and we stress that these views reflect the points made during the interviews. The views do not necessarily present industry-wide, or consensus, views because they are not based on a representative sample or survey process.

Several invitations to participate in the project were sent out and these were then followed up with additional reminders. A reasonably good coverage of sectors was achieved but some gaps remain. These gaps are around construction, film and entertainment and other smaller subparts (e.g. subsectors within agriculture).

Only the observations are outlined, and they are not analysed or assessed for policy implications. The points that are relevant to this assessment are highlighted.

3.1 Main points

The following eight points are discussed:

- Divergent views - no common view on uptake rates and outlook for the sector,
- Market wants a proven solution,
- It is not just the drone,
- Competing against alternatives,
- Getting scale,
- The sector has two distinct parts,
- A challenging regulatory environment, and
- Drones are over the hype curve.

3.1.1 Point 1: Divergent views

Perhaps the most telling observation from the study is the wide range of views held about drones, and their potential. It appears that those sectors that have had more exposure to drones, and that have attempted to put them to use, tend to have more muted opinions on the 'actual' potential to use drones in a day-to-day setting. Where the applications are still in the early stages, the level of optimism appears greater. The scale of the diverging views (and level of optimism) across interviewees was surprising. With reference to operators, their views and opinions appeared to be more realistic, based on actual on the ground experiences and difficulties. But, these challenges did not appear to be in-surmountable. A small segment of users indicated that they hold little hope for drones to make inroads into the marketplace.

It appears that the individuals that operate at the coalface of drone sector had strong views of the potential benefits, but indicated that it would be difficult and take a long time before the technologies would be delivering benefits at a large, 'mainstream economy' level. It was indicated that the scale of benefits delivered by drones is unlikely to meet the envisaged levels in the short term.

3.1.2 Point 2: Market wants a proven solution

A key challenge limiting the uptake and growth of drones is the limited track-record of drones that illustrates reliability and robustness of the solutions they offer. This is something that most emerging technologies face. Where a business is supplying a service to another sector, the use of drones to streamline the existing service, is seen as a way to change 'the way of working' and this is smoothing the way to introduce drones. Existing business relationships and insights into how clients work and the problems/challenges they are facing enables the service provider to exploit drone capabilities. This means that service providers can incorporate the new drone technologies while managing clients' exposure to risks and costs. Using existing relationships provides an avenue to introduce drones into everyday activities. Such an approach appears to lower entry barriers and resistance to mainstreaming drone solutions. However, considering the cost of drones, hardware and software the service provider assumes all the risk without any guarantee of a return on the investment. This suggests that it would be difficult for a new drone operator to simply enter a market without an existing network or a working knowledge of the issues that clients are facing (and evidence that the drone service/solution would address the issue).

Feedback from the drone industry, points to challenging conditions when attempting to introduce drones as an alternative solution or way of doing things. This is partially explained by the friction in shifting from existing know-how, to new and unproven methods. It could be that the additional gains that drones could deliver are unclear. Unknowns around the development and operational costs also influence this. Drones are often seen as a way to reduce cost as opposed to delivering better information (at the same cost) meaning that operators are finding it difficult to achieve widespread uptake. Nevertheless, there are success stories in some sectors like forestry. In the short term, these solutions and drone applications appear to be linked to specific operators and they are not wide-spread.

3.1.3 Point 3: It is not just the drone

A point that was repeated across several interviews is that drones provide the platform for transporting sensors and complementary technologies, and they need to improve to make the most of the opportunities offered by other technologies. Attributes like payload, flight duration (endurance) and stability are important. Some respondents indicated that external factors like wind and weather can have a large effect on the suitability of using a drone platform. This can limit the ability to schedule in flying time making the service unreliable, reducing the convenience and therefore lowering the uptake of drone solutions.

An important challenge is how to translate the information and data collected by drones (and technologies) into something that is useful to end users. Specialist software to translate 'information, data and images' to intelligence is often required. The cost of this software and the specialist skills needed to operate/interpret the software, often puts the drone solution beyond the reach of some users. This has implications for the business model and how drones are rolled out/taken up across different sectors. Essentially, this means that the drone operator must be able to pilot the drone and also be able to use and interpret the collected information.

An interesting point is that the individuals (or businesses) that get additional value from using drones are those that make better decisions using the 'high quality information'. In other words, simply getting better information does not guarantee improvements; it must be used and acted on. Further, the areas where drones are used must align with 'high impact' or priority business areas.

3.1.4 Point 4: Competing against alternatives

Following from the preceding, there are many different technology solutions[33] and they are all competing in the marketplace against each other for clients' attention and investment. In most instances, the potential solutions offered by drones are incremental, not disruptive. This is because in many instances the solutions address only a small part of the total value chain (or the tasks that need to be completed). For example, dairy farmers can already access satellite imaging to assist with pasture management. The satellite services cost varies depending on the level of services but amounts to around $2,000 for 100ha (per year for around 30 runs). The service is affected by weather (cloud) and there could be some gaps in information availability. Another alternative to measure pasture moisture is a tow-behind module (e.g. C-Dax Pasture Meter[34]).

It is important to note that the areas where drones could deliver advantages tend to be in large and mature markets (e.g. dairy farming) with a long track record on enhancing sector performance. This suggests that finding 'step changes' to how the sectors operate would be difficult to achieve, instead any gains are likely to be incremental. It also means that entering the market and gaining traction would be challenging. Most of the challenges are consistent with a new technology entering an established market. Based on the interviews, it appears that drones would face strong pushback from existing approaches because they would enjoy considerable 'first mover advantage'. This does not mean that the drone solutions are inferior, but it suggests that initially, uptake rates and conversions are likely to be slow.

3.1.5 Point 5: Getting scale

Drones are used at different points of the production process and these points are only one small part of the overall industry. For example, using fertiliser in dairying is one part of pasture management, which in turn is only a part of managing a dairy farm. This means that the total size of the 'capturable opportunity' is currently seen as small. Currently, drone uses tend to be centred on simplifying or accelerating a single task that reduces the overall labour requirement. Safety or cost (time) appears to be the primary driver. For example, in forestry, drones are used to fly a 'heaving line' across valleys so that wire cables can be pulled across. They are also used to move seedlings to workers during planting. Traditionally, a person would carry 4-5 boxes of seedlings to the planting area. To keep the drone (and operator) fully engaged, the task should be of a nature that requires a full time equivalent to operate 'the entire day doing the task' or it should be able to move between locations. Getting work that is large enough, and ongoing, appears to be difficult and this is reducing the incentive to invest in drones because entrepreneurs are not sure that they would be able to generate sufficient work (and profit) to keep them meaningfully employed.

The skills required to operate a drone, the time it takes to develop the skills[35] and the fact that most drone operators are young businesses (less than 3-years), means that the industry is facing challenges associated with introducing a new technology as well as those associated with starting a new business. These include normal, start-up issues like access to capital, market recognition, learning client needs, staffing and cost

[33] Drones and the complementary technology (sensors or imaging)
[34] www.c-dax.com. The Pasture Meter costs between $5,685 and $6,990 depending on the model.
[35] One interviewee suggested that it takes around 18 months to become reasonably proficient in flying a drone.

pressures. Combining the new technology with a mostly start-up landscape could explain the reluctance of new drone operators to commit to the opportunities.

Apart from these complexities, some applications are subject to other, non-aviation regulations (e.g. handling of chemicals) adding another layer of intricacy. This combination could explain UAVNZ's observation that operators are not 'in a get rich quick environment' and that 'nobody is getting rich' flying drones.

Commercial operators are associated with businesses, and they have a formal approach to using drones. Safety and regulatory requirements are seen as priority areas. These uses are potentially very varied and far reaching across the economy but the issues around uptake and business models (financial viability) are stopping benefits from materialising. In essence, the tension is between:

- the ability to run a viable business that can charge at price points that can deliver returns to the owner operator (or shareholders), and
- end users' willingness to pay for the service.

3.1.6 Point 6: Two-part sector – leisure and commercial

For the most part, the drone industry consists of two segments, commercial operators and leisure users or hobbyists. Earlier research for Airways reveals that the commercial operators account 41% of drone operators (in Airways' dataset). This translates into 2,850 operators. Around one in seven (14%) of these operators have drones as their main business. The balance either offer drone services as a specific service (30%) or use drones as part of their overall/everyday activities.

The relatively small share of operators with drones as the core business, supports the observation that operating drones is a difficult business. It also supports the feedback that drones are used as part of wider business operations. With reference to the leisure market, while regulations apply to users, the relative ease with which a drone can be obtained means that users might not fully appreciate the responsibilities associated with the device(s). This raises the risk of a rogue (or uninformed) user disrupting other economic activities. It is the airspace where leisure users interact with other economic activities where disruption is anticipated (e.g. around airports). Other areas where there are risks include around emergency situations where helicopters operate (e.g. wildfires or police operations).

3.1.7 Point 7: Regulatory environment

We did not look at the regulatory environment in any detail because this was out of scope. Several interviewees suggested that this is an area that needs ongoing work to balance safety considerations against enabling growth and development. The main points raised during the interviews are listed below and are included for completeness only.

- Some operators highlighted New Zealand's comparative advantage in supporting R&D. This is based on the view that NZ's regulators are 'friendly to industry', 'ask the right questions' and 'positive to work with'. These are viewed as sought-after attributes and the overarching 'safety first' perspective is seen as key. However, some interviewees indicated that the 'safety first' perspective could limit some interactions.
- Integrating airspace so that different aircraft (including drones) could operate in a joint manner, is seen as an area that needs work (not just in NZ but globally).

- There are technology solutions available to counter drone intrusions in controlled airspace (e.g. DroneDome); the potential to use these in the New Zealand context should be considered.
- With the continued and ongoing increase in leisure drones, the number of incidents and disruptions will grow. The need for drone training and supervision (control and regulation) will become increasingly prominent. A by-product of the disruptions is that public acceptance of drones will decline – irrespective of the operator, commercial or otherwise.

3.1.8 Point 8: Drones are over the hype-curve

Some interviewees indicated that drones, and the experience of embedding drones in business activity has now moved beyond the initial hype. However, there are still areas of inflated expectations. Looking forward, disillusion with the technology (drones and complementary technologies) is expected before entering a growth phase (and widespread adoption). The interviewees felt that some drone applications were at different points on the hype-curve (see Appendix 4). Dairying and some agriculture applications are arguably in the early stages (starting the growth phase). Basic forestry applications are building productivity and other sectors, like construction, are seeing an increase in use. However, drones with a basic application (e.g. drone plus camera/GoPro) are over the hype curve, meaning that the technology has moved past the early stages of high expectations and there are challenges around improving products and satisfying early adopters. Drawing from the industry feedback, it appears that more advanced uses i.e. those combining semi-autonomous and autonomous drones are still in the early stages of the overall development cycle (see Appendix 5). Over time, the anticipated benefits of drone (expectations) could develop following the pathway suggested in the hype-curve theory. Of course, the development pathway is uncertain and might not necessarily follow the implied pathway[36].

3.2 Conclusion

The interviews covered a wide area and sectors, and in some instances, the views are conflicting, inconsistent and at odds. One perspective is that the opportunities presented by drones are substantial and efforts must be made to capture the benefits. Conversely, some argued that the opportunities are 'theoretical' because the benefits can be (or are already) captured using other technologies. While the different views reflect alternate perspectives, it is important to capture both positions and not focus on just one to give a balanced view.

The views were all considered in the assessment and resulted in some growth assumptions being relaxed or expanded but others were tightened. The next section discusses the estimated benefits.

[36] The hype-curve is one theory that describes how expectations shift over time.

4 Estimated benefits

This section discusses the potential value of drones. This is done by looking at key economic sectors and estimating the potential benefits that drones could deliver if they are used. The mechanisms through which drones will deliver the change (and benefits) for the different sectors are discussed. We highlight the main assumptions used in the analysis. The analysis was influenced by information availability, which varied greatly across the sectors. As a consequence, the level of analysis and detail provided in the scenario modelling varies across the sectors. The following sectors are covered:

- Agriculture, including:
  - Dairying,
  - Forestry
  - Other agriculture
    - Horticulture,
    - Sheep and beef,
- Electricity,
- Transport (parcels)
- Airports,
- Construction,
- Public safety (including search and rescue, firefighting).
- Other.

In general, agriculture activities have a large body of information to inform the scenario analysis. Unfortunately, this is not the case across the other sectors and several assumptions underpin the analysis. The analysis uses a business-as-usual (BAU) outlook as baseline. The benefits that drones could unlock are compared against the BAU outlook meaning that only the 'additional gains' are considered. The analysis covers 25 years and it is acknowledged that this is a very long assessment period. This long period is needed to illustrate the potential benefits in some of the smaller sectors (like surf lifesaving). In addition, the uptake rates for some technologies span around 10 years and if the analysis looks at this period then some of the benefits barely outweigh the costs[37]. A sensitivity analysis is included and the detail in the sensitivity analysis is subject to information availability. The sensitivity analysis covers different uptake rates (speed) and scale of uptake (size) as minimums. This is paired with a discounted cashflow analysis modelling three discount rates (4%, 6% and 8%)[38].

Many industries are expecting increased drone utilisation, and therefore reap the benefits. Overall this will lift productivity as conventional and traditional business processes are improved and refined. This is true across labour- and capital-intensive industries. Ultimately, the reasons for moving towards drone-based technology options are:

- Increased efficiency (collect more/better data at lower cost and/or faster),
- Improved accessibility (drones can access locations that are difficult/impossible to access by air or land-based vehicles in a more cost-effective manner),
- New applications (technological advancement and recombination of existing technologies open up new uses),

[37] In itself, this suggests that in some cases the benefits are marginal.

[38] The New Zealand Treasury indicates that the discount rate for telecommunication, median and technology, IT and equipment and knowledge economy (R&D) projects is 7%.

- Reduced risk. In industries such as oil and gas, utilities, construction and so on, drones offer a useful (safe) alternative to current practice when inspecting assets.

4.1 Primary Industries

Globally, agricultural uses are expected to see strong uptake of drone technology in the future[39]. The versatility of drones is seen as key to unlocking the practical applications to improve agricultural processes, including:

- Soil and field analysis. Drones can cover much larger areas in the same time as conventional methods, and develop 3D maps which is used for decision-making.
- Crop monitoring and health assessment. Drones are used to generate multispectral images of crops which are used to track changes in plant maturity and health. Early detection of disease is key to cost effective responses. Similarly, livestock can be tracked and assessed. Drones provide farmers the ability to regularly and accurately perform health assessments. Drones can monitor crops more accurately, frequently and affordably, delivering high data into crop growth, improving productivity[40].
- Water management. Drones fitted with equipment such as thermal cameras, can be used to identify areas of insufficient (or excessive) irrigation. Combined with irrigation technology, water can be 'targeted' to areas of need. This will also prevent run-off (of nutrients like Nitrogen and Phosphorus), conserving water and protecting waterways.
- Crop spraying. The ability of drones to easily adjust their altitudes and flight paths according to the surrounding topography, makes them well-suited for crop spraying. This means more efficient and targeted approaches to spraying pesticide and fertiliser. A recent report[41] estimates that aerial spraying can be completed up to five times faster with drone than with traditional machinery. Similar to irrigation, the targeted application reduces runoff and reduces input costs (less overspray or misdirected spraying, and potentially lower delivery cost).

New Zealand's agriculture sector is diverse, ranging from horticulture, kiwifruit, apples, berries, to sheep and beef, and dairying. Forestry is another primary sector (part of agriculture) and this is included in the analysis.

The potential uses of drones in agriculture have a reasonable information base to draw from. Specific mention is made of work Shelly and Andrews for Callaghan Innovation (2015). This assessment updates the earlier work with newer/more recent data and the industry feedback.

4.1.1 Dairying

Section highlights: Using drones in dairying, can deliver benefits. These benefits relate to improved pasture management, reducing inputs (e.g. fertiliser) and improving yields. Currently, drones are not used extensively, and industry representatives are sceptical about drones becoming mainstream over the short term. Overall, the potential benefit to dairy farming from using drones is estimated at between $1.3bn and $1.6bn (over 25 years).

[39] European Commission. January 2018. Digital Transformation Monitor: Drones in Agriculture.
[40] https://waypoint.sensefly.com/agriculture-drones-boost-crop-yield/
[41] PricewaterhouseCoopers. May 2016. Clarity from above – PwC global report on the commercial applications of drone technology. https://www.pwc.pl/en/publikacje/2016/clarity-from-above.html

The use of drones is expected to start on a small scale and will growth over the foreseeable future but there is some uncertainty around New Zealand dairy farmers' appetite to invest in drones. Industry feedback suggests that uptake levels may be low. The specific reasons for this are associated with two points mentioned in the previous section – that a proven solution is sought and there are existing alternatives. For this analysis, we look beyond these barriers, but it is important to remember that, based on industry feedback, **only a very small portion of the uptake is anticipated**, **the confidence of the change actually occurring at any scale is limited. Therefore, these estimates should be seen as the upper limit.**

Estimating the potential benefits of drones to dairying is subject to many assumptions. These assumptions are based on available literature and feedback from the industry – this includes parties like UAVNZ and Dairy NZ. Appendix 6 outlines the main assumptions but fundamentally, the estimates and assumptions draw on the work by Shelly & Andrews (2015).

Implementing pasture management and lifting dairying's performance through the use of drones is shown to deliver a range of benefits to New Zealand. Literature suggests that the main difference between LOS and BLOS in a dairying context is the operating costs (associated with the flights). BLOS is considerably more cost effective than LOS; 43% of the cost of LOS. However, the gains from pasture management appear to be broadly similar. Therefore, the difference in the overall gain (between LOS and BLOS) is driven by the cost differential. Based on the uptake rates (as described in the assumptions), the annual cost associated with operating drones (LOS vs BLOS) is estimated at \$20.8m vs \$8.9m. This suggests that the gain of BLOS over LOS would be \$11.9m/year[42]. Over 25-years, the values are:

	$'m – Cost of Operating Drones	
Discount Rate	LOS	BLOS
4%	223.5	95.8
6%	173.8	74.4
8%	137.4	58.9

The table shows the cost of drones, it does not include the value of the service offered (e.g. any consulting services, use of software, interpretation of data and reporting or client liaison). Including these items will change the cost. However, we expect that the 'per farm cost' of the value-added services will be similar across LOS and BLOS. The gains from moving between LOS and BLOS will most probably fall to drone operators because of the small market (this only compares drone options).

We note that farmers already have access to satellite imaging that they can buy to get information on pasture performance and states (e.g. moisture). It is our understanding that it currently costs around \$2,000/100ha to subscribe to the satellite service (for around 30 weeks' information). This provides a benchmark price point for drone providers.

Of greater importance are the potential effects on farming processes. By improving pasture management, the total value of dairy product exports is lifted because more is produced[43]. This analysis does not consider the interplay between the level of production and global commodity prices. But this interplay is very

[42] Undiscounted.
[43] This is a function of the assumptions.

important because commodity prices influence how much benefit is felt locally. Depending on global commodity prices, the lift in export could deliver **additional revenue to NZ of between $175m and $205m (per year)**[44]. This increase in exports is a direct benefit to New Zealand because it is foreign exchange that flows into New Zealand. This additional revenue is generated by way of improved pasture management, implying higher productivity.

A part of lifting productivity is better cost and input management. The analysis includes Variable Rate Input Application (VRA),[45] one example of how costs can be better managed with improved information and applications. European experience suggests that using VRA[46] could reduce nitrogen application by between 2% and 6%. It can also improve (reduce) nitrogen-leaching by 5% to 20%. Applying the nitrogen saving to available dairy farm budgets and linking it with the assumed uptake of drones enables us to estimate the potential cost savings if drones are used to inform variable rate application across New Zealand. The saving from more efficient/better targeted fertiliser application is estimated to be in the order of $11m per year. While the size of the saving is modest on a per farm basis ($3,000 - $3,900), the cumulative saving over time is not insignificant, coming in at between[47] $68.4m and $112.7m.

Considering dairying's relationship with other types of farms, it is plausible that drones employed by other farms would benefit the dairy industry. For example, dairying procures silage which could be grown on a non-dairying farm. This means that drone uptake in other (non-dairying) farms could create spill over benefits in the dairying sector. However, the benefits would be smaller than those felt via the dairying sector. This is because the dairy farmer would still buy the same volume of inputs (e.g. silage) but the support farm would see the productivity gains, i.e. producing more for less input costs.

Sensitivities

There are several unknowns around the assumptions. As the technology beds in and use increases, the parameters will become clearer. Appendix 7 outlines the results of the sensitivity analysis. The sensitivity analysis illustrates the effects of different growth assumptions, specifically, the productivity gains, uptake of the technology and the milk price.

The sensitivity analysis shows that lifting the uptake and/or the productivity gains will deliver benefits to NZ and the upside of the increase is sizeable. Even if the rate of uptake is reduced (slower uptake), New Zealand still receives benefits from the use of drones.

The sensitivity analysis suggests that the potential benefit to New Zealand from using drones in dairying is potentially large. The desire to use the newer techniques (and technology) is strongly linked to the potential return that farmers could achieve. Under low pay-out conditions, there will be some resistance to investing in new, and unproven techniques. Further, in difficult trading conditions, a cautious approach to new investment is expected as farmers keep a close eye on debt levels and look to minimise risk.

The analysis shows that fertiliser savings, remains in the $1m-$4m (per year) range under the different settings. While not very large, there are flow on effects associated with using less fertiliser, including nitrogen leaching with environmental costs and the detrimental impacts on other priority areas like freshwater quality.

One area where there is a need for further investigation is the ability of drones to capture and respond to the growth opportunity. There are strong opportunities to work with New Zealand's dairy sector to lift

[44] Under conservative settings. Using more aggressive assumptions increases this considerably.
[45] Also called Variable Rate Application.
[46] This example relates to arable land. A dairy farm specific ratio could not be found. Therefore, a conservative position is taken.
[47] The range shows the effect of different discount rates (4% and 8%).

productivity and this analysis suggests that the benefits could be substantial. But, considering that there are around 11,500 herds around NZ and that they are not evenly distributed means there are practical considerations around the ability to service dairy's needs. In addition, breaking into the farming sector to deliver the service will be difficult because of dairy farming's perceptions around the value it will deliver.

Potential Economic Impacts – Value Added and Employment

The analysis suggests that the gains in economic output, and Value Added[48] would be material. The gains arise from the greater volume of product that is available for exports. The lift in on-farm activity flows into the wider economy delivering other impacts. Based on the uptake rates and assumptions, drones could lift Value Added by $230m/year (2042). Most of the lift in VA will be delivered by dairy cattle farming with a third (31%) of the VA increase coming from this sector. This is followed by dairy product manufacturing with a quarter of the increase (23%). Other sectors that will see a lift in activity include those servicing dairy farming and dairy product manufacturing, specifically:

- Professional, scientific, technical, administrative and support services,
- Other transport, postal, courier, transport support and warehousing services,
- Information media and telecommunications,
- Chemical, polymer and rubber product manufacturing,
- Agriculture support services,
- Sheep, beef and grain farming,
- Finance,
- Wholesale, and
- Road transport.

Combined, these sectors account for another third (31%) of the VA effects felt across the economy. It is very important to note that these increases in VA and employment should not be seen as 'benefits' – VA (and GDP) is not the same as benefits. It is a measure of production activity and does not reflect matters like the value of environmental resources used/consumed in delivering the goods or other externalities.

In terms of employment, the higher level of outputs from dairying will flow through the economy, creating demand for additional goods and services. Based on the assumptions, in order to respond to the higher milk take (due to improved on-farm productivity), additional milk processing is needed. Assuming that the existing processing capacity can process the additional milk for export, then the lift in activity triggers other effects throughout the economy. Additional jobs are supported in the economy. The modelling suggests that the increase in activity will sustain between 1,520 and 1,980 jobs[49]. Looking beyond the on-farm employment effects, it appears that the shift will be at both ends of the 'skills-continuum': Road and rail drivers will capture 7% of the additional employment, followed by 5% for factory process workers and 4% for other labourers. This growth is mostly associated with the increase in the volume of goods (milk) that needs to be transported and the processing activities associated with it. At the higher end of the skills-continuum are specialist managers and business professionals. These occupations will account for 17% of the employment growth (10% and 7% respectively). Design, engineering, science and transport professionals will account for a further 4% of the growth.

[48] Value Added is similar to Gross Domestic Product with the main difference being that GDP includes some taxes and VA does not.
[49] Employment is measured using Modified Employee Counts (MEC). MEC is the sum of working proprietors and a head count of employees.

Other considerations

Dairying competes on the global stage, but its effects are felt at a local level. Improving the sector's performance will flow through and have a positive outcome for New Zealand. This is especially the case for emerging priorities like environmental pressures. By using technology, it is possible to increase the sector's economic contribution while reducing the ecological footprint. Drones provide an opportunity to improve environmentally friendly growth. Similarly, using drone-technology could assist in maintaining production while improving eco-outcomes. Apart from minimising fertiliser inputs, the direct (and specific) contribution of drones to improving environmental outcomes is unknown. Many of the potential environmental gains are made through physical tasks (e.g. fencing off water ways and riparian planting) and drones would offer benefits in terms of monitoring and surveillance work. In the overall context of dairying and the sector's environmental management tasks, the potential role for drones in the environmental management is minor (with several alternatives).

In terms of alignment with other agriculture technologies, there are alternatives (e.g. using terrestrial based sensors and vehicles) that could be used to do the same or similar tasks as those envisaged for drones. Therefore, drones are not the only solution and the same outcomes could be achieved using different technology.

With reference to the uptake of drones, we did not consider the sequencing and adoption of different technologies and drone-enabled technologies might not be the most cost-effective option to achieve pasture management. For example, using global positioning systems (GPS) soil mapping, yield mapping, equipment auto-guidance systems and variable rate applications all have different requirements before they can be used effectively. Often, technologies are implemented in a one-at-a-time fashion. While this might not be the most time or cost-efficient way to implement technology changes, a sequential approach is frequently seen as a way to minimise budget risks and to avoid sunk costs. This suggests that drones will compete for the tech-dollar and the concept and benefit must be proven before drones will receive the funding and enter mainstream. Farmer education will also influence adoption. It is worth noting that in some cases, the on-farm priorities might dictate that other technology avenues be pursued, and drones might not be the first in-line.

The analysis shows the potential gains to dairying and the New Zealand economy. It is worth noting that one of the issues that will limit the uptake of drones is likely to be the availability of skilled operators. As illustrated in section 2, most drone operators are Auckland-based. Operating drones requires an advanced set of skills and the level of technical capability and competency required to get the most value out of the equipment will be in the medium to high category. One factor that will determine the adoption pathway is the ability of drone operators to operate a financially viable business. The costs of the equipment, operator's time, business expenses, software (licensing), time to interpret and analyse the collected data and communicate the findings to the farmer, are likely to be substantial. And, these costs will need to be recovered by selling a service. The overall cost is not just the cost of operating the drone, but all the other items listed. Illustrating the return to the farmer will be key to ensuring success. The actual value of drones is in the data and information they collect, but the value to dairying is in the 'intelligence' that can be developed from that data. This means that a drone is necessary but not sufficient to deliver the gains. It must be combined with other technologies to develop useful knowledge/intelligence. If the intelligence cannot be delivered at a price-point that is acceptable, then uptake will be slow, and the benefits won't crystallise.

4.1.2 Forestry

Section highlights: Forestry activity covers large swathes of land, making drone use ideal to improve sector performance. Using drones to improve disease control is a good example of such an improvement. Two diseases, Dothistroma and Cyclaneusma, were considered and the potential gains from better disease control from using drones, were estimated. The gains are in the form of lower cost and improved yields. In addition, using drones to combat Paropsis Charybdis (tortoise beetle) will also deliver benefits. Importantly, there is a lag between when drones are used and when the benefits are felt because the impacts arise when the timber is harvested and not when the disease/pest management is undertaken. The overall benefits are estimated between $91m and $149m (NPV over 25 years).

Forestry is an important part of the New Zealand economy. In 2017, the sector employed 5,900 people up from 5,400 in 2010. Estimates put the number of forest owners at 11,750. There are 1,750 owners with more than 40ha of forests. The vast majority (95 percent) owned between 40 and 999 hectares of forest (14% of the total area). In contrast, the 5 percent of owners with +1,000ha accounted for 69 percent of total area. The number of owners with less than 40ha is difficult to estimate but is likely to be over 10,000. (Shelly & Andrews, 2015). It is estimated that these owners represent around 16 percent of total forest area. Ninety-six per cent of New Zealand's exotic forests are privately owned.

Like agriculture applications, forestry could also benefit from adopting drone-technologies. The key applications include:

- Mapping and aerial surveying. While drone-based mapping of entire forests/plantations might not be practical under the current restrictions on BLOS flights, drones are nevertheless useful in mapping smaller blocks. Drones can be used to estimate pre-harvest inventory, 3D mapping, and aerial surveying[50]. Collecting data on specifics such as identifying damage, post-harvest waste, cut-over and so on, could be done with drones
- Monitoring. Drones allow stakeholders to monitor key parameters like growth rates, volume, canopy cover (and height), and so on. In addition, regulatory agencies can apply drones as part of compliance checks e.g. using drones during harvesting[51] to assess compliance. Drones can also be used to monitor tree health and help detect illegal activity[52]. Drones can cover a large area in a relatively short period of time, meaning some tasks can be done at a higher frequency (and more cost-effectively) compared to current alternatives e.g. on foot, by vehicle or helicopter.
- Applying fertilizer or pesticide. Once the symptoms/issues have been identified, it may be possible to also use a drone to deliver pesticides or appropriate chemicals in a highly targeted manner. The potential value of such targeted application lies in the ability to reduce the total volume of chemical that is applied. (This is similar to the Variable Application Rate discussed in the preceding section)

Currently, the use of drones in forestry is limited by a combination of regulatory, technical and topographical constraints. Earlier research has indicated that conventional methods (i.e. fixed wing aircraft) are more cost effective for larger forestry blocks (>200ha). This is however, based on the current technology and regulations and there could be opportunities to substitute manned aircraft for drones if

[50] https://openforests.com/drone-mapper/
[51] Marlborough District Council. https://www.radionz.co.nz/news/regional/287157/marlborough-council-sends-in-the-drones
[52] https://www.worldwildlife.org/stories/drones-provide-an-up-close-look-at-the-health-of-forests.

routine BLOS operations are approved. In addition, the endurance of drones would need to improve before the associated opportunities can be captured.

As at 1 April 2017, over 1.7million hectare (net stocked) area was planted. The area by species is summarised below:

Specie	Ha ('000)	% of total
Radiata Pine	1,536	90.0%
Douglas-fir	104	6.1%
Cypress species	10	0.6%
Other softwoods	23	1.3%
Eucalyptus	22	1.3%
Other hardwoods	12	0.7%
Source: Ministry for Primary Industry		

Radiata Pine is the main species being grown. It is expected that most of the benefit would be associated with this species, but there could be benefits if drones are deployed in the other species. But, in light of the size of Radiata Pine as a share of the total area, we focus on this species.

The potential benefits of drones in forestry are anticipated in areas associated with improved disease control and pest management. Improved disease control will lift yields whereas better pest management could result in import substitution. A scenario approach is used to estimate the size of the benefits. The earlier work of Shelly and Andrews (2015) forms the basis for the analysis and scenarios.

While there are several aspects of forestry operations that could benefit from drones, some of these are unlikely to deliver very large and material benefits when compared to existing approaches and alternatives. For example, cut-over mapping could be improved using drones and this could deliver cost savings but in the overall context, this is not expected to be very large. Most of the gains will be in disease detection and control.

Using the same approach followed by Shelley and Andrews (2015), the potential benefits of using drones in forestry are estimated. The benefits are in the form of avoided cost associated with spraying and treatment and avoiding losses associated. The following diseases and pests are included: *Dothisroma, Cyclaneusma* and Eucalyptus Tortoise Beatle *(Paropsis Charybdis).*

The benefits are estimated by considering:

- the age profile (of the trees when they are most susceptible),
- the average price ($\$/m^3$), and
- the share of existing losses that are avoided.

The potential losses from *Dothisroma is estimated* at $0.5m^3$/ha planted area (by age of the trees). The area planted and age of the forestry assets are based on information published in the 2017 National Exotic Forest Description. In addition to the loss due to the diseases, there could be opportunities to displace (substitute) radiata with locally grown hardwood. Around two thirds (64%) of the hardwood grown in New Zealand is Eucalyptus but Eucalyptus sub-species are susceptible to the Eucalyptus tortoise beetle, *Paropsis Charybdis.*

The avoided losses are presented in the context of the existing management regime and the cost associated with manned flights. It is worth noting that the benefits do not materialise immediately – treating the diseases may reduce the effects (increase yields) but the benefits will only manifest when the trees are harvested. **This means that there is a lag between switching to drones and when the benefits are felt**. This assumes that using drones to manage the diseases (apply the chemicals) will improve the outcomes (i.e. better coverage and lower application rates). The cost savings arising from using drones vs manned aircraft are included in the assessment based on the cost differential ($/ha) between the two approaches.

Little information explaining the uptake and use of drones in the sector could be found. Like dairying, assumptions around uptake rates were used to illustrate the anticipated scale of benefits. Importantly, this assumes the drone market can actually deliver the services that are required.

KEY FINDINGS

The potential benefits of using drones in forestry are presented below. There are several uncertainties and unknowns, and these are addressed using assumptions and a sensitivity analysis is used to show the range of the benefits. The potential benefits are discussed for improved disease management and then hardwood substitution.

Improved disease management

It is difficult to put a firm number on the likely uptake of drones for improve disease management. As indicated earlier, there are around 11,750 forestry owners with most (85%) owning forest estates of less than 40ha. This group is considerably larger than the other size cohorts and we assume that the uptake of drones is influenced by ownership size. The owners of smaller forests are assumed to be more price sensitive and elect to use drones to better manage their costs. We assume the following uptake rates:

Uptake	% using drones	Number	Area covered
Small (<40ha)	65%	6,500	63,600
Medium (40-999ha)	25%	416	21,400
Large (+1000ha)	10%	9	42,800

Based on the assumed uptake rates and applying it to the total area that is susceptible[53] to *Dothisroma* suggests that a total of 127,800ha could be treated using drones. Under these uptake rates, 21% of the total susceptible area would be treated using drones. A 10-year uptake rate is assumed. The specific transition pathway is a function of the available substitutes (e.g. manned aircraft) and their costs. The actual benefits of drones are the cost savings and the improvement in disease management. That is, avoiding the losses associated with the diseases. In addition, there are other benefits like the environmental gains of limiting the applications/spraying of toxic substances.

Dothistroma

Dothistroma is controlled by various means ranging from pruning/thinning to chemical spraying[54]. The New Zealand Farm Forestry Association (NZFFA) advises a pruning regime with up to five rounds of pruning. Spraying with copper is generally reserved until the level of infection reaches approximately 15% - 20% of trees. The improvement/gains from using drones (vs manned aircraft) are put at between 40% and 60%

[53] Radiata Pine is susceptible to Dothistroma between the ages of 1-15years.
[54] Cuprous oxide or copper oxychloride.

but we take a conservative approach and estimate the effects using a 30% improvement. *Dothistroma* affects Radiata trees that are between 1y and 15y.

Table 4-1 summarises the base results and the sensitivities associated with using drones to combat *Dothistroma*. The analysis shows that the potential benefits arise from cost savings.

Table 4-1: Dothistroma – Estimated benefits of using Drones

Item	Min (8%)	Mid-point (6%)	Max (4%)	Annual Max (undiscounted)
	($'m)			
Base				
Cost savings	39.7	50.0	64.1	6.0
Gains from improved value	3.1	4.4	6.4	2.1
Sensitivities				
Greater cost difference (vs Manned Aircraft) +20%				
Cost savings	47.6	60.0	76.9	7.2
Gains from improved value	3.1	4.4	6.4	2.1
Improved effectiveness (+20%)				
Cost savings	39.7	50.0	64.1	6.0
Gains from improved value	4.5	6.4	9.2	3.0
Greater Uptake (+20%)				
Cost savings	47.7	60.0	76.9	7.2
Gains from improved value	3.7	5.3	7.7	2.5
Maximum (100%) uptake				
Cost savings	190.0	239.2	306.5	28.7
Gains from improved value	14.8	21.2	30.7	10.1

Overall, the size the benefit is put at $6m per year for the base case. Under the maximum uptake scenario, where the entire (susceptible) forest estate is treated using drones and not manned aircraft, the cost saving is $28.7m (per year). Over the assessment period (out to 2042), the value of the savings is estimated at between[55] $39.7m and $64.1m with $50.0m. The main points of the sensitivity analysis are:

- Using a higher cost difference (+20%), that is assuming that drones can deliver the spraying service more cost effective than current approaches, increases the cost savings by the same ratio. The annual saving increases from $6.0m to $7.2m (once fully transitioned after 10 years).
- In terms of improved effectiveness, increasing the rate by 20% lifts the potential benefits from between $3.1m and $6.4m to between $4.5m and $9.2m. The annual maximum increases from $2.1m to $3.0m.
- If greater uptake is facilitated, then the benefits of using drones will be greater. Using higher uptake rates (+20%) means that the overall area (ha) being treated using drones is estimated at some 25% of the susceptible area (153,000ha). Under this scenario, the total cost savings is put between $47.7m and $76.9m and the annual maximum saving is $7.2m. Covering a larger area will

[55] The range reflects different discount rates.

also deliver improved values (from better yields) and this is estimated at between $3.7m and $7.7m.

Combining the cost savings and gains from improvements, show the overall benefit from drones is substantial. Over 25 years could be in the order of:

- Base $54.4m,
- Improved effectiveness $64.4m,
- Greater uptake $65.3m,
- Maximum uptake $260.4m.

<u>*Cyclaneusma*</u>

Drones can also be used to combat another disease – *Cyclaneusma.* The approach followed to estimate the benefits of using drones for this follows the same structure and approach as with *Dothistroma.* The main difference is that susceptibility to the two diseases covers different age cohorts. Radiata Pine is susceptible to *Cyclaneusma* between the ages of 6 – 20 years and impacts growth resulting in losses of some 6.6% (in m^3/ha). Avoiding yield losses translate into the benefits. Table 4-2 summarises the results.

Table 4-2: Cyclaneusma - Estimated benefits of using Drones

Item	Min	Mid-point	Max	Annual Max (undiscounted)
	($'m)			
Base				
Cost savings	38.4	48.4	62.0	6.0
Gains from improved value	5.8	8.0	11.1	2.1
Sensitivities				
Greater cost difference (vs Manned Aircraft) +20%				
Cost savings	46.1	58.1	74.4	7.2
Gains from improved value	5.8	8.0	11.1	2.1
Improved effectiveness (+20%)				
Cost savings	38.4	48.4	62.0	6.0
Gains from improved value	8.4	11.5	16.1	3.0
Greater Uptake (+20%)				
Cost savings	46.1	58.1	74.5	7.2
Gains from improved value	7.0	9.6	13.4	2.5
Maximum (100%) uptake				
Cost savings	183.9	231.6	296.8	28.7
Gains from improved value	28.0	38.4	53.3	9.8

The scale of the benefits arising from using drones for *Cyclaneusma* is broadly similar to those estimated for *Dothistroma,* especially the cost savings component. Other observations include:

- Under the base case, most of the benefits arise due to the cost savings. The savings (in NPV terms over 25 years) are estimated at between $38.4m and $62.0m. The annual maximum is $6.0m. The gains from improved yields (avoided losses) are almost double that of *Dothistroma,* coming in at between $5.8m and $11.1m.

- Applying a greater cost difference shifts the overall benefit by the same percentage because there is a direct relationship between the cost factor used and the area (ha) covered.
- The gains from improved value are greater. This is partially a function of the effect of *Cyclaneusma* on yields and then avoiding the losses. Under the higher effectiveness scenario (+20%), avoided losses are predicted to be 44% greater than the based scenario (under the mid-point setting).
- The greater uptake scenario (+20%) points to higher cost savings as well as a lift in gains from improved value. The costs savings are up from $48.4m to $58.1m and the additional gains from avoided losses are $1.6m (under the mid-point discount rate).
- If all susceptible forests are treated using drones (680,500ha), then the cost savings would be in the order of $183.9m to $296.8m. The avoided losses are valued at between $28.0m and $53.3m.

Overall, the use of drones in forestry to better manage *Cyclaneusma* could deliver:

- Base $56.4m,
- Improved effectiveness $66.1m,
- Greater uptake $67.7m,
- Maximum $269.9m.

Substituting hardwood (Paropsis Charybdis)

Eucalyptus species are grown on 22,300ha across New Zealand and account for 64% of hardwood species. Eucalypt subspecies grown in New Zealand are susceptible to the tortoise beetle (*Paropsis Charybdis*). Tortoise beetles are currently controlled through aerial spraying of a broad-spectrum synthetic pyrethroid insecticide. Unfortunately, the insecticide also kills other insects, including native insects. Ongoing research is attempting to identify biological control agents (e.g. parasites and fungal diseases that will attack the tortoise beetle) and alternative sprays.

Shelly and Andrews (2015) assert that drones 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 drones that are suitable for spraying disease would be appropriate for spraying pests. Application of sprays or other control agents would often need to be conducted using BLOS.

Effective control of tortoise beetle could allow Eucalyptus to be more commercially viable, enabling larger quantities of eucalyptus to be planted and harvested. Using the logic outlined in Shelly and Andrews around substituting hardwood imports for locally grown hardwood, we estimate the potential value to NZ of such substitution. Managing tortoise beetles is an important factor that would be considered before an investor would convert to Eucalyptus, but it is not the sole determining factor. Therefore, the benefits outlined in this section must be treated with caution because they are illustrative. The gains are also net of alternatives like replanting with Radiata.

Eucalyptus has an average rotation of 19 years compared to Radiata Pine's 29 years. Over 25 years, the net gain to NZ from effective control of Eucalyptus pests could, therefore, be in the order of $54.1m per year if all sawn hardwood imports are displaced with Eucalyptus. This accounts for the shift in use from Radiata (and the loss of that value). It is worth noting that this is if <u>all</u> hardwood imports are substituted.

In reality this is unlikely to occur[56]. If 10% of the imports are substituted, then the value to NZ would be between $19.1m and $40.7m. The equivalent figures are $47.9m and $101.8m if 25% of hardwood imports are grown locally.

The benefit of using drones is mostly associated with BLOS and not LOS applications.

Potential benefits of displacing hardwood imports:

Discount Rate		$'m
Present value (25 years)	**Low (4%)**	407.2
	Medium (6%)	278.3
	High (8%)	191.5
Annual max		114.1

There are concerns over the toxicity of copper to aquatic life. High concentrations of copper have been detected in streams an hour after spraying in areas with young trees and without riparian vegetation. However, mature trees and riparian vegetation resulted in little copper being detected (in streams). Using drones to limit the amount of chemicals applied will have environmental benefits but it is not possible to value these benefits. Nevertheless, the environmental gains could be material because targeted application will avoid situations where large swathes of forests are sprayed (with indiscriminate effects).

4.1.3 Other agriculture

Section highlights: Drone-technologies can also be used in other farming activities, like sheep and beef, horticulture and the like. There is little existing research on how drones could be used in the NZ context so international literature about precision agriculture is used. The information suggests that the benefits could range between $403m-$870m for LOS-services, increasing to $710m - $1,169m for BLOS-based services.

New Zealand has large areas with rich soils and good climate conditions, and it is not just dairying and forestry that could gain from drones. Other primary sector activities could also gain. For example, horticulture as well as sheep and beef farming could also gain from adopting drone-technologies.

<u>Horticulture</u>
We do not have any data on the potential changes that using drones could deliver to horticulturalists. Therefore, we use the following assumptions. We assume that horticulturalists would use drones to implement precision agriculture (e.g. variable application rates) and that this would result in cost savings. These cost savings are in the form of lower inputs from chemical suppliers (fertiliser and pesticides). In addition, the overall process would also see a lift in the degree of automation with a change in the level of inputs needed from the support sectors. The usefulness of drones to horticulture is unknown because there are many other 'land based unmanned vehicles' that are being developed and already in use. To illustrate the potential gains from using drones, we assume that quarter of horticulture businesses will use the opportunities, and the (net) savings[57] would be around 10%. The uptake is distributed over 10 years. Based on these assumptions, the potential benefits are estimated as follows:

[56] Factors like the location of growing areas relative to processing plants, local cost structures, climate considerations and market prices all play a role in determining if a development is viable or not.
[57] After adjusting for costs to deliver/procure the drone services.

	$'m		
	4%	6%	8%
Horticulture benefits	76.6	63.2	54.5

Importantly, these gains do not reflect a lift in output (like the lift associated with pasture management). The benefits are purely based on substituting existing processes for new drone-based processes.

Sheep and beef

In contrast to dairy farms, sheep and beef farms differ considerably depending on their location in New Zealand and the farming system. To estimate the potential benefits to sheep and beef farms of using drones we update the work completed for Callaghan Innovation (Shelly & Andrews, 2015). The approach covers:

- North Island
  - Hard hill country,
  - Hill country,
  - Intensive finishing.
- South Island
  - High country,
  - Hill country,
  - Finishing-breeding,
  - Intensive finishing,
  - Mixed finishing.

For each farm-type, Beef + Lamb model farm profit information was extracted (Beef + Lamb, 2018) and the performance ratios were replicated. In general, sheep and beef farms are bigger than dairy farms so the drone costs are commensurately greater. The potential impact on profitability is based on improved pasture management. In terms of the uptake rate, it is assumed that between 15% and 25% of farmers make use of drone-technology and that the minimum increase in profitability below which a farmer would not use the technology is set at 5%. The analysis illustrates that drones could deliver benefits to sheep and beef farming that is between $284.4m and $413.3m. Table 4-3 summarises the sensitivity analysis

Table 4-3: Sheep and Beef (LOS) – sensitivities

	NPV (25 years); $'m		
	4%	**6%**	**8%**
Base	284.4	328.0	413.3
Faster uptake (5 years)	348.7	395.7	486.0
Higher uptake (25%)	349.4	408.4	514.5
Lower threshold (3%)	294.5	336.1	423.4

Relaxing the assumptions and using more aggressive assumptions all lift the anticipated benefits as shown in the above table.

With reference to BLOS services, those farms that are on 'hill country' will see the largest increase in net benefit. The analysis suggests that the hill country in the South Island will see the largest gain (relative to the LOS). Under LOS, these farms' gains are too small for them to consider using drones. But under BLOS, the gains are greater than the 5% threshold (mentioned above). For these farms the gains under BLOS are put between $68.9m and $107.0m. For the other hill country farms the gains of BLOS over LOS range between 113% and 143%. The non-hill country farms see much smaller gains from using BLOS (vs LOS) with the improvements falling in the 23% to 62% range.

The results from the sheep and beef analysis were transferred to (with several adjustments) deer and livestock farming sector. Overall, these sectors are relatively small, and the potential benefits are put at between $8m and $18m. Grain farming will see a gain of between $13.1m and $29.8m (over 25years).

4.2 Utilities

Section highlights: Utilities, specifically the electricity network, will see benefits from more drone use. Transpower is already using drones and is investigating the potential to make more use of drones. The benefits are associated with improving network reliability, through improved condition assessments and reducing unplanned interruptions. In addition, the costs associated with inspections can be reduced. The benefits (NPV over 25years) are in the range of $21m to $192m. This is a wide range and reflects alternative ways of applying the Value of Lost Load parameters.

Utilities cover a wide range services and typically refer to services like electricity, water, wastewater and stormwater, provided to the wider public. Utilities are often subject to some form of public control and regulation. With reference to the use of drones, the electricity sector is seen as an obvious user of the technology. In fact, Transpower is already using drones. Other utilities, like water and wastewater, could also use drones but these are likely to be land, subterranean or surface based and therefore excluded from this analysis.

The electricity sector has investigated the use of drones as part of its ongoing drive to modernise the sector, manage costs and improve safety. New Zealand's electricity network is extensive, covering over 105,000km[58] (overhead lines) and is distributed over a large area. Eighty-two per cent of overhead lines are in non-urban areas. 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 anomalies.

Transpower reviewed opportunities for using drones in the electricity sector. **The main benefit of using drones in the electricity sector (Transpower, 2017) is associated with removing inspection personnel from potentially hazardous situations and to gather information more efficiently.** Transpower identifies the following potential applications for drones:

- Visual inspection,
- Corona detection,

[58] This figure shows the lines owned by electricity distribution companies.

- Thermal inspection,
- Under-build inspection, and
- Vegetation management.

Currently, most drone applications are carried out in LOS missions, but it is expected that the benefits of drones will increase over time as BLOS operations become more widespread. Developing BLOS capabilities should allow for large scale inspection missions, wider area/incident response, and the gathering of high(er)-quality data with low risk to personnel.

Work completed by Transpower and Unison Networks (as reported by Shelly & Andrews, 2015) suggests that the overall improvement (benefit) arising from using drones would be through enhanced, pro-active maintenance and therefore reducing the unplanned electricity interruptions. Using work done by Unison and applying it to the wider network makes it possible to estimate the network wide (across New Zealand) implications. Unison tested two scenarios and these are applied here. The scenarios reflect how the drones would be managed i.e. centralised by way of a booking system or decentralised through an outsourced approach.

Unison estimated that the net benefit to Unison would be in the order of $150,000 per year under the centralised approach and between $100,000 and $700,000 per year (best estimate of $350,000 per year) for the outsourced approach. The net benefits are delivered through a combination of:

- Better (timelier and more focused) information about the network,
    - Reduced reactive maintenance (better information allows better planning and better targeted proactive maintenance so less reactive is required)
- Improved response times and reduced outage times – the drones can identify the location of the outage so that crews can travel directly to that location, and
- Reduced routine maintenance – the lower cost of drones relative to helicopters means that inspections can be conducted more frequently, and routine maintenance can be better targeted.

Unison reported that a significant portion of the potential gains were related to vegetation encroachment, with more frequent inspections being more likely to detect issues with vegetation and enabling better responses.

We apply Unison's estimates to the other electricity distribution companies using information like kilometre overhead lines. We ignore those instances where the benefit would be less than $25,000. **The analysis suggests that the annual benefit to electricity distribution companies could be between $2.8m and $6.7m per year (subject to uptake).**

A by-product of the improved management is reduced outages to consumers – residential and business. Using the concept of Value of Lost Load (VoLL), the benefit of avoiding outages can be estimated. VoLL represents the economic value ($/MWh) that a consumer places on electricity they plan to consume but do not receive because of an interruption. The VoLL ranges between[59]:

- $VoLL_{Min}$ $17,000/MwH,
- $VoLL_{Centre}$ $25,000/MwH, and
- $VoLL_{Upper}$ $40,000/MwH.

The cost of an interruption can be calculated by multiplying VoLL by the amount of electricity that would be lost in a power interruption. VoLL is an important indicator when considering the size of a benefit/cost

[59] Based on PWC (2018)

of investing to avoid interruptions. It is important to note that the VoLL is a useful measure but that it attempts to express a very complex landscape in one, single figure and is determined by the attributes of the catchment being serviced, including:

- The composition of users (residential vs large industrial),
- The duration of the outage,
- The time of the outage, including the day (peak time vs off-peak and weekday vs weekend), seasons (winter vs summer), and
- The Points of Supply (PoS) on the network where the outage originates.

Clearly, there are many factors to consider when applying the VoLL, meaning that the results presented here should be seen as high-level only. Using these metrics (VoLL) and applying it to the outages that could be avoided, suggests that the VoLL across the entire network could be:

- $VoLL_{Min}$ $10.1m,
- $VoLL_{Centre}$ $14.8m, and
- $VoLL_{Upper}$ $23.7m.

This assumes that all electricity distribution companies take up the opportunities presented by drones. However, this is unlikely because the companies will have different risk profiles, ability/appetite to implement and respond to new technologies.

Several different scenarios were considered to show the range of effects based on the different attributes. Appendix 8 outlines the scenarios and the findings.

The potential benefits to the electricity sector and consumers from using drones could be substantial. The main points are:

- The benefits are split into two parts, firstly the potential cost savings that electricity companies could enjoy if they use drones and secondly, the value of improved network reliability.
- Improved network reliability arising from using drones is the main benefit. How the reliability manifests (i.e. which electricity distribution companies take up drones) will drive the scale of benefits. Using the central VoLL value ($25,000/MwH) and a 6% discount rate suggests that the benefits would range between $19.6m and $94.5m (in NPV terms).
  - If the uptake is concentrated in the distribution companies with large networks (largest km of rural overhead network), then the benefit would be the greatest. The potential benefit is estimated at between $78.4m and $116.1m (using the central VoLL and different discount rates).
  - The second highest benefit will arise if uptake is concentrated in distribution companies with the largest potential SAIDI gains. The potential benefit of using drones is estimated at between $60.0m and $88.8m.
  - If uptake focuses on the electricity distribution companies with the highest use per ICP, then the benefits are estimated at between $35.2m and $52.2m.
- In terms of the cost savings, the overall values are smaller than the benefits arising from improved network reliability. Regardless, these savings are important because they reflect the size of the incentive to change behaviour. If the drone opportunity is explored using internal resources, then the cost savings could be between $7.9m and $17.3m. This range is due to the different uptake scenarios. If all electricity distribution companies migrated to drones then the cost savings would be between $26.5m and $62.5m, depending on how the drone services are procured.

There are several unknowns and the scenarios reflect some high-level assumptions around uptake rates and the distribution across the sector. Changing the input parameters show how sensitivity the benefits are, highlighting the effects of higher or lower industry uptake. The sensitivity analysis revealed the following:

- Doubling the time it takes the industry to introduce drones to 10 years, reduces the benefits so that only 83% of the anticipated effects are felt. Halving the time, increased the benefits by 11%.
- If the uptake rates are greater and 90% of the (relevant) electricity distribution companies switch to drones, then the benefits are expected to lift by 12.5%. Similarly, if only 70% of electricity distribution companies switch to drones, then the benefits would be 12.5% lower. This is because there is a linear relationship between the level of benefits and drones use. An uptake rate of 80% is used but this might be unrealistically high and might not reflect sub-regional considerations and constraints. However, as drone-technology improves, the use is likely to become more widespread. Therefore, the issue is more associated with the timing (of uptake) than the level of use.

The sensitivity analysis suggests that drones will be valuable because they drive down costs and improve reliability for distribution companies that:

- Service very large areas (spatially dispersed),
- Have large rural communities.

This illustrates the benefit of drones i.e. that they make it easier and more cost effective to oversee large areas, improving network resilience. By extension, the unplanned outages are then reduced/avoided. Coupled with labour pressures in rural areas and the difficulties in attracting suitably qualified staff means that drones could be a way to get around these issues (i.e. access to staff). Similarly, with networks in rural areas, the potential to use drones in the short term is also greater than when compared against urban opportunities. This is because there are fewer buildings to fly over, however owner approval is still needed when flying over private properties.

It is worth viewing the potential benefits in the context of risk – using a drone is not risk free. A drone could malfunction and potentially cause an outage. In September 2015, a drone near Waimate lost communications and automatically returned to base. During its return, it struck a 220kV transmission line and became struck. Its removal necessitated a reconfiguration of the network and a line crew to do the work. The retrieval process took three hours. A similar incident was recorded on Northpower's network (Transpower, 2017). Using the VoLL and SAIDI information for Northpower, suggests that the three-hour is valued at $1.3m (ranging between $870,000 and $2.0m). The value depends on the point of loss, the actual duration and the electricity users that were affected. This is almost equivalent to two years' worth of benefits that using drone could deliver in the Northpower area. This points to the degree of reliability and performance that is needed from drones so that the technology will deliver sustainable and long-term benefits. It also underscores the need for drone-technology (and operators) to build the sector's reputation. A small number of incidents could negatively impact public (and industry) perceptions about the viability and suitability of using drones.

4.3 Transport (parcel delivery)

<u>Section highlights</u>: There is a lot of articles in the mainstream media about how drones are being used to transport parcels. Currently, there are many practical limitations to overcome before widespread uptake can be expected. Nevertheless, the change in consumer shopping patterns (e.g. buying online) means that parcel deliveries and the interface with consumers present opportunities to shift from current transport modes (and models) to drones. The potential benefits are based on cost savings associated with moving to drones, and reducing the transport costs. The benefits will to be in the order of $20.8m-$34.8m (NPV over 25years).

Transport covers many different modes and functions. This section focuses on the transport of goods, specifically parcels. The narrow focus is due to the practical limitations of moving goods using drones[60]. These include issues associated with the 'last mile' of delivery[61] and delivery densities. It is worth noting that reports from four years ago indicated that drones would be used to deliver parcels in 2 years (so two years ago). At the time of writing, internationally the trials are still ongoing and large, widespread roll-out of drone deliveries is not on the immediate horizon.

It appears that one of the main reasons why drones as a delivery option is being pursued is because it removes (or greatly reduces) the human element in the process, thereby lowering overall cost. It also switches the power source to electricity (battery) powered propulsion. However, there are several practical barriers to overcome before widespread transition to drone-based delivery takes place. Some of the obvious obstacles include:

- Payload limitations – currently, the practical limit for a drone is around 2.3kg,
- Security concerns around drones being intercepted or lost,
- Public perceptions,
- Autonomous decision-making (e.g. where to leave the parcel when there is no clear landing/delivery area),
- Hazard detection and avoidance (e.g. trees or powerlines around or a property) or and so forth.

In New Zealand, more than 70 million parcels are processed by NZ Post every year (New Zealand Post, 2017). This excludes parcels processed by the likes of Freightways (DXMail, NZ Couriers, Toll etc.). Based on the information in annual reports, the total number of parcels that are processed in New Zealand could be well excess of 104 million parcels per year[62]. With shifts in how goods are sold to consumers, and new product offers (like MyFoodBag), this figure is expected to increase. International parcels processed (inbound and outbound) have increased by 18% in the past year. Available literature suggests that the parcel market is growing strong and the outlook is also very positive.

The potential gains from using drones to deliver parcels are a function of the cost savings associated with moving from vehicle to drones. The savings are then the reduced vehicle operating costs as well as the associated staff cost savings. Using NZ Post's information (as presented in different integrated reports and annual reports), we estimate the potential savings. The estimate was done by:

[60] In the next section, we explore a more futuristic scenario in which drones can transport people.
[61] This is often used in the context of a supply chain. It refers to the portion of the network chain that physically reaches the end-user's premises. This is often the most difficult/challenging and costly part of the chain.
[62] This is based on available information but many of New Zealand's courier companies do not publish their annual reports, so it is not possible to estimate their market share. In turn, this makes it difficult to estimate the total number of parcels transported around NZ every year.
not be verified because the information is commercially sensitive. The estimate is based on information published by NZPost, Freightways

- Reviewing the transport mode and area where the parcels are delivered i.e. rural vs urban and cycling, walking, motorbike/car, Paxsters or couriers,
- The current estimated cost per kilometre[63] (per mode);
- The potential to shift to drones.

For the baseline assessment, it is assumed that 10% of parcels are shifted to drones for selected categories (i.e. rural, motorbikes and cars and some of the courier services). Truck and air-transport services are assumed to continue without any change. Table 4-4 shows the potential benefits that could be gained in terms of operating cost savings.

Table 4-4: Potential benefits from using drones for parcel delivery

	$m (over 25 years)		
	4%	6%	8%
Base	34.8	26.6	20.8
Higher uptake (aggressive)	74.5	58.4	46.6

The potential benefit from shifting a portion of eligible parcel deliveries to a drone-based system is shown above. Under the base scenario, the gains are between $20.8m and $34.8m. Under an aggressive uptake scenario where 25% of the eligible parcels are delivered using drones, the benefits increase to between $46.6m and $74.5m. Under the higher (aspirational) settings, with 90% of the eligible parcels being delivered by drones, the benefits fall between $141.3m and $225.7m. However, it is difficult to see this level of uptake in the short or medium term.

Looking beyond parcel delivery to the retail landscape, retailers operate in very competitive markets with thin margins. Retailers are always looking for new ways to engage with clients and improve the retail experience while at the same time reducing costs across the supply chain. This includes delivering the goods to customers. Drones could play a part in reducing transport costs because they could cut out parts of the logistics/supply chain, simplifying. These gains would be part of the parcel delivery picture discussed above because NZ retailers are using the existing system.

When it comes to shopping, New Zealanders are increasingly digital, with 66% shopping online in the last 12 months – up from 37% in 2006 and expected to hit 83% by 2026 (Boyte, 2018). According to NZ Post research, 1.5 million New Zealanders shopped online during 2017, spending a total of $3.6m (NZ Post, 2018). This confirms the expectation that there will be lift in demand for parcel delivery services going forward. The potential role of drones in meeting the demand will depend on technology's ability to navigate the practical considerations (e.g. last mile challenges). It is worth noting that consumers are unlikely to replace 'in-person shopping' to be exclusively online. The approach to shopping will be 'blended' with both online and physical channels used. Matters like trust, convenience, social interactions and user experience will remain important across both channels. Using drones as part of the retail offering would need to add to (improve) and lift, the overall retail experience otherwise shoppers are likely to shun the technology. Again, this points to the need for a 'market ready solution'.

[63] Based on the New Zealand Transport Authority's Economic Evaluation Model

4.4 Airports

<u>Section highlights</u>: New Zealand's airports and aviation sectors make valuable economic contributions. Most of the impacts of drones in these sectors will come from replacing human capital (labour). A shift towards transporting people using drones is some time away (20 years) but there are parts of airport operations that can be delivered using current drone technology. The analysis suggests that the potential gain to airports from replacing labour with drones is in the order of $1.5m to $2.2m (NPV over 25 years). This includes using drones for tasks like perimeter monitoring, runway checking and so forth.

The airport and aviation sector will also see benefits from using drones. Several studies on New Zealand's airport and aviation sector illustrate the important role that air transport plays. Using the information in a 2010 report for New Zealand Trade and Enterprise (Knotridge Limited, 2010), the sector's economic impact is estimated. Table 4-5 presents the updated figures.

Table 4-5: Aviation's Economic Impact

Component	Total VA 2017 ($bn)
Aircraft manufacturing and servicing	0.9
Air passenger and cargo services	7.3
Airport operations and support	2.4
Pilot training	0.1
Total	**10.8**

Source: Update of figures in the New Horizon Report

The New Zealand aviation sector is estimated to have a total economic impact[64] of $10.8bn for 2017. The size of the sector and its linkages illustrates how important it is to the functioning of the NZ economy. Most of the impacts (67.6%) are in air passenger and cargo services. With airport operations and support services adding another $2.4bn to the overall impact (22%). Aircraft manufacturing and servicing and pilot training are relatively small components, but combined, they add $1bn of VA to the NZ economy.

The use of drones to replace air transport (passenger and cargo) will have effects on the overall industry. However, most of the effects will be via the impacts on human capital i.e. substituting labour. Morgan Stanley (2018) suggests that commercial adoption (at scale) of using drones to transport humans is more than 20 years away, starting in 2040 and beyond. However, some drone developers are claiming that they will be able to substantially shorten this time. In light of these contrasting claims, we examine passenger transport separately, as a futuristic scenario.

Looking at airports and their current operations, local industry stakeholders suggest that there are opportunities where drones could be used in the short and medium term. The areas where drones could be used are associated with labour intensive tasks, like wildlife management and patrolling perimeter fences. Currently, these tasks are part of a person's daily routine work. Replacing these tasks with drones would free up the human resource to focus on other, higher value work.

[64] This figure reflects the total impact and includes direct, indirect and induced impacts i.e. the total economic flow-on impacts.

The analysis suggests that the potential gain to airports from replacing labour with drones is in the order of $1.5m and $2.2m over 25 years. This assumes that the medium to large airports around New Zealand take up the drone technology over a 5-year period.

During the sector engagement, NZ Airports made several interesting comments around the use of drones around airports. The main points were:

- Drones will be an important part of the overall aviation landscape. and the integration will be critical,
- Drones could be used to unlock regional opportunities e.g. regional services and freight handling,
- If drones replace shuttle services/taxis, then the land area that is required for airport operations would be different.
- Perhaps the biggest issue is unexpected intrusion of a drone into controlled air space, especially around passenger jets.

4.5 Construction

Section highlights: Drones can contribute towards lifting construction's productivity by accelerating data collection, improving data quality and reducing data collection costs. Construction is diverse, with many different sub-sectors and the drones will touch the sub-sectors differently – some parts will be directly impacted (e.g. surveyors, geologists and estimators) and other will be impacted in an indirect manner. Armed with better information, other sub-sectors (e.g. earthmoving, project managers, etc) will also experience gains. These wider gains are spill-overs from better quality data and information. The benefits are estimated at between $690.1m and $1,116.7m (NPV over 25 years).

New Zealand's construction industry is a large employer, with over 210,000 employees and working proprietors. The sector is projected to see sustained growth over the next six years and the growth is expected to be broad-based, covering residential and non-residential construction (Ministry of Business, Innovation and Employment, BRANZ, & Pacificon, 2018). Productivity in the construction sector is an important issue as is evident by ongoing research into the sector's performance by organisations like the New Zealand Productivity Commission.

Globally, drones are starting to be used in construction to assist during maintenance, aerial surveying and mapping, progress monitoring and infrastructure inspection. Land surveyors are turning to drones to acquire accurate (digital) survey data from the air in a fraction of the time (and expense) required by ground-based survey teams. Using reference data and GPS, specially equipped drones can gather three-dimensional cartographic information with an accuracy of within 1 to 2 centimetres after processing. Cartographic surveys are used in many industries (not just construction[65]).

Essentially, drones can be used in the construction industry to accelerate information collection while at the same time improving data quality. The tangible benefits include:

- Increased efficiency,
- Lower costs (of site surveying),
- Improved quality, and
- Enhanced data sets (e.g. moving from 2-dimensional to 3-dimensional information).

[65] Such as forestry, mining and flood and pollution monitoring.

Further, because it is easier and cheaper to collect information, it is possible to expand drone use to more frequent surveying of projects. This increases the quality of information and data inputs used during project management, enhancing process efficiency.

Estimating the potential gains from drones in the construction sector is difficult because the sector is diverse, covering many different aspects. We reviewed several sources (Costbuilder, 2019, Norman, Curtis, & Page, 2014) to identify the specific parts of the sector that would be impacted and how important those parts are in the overall sector. Several construction-related drone operators were contacted to get first hand input into the assumptions, but unfortunately, no responses were received. This means that the following analysis is based on unconfirmed assumptions. Further work is needed to refine and adjust the assumptions and logic. These results are indicative at best.

The construction sector's occupation structure was reviewed and those occupations that could benefit from using drone-derived information were isolated. Examples of the identified occupations include:

- Engineers (geotechnical),
- Quantity surveyors,
- Construction estimators,
- Surveyors and spatial science technicians,
- Geologists, and
- Building inspectors, and so forth.

It was assumed that by using drone technologies (and the improved information), that workers in these occupations would see a one-off productivity gain of around 2%. This suggests that these workers gain about 40-hours per year because of better information that assists them to complete their work faster, reducing the need for rework and lifting the quality of their outputs. Workers in the identified occupations account for around 5% of all construction employees. In addition, because of improved information in the overall construction system, the sector can improve planning and scheduling performance. In turn this increases the productivity of other construction workers, like:

- Construction project managers,
- Project builders,
- Engineering managers,
- Building and engineering technicians,
- Earthmoving plant operators,
- Mobile plant operators,
- Contract, programme and project administrators, etc.

These workers account for a further 16% of construction workers. For this analysis, we assume that these other workers experience a 1% productivity gain based on the effects of the better scheduling (and less idle time). These gains are felt across a large part of the construction sector. Applying these gains to the construction sector's growth outlook provides insight into the potential benefits. It is assumed that the gains outweigh the costs. We assumed that the use of drones is rolled out over 10-years so that 80% of tasks[66] that could use drones are delivered using the technologies. The analysis considered three sub-sectors:

[66] This uses occupations as a proxy. It is also assumed that the productivity gains reflect the costs of procuring the drone services (i.e. is net of the drone costs).

- Residential construction,
- Non-residential building construction, and
- Infrastructure.

Table 4-6 summarises the estimated benefit that could be delivered to New Zealand if drones are used in construction. The table shows the base scenario and an aspirational scenario reflecting higher productivity gains and uptake rates.

Table 4-6: Drones' potential contribution via construction

		$'m over 25 years		
		4%	6%	8%
Base scenario	Direct	423.1	329.5	261.5
	Indirect	693.6	540.1	428.6
	SUM	**1,116.7**	**869.6**	**690.1**
Aspirational scenario	Direct	683.6	546.5	445.6
	Indirect	1,494.1	1,194.5	973.9
	SUM	**2,177.7**	**1,741.0**	**1,419.5**

The modelling illustrates the potential benefits that using drone-technology in construction could be between $690.1m and $1,116.7m over 25 years. On an annual equivalent basis, this is between $27.6m and $44.7m.

Considering the scale of construction, this appears relatively small. But it is important to keep in mind that $-values of construction projects, are very large, and some projects are multi-year. For example, the Kaikoura earthquake damaged 200km of road, 190km of rail and took 2 million hours to repair. The budget for this work is estimated at $1.1bn (excluding other elements of the recovery such as residential rebuilds). The New Zealand International Convention Centre was originally estimated to cost $703m to build and take around 5 years to complete. Regardless of the relative size of drones' contribution, the gains would enable construction to lift its overall productivity.

4.6 Public service, safety and security

Section highlights: Public service, safety and security covers many activities and drones can be used to supplement current activities. Crucially, drones are unlikely to replace current activities and the gains will be though achieving 'better outcomes' with the same resources. Looking at the Search and Rescue (SAR) landscape (Surf Life Saving, LandSAR and Coastguard) suggests that there are some areas where drones can be used. The gains of using drones will be to avoid fatalities and minimising risk to persons. Drones can also be used in firefighting, but the benefits of using drones are associated with limiting the cost of fires – that is the cost in anticipation of a fire, responding to a fire and reducing the consequential costs (of a fire). The benefits arising from drone use in SAR and firefighting contexts are estimated at $869m to $1,495m (NPV over 25 years).

Public service, safety and security include a diverse array of activities. It covers local and central government as well as defence. It also includes areas like:

- The fire service,
- Search and rescue,
- Police force,
- Military/defence force.

Using drones in day-to-day operations of these areas is expected to deliver benefits. Crucially, during the sector engagements it was mentioned that in most cases drones would be used together with/in parallel to current approaches. **It is not seen as a substitute for existing approaches where human presence is needed**. For example, in some cases, immediate medical intervention and assistance would be needed to stabilise an individual before extracting him/her. Therefore, drones would not replace existing systems but would complement them, delivering better outcomes and freeing up resources for alternative deployment. This means that it is difficult to isolate and report on drone-specific benefits because the technology would form part of the wider service.

Drones can be applied by public safety providers in many different ways, including but not limited to:

- Surveillance and intelligence gathering,
- Emergency assistance – delivering emergency medical supplies, e.g. defibrillators; real time data to fire fighters and police,
- Traffic monitoring,
- Search and rescue – using thermal imaging and/or delivering rescue equipment to individuals in need,
- Disaster management and post-disaster recovery by supporting greater situational awareness,
- Assisting with conservation efforts like pest monitoring (using thermal imaging),
- Monitoring waterways for water quality or pollution issues,
- Assisting with crowd control by providing real life information. This includes peaceful events (e.g. concerts) or civil disobedience events (e.g. riots).

The specific role of drones in these applications varies. With reference to drone use by the police (and other organs of state), issues of privacy and civil rights and (inappropriate) surveillance and intelligence gathering was mentioned. Obviously, there are trade-offs and ethical questions around police work and individuals' rights to privacy; but these are beyond the scope of this report. Regardless, these trade-offs and ethical questions are very important and will impact on the future roll-out and use of drones.

The following areas were investigated as part of this study:

- The potential use of drones in a search and rescue context,
- The use of drones in firefighting.

Some background information is also provided.

Search and Rescue (SAR)

The SAR landscape consists of different organisations and entities with the main ones including:

- Surf Life Saving New Zealand (SLSNZ),
- LandSAR, and
- Coastguard New Zealand (CNZ).

These entities are mostly funded through New Zealand lottery grants and donations. Their respective expenditures[67] during 2017/18 were:

- Surf Life Saving New Zealand $9.9m,
- LandSAR, and $2.7m, and
- Coastguard. $$9.9m.

Search and rescue operations are coordinated by either the NZ Police or the New Zealand Rescue Coordination Centre (NZRCC). The different entities record their statistics using the same basic structure:

- Lives saved Where, if the SAR agency had not intervened, a life would definitely have been lost,
- Lives rescued Where a SAR agency locates and rescues a person or people at risk and return them to a safe location.
- Lives assisted Where SAR agencies aid a person or people at low risk, but who, if left, would be at risk.

The statistics[68] for the SAR entities clearly show their immediate impacts. Table 4-7 shows the figures for LandSAR, Surf Life Saving and the Coastguard. In addition to the lives saved by SLSNZ during Search and Rescue Operations (SAROPs), the entity saved 1,221 during 2017/18.

Table 4-7: SAR Statistics

Entity	Lives Saved	Lives Rescued	Lives assisted	Perished
LandSAR	64	187	376	51
Coastguard	28	187	361	23
Surf Life Saving*	15	50	33	

* as part of Search and Rescue Operations (SAROP)

Sourced from: Annual reports

Applying the widely used social cost of a life value of $4.2m, the social value that these entities deliver to New Zealand is evident and the 'value of lives saved' is estimated at $448.7m. If the value of lives rescued and assisted are valued at the same rates as the social cost of a serious injury ($786,000) and a minor injury ($82,000), then the value of the services is a further $295m. In addition to the above statistics, the NZ Police also conducted and oversaw SAR activities that saved 54 lives, rescued 335 and assisted 540 lives. Combined, the value of this activity is $536.7m.

When looking at the statistics over the past number of years, the trend is broadly stable with minor annual movements (up and down). Combining the statistics with New Zealand population data provides a useful starting point to estimate the potential benefit that using drones in a SAR and surf lifesaving context could deliver. Table 4-8 shows the estimated incidents per 10,000 population.

[67] Sourced from annual reports.
[68] The information was sourced from the SAR entities' most recent annual reports.

Table 4-8: Incidents per 10,000 population for SAR and SLS

#/10,000	Lives saved	Lives rescued	Lives assisted	Fatalities
SAR	0.30	1.27	1.82	0.11
SLS	2.22	4.88	246.64	0.03
Source: Own calculations based on Statistics New Zealand and SAR entities' annual reports.				

Assuming that the incidence rates remain constant and applying these to NZ's population projections shows that by 2043, the number of lives lost would increase to around 80. The lives saved would increase to 1,500, lives rescued to 3,650 and the lives assisted would increase to 147,160. It is possible that through rolling out a programme using drones to reduce risks and save, rescue and assist lives (i.e. fewer people are at risk and relatively more people are saved, rescued and assisted). The size of this 'saving' is not known and it is not possible to put a firm figure on this. But it is possible to illustrate the potential value of drones using different assumptions. Table 4-9 shows the potential benefit from using drones in a SAR context. It illustrates the potential benefits from avoiding fatalities, saving lives, rescuing lives and assisting lives. The figures show the gains if 1%, 3% and 5% of the future events are avoided because of drone technology.

Table 4-9: SAR – Potential Benefits (range)

Area	% of anticipated events avoided	Discount Rate; ($'m)		
		4%	6%	8%
Lives saved, rescued or assisted	1%	340.8	257.9	199.5
	3%	1,022.5	773.8	598.6
	5%	1,704.1	1,289.6	997.7
Avoided fatalities	1%	5.5	4.1	3.2
	3%	16.4	12.4	9.6
	5%	27.4	20.7	16.0

The table shows the magnitude of the benefits (s to society) of putting measures in place to reduce the risk to life. Using drones to achieve these gains is one avenue (other options could also deliver these gains). Over a period of 25years, the values are substantial ranging between $199.5m and $340.8m for the 1% scenario (the range reflects the discount rates). These figures illustrate that a small increase (saving) in the SAR efficiency would translate into large benefits for the community as a whole. With reference to avoided fatalities, again we use three shares (%) to illustrate the potential gains. Under the 1% scenario, the present value of the gains over 25-years is estimated at between $3.2m and $5.5m.

DJI (a leading drone manufacturer), reports that between May 2017 and April 2018, 65 people[69] were rescued from dangerous situations using drones. This includes buoys being dropped to swimmers at risk of drowning, finding a party of lost hikers on a mountain and dropping life vests to stranded fishermen. The drones were combined with thermal imaging cameras allowing operators to find people who would otherwise have been hidden from sight and very difficult (even near impossible) to find.

While not shown in the above figures, SLSNZ is overrepresented in the above figures. Over 90% of the potential benefit for lives saved, rescued or assisted is associated with SLS. This is partially due to the

[69] https://www.dji.com/newsroom/news/drones-rescued-at-least-65-people-in-previous-year

nature of SLSNZ's work and coverage across NZ. It also reflects the risks and level of use (people swimming in the ocean) across New Zealand. There are many practical considerations and issues to address before all the benefits can be captured. For example, SAR activities are spatially dispersed meaning that there might be issues with rolling out drones across NZ and all regions. Surf Life Saving is spread over four regions with separate clubs:

- Northern Region (17 clubs),
- Eastern Region (19 clubs),
- Central Region (20 clubs) and
- Southern Region (18 clubs).

In total, there are 74 clubs with over 18,640 members. Making a drone available to each club would require a sizable, one-off investment. Assuming that each device costs $2,000 and each club gets one, then the total investment is $148,000. That is 1.5% of SLSNZ's annual expenditure. Crucially, it is not just providing the hardware that needs to be considered (i.e. the costs) but also things like storage, servicing and maintenance, training, insurance (e.g. public liability) and storage during off-seasons[70]. If the one-off costs are a quarter of the overall cost, then total cost is $592,000. While a large cost in terms of SLSNZ's operating expenditure, when viewed against the potential benefit, it appears comparatively small. The potential to use drones together with the existing approaches (e.g. rigid-hull inflatable boats) and SLSNZ's own spending priorities would determine the potential uptake/rollout of drones.

There are 62 coastguard units that are spread out throughout NZ. The potential to use drones in a maritime emergency, is unknown. Often maritime rescues occur in adverse weather conditions and some distance away from shore. Nevertheless, it is likely that drones could offer some benefits to maritime SAR but the overall gains are unknown and the potential uses are not known.

Based on the feedback and insights from the sector engagements, we do not see a situation where drones replace current SAR methods. Instead, the technology will be used in parallel, and in support of, operations.

Firefighting

Another area where drones are being used is firefighting. The advantage that drones bring to the firefighting process is an ability get a high degree of situational awareness using an aerial view and infrared (thermal) cameras. This enables firefighting crews to see through the smoke to identify hotspots and patterns.

Estimating the potential value of drones in a firefighting capability requires some way to estimate the value, or cost, of fires. There are several New Zealand studies that look at the cost of fires, but they are somewhat dated. Using the key ratios in these reports (with minor updates) and combining the information with international literatures helps to show the potential contribution that drones could make to the reducing the cost of fires. The cost of fires can be expressed as a share of GDP. Ashe, McAneney, & Pitman (2015) report the cost of fire for different countries as a percentage of GDP:

- UK 0.9%,
- Denmark 1%,
- USA 2%,
- Canada 2%, and
- Australia 1.15%.

[70] This should not be a critical issue because many clubs have Rigid Hulled Inflatable Boats (RIBs) that are stored at clubrooms over winter.

In addition to the total value (as a % of GDP), the costs can be grouped into three components. The cost of fires has three components:

- The cost in anticipation of a fire,
- The cost of the response, and
- The cost as a consequence. (Ashe, McAneney, & Pitman, 2015).

New Zealand research[71] shows that, for wildfires and non-residential fires, the costs are concentrated in the 'anticipation component'; accounting for 61% and 59% of the cost of wildfires and non-residential fires respectively. The cost of the response is estimated at 12% and 21%, respectively. The balance is the consequential costs - 26% and 20% for these[72] types of fires.

Clearly, the largest cost component is in the pre-event category and it is not clear how drones could reduce this cost. One possibility could be to use drones to estimate the fuel loads (in rural areas) and to improve fire prevention actions by being more targeted.

To estimate the potential gains from using drones in reducing the total cost of fires, we used the following assumptions:

- The uptake is spread over 10 years,
- The saving (avoided costs) per category is assumed to be:
    - Cost in anticipation -0.05%,
    - Cost of the response -0.25%,
    - Cost as a consequence -0.5%.

To put these assumptions into context, the 2017 Port Hills fire in Christchurch burnt for 66 days, consuming 2,075ha. The 2019 Nelson fire lasted for 29 days and burnt 2,400ha. Reducing the Nelson fire by 1 day equals a 3.4% saving and in the Port Hills case, reducing the duration by 1 day is a 1.5% gain. But, not all fires are of this magnitude and these two examples are at the upper end of the spectrum. We use considerably lower values. We also considered more optimistic assumptions and doubled the above rates (i.e. doubled the level of savings but still below the illustrated percentages). Table 4-10 reports the estimated benefits of using drones in a fire fighting context.

Table 4-10: Potential gains from using drones in firefighting

		$'m		
	NPV	**4%**	**6%**	**8%**
Base	In anticipation	73.0	54.7	41.8
	Cost of response	101.5	76.1	58.1
	As a consequence	281.8	211.3	161.3
	Total	456.3	342.1	261.1
High uptake and increased savings	In anticipation	176.5	136.6	107.7
	Cost of response	245.6	190.0	149.9
	As a consequence	681.6	527.5	416.0
	Total	1,103.7	854.0	673.6

[71] BERL, (2009, 2012). We also considered Monge, Langer, Velarde, & Pearce (2016).
[72] We could not locate similar figures for residential fires.

While there is uncertainty around the uptake rates and the benefits/saving that drones could deliver, the potential savings are substantial. The analysis suggests that applying drones in a firefighting context could deliver benefits ranging between $261.1m and $456.3m under the base case. Using more aggressive assumptions lift the gains to between $673.6m and $1,103.7m (over 25 years). Almost two thirds (61.7%) of the gains relate to reducing the consequential costs of fires. This highlights the devastation that can be caused by fires and underscores potential contribution of drone in a fire fighting context i.e. improving the ability to respond to fire to contain the fires and limit the damage.

4.7 Other

There are other areas where drones could be (and are) used to deliver uses of drones across the economic spectrum, including:

- Photography for real estate marketing. For a residential marketing campaign, the cost of taking aerial photos with a drone is $100-$200. This cost is normally rolled into the overall photographic costs.
- Using drones to take photographs or still images for an artistic purpose.
- Collecting samples as part of environmental monitoring or compliance processes.
- Using drones in a recreational manner e.g. drone racing or competitive flying.
- Using drones in the media, entertainment and filming industries. In 2015, the screen industry contributed over $1bn to the NZ economy (NZIER, 2017). The sector already uses drones as part of the filming process. While we could not find any specific information or literature about the share of activity that is directly related to drones, it is not expected to be large. But in light of the importance of the screen sector to NZ, it would be remiss to not consider this sector's drone needs as part of future policy development processes. News coverage and journalism can use drones to get aerial footage of a story.
- Insurance companies are using drones to collect images of properties before providing cover. This reduces the potential for claims fraud and issues. With the available information, insurance companies can also speed-up the claims process. Of course, insuring drones is another avenue where insurance companies could benefit (i.e. it is a new market)[73].
- Using drones to film sport and community events.
- Manufacturing and inventory management. Robotics are playing an increasingly important role in business and manufacturing processes. The potential use of drones in the manufacturing process is limited but they can be used to estimate inventory.
- Attracting investment to New Zealand in the form of international companies that want to undertake R&D, test prototypes and refine their concepts. This brings foreign exchange to NZ. The drone testing facilities at Kaitorete Spit is specifically mentioned.

A paucity of information limits our ability to estimate the potential value that drones could deliver if they are fully employed across these, and other sectors.

[73] (Shmat, 2018)

4.8 Total effect and aspirational settings

The analysis is generally based on conservative settings, assumptions and uptake rates and the sensitivity analysis use more aggressive assumptions. Adding the benefits across all the considered sectors together gives an indication of the overall scale of the effects. As mentioned throughout the report, the figures are uncertain and subject to many assumptions. The benefits are not guaranteed and are indicative only. For example, consider the feedback from DairyNZ, they indicated that drones are not seen as a likely solution so uptake rates will be very low.

Under the base settings, the aggregate benefits are estimated as follows:

- Aggregate (Line of Sight, Excl Dairying) $1.2bn – 2.3bn,
- Aggregate (Beyond Line of Sight, Excl Dairying) $1.9bn - $3.4bn.

Clearly, these potential benefits are substantial even if they exclude dairying. If dairying is included, the potential benefits increase as follows:

- Aggregate (LOS, Incl Dairying) $2.5bn - $3.9bn
- Aggregate (BLOS, Incl Dairying) $3.2bn - $5.0bn

Whether dairying is included or excluded, the potential benefits are large. We note that the analysis covers 25 years, a long period with a lot of uncertainty. Using a shorter timeframe that captures only 10 years will lower the results. Under a short timeframe that only captures the uptake period and only one year at 100% of the assumed level, the benefits are estimated as follows[74]:

- Aggregate (LOS, Excl Dairying) $463m - $678m
- Aggregate (BLOS, Excl Dairying) $706m - $991m.

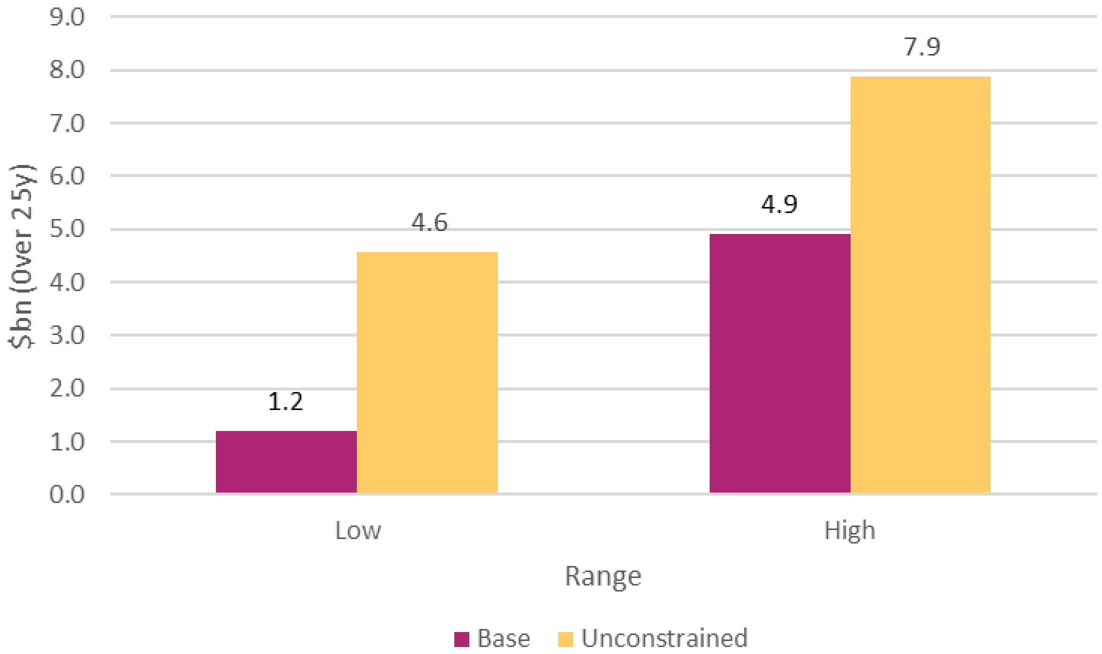
To put these estimates into context, a recent study by NZTech suggest that better use of the Internet of Things (IoT) could deliver net benefits in the order of $2.2bn (ranging between $1.1 and $3.3bn) and compared against $463m to $678m. Taking the information in that study and projecting it out over a 25 period also helps to put the longer timeframe used in this study into context. The long-term value of the IoT is estimated at over $19.5bn compared to the $1.2bn - $2.3bn value estimated for LOS-drone scenarios.

As part of the assessments, we were asked to consider the potential benefits under higher/more aspirational settings. Using more aggressive uptake rates for the different sectors (to reflect a blue-sky scenario), and increasing (relaxing) the assumptions about the share of benefits (cost savings) that manifest, presents a substantially more upbeat picture. Figure 4-1 shows the results.

If the assumptions around uptake rates, appetite to shift towards drone technologies and the potential uses are relaxed, then the benefits are substantially greater. The range shifts from $1.2bn-$4.9bn to over $4.6bn-$7.9bn. This illustrates the upside potential of the technology, but we would caution against reading too much into these figures since they are based on aspirational assumptions[75].

[74] These figures exclude dairying. The estimated range for this sector is $653m - $830m.
[75] The risks associated with using these very high figures were communicated to the Ministry.

Figure 4-1: Aspirational (Unconstrained) Outcomes



Clearly, there are several unknowns and uncertainties that would affect the scale of benefits. The willingness of industries to transition to drone-based technologies, uses and opportunities on the one hand, and the drone sector's ability to deliver the services in a cost and time effective manner, on the other are perhaps the two most pressing issues. The next section discusses two, long term scenarios and looks at the wider flow-on effects.

5 Futuristic scenarios

Looking at the long term, there is still considerable uncertainty about how drones could be used beyond those uses that are currently imagined. One possible way includes shifting how society connects to airports. Another is how deliveries are made. Currently, most of the potential drone applications are hamstrung by poor transport economics, technical limitations and practical considerations. With the ongoing developments in supporting technologies, like Artificial Intelligence, many of these challenges will be addressed, enabling new ways to use drones. Crucially, the challenges around safety, navigation and practical issues (like dealing with weather) are not trivial and should not be underestimated. Regardless, overcoming the challenges will unlock new markets and deliver benefits.

This section considers two futuristic scenarios and explores the potential benefits that they could deliver. It is impossible to put firm or robust estimates on the benefits because the effects and how people or businesses respond to the change are unknown. Therefore, the results in this section are exploratory.

Two scenarios are discussed. The first scenario investigates the potential benefits that drones could have in improving regional connectivity by enabling easier linkages to regional airports. The second scenario looks at using drones as part of the parcel delivery network. These are purely hypothetical scenarios and it is easy to expand them to cover many aspects. For simplicity and to show the potential value, they are kept relatively simple.

5.1 Connecting regional NZ

Most of New Zealand's air connections and air traffic movement take place on the hub-routes: Christchurch, Wellington and Auckland. There are also movements between large[76] airports and regional[77] airports. Small regional airports (and therefore, small regional towns) are facing challenges to retain their air connections. Cost pressures, changes to the aircraft fleet and swings in the international tourism market are impacting on the long-term viability of small and regional airports. These pressures are even more acute at small regional airports (e.g. Whakatane, Kapiti Coast, Whangarei and Whangarei). Recently, AirNZ cancelled the services they provide to some of these airports. While independent airlines, like Air Chathams, have stepped into the market void, the long-term viability of some of these routes remains finely balanced due to:

- Fleet characteristics,
- Operating costs,
- Fuel and input costs (exposed to international commodity prices),
- Infrastructure (airport costs),
- Potential changes in the network configuration.

There are also other dynamics that will impact on New Zealand's domestic airport network, such as AirNZ retiring the Q300-fleet it currently uses to service some regional airports. In some cases, the existing airport infrastructure cannot accommodate larger aircraft (like ATRs, as is the case in Whangarei).

[76] Such as Dunedin, Queenstown and so forth.

[77] Like Tauranga, Rotorua, Gisborne Hawke's Bay, Timaru and so forth.

In future, there could be a case for using drones to transport people between small regional airports and hub or larger regional airports. This means that if the conventional regional services are withdrawn and replaced by drones, then the benefit of the drones are equivalent to the current value of the regional air services plus any costs savings. **This suggests that the potential value of drones could be in the order of $794m[78]. This value is associated with the small regional airports and the economic activity they support in the regional economies.** It excludes the activity of airports (as businesses) or those activities that are associated with airports (e.g. refuelling).

Ultimately, the benefits are in retaining the value that airports, and the air connections they facilitate, are delivering to remote communities. These are especially valuable to small communities like Westport, Hokitika and other small areas on the South Island's West Coast.

In addition to protecting the existing benefits, using drones to enhance the air transport network will deliver a separate set of benefits.

Improved access to regional air services: Most movements on the New Zealand domestic network are between the three key cities – Auckland, Wellington and Christchurch. Three percent of movements were between regional airports. These proportions highlight the hub-and-spoke nature of the NZ domestic network and underscore the importance of domestic connections when considering the overall network. These connections enable rural NZ to connect to international flights and other parts around NZ.

Most towns with more than 20,000 residents have domestic air services. Earlier research for the Ministry of Transport[79] indicated that the main drivers of the domestic air network are:

- The potential number of passengers (size of the local population),
- The cost of operating the aircraft and the relative efficiency of the fleet (cost per passenger), and
- The potential revenue.

These points suggest that the ability to return a suitable profit is the main driving force. In other words, airline behaviour and their ability to generate a profit on a particular route is the first driver of the domestic air network. In addition, route potential is influenced by the size and structure of the local economies that are connected.

There is very little information to draw from to estimate the potential demand for travel between different cities/towns that are not currently serviced by airports. Similarly, there is a general shortage of data on car based regional travel patterns (e.g. people moving between towns). So, the following is indicative at best. It draws on other NZ and international studies to estimate the potential benefits.

The underlying assumption is that if drones reduce the total cost of travel, then it will change travel patterns and how people interact with other transport modes. In turn, this will unlock changes in economic geography. That is, assuming that drones are able to provide a viable transport alternative, then they will change the generalised travel cost[80] users face when travelling between (to/from) cities and towns. By changing the generalised cost, the 'proximity' between locations is altered and this influences how individuals and businesses see the travel relative to the anticipated benefits they receive from that travel.

To estimate the potential benefits arising from easier access to the air transport network, we approached the analysis as follows:

[78] Calculation based on Market Economics, 2013
[79] (Market Economics & Astral Aviation, Future Domestic Air Network Analysis, 2016).
[80] Generalised travel cost includes the sum of monetary and non-monetary costs of a journey.

- We estimated the existing propensity to fly for different areas around New Zealand based on the total number of domestic passenger movement through local airports and the size of the local population[81],
- The population was reviewed and segmented into urban and rural population. The scenario focuses on the rural population component.
- The potential change in passenger demand was estimated by applying the propensity to the rural population and by adjusting the propensity to fly ratios to reflect a lift in demand due to the 'easier' access to airports. The adjustments were based on a comparison across regional airports throughout NZ. The adjustments correspond with increases ranging between 5% and 10%.
- The lift in passenger numbers is then translated into economic benefit. The benefits are based on earlier research for the Ministry of Transport (Market Economics, 2018). The ratios in that study are Value Added (similar to GDP) and they are adjusted to reflect benefits because VA (or GDP) should not be treated as a 'benefit'. The adjustment accounts for displacement effects and the opportunity costs of labour.
- The benefits include the gains associated with different components, like business and domestic travel, change in trade activity and airport related activity. These benefits are applied to 'new travellers'.
- The existing users will experience gains in the form of timesaving. Using the value of travel time (VOTT) ratios in the Economic Evaluation Manual (New Zealand Transport Authority , 2016) and relevant updating factors, the travel time was estimated. It was assumed that existing (rural) users would, on average, gain an hour's travel time saving. This is equivalent to 30 minutes for both the inbound and outbound trips. Business and non-business trips are dealt with separately because business trips have a higher VOTT than non-business trips[82].

The analysis suggests that potential benefits could be material. **Overall, the annual gain is between $53.5m and $145.5m and the range reflects the degree to which wider business activity (interregional trade) is facilitated. The net benefit[83] of the trade component is estimated at between $40.3m and $57.7m. Over the medium (10 years) to long term (25 years), the benefits of using drones to improve regional access to the air network are estimated at (6% discount rates):**

	$'m (PV @ 6%)	
	10 y	25 y
Low	235.9	519.1
High	641.3	1,411.3

These benefits do not account for any costs associated with delivering the drone services (e.g. navigation aids, traffic control and so forth). It also does not include the costs associated with servicing the additional passengers (e.g. airfares, adding new routes or adding capacity on existing routes). It also assumes that there is demand for the services (i.e. that travellers make use of the services and that there is demand for the goods/services associated with the trade).

[81] This is seen as a proxy for propensity to fly.
[82] Based on NZTA EEM values. The 2018 values are estimates as $36.47 and $10.55.
[83] This is based on high level ratios of the compensation of employees (with adjustments for displacement effects and opportunity costs) as well as operating surplus.

With reference to the travel time savings for existing users, this is estimated at between $24.9m and $27.6m per year. Over 10 and 25 years, the time saving is estimated at $54.1m and $119.1m respectively (using 6%).

These values reflect the potential economic benefits arising from a lift in the demand for regional air travel (through the smaller regional airports) and the travel savings for existing users.

Clearly, using drones may enable more individuals to access New Zealand's domestic air networks, building traffic volumes and generating economic benefits. In addition, there are other economic benefits that are delivered to non-travellers and these are referred to as wider economic benefits – WEBs (or wider economic impacts, WEIs). These benefits enable long term growth in economic output and reflect the spill-over benefits of transport gains to the wider economy. WEBs generally consider the long-run employment and productivity changes in the economy. They reflect the change in connectivity, costs and how these changes impact investment, trade, efficiencies, innovation, and competition. The gains are normally measured in terms of:

- **Productivity**: increased efficiency and innovation can occur in the production process, improving the efficiency of firms, and reducing costs to consumers.
- **Investment**: increased investment by firms improves efficiency and productivity. Labour market improvements, competition, and agglomeration can all lead to increased investment.
- **Trade**: increases in trade can lead to higher productivity through specialisation. Agglomeration, competition and increased output in imperfectly competitive markets could all increase the level of trade.

International literature shows that most WEBs are associated with agglomeration benefits. WEBs tend to be greater where the economic density, commuting costs and business benefits are high (Kernohan & Rognlien, 2011). Most of the WEBs are associated with transport improvements within an urban area[84] and not across regions. Nevertheless, some gains could be expected even if they are small.

5.2 Delivery of goods using drones

An area that is often mentioned in drone literature is the transport and delivery of goods. Many types of goods are cited, but consumer goods are the most common, due to their relatively low value and weight. One possible way to use drones could be to deliver parcels to residential and business addresses in an autonomous fashion. The delivery network could be structure in different ways, like a central hub with drones servicing specific areas or a hub a spoke model. Another way could be to have vehicles (trucks) moving along roads with drones then dropping off the parcels at properties.

The design of the delivery network and the practical matters will determine the scale of benefits (and costs) of approaching delivery in such a way. Estimating the benefits that such an approach could deliver is very difficult and uncertain. Factors that make it difficult include the fact that technologies develop at the same time but along different trajectories. For example, when looking at the potential emissions savings of removing trucks from roads, then it is important to also consider that there could be alternative technologies that would reduce emissions (i.e. transitioning from fossil fuels to electricity). This means that the benefits would not be driven by drones alone but by the other technologies. Looking at emissions, the Ministry for the Environment found that found that between 2001 and 2013, estimated emissions for five

[84] Like the Second Harbour Cross in Auckland, the Central Rail Link and internationally for large rail infrastructure projects (e.g. Cross Rail).

key pollutants from road vehicles fell between 26% and 52%. The decrease was put down to improvements to fuel and stricter emission limits on new vehicles. (Ministry for the Environment, 2015). Specifically, carbon monoxide emissions from transport have declined by 46% since 2001 (Ministry for the Environment, 2015).

This means that while using drones as part of the delivery network might lead to a reduction in overall emissions, there are likely to be other areas that will deliver greater gains and trying to estimate the share that is attributable to drones is unlikely to be accurate.

Other potential areas where gains could be experienced include cost savings like reducing human resources costs. These costs include salaries and wages that are paid to delivery drivers (e.g. couriers) and those working at depots. NZ Post indicated (2018) that its employee expense is 64% of its total expenditure. This includes contracted delivery services ($317m), and salaries and wages ($280m). Contracted delivery services incorporate couriers and their salaries and wages is normally between a third and half of the revenue. This suggests that the total salary and wage cost is between $381m and $425m. It is important to note that the potential cost savings from using drones could be at the expense of the labour i.e. a shift towards more capital-intensive ways of working. In addition, the costs of acquiring drones and putting the supporting infrastructure in place are unknown. To put the potential benefits in context, we assumed that the net gains (after accounting for the cost) are in the form of improved productivity gains as well as cost savings. We tested three hypothetical scenarios: 5%, 10% and 25% gains[85] and the analysis suggests that the savings would be reasonable but with a considerable spread.

Table 5-1: Potential gains of using drones for parcel delivery

Scenario	$'m			
	10 years		25 years	
	Low	High	Low	High
5% Scenario	70.0	106.6	140.9	264.3
10% Scenario	140.0	213.1	281.8	528.5
15% Scenario	210.1	319.7	422.6	792.8

Over the short term (10-years), the potential benefits from switching to drones for delivery is estimated to be between $70.0m and $319.7m across the three scenarios. Over the longer timeframe, the potential benefits are greater, coming in at between $140.9m and $792.8m. To put these figures in context, the high estimate under the 15% scenario (for 10 years) is around half, or 46%, of the aggregate total (excluding dairy). Looking at the high estimate under the 15% scenario (25-year) illustrates that for parcel delivery compared to the other estimates, the potential benefits are a third (34%) of those estimated for the aggregate economy-wide benefits discussed in section 4.8.

[85] The gains are a combination of improved productivity and cost savings. The uptake was spread over 10 years.

6 Concluding Remarks

The analysis shows that drones are currently in use across the wider economy but are mostly concentrated in the urban areas and lower value operations. There is limited use of drone applications in large sectors like dairying, horticulture or construction. Forestry is making good use of drones, but it appears that application is not widespread across the country. Anecdotal information suggests that a few operators are having successes in building business opportunities using drones. Based on earlier research, using drones to improve pasture management is identified as one with substantial growth potential. It would be necessary to overcome industry pushback and resistance to using drones before large uptake can be expected. We anticipate that over time, the use of drones will increase – the question is if the natural uptake rates are fast enough. Accelerating the uptake beyond business as usual levels will translate into greater benefits to New Zealand.

While the analysis is underpinned by a number of assumptions and uncertainties remain, the results suggest that drones could assist in lifting productivity across large parts of the economy. Even under constrained assumptions, the benefits are substantial and small changes in drone uptake will multiply through, delivering even greater benefits.

Looking further into the future to opportunities like transporting people with drones, again it is difficult to put a firm figure on the gains. Nevertheless, in light to the potential of drones to disrupt traditional travelling, and how communities connect, the changes can be substantial with positive outcomes.

The growth in drones, using new and emerging technology will not be without any risk. It will be necessary to manage the growth in a way that ensure that opportunities can be captured while minimising the risks.

7 List of References

Airways. (2018). *2018 Drone tracker report.*

Airways. (2018). Drone Tracker.

Anand, S. (2007). *Domestic use of unmanned aircraft systems: an evaluation of policy constraints and the role of indtustry consensus standards.* Washington: Washington Internships for Students of Engineering.

Ashe, B., McAneney, J., & Pitman, A. J. (2015). *The cost of fire in Australia.* Macquarie University, University of New South Wales.

Association for Unmanned Vehcile Systems International. (2013). *Teh Economic Impact of Unmanned Aircraft Systems Integration in the United States.*

Barton, J. (2012). Fundamentals of Small Unmanned Aircraft Flight. *31*(2), pp. 132-149.

Beef + Lamb. (2018). Economic Service. *Sheep and Beef Farm Survey, 2018/19 Forecasts and Quintile Analysis*. Beef + Lamb.

BERL. (2009). *The economic cost of wildfires.* Wellington: New Zealand Fire Service Commission Research Report Number 99.

BERL. (2012). *The economic cost of fire in non-residential buildings.* Wellington: New Zealand Fire Service Commission Research Report, Report no 126.

Bleyenburgh, V. (2006). UAV systems: global review. *Presented at the Avionics'06 conference.* Amsterdam,.

Boucher, P. (2015). Domesticating the drone: The demilitarisation of unmanned aircraft for civil markets. *Science and engineering ethics, 21*(6), 1393-1412. doi:10.1007/s11948-014-9603-3

Boucher, P. (2015, December). Domesticating the Drone: The Demilitarisation of Unmanned Aircraft for Civil Markets. *Science and Engineering Ethics, 21*(6), 1393-1412.

Boyte, T. (2018, May 4). *Online shopping seeing huge growth in New Zealand*. Retrieved from https://www.nielsen.com/nz/en/insights/news/2018/online-shopping-seeing-huge-growth-in-new-zealand.html

Christensen, B. R. (2015). Use of UAV or remotely piloted aircraft and forward-looking infrared in forest, rural and wildland fire management: evaluation using simple economic analysis. *New Zealand Journal of Forestry Science, 45*(1), 16-24. doi:10.1186/s40490-015-0044-9

Coastguard New Zealand. (2018). *Annual Report.*

Cohn, P., Green, A., Langstaff, M., & Roller, M. (2017). *Commercial drones are here: The future of unmanned aerial systems.*

Costbuilder, Q. (2019). *QV Costbuilder*. Retrieved from https://www.qvcostbuilder.co.nz

DeBusk, W. M. (2009). *Unmanned aerial vehicle systems for disaster relief: Tornado Alley.* Atlanta. Retrieved from https://ntrs.nasa.gov/search.jsp?R=20090036330 2018-11-22T23:22:04+00:00Z

Department for Business, Energy & industrial Strategy; Goverment Office for Science. (2017). *The UK value stream for remotely piloted civil aircraft systems (RPAS). Literature Review.*

Department for Transport. (2018). *Taking flight: the future of drones in the UK. Moving Britain Ahead.* London, UK.

Domino's. (2016, November 16). *Pizz-by-drone a reality with world-first customer deliveries in New Zealand*. Retrieved from Domino's: https://www.dominos.co.nz/inside-dominos/media/firstcommercialdeliverydrudronebyflirtey

DroneDeploy. (2018). *2018 Commercial Drone Industry Predictions. DroneDeploy weights in on the future of drones in 2018 and beyond.* San Francisco.

DroneDeploy. (2018). *Commercial drone industry trends.* San Francisco.

DroneDeploy. (2018). Drones for Construction Project Management. San Francisco.

Editor: Sylvester, G. (2018). *e-Agriculture in action: drones for agriculture.* Bangkok, China: Food and Agriculture Organization of the United Nations; International Telecommunication Union.

European Union. (2016). *European Drones Outlook Study.* European Union and EuroControl.

Eurostat. (2018, February 13). *European Commission information* . Retrieved from https://ec.europa.eu/eurostat/data/database?node_code=proj

Gheisari, M., Irizari, J., & Walker, B. N. (2014). UAS4SAFETY: The potential of unmanned aerial systems for construction safety applications. *Construction Research Congress*. doi:10.1061/9780784413517.184

Iizuka, K., Masayuki, I., Shiodera, S., Matsubara, T., Dohar, M., & Watanabe, K. (2018). Advantages of unmanned aerial vehicle (UAV) photogrammetry for landscape analysis compared with satellite data: A case study of postmining sites in Indonesia. *Cogent Geoscience, 4*(1), 1-15. doi:10.1080/23312041.2018.1498180

Irizarry, J., & Johnson, E. N. (2014). *Feasibility study to determine the economic and operational benefits of utilizing unmanned aerial vehicles (UAVs).* Georgia.

Jenkins, D., & Vasigh, B. (2013). *The economic impact of unmanned aircraft systems integration in the United States.* Arlington: Association for Unmanned Vehicle Systems International (AUVSI).

Jones, T. (2017). *International Commercial Drone Regulation and Drone Delivery SErvices.* Santa Monica: Rand Corporation.

Kernohan, D., & Rognlien, L. (2011). *Wider economic impacts of transport investment sin New Zealand.* NZ Transport Agency.

Knotridge Limited. (2010). *New Horisons: Ar report on New Zealand's Aviation Industry.* Prepared for New Zealand Trade and Enterprise.

Land Search and Rescue New Zealand. (2018). *Annual Report 2017/18.*

Market Economics. (2013). *Economic and Social Contribution of New Zealand's Airport.* Wellington: New Zealand Airport Association.

Market Economics. (2018). *Regional Airports - Economic Contribution (Model and Ratios for Indicative Assessment).* Wellington: Ministry of Transport.

Market Economics, & Astral Aviation. (2016). *Future Domestic Air Network Analysis.* Wellington: Ministry of Transport.

McKinsey & Company. (2017, December). Commercial Drones are here: The future of unmanned aerial systems. *Capital Projects and Infrastrcuture*.

Meola, A. (2017, July 13). *Drone Market shows positive outlook with strong industry growth and trends*. Retrieved from Business Insider: https://www.businessinsider.com/drone-industry-analysis-market-trends-growth-forecasts-2017-7/?r=AU&IR=T

Ministry for the Environment. (2015). *Environment Aatearoa.*

Ministry of Business, Innovation and Employment, BRANZ, & Pacificon. (2018). *National Construction Pipeline Report.* Wellington: MBIE.

Ministry of Transport. (2017). *Social Cost of Road Crashes and Injuries* . Wellington: Ministry of Transpor.

Monge, J. J., Langer, E. R., Velarde, S. J., & Pearce, H. G. (2016). *Development of an integrated framework to assess after-fire economic impacts.* Scion.

Morgan Stanley Research. (2018). *Flying Cars: Investment Implications for Autonomous Urban Air Mobility* . Morgan Stanley.

New Zealand IoT Alliance. (2017). *The internet of things. Accelerating a connected New Zealand.* Retrieved from https://iotalliance.org.nz/wp-content/uploads/sites/4/2018/09/Accelerating-a-Connected-New-Zealand-eBOOK.pdf

New Zealand Post. (2017). *Integrated Report 2017.*

New Zealand Technology Industry Association. (2018). Digital Nation New Zealand: From tech sector to digital nation. Retrieved from https://nztech.org.nz/wp-content/uploads/2014/10/from-tech-sector-to-digital-nation-2nd-edition-ebook.compressed.pdf

New Zealand Transport Authority . (2016). *Economic Evaluation Manual.* Wellington: NZTA.

Norman, D., Curtis, M., & Page, I. (2014). *A cost-benefit analysis of improved working at height regulatio.* Porirua City: BRANZ.

NZ Post. (2018). *Integrated Report.* NZ Post.

NZIER. (2017). *The economic contribution of the Screen Industry.* Wellington: November.

Panetta. (2017, August). *Top Emerging Trends in the Garntner Hype Cycle for Emerging Technologies, 2017*. Retrieved from https://www.gartner.com/smarterwithgartner/top-trends-in-the-gartner-hype-cycle-for-emerging-technologies-2017/

Panetta, K. (2018, August 16). *5 Trends Emerge in the Gartner Hype Cycle for Emerging Technologies, 2018*. Retrieved from https://www.gartner.com/smarterwithgartner/5-trends-emerge-in-gartner-hype-cycle-for-emerging-technologies-2018/

PricewaterhouseCoopers LLP. (2018). *Skies without limits. Drones - taking the UK's economy to new heights.*

Probst, L., Pedersen, B., & Dakkak-Arnoux, L. (2018). *Digital transformation monitor: Drones in agriculture.*

PWC. (2016). *Clarity from above. PwC global report on the commercial applications of drone technology.*

PWC. (2018). *Estimating the Value of Lost Load in New Zealand.* Wellington: Transpower New Zealand.

PWC. (2018). *Skies with limits. Drones - taking the UK's economy to new heights.* PricewaterhouseCoopers LLP.

Rao, B., Gopi, A. G., & Maione, R. (2016). The societal impact of commercial rones. *Technology in Society, 45*, 83-90. doi:10.1016/j.techsoc.2016.02.009

Sandbrook, C. (2015). The social implications of using drones for biodiversity conservation. *Ambio, 44*(4), 636-647. doi:10.1007/s13280-015-0714-0

SenseFly. (2016). *Flying High - how a french farming cooperative used drones to boost its members' crop yield.* Cheseaux-Lausanne, Switzerland.

SESAR Joint undertaking. (2016). *European Drones Outlook Study.*

Shakhatreh, H., Sawalmeh, A., Al-Fuqaha, A., Dou, Z., Almaita, E., Khalil, I., . . . Guizani, M. (2018). Unmanned aerial vehicles: a survey on civil applications and key research challenges. *arXiv preprint arXiv:1805.00881*.

Shelly, A., & Andrews, H. (2015). *Economic benefits to New Zealand from Beyond-Line-of-Sight operation of UAVs.* Callaghan Innovation.

Shmat, D. (2018, February 01). *Taking to the skies - using drones in the insurance industry*. Retrieved from Digital Transformations in Banking and FinTech: https://www.cio.com/article/3252093/taking-to-the-skies-using-drones-in-the-insurance-industry.html

Steger, I. (2018, January 18). *A drone was just used to rescue swimmers, and it recorded the whole event*. Retrieved from Quartz: January 2018. Website: https://qz.com/1182580/lifeguards-in-australia-make-history-by-using-a-drone-to-rescue-swimmers/. Date accessed 20/02/2019.

Stribling, D. (2018, May 3). *Walmart's Future May Include In-Store Drone Assistants And Smart Shopping Carts*. Retrieved from BISNOW: https://www.bisnow.com/national/news/retail/walmarts-future-may-include-in-store-drone-assistants-and-smart-shopping-carts-89040

Surf Life Saving New Zealand. (2018). *Annual Report .*

Transpower. (2017). *Utilising Remotely Piloted Aircraft Systems.* Wellington: Transpower.

Valavanis, K. P., & Vachtsevanos, G. J. (Eds.). (2015). *Handbook of Unmanned Aerial Vehicles.* Netherlands: Springer.

Valavanis, K., & Vachtsevanos, G. J. (2015). *Handbook of Unmanned Aerial Vehicles.* Dordrecht: Springer Reference.

Volpe National Transportation Systems Center. (2014). *Unmanned aircraft system (UAS). Service demand 2015-2035: Literature review & projections of future usage.* U.S. Department of Transportation. Cambridge: United States Air Force.

Watts, A. C., Ambrosia, V. G., & Hinkley, E. A. (2012). Unmanned aircraft systems in remote sensing and scientific research: clasification and consideration of use. *Remote Sensing, 4*(6), 1671-1692. doi:10.3390/rs4061671

Appendix 1: Sector Engagements

Parties/organisations interviewed

- Airways
- Civil Aviation Authority
- NZ Search and Rescue
- Aviation NZ
- UAVNZ
- Zephyr Airworks
- Callaghan Innovation
- University of Canterbury Drone Lab
- Altiscope
- Fire and Emergency New Zealand
- New Zealand Airports Association
- NZ Police
- DairyNZ
- Transpower

Other parties that were invited to participate, include:

- Tourism Industry Aotearoa
- Private operators
- LINZ
- DOC
- NZDF
- AirNZ
- FilmNZ
- NZTE

Appendix 2: Brief definition of drones

The terms drones, UAVs and UAS have distinct definitions but these definitions have evolved over time. At first, a UAV related to a pilotless aircraft, a flying machine without an onboard human pilot or passengers. As such, 'unmanned' implies total absence of a human who directs and actively pilots the aircraft. Control functions for unmanned aircraft may be either onboard or offboard (remote control). The term UAS was introduced by the U.S. Department of Defence, followed by the FAA and the European Aviation Safety Agency (EASA). This term was meant to signify that UAS are aircrafts, and as such, airworthiness needs to be demonstrated, and they are also systems consisting of ground control stations, communication links and launch/retrieve systems in addition to the aircraft itself. Similar distinctions are true for RPA versus RPAS.

Other names include remotely piloted vehicles (RPVs), a term that was used in the Vietnam War, while the U.S. military also calls them RPA, a term used to include both the aircraft and the pilot, while the UK and ICAO have designated them as RPAS, to demonstrate the presence of a human in the loop to control them. ICAO recommend the following definition for RPAS: *'A set of configurable elements consisting of a remotely-piloted aircraft, its associated remote pilot station(s), the required command and control links and any other system elements as may be required, at any point during flight operation.'* Adopted from Valavanis & Vachtsevanos (2015).

The above classification helps to differentiate between drone types and internationally, the classifications have regulatory importance. A classification approach that uses different features can be useful in determining the regulatory approach. This is consistent with approach the FAA uses when dealing with manned aircraft[86]. These sub-classes are based on mean take-off weight (MTOW) and engine type with different target levels of safety for each class. Globally, several metrics are used to classify drones, including:

- Mean take-off weight (MTOW),
- Size,
- Operating conditions,
- Capabilities, or
- A combination of these and other characteristics.

The table shows basic a drone classification, highlighting the variety of drone systems and dimensions of differentiation. In general, the classifications reflect three areas:

- MTOW and ground impact risk,
- Operational altitude and mid-air collision risk, and
- Autonomy.

[86] For example, the Federal Aviation Authority (FAA) uses sub-classes within the 'small aircraft class' (Less than 19 PAX). These sub-classes are based on mean take-off weight (MTOW) and engine type with different target levels of safety for each class.

Table: Drone categories and differentiation

Class	Mass (kg)	Range (km)	Flight Alt. (m)	Endurance (h)
Micro	<5	<10	250	1
Mini	<20/25/30/150	<10	150/250/300	<2
Tactical				
Close range	25–150	10–30	3,000	2–4
Short range	50–250	30–70	3,000	3–6
Medium range	150–500	70–200	5,000	6–10
Medium range (endurance)	500–1,500	>500	8,000	10–18
Low altitude deep penetration (LADP)	250–2,500	>250	50–9,000	0.5–1
Low altitude long endurance (LALE)	15–25	>500	3,000	>24
Medium altitude long endurance (MALE)	1,000–1,500	>500	3,000	24–48
High altitude				
High altitude long endurance (HALE)	2,500–5,000	>2,000	20,000	24–48
Stratospheric (Strato)	>2,500	>2,000	>20,000	>48
Exo-stratospheric (EXO)	TBD	TBD	>30,500	TBD
[a] – varies by country				

Source: Valavanis & Vachtsevanos, 2015

Based on the classification, it is evident that most NZ uses fall in the micro, mini and close to short range classes. To put the sizes into perspective, a microlight or Very Light Aircraft (VLA), has a Maximum Take-off Weight (MTOW) of 750kg. This suggests an unloaded, wet[87] weight (no passenger) of between 600kg and 650kg.

In this study, we consider drones in general. We do not distinguish between different UAVs, or UAS, on a technical basis. Military and high-altitude drones are excluded.

Arguably, the primary capability drones offer is an aerial platform. The quality and configuration[88] of the drone influences how it can be used. Some drones can only be used in a Visual Line of Sight (LOS) fashion and others have Beyond Line of Sight capability (BLOS). In addition, the level of control input needed from the operator varies from fully remote controlled to semi-autonomous to fully autonomous.

Obviously, drones can be used for many applications across large parts of the economy, particularly space extensive activities and those that require a stable, aerial platform.

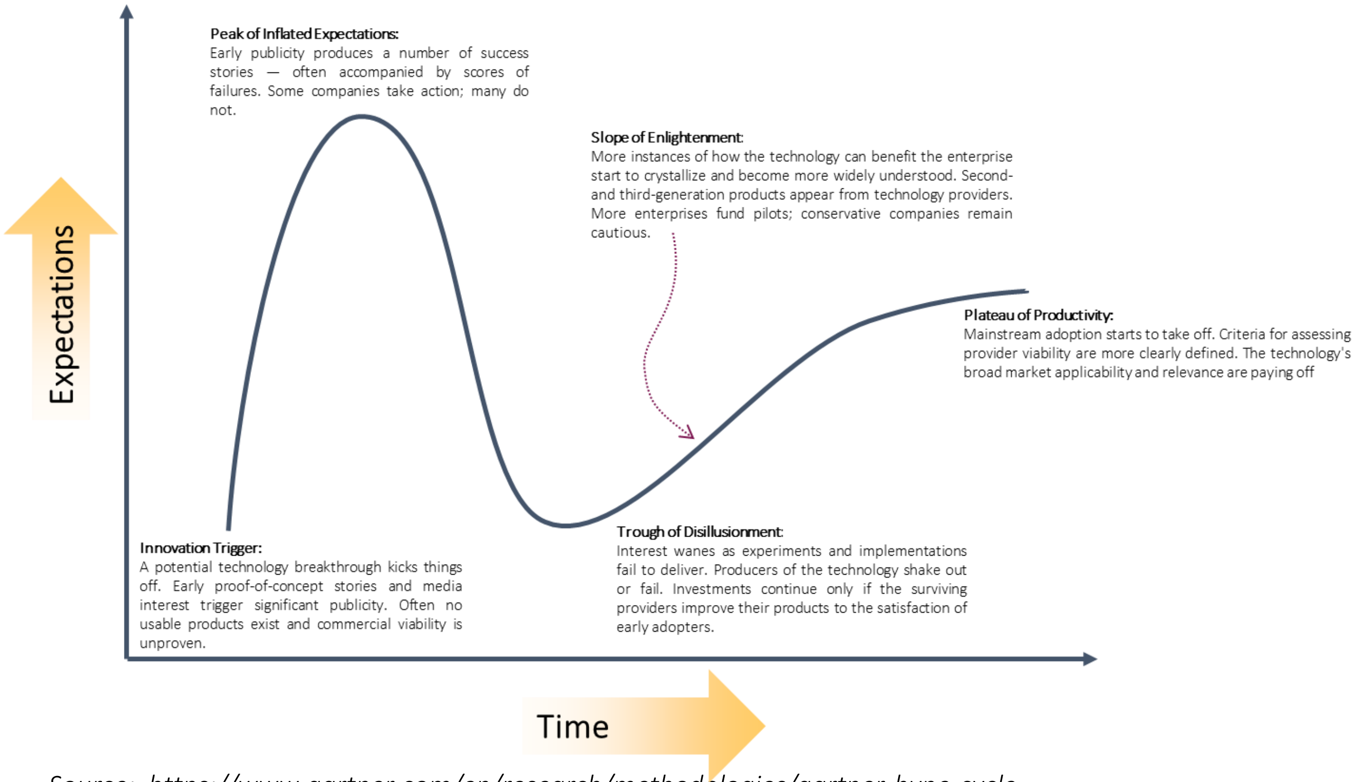
[87] Including fuel.
[88] Drones vary in terms of size and payloads as well as the flight configuration (fixed wing, rotary or multi-rotors).

Appendix 3: Sectors that could use drones (directly or via contracting)

- Horticulture and fruit growing
  - Floriculture production
  - Vegetable growing
  - Grape, apples, kiwifruit, berries (etc) growing
  - Other fruit and tree nut growing
- Sheep, beef cattle and grain farming
- Dairy cattle farming
- Poultry, deer and other livestock farming
- Fishing and aquaculture
  - Longline and rack (offshore) aquaculture
  - Caged (offshore) aquaculture
- Forestry and logging
- Fishing and aquaculture
  - Line fishing
  - Fish trawling, seining and netting
  - Other fishing
- Oil and gas extraction
- Metal ore and non-metallic mineral mining and quarrying
- Petroleum exploration
- Mineral exploration
- Other mining support services
- Electricity generation and on-selling
- Utilities (gas, water supply)
- Building construction (residential and other)
- Heavy and civil engineering construction
- Construction services
  - Land development and subdivision
  - Site preparation services
  - Concreting services
  - Roofing services
  - Other building installation services
- Road transport (freight transport)
- Air and space transport
- Other transport
  - Scenic and sightseeing transport
  - Pipeline transport
- Postal and courier pick up and delivery services
- Transport support services
  - Port and water transport terminal operations
  - Airport operations and other air transport support services
- Motion picture and sound recording activities
- Health and general insurance
- Auxiliary insurance services
- Rental and hiring services (except real estate); non-financial asset leasing
- Non-residential property operation
- Real estate services
- Advertising, market research and management services
- Professional photographic services
- Building cleaning, pest control and other support services
- Defence
- Public order, safety and regulatory services
  - Police services
  - Investigation and security services
  - Fire protection and other emergency services
  - Correctional and detention services
  - Other public order and safety services
  - Regulatory services
- Medical and other health care services
- Ambulance services
  - Other health care services n.e.c.
- Heritage and artistic activities
  - Zoological and botanical gardens operation
  - Nature reserves and conservation parks operation
  - Performing arts operation
  - Creative artists, musicians, writers and performers
  - Performing arts venue operation
- Sport and recreation activities
  - Sports and physical recreation clubs and sports professionals
  - Sports and physical recreation venues, grounds and facilities operation
  - Sports and physical recreation administrative service
  - Horse and dog racing administration and track operation
  - Amusement parks and centres operation
  - Amusement and other recreation activities n.e.c.
- Parking services
  - Business and professional association services
- Religious services; civil, professional and other interest groups
  - Labour association services
- Religious services; civil, professional and other interest groups

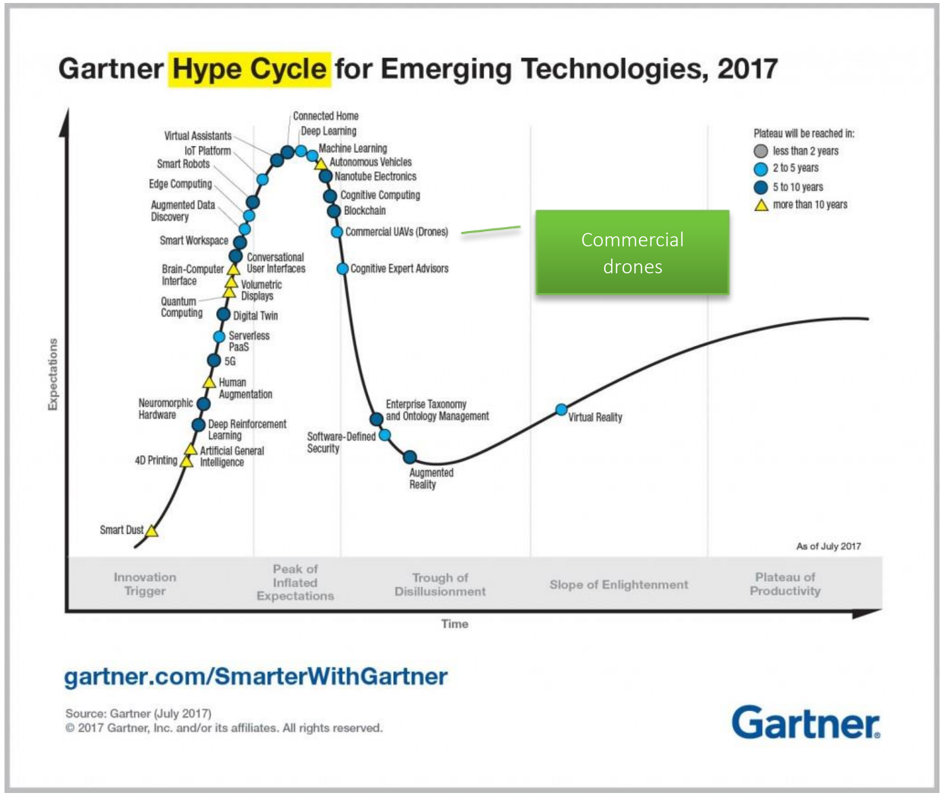
Appendix 4: Gartner's Hype Cycle

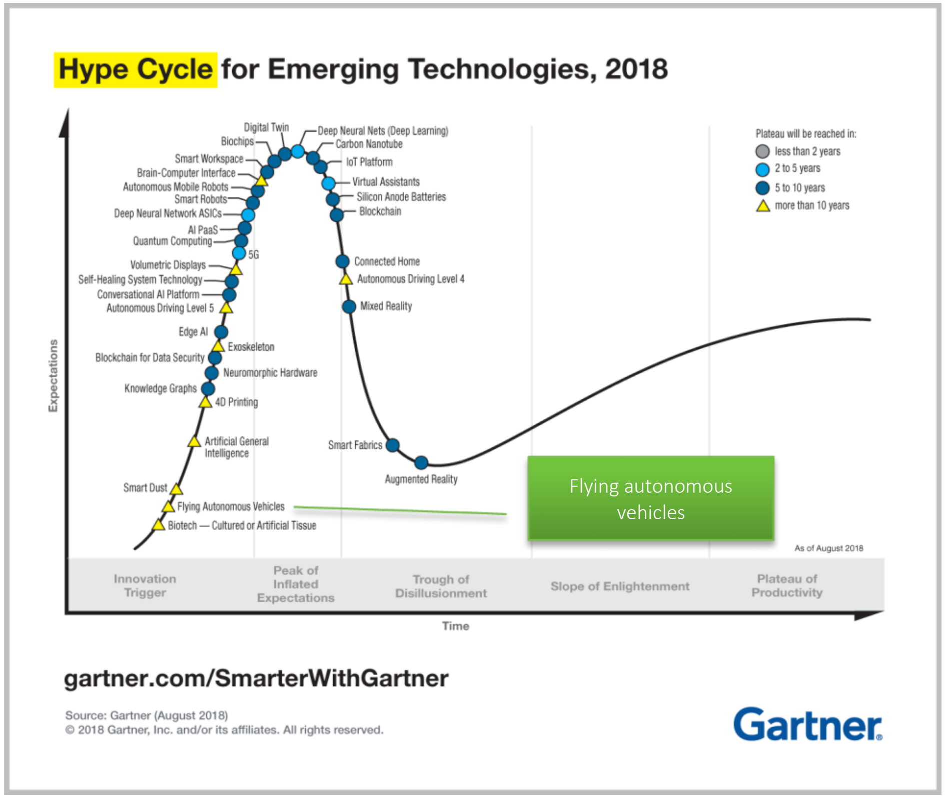
Gartner Hype Cycles provide a graphic representation of the maturity and adoption of technologies and applications, and how they are potentially relevant to solving real business problems and exploiting new opportunities. Gartner Hype Cycle methodology gives you a view of how a technology or application will evolve over time.



Source: https://www.gartner.com/en/research/methodologies/gartner-hype-cycle.

Appendix 5: Hype Cycle





Sourced: Panetta, 2017, 2018

Appendix 6: Dairying assumptions

The benefits that drones could deliver to New Zealand's dairying sector were identified by way of a literature search. The available information and datapoints were then updated, ratios re-estimated and then applied to industry information. The productivity gains (i.e. the direct effects of drones) to dairy farming were derived from work by Callaghan Innovation and provides the foundation for assessing the benefits of drones on the sector. They identify the main effect of using drones as a lift in production arising from pasture management. They identify the additional international revenue flowing to New Zealand due to higher production levels (i.e. better productivity per cow and/or better carrying capacity) as a way to estimate the potential gains.

The lift in Milk solid per cow (MS/cow) is combined with a basic projection of the dairying sector over 25 years. The outlook considers trends in herd numbers, cows per hectare, Milk Solids (MS)/cow, farm size (ha) and so forth. In light of environmental constraints and considerations, the future outlook of dairying is tempered. Essentially, this limits the sector's future size and spatial footprint. The rationale for limiting the sector's growth is to reflect higher levels of environmental pressures the sector is facing, and to make sure that a more conservative position is taken. Using the constrained baseline lowers the potential size of the benefits that could be derived from drones. The higher production is translated into additional export values. It is important to note that the lift in production occurs at a farm level, but the extra milk is then processed before exporting. The flow-on effects of the lift in exports is derived through increased milk product exports. How the industry responds to better pasture management is difficult to predict. Farmers can either optimise production to match the opportunities provided by improved pasture management or simply keep production levels stable to manage pasture conditions. If the latter approach is taken, then it is difficult to see the motivation for investing in drone services.

Several assumptions underpin the analysis of drones' potential effects on dairying. Overall the approach used to estimate the potential benefits are consistent with that outlined by Shelly and Andrews (2015). Essentially, drones will be used to improve pasture quality by enhancing the understanding of fertiliser requirements. This will reduce the barriers to gathering high quality data about pasture conditions (water and nutrient) and enable farmers to actively manage pastures. Not all farmers share the same level of motivation in terms of maximising profitability and outputs. And there is considerable variance between profitability due to factors such as: topography, soil conditions, climate variation and so forth. Therefore, the impacts and effects of drones on different farms will vary. A conservative approach is followed by using ratios that are at the lower end of the spectrum to avoid overstating the potential effects. Undertaking dedicated, farm level research to refine the input assumptions will improve the results.

Dairy farm statistics going back to 2000 were sourced from Dairy NZ (DairyNZ Economic Survey[89]). This provided almost twenty years' worth of trend data covering:

- Average number of cows per herd,
- Effective hectares used,
- Production levels on a per cow basis (in terms of Kg milk solids per cow).

This information was used to estimate the milk production across New Zealand. A growth profile for the industry was developed based on historic trends. Future growth was tempered (reduced) to reflect environmental (e.g. water pressures) and public perception matters.

[89] Earlier versions were prepared by the Livestock Improvement Corporation (LIC).

Any improvements in pasture management (due to drones) were translated into productivity gains that manifest in milk solids (MS) production. The productivity gain is estimated at between 5.1% and 8.1% for dairy farms and between 2.3% and 3.8% for hill country farms. In the analysis, a rate of 4.5% is used. This productivity gain is associated with active pasture management and is used as a proxy for drone use. In reality, drones will be part of a package of activities, but it is argued that the intelligence and detailed insights that are enabled by drones (and the sensors and software applications) will drive the improvements. There is little information that can be used to attribute a share of the productivity gains to drones, or any of the technologies (e.g. sensors) individually.

In terms of the uptake to improve pasture management, it was assumed that over time, 40% of farms will start to use drone for pasture management. The transition will take place over 10 years and farms will take three years for the total gains to bed in, with half (50%) of the gains materialising in season 1, and the balance distributed evenly over seasons two and three. It is assumed that, around three per cent of farms currently use drones and are already experiencing the benefits.

In terms of the revenue from the milk products, the 'export' value was used. This is a function of the farm gate milk price, the capital costs as well as other costs (e.g. transport). The value was estimated using Fonterra's Farmgate Milk Price Statement. Over the past five years, the average total price was $7.75 and average Farmgate Milk Price was $6.02. Importantly, these prices are held constant and we did not attempt to forecast future milk prices.

Appendix 7: Dairying - sensitivities

The following table summarises the results.

Setting	Shift	Effect
Higher productivity	Productivity gain of 8% in pasture management (vs 5%)	*Additional export revenue* $677m-$1.1bn ($27m-$45m/year)
Higher uptake	Greater adoption of drone technology and supporting activities. Increase from 25% to 45% of herds/farms	*Additional export revenue* $0.9bn-$1.5bn ($36m-$59m/year) *Additional* drone *costs* *LOS:* $110m-$178m ($4m-$7m/year) *BLOS:* $47m-$76m ($2m-$3m/year) *Fertiliser saving* $55m-$90m ($2m-$4m/year)
Slower Uptake	Slower uptake of drone technology. Uptake spread over 25years (vs 10years)	*Less export revenue* $523bn-$797bn ($21m-$32m/year) *Additional* drone *costs* *LOS:* $65m-$97m ($3m-$4m/year) *BLOS:* $28m-$42m ($1m-$2m/year) *Fertiliser saving* $32m-$48m ($1m-$2m/year)
Lower commodity prices	Dairy prices have been trending down for the past season or so. The base assessment uses the average values of the past 5 years. The sensitivity analysis lowers this by 20%.	*Less export revenue* $226m-$372m ($9m-$15m/year)

Appendix 8: Summary of scenario findings (electricity sector)

The following table summarises the results under different uptake scenarios. It shows the following settings:

- 80% uptake of the opportunity to use drones by electricity distribution companies that have the longest (largest) network as expressed in terms of Overhead Rural Lines (km) per ICP (i.e. lowest density),
- 80% uptake of the opportunity to use drones by electricity distribution companies that have the longest (largest) network as expressed in terms of Overhead Rural Lines (km) (i.e. largest network),
- 80% uptake across all electricity distribution companies with the largest System Average Interruption Duration Index or SAIDI (in minutes).
- 80% uptake by the electricity distribution companies that have the highest use per ICP.

The uptake is spread out over five years and the assessment period covers 25 years. Three discount rates are used (4%, 6% and 8%).

Breakdown of benefits by scenario

			$m	
Setting	*Scenario*	*4%*	*6%*	*8%*
		Improved Reliability		
$VoLL_{Min}$	Km/ICP	16.3	13.3	11.0
	Largest	78.9	64.3	53.3
	SAIDI	60.4	49.2	40.8
	Highest Use	35.5	28.9	23.9
$VoLL_{Centre}$	Km/ICP	24.0	19.6	16.2
	Largest	116.1	94.5	78.4
	SAIDI	88.8	72.3	60.0
	Highest Use	52.2	42.5	35.2
$VoLL_{Upper}$	Km/ICP	38.4	31.3	26.0
	Largest	185.7	151.2	125.4
	SAIDI	142.1	115.7	96.0
	Highest Use	83.4	67.9	56.4
		Savings		
Maximum (100%) uptake				
	Internal resources used to deliver drones services	32.6	26.5	22.0
	Drone services procured via outsourced approach	76.8	62.5	51.9
Internal resources used to deliver drone services				
	Km/ICP	9.7		6.6
	Largest	21.3	17.3	14.4
	SAIDI	16.1	13.1	10.8
	Highest Use	12.2	9.9	8.2
Drone services procured via outsourced approach				
	Km/ICP	22.7	18.5	15.3
	Largest	49.7	40.5	33.6
	SAIDI	37.5	30.5	25.3
	Highest Use	28.5	23.2	19.2