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AN IN-DEPTH PRACTICAL EXAMINATION OF BUSINESS POTENTIAL OF DRONES

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ABSTRACT

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Within the last decade, drone technology has seen an enormous boost in popularity and interest as they make their transition into the commercial sector. From a business perspective, the market potential is growing steadily but there is limited research into just how drones will impact industries. The main objective of this research is to analyze the benefits and cost-effectiveness of a drone, given a single use case application from an appropriate industry. The method used for this research was a single case study with descriptive data analysis. Preliminary interviews were conducted with Nokia Drone Network employees to identify the industry and application. For this research, this was determined to be telecommunication mast inspections. Secondary interviews were conducted with industry experts in order to understand the process and costs involved for preforming mast inspections with drone or by conventional methods. A simulation model was used to emulate the operational processes for both methods of inspection in order to understand the amount of time and costs needed. The outcome of the simulation determined total mast inspection time for drone or conventional method. Using activity-based costing model, the resources needed to complete inspections were identified in the form of costs and labor by unit cost per hour. The results of the study for telecommunication mast inspections were twofold: drones would be a more cost-effective alternative but would use more time to implement. It is worth mentioning that this study was based on the simulation parameters and industry expert opinions. The scope of this research was limited to only multi-rotor drones use cases.

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LIST OF SYMBOLS AND ABBREVIATIONS

ABC	Activity-Based Costing
AGL	Above Ground Level
AIRAC	Aeronautical Information Regulation and Control
ANS	Finnish Air Navigation Services
BLM	Interior Bureau of Land Management
CBA	Cost Benefit Analysis
CEA	Cost Effective Analysis
CER	Cost Effective Ratio
CUA	Cost Utility Analysis
ESC	Electronic Speed Controller
LTE	Long Term Evolution
MSL	Mean Sea Level
NDN	Nokia Drone Network
NSL	Nokia Saving Lives
ST	Setup Time
TBC	Time to Change Battery
TIT	Total Inspection Time
TMIT	Total Mast Inspection Time
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicles

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1 INTRODUCTION

The introductory chapter justifies the idea for attempting a research study of drone or UAS as an alternative solution for inspection purposes. The purpose of this chapter is to emphasize the gap in research for business or commercial related studies about drones as a reason for this research. A brief overview of the case company is presented, after which the main research problem is stated with any supporting questions along with the overall objective of the study. After which, the scope and limitations of the research are presented.

1.1 Background Information and Research Gap

In the decades to come numerous technologies will emerge that will change the world and transform economies. Among these changes are things such as cloud computing, Internet of Things, artificial intelligence and autonomous systems. One technology that has received great demand and exposure is unmanned aerial vehicles (UAVs), better knowns as drones (Choi et al., 2016). Drones are quickly becoming a fast-growing area of interest in the field of the information technology. During the past few years, many large organizations either created or invested heavily into the drone phenomenon. Such companies including the likes of Amazon, Google, Domino’s Pizza, and EasyJet have all started to slowly incorporate drones into their business practices (PwC 2016). The basic concept of drones has gone from being perceived as a military controlled device or hobby for enthusiasts, into becoming this transformative technology with various commercial applications over different industry sectors. The private business sector has only marginally taken advantage of the potential that drones can offer when considering security, business costs, and time-to-market evaluations (Bamburry, 2015). However, despite the slow adaptation analysts suggest that the commercial unmanned aircraft system (UAS) market is forecasted to reach nearly $15 billion by the year 2027 as shown in figure 1 below. This expected growth in demand for drones and UAS applications is likely to affect commercial services once businesses realize the added value and revenue possibilities.

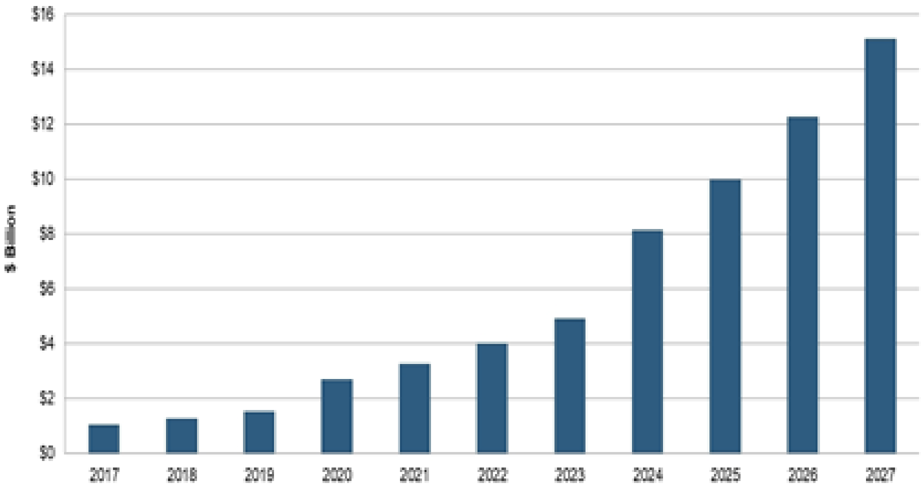


Figure 1. Commercial UAS Market Outlook (Anwar, 2019)

Parallel to the growth of the drone market is the abundance of research that can be found with just a basic search using UAS or Drone as keywords. Since 2013, the trend in drone-related research papers has increased from 544 to an astounding 4729 (Chabot, 2018). This represented visually below in Figure 2.

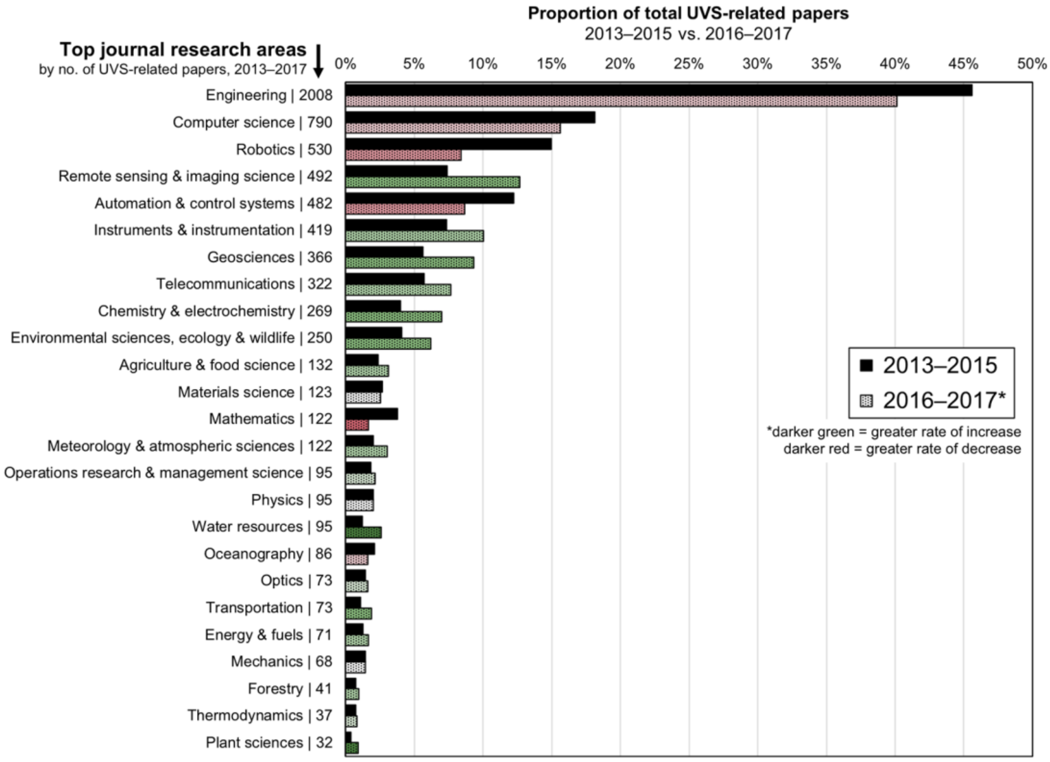


Figure 2. UAV/UAS Related Research Papers (Chabot, 2018)

The focus of this research is nearly completely dominated by engineering-oriented publications showing a clear lack of business research studies towards drones. In order to bridge the gap between drone engineering and businesses, more research is needed to comprehend the feasibility and potential benefits for UAS and drone applications. Thus, the purpose of this thesis is to find answers to questions regarding whether or not and to what extent UAS and drones would be beneficial and cost-effective. Drones present an alternative solution as a powerful tool for a multitude of scenarios. The research should drive businesses in determining whether the investment into drone technology and its efficacy make it a viable option in comparison to current methodology.

1.2 Nokia Drone Networks

Nokia is a multinational corporation originating from Finland founded in 1865. The company is headquartered in Espoo, Finland but has operations in over 100 countries with a total of 103,000 employees worldwide (Nokia, 2019a). Nokia Saving Lives (NSL) initially launched as an innovative tech project to assist in natural disaster circumstances. Some of the products introduced were based on different crisis management use cases including portable long term evolution (LTE) networks and drones (Nokia, 2019c). The NSL drones received much attention in 2017 winning the United Arab Emirates Drones for Good Award. The product showcased its ability to use drones for first response in a natural disaster simulation (Eder, 2017). The byproduct of the NSL initiative is the Nokia Drone Networks (NDN), which is Nokia’s end to end solution for drones connected and operated over a private LTE network (Nokia, 2019b). The NDN project serves as the basis for this case study research.

1.3 Research Problem

The relevance of this study was established while the author was working for the NDN project. The idea for this research stemmed from the lack of information and need for a study of cost analysis of drone applications in relation to the project. The objective is to study the cost analysis and benefits of a single drone application to allow for easier understanding of implementation of UAS over conventional methods. The application that will be used for this study will come from inside the telecommunication industry in the form of a simulated cellular tower or mast inspection. The outcome will create a framework for analyzing a cost benefit analysis to compare and contrast drone technology versus human resource intervention. Simultaneously, this thesis will also provide valuable insight into UAS market segmentation and drone applications filling the gap provided in lack of business research papers in the field. The following research question was formulated for study:

"To what extent are drones beneficial and cost-effective to operate?"

With the main research question establish, a series of more detailed research sub-questions are proposed in order to support and answer the main research question:

- What are possible drone applications?
- What are drone characteristics and associated costs?
- What are the processes for mast inspection and their associated costs?

1.4 Scope and Limitations

The scope of the research is to identify highest value industry for a drone application and compare whether or not the drone is more beneficial and cost-effective than the conventional method. The study should only consider scenarios that are relevant for NDN project meaning that only multi-rotor drones use cases are considered for analysis. Research limitations are based around the type of cost analysis of the drone application and conventional method. Therefore, manufacturing and assembly costs for drone are not included.

1.5 Methods and Organization

Research will open with a literature review on the different cost analysis types and their characteristics followed by introduction to UAVs and applications to identify highest value drone use case scenarios. The approach for this research is to use a case study to assist in applying theoretical concepts for real world applications or scenarios. The case study is supported through the findings of a simulation. This thesis is dived into seven chapters. The first chapter gives insight in to the interests and reasoning for the research topic. The second chapter presents the theoretical background of the study including a literature review of UAVs from historical to current use cases and costs analysis types and characteristics. Chapter three is dedicated to the research methodology. Here the methodology is presented along with data collection, research design, data analysis and criticism. The forth chapter of the study presents the case company in which the research is geared towards. This chapter includes the presentation of the data collected from interviews, scenario proposals, and simulation protocols. The fifth chapter is the cost analysis framework of the scenario simulations for the selected use case of drone and conventional method. The sixth chapter presents the results of the simulation and cost analysis. The seventh and last chapter summarizes the major findings, provides a conclusion to the study, suggestions for managerial implications and future research along with presenting the limitations of the research.

2 THEORETICAL BACKGROUND

This chapter presents the literature review to provide a basis for the research. To an extent, it is necessary to understand all relevant and relatable information from previous studies to define the gap in research. The purpose is to assess and not to summarize previously stated works (Mark et al., 2009). This review will help to shape and design the research and select an appropriate method. In order to understand the cost analysis in the context of drones and conventional method, a theoretical research is necessary for both concepts.

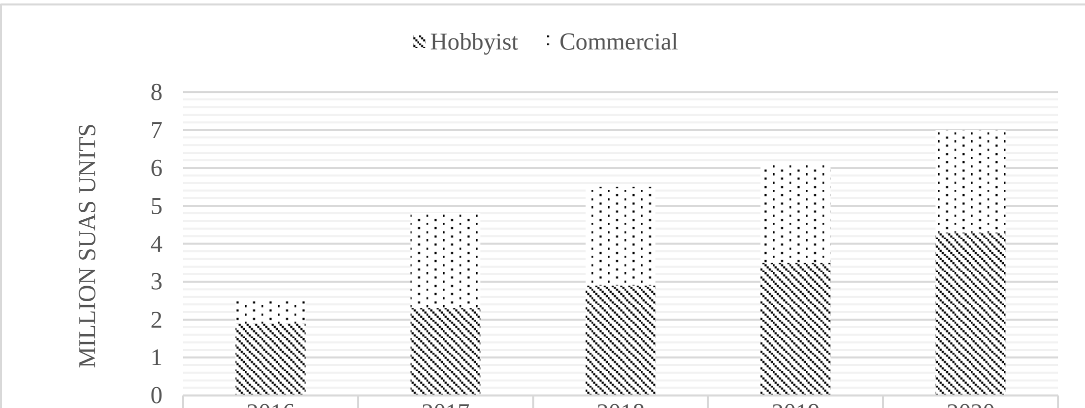
2.1 Unmanned Ariel Vehicles (UAVs)

2.1.1 History of UAVs

The first recorded UAV was invented by Joseph and Jacques Montgolfier in 1782 by using a hot air balloon. Hot air was vented through the bottom of a balloon causing it rise up in to the air until the air cooled and the balloon returned (Karwatka 2002). This prototype is considered to be one of the first successful UAVs. Since then, hot air balloons have been utilized throughout history used to carry incendiary devices in war. During the United States Civil War the Confederate and Union Armies launched balloons to destroy the enemy force. The Japanese Imperial Army also attempted to use balloons during WWII with the idea of sending them at high altitudes to reach the boarders of the U.S., which ultimately was an unsuccessful UAV attack (Garamone 2002). The first U.S. developed UAV came during WWI in 1917 known as the Crutiss N-9 seaplane. This UAV featured a fully automatic control system but due to several crashed trials and engine failures the seaplane never took flight. By the year 1950, the U.S. Air Force began development of a remote controlled drone for photographic and surveillance purposes call BQM-34A Firebee which pioneered the modern UAVs we use today (Cook 2007). The Israeli Army was able to successfully develop UAVs during the conflict with Lebanon creating complex UASs that were equipped with lightweight cameras able to deliver real-time video of the battlefield (Zaloga 2008). During the Gulf War of the late 1990's, the U.S. utilized Israeli UAV technology giving way to the AAI RQ-2 Pioneer Drone which proved to be successful in its application (Garamone 2002). This steered the U.S. to invest heavily into UAV and UAS systems creating a drone that would change the landscape of UAV application, the Predator Missile. The Predator Missile was a remote guided drone that allowed for attack or surveillance of a target from a virtually anyway (Terdiman 2014). With the introduction of the Predator Missile and the conflicts in Iraq and Afghanistan taking form, the U.S. introduced what is claimed to be the next wave of UAV technology. With its success and prevalence on the battlefield, domestic markets have looked to capitalize on the civilian drone applications and technology.

2.1.2 Domestic Use of Drones

Preceding its use for warfare throughout history, drones of all shapes and sizes have now become the focus of many in the public and private sector. Drones in the public space give users more opportunities to solve problems with the collection of aerial imagery and monitoring capabilities, thus making the applications for drones and UAS virtually endless. Drones make for the most ideal solution for monitoring or surveying sensitive areas which are unreachable or in some cases hazardous (Anderson 2014). Larger drones are equipped with tools and devices that are beneficial for first responders in the event of an emergency. For instance, after a natural disaster drones are dispatched to assess the situation allowing for safe entry and exit of workers (Adams and Friedland 2011). Recently, Micro-drones have become widely popular for their aerial photographic and videoing capabilities which is arguably most compelling attribute. Aerial imagery by definition is the remote sensing in which data is collected from an elevated distance. In its purest form this can imply a simple image of the earth’s surface captured with a camera (Cambell and Wynne, 2011). Images of this nature are considered to be spatial data representing the location, size and shape of an object at any given time. Thus, aerial imagery can have a number of functions from map creation to analyzing changes in any given environment. Drones capacity in providing universal scale images can be useful in compiling data libraries for governments, businesses, or enthusiasts which can be shared over the web (McKellar 2015). This is most beneficial for interpretation of data sets from various points in time. Temporal data gathered from drones helps to establish a visual record of an area being inspected or in some cases monitored. When this is combined with more advanced geographical information platforms, the data is transformed into a digital record which can be easily analyzed (Abbott 2004).The drone’s maneuverability makes aerial imagery simple in collecting large amounts of data in a rather short timeframe. With one set of aerial images from a designated surface area the locations condition could be analyzed in only a moment's notice. Simultaneously, doing this same process manually collecting data via GPS coordinates can takes several minutes to hours. Temporal imagery collection does have its disadvantages in the face of natural disasters i.e. tornados, hurricanes, earthquakes, tropical storms etc. leaving the surface area undistinguishable for real-time decisions. Thus, the aerial capabilities provided by drones makes it possible to keep mapping and image data bases updated at low costs (Falkner and Morgan 2002).Moreover, the rise in popularity has come much from its developments in drone tech, price point, small learning curve to operate, and payloads attachments (Gademer et al. 2009). Micro-drones are used frequently by realtors who want to capture a different perspective of a property for marketing purposes. Drones have also made their way into various sporting events like American Football and Soccer games capturing unique videos of the gameplay. Drones popularity can also be attribute to social media with many short video clips being taken from an aerial point of view. Companies, such as Amazon, are now aiming to use drones to automate their delivery processes. The customer could receive their products within hours of having placed an order making for a fast and efficient way of deliveries (PWC 2016). Additionally, according to the information provided by the Federal Aviation Administration (FAA), UAS sales are project to increase nearly two fold by the end of 2020. This is represented in figure 3 below.



	2016	2017	2018	2019	2020
Commercial	0.6	2.5	2.6	2.6	2.7
Hobbyist	1.9	2.3	2.9	3.5	4.3

Figure 3. Prediction of small UAS units sold per year (FAA, 2016)

2.1.3 Drone Types

Drones are typically classified into three generic categories based on the capabilities and functions: fixed-wing drone, multi-rotor drone, and hybrid drone. Table 1 below is an overview of the different drones by characteristics.

	Fixed Wing Drone	**Multi-Rotor Drone**	**Hybrid Drone**
Style	Aero plane style	Quad-copter, helicopter or octo-copter style	Combines the properties of Fixed Wing and Multi-Rotor Drone
Speed	Speeds up to 100km/h	Speeds up to 45km/h	Speeds up to 100km/H
Travel	Long distances up to 150km	Short distances up to 20km	Long distances up to
Payload	1.5-5kg	5-10kg	5-15kg
Take-off/Landing	Landing strip and catapult required	Vertical landing/take-off	Vertical landing/take-off
Duration	one way only; no return possibilities	Battery operated; return possibilities	Battery operated; return possibilities
Misc.	Moderate costs	Low costs	High costs

Table 1. Drone Types by Characteristics (Anderson and Gaston 2013; DHL, 2014)

Fixed wing drones are similar to airplanes as they call for large surface areas required for landing and take-off as shown in figure 4 below. They fly in a straight path used for long hauls.

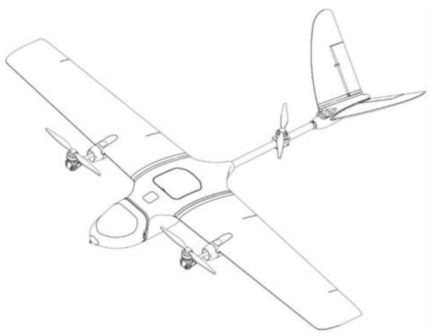


Figure 4. Fixed Wing Drone (Drone onDemand, 2020)

Multi-rotor drones are typically small in size and have the capabilities for vertical landing and take-off, mid-flight turning, and hovering as displayed in figure 5 below.

Figure 5. Multi-Rotor Drone (Nokia, 2019b)

The hybrid drone is essentially a combination of fixed wing and multi-rotor drone which is represented in figure 6 below.

Figure 6. Hybrid Drone (Glaive Store, 2020)

Of the three drone types, the multi-rotor drone is the most common. Their ability to maneuver in just about any direction and fly stationary makes them the most ideal choice for drone solutions. The purpose of having four or more rotors enables the drones to remain airborne in the event that one of the rotors were to fail. One slight drawback to the multi-rotor drones is that they are unable to travel at high speeds (Anderson and Gaston, 2013). Drones can run on a variety of power sources like batteries, petrol, or even solar power. Their flight duration can be limited dramatically by payload size or battery weight and charge capacity (DHL, 2014). Essentially, each drone is different in just about every aspect from design, power source, range, costs, and payloads. In a business context the operational expenses can depict the drone's application in order to select an appropriately spec drone for its purpose. Thus, it is important to assess the leading drone applications taking into consideration all drone characteristics which can be applied to that given industry.

2.1.4 Drone Applications

The possibilities for drone applications are endless across various industries. Some of the more predominate uses cases for drones have been aerial imagery, last-mile shipment deliveries, line inspection, agriculture monitoring, cargo transport, search and rescue, natural disaster intel, law enforcement, and border patrol (Joshi, 2017). The biggest industries for these uses case are media entertainment, telecommunications, infrastructure, transportation, agriculture, security surveillance, and mining (PwC, 2016). Figure 7 below shows the top industries for drone applications that are exempt from any Federal Aviation Administration (FAA) regulations:

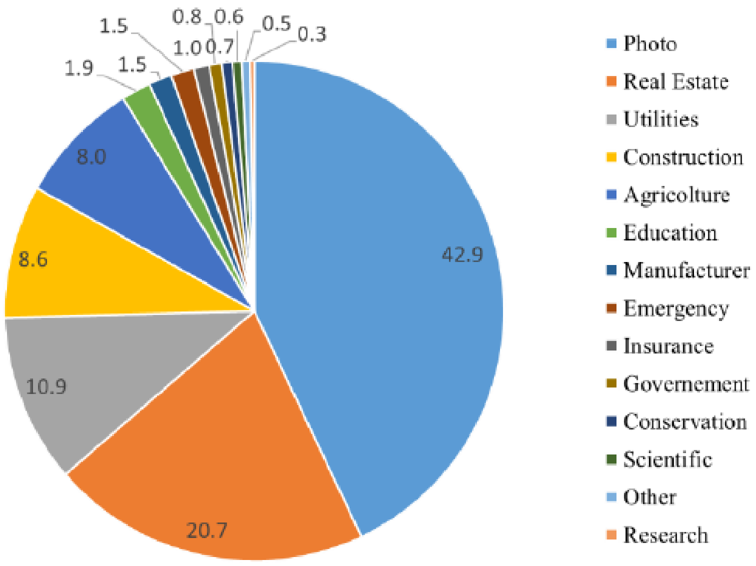


Figure 7. Top Commercial Drone Industries (Popper, 2015)

- **Photography/Aerial Imagery** – Use cases can include anything media, entertainment or arts related. This mainly applies to drones that would be utilized for shooting movies, recording stunts, or capturing news broadcasts (PwC, 2016). Drones used in journalism are an easy way to safely provide coverage without jeopardizing workers. Although drones are considered to be a disruptive innovation displacing workforce and technology, this particular industry depends heavily on helicopters, storm chasers, reporters in the field, and crew members using handheld cameras or equipment.

- **Infrastructure/Construction –** Drones can be exceptionally useful for assessing the structural integrity of bridges, highways, roads or streets, powerlines, pipelines, and building rooftops (Dobson, 2013). The inspection of these kinds of infrastructures can in some cases be hazardous for workers but this risk is minimized when drones are used. Places that are difficult or unreachable becoming easily accessible for analysis such as oil rigs, wind turbines, and estate/property inspection. In construction, drones help to provide transparency in data collection during every stage of the project. Construction project benefit from high definition 3D modelling and images to assess the design process, security, and speed of the project (Choa, 2015).

- **Security/Monitoring –** Security and surveillance, although sometimes independent from one another, can incorporate just about anything depending on its application. Applications can be classified by drones between line inspection and site inspection. Line inspection benefit from fixed wing drones and site inspection from multi-rotor drones. Monitoring can extend into ecology, wildlife and habitat monitoring, permafrost detection, boarder and costal control, and waterworks (Choi-Fitpatrick et al., 2016; Fraser et al., 2015; Ford, 2016). Many businesses consider substituting drones for the likes of helicopters, planes, and vehicles to survey an area. Respectively, drones for monitoring purposes can provide critical information for first responders.

- **Agriculture –** Precision agriculture involves the monitoring of large crops for health, cultivation, and measuring agriculture sciences. Uses cases can range from pesticide application, irrigation and livestock monitoring, crop field surveillance, and mapping of crop territory (Bamburry, 2015). Agriculture suffers from irregular weather patterns which can increase the cost of year round maintenance making drones a cost effective solution replacing tractors, soil cultivators, sprinkler systems, and pesticide and fertilizer sprayers. Drones used for spraying crops can help improve efficiency by controlling the amount of overspray that general ends up corrupting the soil when done with more traditional systems (Zhu, 2009).

- **Transportation/Logistics –** Drones have become the focus for a lot of transportation and forwarding companies having miscalculated the value drone applications could potentially provide initially. This has swiftly changed over time as the industry has seen a boost for efficient supply chains in service deliveries and last mile transport (PwC, 2016). Some of the most productive applications include parcel, postal, and food deliveries.

- **Emergency/Health –** In the industry of emergency and health, drones are can be a crucial asset in gathering Intel for firefighters, police officers, and emergency medical technicians. Specifically, drones can be used for dangerous goods delivery, wildfire monitoring and dispersal of extinguishing agents, delivery of medical supplies, and riot/protest assessment (McGonigle et al., 2008). Furthermore, drones can assist in search and rescue missions and lab specimen carriage (Choi-Fitzpatrick et al., 2016; Lippi and Mattizzui, 2016)

- **Other –** All remaining drone applications that have yet to be revealed and/or classified are placed under this category. These applications may include but are not limited to educational purposes, research and development, real estate, and various deliveries.

Businesses from all of the above cited industries have realized the value captured by drone technologies allowing for many to create new operating models and business processes. Every industry comes with its own set of challenges and a result may require a different type of drone solution with different capabilities and functionalities. Some business may rely on cost efficiency while some may focus on payload capacity and flight time.

2.1.5 Drone Challenges

With regards to drone applications and their benefits, many challenges have been discovered during the research process. Some of the most prevalent issues lie in privacy and data rights, design infringement issues, and ethical questions. Some critics are concerned with the lack of drone laws and regulations concerning the increase in their capabilities and autonomous nature. As for drone development, many criticize how to regulate the airworthiness and appropriateness of what is considered to be safe flight, autonomous controls, and the diminishing role of human operators (Clarke, 2014a). In terms of risk management, emphasis should focus heavily on drone classification by type and capabilities. Drones that are larger in size are categorized much similar to UAVs, regulated by operators, manufacturing, and maintenance. These drones in particular are trivial in comparison to the gap left by mini drones, the increase of micro drones, along with the emergence of nano drones (Clarke, 2014a). Many critics are sceptic to drone development claiming high risks and disadvantages coupled with unstructured decision making when it comes to drone legislation (Clarke, 2014b). Furthermore, the gap created by drones that threatens social, economic, and political performance. These can include negative environmental impacts, job displacement, and distribution of assets/resources (Clarke et al., 2014).

2.2 Cost Analysis Methodology

The most common cost analysis methods often associated with value generation are cost-effectiveness analysis (CEA) and cost benefit analysis (CBA). These two analysis are also joined by a third method that is recognized as the cost utility analysis (CUA) (McEwan, 2012). In comparison to the more traditional approaches, activity-based costing (ABC) is another methodology that follows any cost analysis in order to understand the method for assigning costs to activities. The motive behind any cost analysis is to help facilitate the decision making process and help identify and evaluate what are all possible effective outcomes and costs of projects, policies, or programs. Any cost analysis or assessment can be carried out at any period of time during the decision-making process. The assertion is that the analysis is coherent to the timing and cost analysis which can be categorized in the following manners:

- Ex ante – executed preceding the program/venture; is generally valuable for settling on asset distribution choices.
- Ex post – executed at the conclusion of the program/venture. Gives data about all out possible expenses and advantages upon completion. Generally, valuable for evaluating the productivity postop.
- Medias res – executed during program/venture. Gives information on whether the expenses merit the current investment (Levin and McEwan, 2001; Boardman et al., 2006)

The type of analysis will be entirely dependent on the nature of its attributes, use case, and limitations. For example, in an Ex ante analysis, the costs and benefits are not easily estimated or they have yet to be defined or manifested. The dilemma with this analysis lies in the level of assumption required leading to inaccurate results. Unlike Ex ante analysis, ex post analysis deludes the level of assumption as costs and outcomes are known meaning that estimation is more accurate. However, the issue with this analysis is the possibility of overlooked costs or benefits. The medias res analysis is the middle ground between both ex post and ex ante analysis. Its purpose to identify the projects existing benefits against costs (Cellini and Kee, 2015). Ex ante cost benefit analysis will be the subject of this study but the intention of this section is to distinguish between the different cost analyses methodologies.

2.2.1 Cost Effective Analysis

The CEA compares the different financial opportunities of different programs which have the same outcome and the similar measure of effectiveness (Levin and McEwan, 2001). The CEA is calculated using the cost effectiveness equation that determines the ratio of the costs to effort versus the unit of effectiveness. The purpose of the CEA analysis is to give an accurate comparison of different programs which can support the decision making process for any given cost limitations. The formula for calculating the cost effectiveness ratio (CER) is as follows:

$$CER = \frac{Total\ Costs}{Unit\ of\ Effectiveness}$$

This method of analysis is generally helpful for governmental or public sector projects and programs during pre-implementation phase as the outcomes are not expressed in any financial values. An example of this is easily seen in the healthcare industry where the results can be derived in the form of quality of life, accidents averted, or living years saved. In recent years, CEA has also found its way into other industries. The analysis was used as a tool for assessing the cost efficiency of energy in infrastructures (Tuominen et al., 2015). The purpose of the CEA is to establish the level of effectiveness possible dependent on the budget or lowest possible alternative. This outcome is then translated to a non-monetary value or measurement (Cellini and Kee, 2015). Thus, the CEA is a tool that can be extremely effective during any decision making process providing a designated level of effectiveness at lowest incurred cost or maximum level of effectiveness at the highest possible cost. The CEA has four distinct stages:

- Stage 1 (definition): objectives and unit of measurement
- Stage 2 (assessment): includes all financial resources involved including those costs and revenues which can be monetized
- Stage 3 (measurement): tangible quantities for outcomes
- Stage 4 (calculation): ratio between unit costs by impact (Tuominen et al., 2015).

The CEA is moderately simple when the analysis only includes a single unit cost against multiple scenarios. Conversely, the applications that call for this analysis such as in government policy creation or public sector programs, call for a compassion between multiple units of measurement. In this case, a multi-objective analysis is necessary in order to compare unrelated units of costs to the effectiveness of different outcomes. The derivative of this analysis yields the cost effective outcome (Wall and MacKenzie, 2013).

2.2.2 Cost Utility Analysis

The CUA is a multi-criteria methodology which assess the utility contrasted to the resources required to aid decision or policy makers (Levin and McEwan, 2001). Many studies suggest that this form of analysis relies on both internal and external data related to the project or program such as effectiveness, expenditures, economics mechanics, and societal patterns. The CUA outcomes are measured by disability-adjusted life year (DALYs) which is equal years lived with a disability and sum of years of life lost or by the quality-adjusted life years (QALYs). Therefore, the advantage of the CUA is its ability to simultaneously calculate the expenses and outcomes for programs based on QALYs and DALYs. The results themselves are a representation for the costs of healthy year gained or the costs of quality adjusted life gained. The utilities can vary as a result of societal and individual differences which need to be taken into account when assessing the economical outcomes of the program (Drummond et al., 2005).

2.2.3 Cost Benefit Analysis

CBA is a method of formal analysis that utilizes a comparative analysis of all anticipated benefits and costs (Rakhra, 1991). CBA is often used in public and private sector investments along with program and policy decision making. Essentially, CBA is a representation of measured costs and advantages as a result of a completed project, phase, or process. CBA is the most practical analysis for comprehending feasibility studies of economical, sociological, technological, or environmental matters for choosing the best possible alternative for investment (Hanley and Spash, 1993). With respect to cost-income ratio analysis, CBA is not an alternative for financial justification. When CBA is used for decision making, it measures the value of each possible impact in financial terms which implicates all parties involved (Boardman et al., 2006). The structure of the CBA methodology is expressed as all of the benefits (B) minus all of the incurred costs (C). The formula for calculating the net benefit (NB) is as follows:

$$NB = B - C$$

The level of investment that is needed are measured using the CBA method and can be seen as earnings or cost savings. In the CBA, the net present value (NPV) is noted as being any related costs or benefits because there are not circulated equally over time (McEwan, 2012). After any or all additional benefits (B) have been calculated, B is subtracted from C which yields the net benefits of the event. The formula for calculating the net present value (NPV) is as follows:

$$NPV = \sum_{t=0}^{n} \frac{B_t}{(1+r)^t} - \sum_{t=0}^{n} \frac{C_t}{(1+r)^t}$$

The function of the CBA is to provide reasoning for decisive and effective decision making. To a certain degree, the findings from CBA can determine the best possible resource allocation for programs, policies, or projects when resources are threatened (Levin and McEwan, 2001). Speculation suggests that there are two decisive arguments against CBA. The first argument proposes that there is a lack of theoretical foundation for quid pro quo between costs and benefits, arguing the assumptions made from the analysis. The second argument proposes the policy makers inability to agree on monetizing and recognizing the costs and benefits of CBA (Boardman et al., 2006). CBA is deemed as being a formal method of analysis for benefits and costs which can be used in various industries including transportation, construction, agriculture or tourism. CBA can be used to assess the appeal of any type of investment project with regards to both private and public sectors (Dreze and Stern, 1987). CBA within the private sector is used for assessing business investment projects, whereas in public sector it is used to gauge the level of actions and programs implemented at different levels of the organizational system (Clinch, 2003). Academically, the use of CBA methodology includes a variety of definitions and clarifications. The purpose of CBA becomes redundant if the sum of the impact does not exceed the net benefit of society (Henley and Spash, 1993; Randall, 1987). Net benefit of society equates to the sum of non-momentary and monetary benefits as an outcome of the rational manipulation of the environment. In addition, cost benefit can be broken down in to three sub categories: economic ratio (costs), environmental ratio (damages/improvements), and social ratio (employment, well-being, living standards etc.).

Many suggest that the CBA method contributes mostly to the impact evaluation of the investment project varying upon estimated costs versus the benefits of different alternatives (Toh, 2012). Additionally, the importance of alternative selection for either projects or policy management is necessary for assuring maximum benefit. Therefore, CBA should include a series of standardized calculations dedicated for providing projections and assumptions. (Carpenter et al., 2009; Cellini and Kee, 2015). Nevertheless, many have stated that CBA method is inherent to some degree of flaws as it does not give an objective analysis. In retrospect some claim that CBA lacks transparency when it comes to providing alternative selections (Hahn and Sustain, 2002). In spite of criticism about CBA's limitations, many hold the method with high regard with its ability to equally distribute information efficiently between parties i.e. citizens, officials, and politicians. This allows for a shared database for those who will participate in the decisions making process and ideally creating information symbiosis (Schmid, 1989). Moreover, CBA is credited for identifying the best possible alternative or solutions for users from all considered outcomes (Wegner and Pascual, 2011). CBA can be a valuable tool in comprehensive investment projects showing stakeholders whether the investment is worthwhile or not (Linn, 2011). The common unit of measurement in CBA should be represented by currency and all aspects should measurable through monetary terminology. Quantifiable factors in CBA allows for comparison of cost and benefit to happen over an extended period allowing users to glimpse into the result of the each possible alternative (Clinch, 2003). There are a variety of ways to classifying the benefits and costs of the analysis. There can be two distinguishes of cost and benefits: physical and pecuniary; both of which are either direct or indirect and tangible or intangible (Quah, E. and Toh, R., 2012).

2.2.4 Activity-Based Costing

The cost structures of enterprises tend to become more complex over time as companies expands. As a result, budget planning and rolling forecasts need to be examined and updated frequently in order to understand the cause and effect relationship of costs and most importantly overhead costs. This is more beneficial then checking costs as they are incurred. In ABC, budgets are planned from each level of activity that has a driving cost. The purpose of ABC is to recognize overhead costs by following them back to their source of origin (Raiborn and Kinney, 2010). ABC is a realistic division of capital through financial resource allocation. Any cost-focus will come with a cost record which can be deducted to its respectful activity. By assigning costs to activities, ABC eliminates the possibility for overhead cost to be mishandled (Kalpan et al., 2009). When new products or product groups are created it is natural that costs are generated and associated as the cost drivers. The cost drivers are any related factors that affect the total costs of the time. Costs drivers are characterized by the unit of activity which cause change over time (Horngren et al., 2009).

Depending on the complexity of the ABC, a two dimensional costing model makes allocating costs and monitoring the process more easily to follow as show in the figure 8 bellow. The vertical axis of the model is considered to be the first dimension which consists of the allocating costs to activities and defining the cost objectives. The purpose of this dimension is to understand the importance of decision making process from turning the cost into an activity. The horizontal axis or the second dimension is responsible for the process of conversion and shows the need for new data. This data is related to the event from cost driver to performance measurement indication. For example, what is the performance of the activity and its level of completion to what is the main cost driver and how it performs (Turney, 1994).

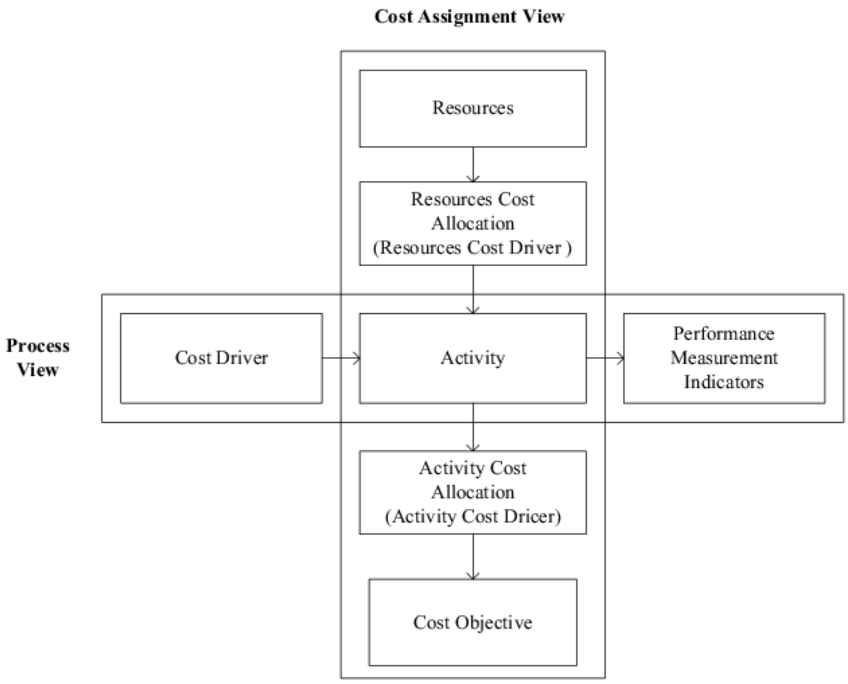


Figure 8. Two Dimensional Activity-Based Costing Model (Tsai, 1996)

The functionality then of the ABC system is to understand new detailed information at different levels of activities in relation to the product or service (Tsai, 1996). Conventionally, the ABC method is used to allocate either fixed, variable, or overhead costs into their appropriate activity but at the same time identify areas of surplus (Gunasekaran and Sarhadi, 1998). This process will produce more accurate costs and marginalize errors and unnecessary information. Unlike traditional costing where rough estimates are assigned to the final product or service, ABC does what they cannot (Horngren et al., 2009).

2.2.5 Cost-Benefit Analysis of UAV

One of the most apparent themes within the literature is just how useful and cost beneficial UAVs and drones can be when it comes to aerial imagery. Traditionally, this method was done with helicopters and planes where the costs can be astronomical in addition to the long lead time needed for data collection and interpretation. Military applications have already been cited at potentially saving lives during combat scenarios. For businesses, the initial investment of a drone including all related hardware and software needed for safe operation needs to be considered before using the conventional aerial imagery methods. One project done in cooperation with the U.S. Department of the Interior Bureau of Land Management (BLM) conducted a survey of a wildlife refuge's crane population (Mailey, 2013). The study did a cost comparative analysis between different applications in order to collect the crane population. The direct costs without time considerations are displayed in table 2 below.

Application	Cost ($)
Third-party Contracted Aircraft	$35,000.00
Government Funded Aircraft	$4,300.00
U.S. Army UAV	$2,600.00

Table 2. Wildlife Refuge Aerial Application Cost Comparison (Mailey, 2013).

Similarly, another BLM project compared the costs required for aerial imagery of a mining facility specifically for landfill and gravel pits over periodical basis for collection of spatial data of the areas (Mailey 2013). The direct costs without time considerations are displayed in table 3 below.

Application	Landfill Cost ($)	Gravel Pit Cost ($)
Third-party Contracted Aircraft	$10,000.00	$10,000.00
U.S. Army UAV	$300.00	$120.00

Table 3. Mining Facility Aerial Application Cost Comparison (Mailey, 2013)

The outcomes of these studies does provide evidence that UAV applications can deliver significant value in cost savings but these studies are government funded and do not represent the same scalability and resources needed for a business level investment. Another industry that relies heavily on aerial imagery is precision agriculture. Precision agriculture needs properly managed and monitored crops in order to reduce costs and maximize profits. Farmers use all forms of videography where costs can start to accumulate rapidly. Aerial imagery taken from an airplane can cost up words to $3.50 an acre, cannot always provide high-resolution images and the lead time to produce these images can be lengthy. A basic UAS can roughly cost $5,000 - $7,000 and can produce high-resolution images instantaneously (Bedord 2013). Other precision agriculture studies on crop monitoring have shown using geological satellite imagery to cost $0.25 to $0.30 per acre which also lacks high-resolution and is only possible periodically as satellites take time orbiting to a specific location (Wang 2014).

3 RESEARCH METHODOLOGY

This chapter presents the research method that was employed for the study followed by how the research was designed. Thereafter, data collection for the selected method is presented describing in detailing the steps involved. The purpose of the research methodology section is to describe in detail how the study was carried out and what techniques were used for data collection and analysis which are most suited to the research.

3.1 Methodology

The methodology of any study includes different research techniques which have been widely established and accredited by most academics. Thus, its purpose is to clarify which technique matches the study, define the steps involved, and consider any limitations. Research can either be quantitative or qualitative by nature. However, a case study in some situations or other areas of research, can be a valid method over others due to its ability to navigate more easily over different sources which can include qualitative and quantitate information (Yin, 2014). By definition, as case study should be an in-depth empirical study into a contemporary phenomenon within its real life context specifically when the setting of the phenomenon and the context are not stated (Merriam, 1998). A case study suits well for the objective of this study which is descriptive by nature. A descriptive research should describe the phenomenon (Yin, 1994). Thus, a descriptive research should not provide the answer to the question why but rather the answers to the questions of who, what, where, and how. For a business related phenomenon, it is often sufficient enough to describe the event of a situation rather than providing explanations as to why (Zikmund, 2000). For the purpose of this research, a descriptive single case study is used to analyze drones in comparison to a conventional method.

3.2 Research Design

The main objective of the research was to study the cost analysis of a single drone application to allow for easier understanding of implementation of UAS over conventional methods. The drone application is the unknown variable which also determines what the conventional method would be. The main research question should be separated as two driving factors in determining whether or not a drone is the right solution, these being benefits and cost-effectiveness. Benefits in this context refers to time or total working hours saved. Cost-effectiveness in this context would mean effective or productive in relation to its cost. By definition, the results of the main research question should be derived from quantitative analysis in the form of numbers or statistics. However, this is unachievable without understanding the context of drone application and its operational function. To facilitate this, a series of sub-questions were created to dissect the most important components of the main research question. The methodology and source for each sub-question is presented below in table 4.

Main Question	Sub-Research Questions	Methodology	Source
To what extent are drones beneficial and cost-effective to operate?	What are possible drone applications?	Qualitative	Theoretical Research Interviews
	What are drone characteristics and associated costs?	Qualitative	Theoretical Research Company Data Interviews
	What the processes for mast inspection and their associated costs?	Qualitative	Interviews Theoretical Research

Table 4. Research Framework

The first sub-question clarifies the different drone applications possible. The second sub-question is a breakdown of drones by their physical characteristics and attributes followed by their related costs. The third sub-question selects one application from the results of the second sub-question and analyses the conventional method and its associated costs. The sub-questions should be derived from interviews answers and simulation results.

3.3 Data Collection

Two sets of interviews were used during the qualitative stage of the research. The first set of interviewers were semi-structured conducted internally with members of the NDN project. The potential industries suitable for drone application were identified and listed for selection based on the theoretical background. The industries used for the interviews were collected by the research from the theoretical background and company materials. Due to the sheer size of the company and international environment, the interviewees were limited to the members of the NDN project only. The respondents were sent the interview questions during week five (January 28, 2019 - February 3, 2019) by email and answers were collected a week later during week six (February 4, 2019 - February 10, 2019). This allowed respondents enough time to select an industry and suggest a possible drone application. Respondents were asked to provide their role or title within the project in order to understand their connection to the project. The list of the respondents from the interviews is presented below in table 5.

Title
Product Manager
Drone R&D Lead
Lead Mechanical Engineer
Senior Specialist
Systems Architect
Systems Engineer
UAV Operation Specialist
Mechnical Engineer
Flight Dynamics Engineer
UAV Mechanical Trainee

Table 5. List of NDN Interviewees

The second set of interviews conducted were semi-structured and flexible by nature having a set of questions prepared based on a set of relevant themes from the first interviews. The themes are areas in which the interviewer should cover, in a way acting as a guideline for the interview. Introduction emails and phone calls were held requesting for interviews which included a brief overview of the research involved. After initial contact, participants who wished to participate arranged a time suitable for them to have an over the phone interview. Interviews were conducted during the months of May to August, 2020. Before the interviews were conducted, the researcher asked for permission to record the dialogue. During the interview additional notes were made when necessary alongside the interview questions for support. The researcher had a general structure prepared in order to ensure all themes and questions would be covered. The participants chosen to for interviews all different professional backgrounds in the telecommunication industry. The interviewees are presented in figure 6 below.

Interviewee	Title
Participant 1	Drone R&D Lead
Participant 2	UAV Operations Specialist
Participant 3	Customer Executive
Participant 4	CFO
Participant 5	Systems Manager

Table 6. List of Telecommunication Industry Interviewees

Once both sets of interviews were completed and transcribed, the drone application was selected. This was determined to be high structure evaluation/inspection. A simulation was set up to mimic the inspection environment for both drone and conventional methods. The formula for calculating the total mast inspection time (TMIT) with a drone was as follows:

$$TMIT = ST + \sum_{i=1}^{n} TIT_i + (x * TBC)$$

The purpose of the TMIT is to add the setup time (ST) with the sum of all sections including ten inspection interest points (TIT) plus the time to change battery (TBC). The x variable represents the number of times the battery needed to be changed. A simulation protocol was created to show how each variable interacted with one another at every stage of the simulation. This information is displayed in figure 9 below.

ID	VARIABLE	VALUE
(A)	Drone Flight Speed (km/h)	3 sec / ft
(B)	Number of Interest Points per Section	10
(C)	Drone Flight Time	40 mins
(D)	Number of 50 (ft) Sections	-
(E)	Number of remaining _ (ft) Sections	-
(ST)	Setup Time	20 mins
(ID_1)	Flight Time per 10 Interest Points (50ft)	(A) * 50 / (60/1)
(ID_2)	Flight Time per 50ft Sections	(B) * (ID_1)
(TIT_1)	Total Inspection Time of All 50ft Sections	(D) * (ID_2)
(ID_3)	Flight Time per 10 Interest Points (_ft)	(A) * _ / (6/1)
(ID_4)	Flight Time per remaining _ ft Section	(B) * (ID_3)
(TIT_2)	Total Inspection Time for remaining Section	(E) * (ID_4)
(ID_5)	Number of Battery Changes	(TIT_1) + (TIT_2) / (C)
(ID_6)	Time to Change Battery	6 mins
(TBC)	Total Time for Battery Change (TBC)	(ID_5) * (ID_6)
(ID_7)	Total Data Collection Time	(ST) + (TIT_1) + (TIT_2) + (TBC)
(TMIT)	**Total Mast Inspection Time**	**(ID_7) + (C)**

Figure 9. Drone Simulation Protocol

The formula for calculating the total mast inspection time (TMIT) with conventional method was as follows:

$$TMIT = ST + \sum_{i=1}^{n} TIT_i$$

The purpose of the TMIT is to add the setup time (ST) with the sum of all sections including ten inspection interest points (TIT). A simulation protocol was created to show how each variable interacted with one another at every stage of the simulation. This information is displayed in figure 10 below.

ID	VARIABLE	VALUE
(A)	Climbing Speed (km/h)	15ft / min
(B)	Number of Interest Points per Section	10
(C)	Number of 50 (ft) Sections	-
(D)	Number of remaining _ (ft) Sections	-
(ST)	Setup Time	60 mins
(ID_1)	Climbing Time per 10 Interest Points (50ft)	(A) * 50 / (60/1)
(ID_2)	Climbing Time per 50ft Sections	(B) * (ID_1)
(TIT_1)	Total Inspection Time of All 50ft Sections	(C) * (ID_2)
(ID_3)	Climbing Time per 10 Interest Points (_ft)	(A) * _ / (6/1)
(ID_4)	Climbing Time per remaining _ ft Section	(B) * (ID_3)
(TIT_2)	Total Inspection Time for remaining Section	(D) * (ID_4)
(ID_6)	Total Data Collection Time	(ST) + (TIT_1) + (TIT_2)
(TMIT)	**Total Mast Inspection Time**	**(ID_6)**

Figure 10. Conventional Simulation Protocol

3.4 Data Analysis

After reviewing the data transcribed from interviews, different themes were recognized. Through the process of recognition, coded categories and concepts can be formulated (Eriksson and Kovalainen, 2008). These categories can then be prescribed to their corresponding themes. This is a continuous comparative method of examination that includes coding and analysis (Hirsijärvi and Hurme, 2004). The purpose of themes and coded categories is to dissect the data into easier digestible portions. The idea is to methodically comb through the data. Using this method of data analysis, it becomes easier to establish scenarios and conclusions further in the research. The recordings along with the notes taken during the interviews were materialized and highlighted with different colors to create a visual representation of the various themes. In doings so, the researcher was able to locate any correlating parts from the interviewees responses and formulate arguments and conclusions. Once the data was redistributed to its corresponding theme, the analysis can commence. The themes derived from the interviews were then compared to the main and sub-research questions. Thus, only the utmost integral and relevant data remains from the data as a whole (Eskola and Suoranta, 1998). Interviews as a means for data collection is valid when the information is derived from suitable participants.

4 CASE STUDY

In this chapter, the case study is expanded upon in greater detail. Additionally, this section introduces the proposed drone application and industry along with simulations of scenarios. This section intends to use the data and methods obtained and prescribed from the qualitative portion of the methodology.

4.1 Drone Application Proposal

The process involved for selecting a single drone application is based on the literature review of UAVs in reference to section 2.1.3 (Drone Applications) and 2.1.4 (Drone Type) of this thesis along with the interviewees' responses. The highest value captured by industry from potential drone applications was determined to be the focus of this study, in this case being infrastructure or construction. This is represented in figure 11 below.

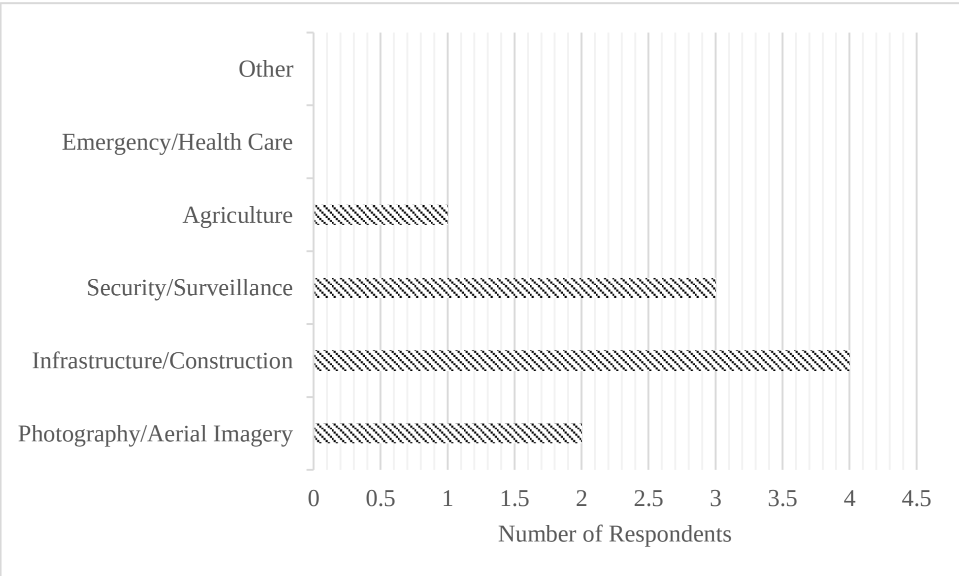


Figure 11. Drone Application Reponses from Sample Group

In addition to identifying the industry, respondents were urged to suggest a possible drone application. Three out of the four respondents who selected infrastructure/construction industry suggested inspection types of applications and the remaining respondent suggested 3D modeling. All of the infrastructure/construction suggestions had to deal with high structure evaluation/inspection of which three were related to cellular mast or radio towers.

The suggestions for drone application based on the infrastructure/construction industry are presented below in table 7.

Respondent	Drone Application Suggestion
UAV Operation Specialist	Powerline Inspection
Drone R&D Lead	TV/Radio Tower Inspection
Systems Architect	3D Modeling of Communication Towers
UAV Mechanical Trainee	Cellular Mast Inspection

Table 7. Drone Application Suggestion for Infrastructure/Construction

Drones can improve the efficiency and accuracy of assessments in supporting human efforts, this can include the likes of area mapping, construction progress, and high structure evaluation/inspection. In the space of infrastructure, drones can provide tremendous value for structure monitoring and inspections. Consequentially, overlooking inspections can have implications ranging from minor to disastrous. Thus the choice of application was high structure evaluation/inspection. By definition, for the purpose of this research high structures can include but are not limited to telecommunication masts and towers. The initial cellular tower mast inspection and end-of-life infrastructure examination with a drone would be beneficial for quickly surveying for components, repairs and maintenance purposes (Participant 4, 2020). The use of drones could be of a particular interest when the need for real-time onsite aerial imagery and video is necessary for tower inspections (Participant 3, 2020). The maintenance of telecommunication towers helps to maximize the lifespan of the tower also preserving the investment of tower attachments.

4.1.1 Conventional Structural Inspections of Towers and Masts

Telecommunication towers or radio masts are needed for wireless communications, mobile networks, radio broadcasts and television programming (Participant 2, 2020; Participant 3, 2020). Communication towers can differ in height depending on their location or purpose. A thorough examination of the towers is mandatory during its first year of erection. The different types of communication towers are presented below in figure 12.

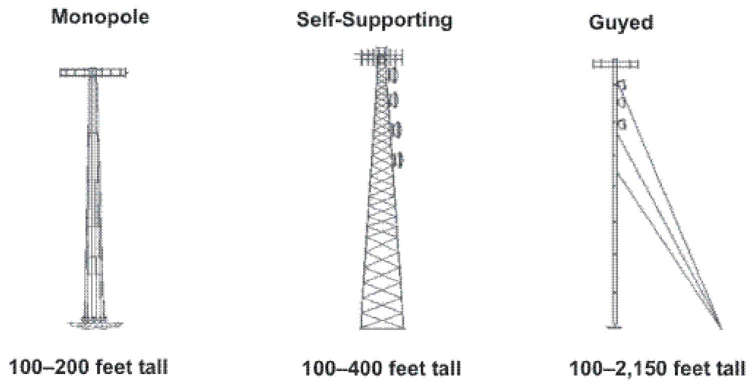


Figure 12. Different types of communication towers (Elcosh, 2011).

By nature, these towers and masts can be decades old and are exposed to the different elements and loads. The frequency of tower inspections may differ, for example, guyed towers require three year interval inspections and self-supporting towers five year intervals but annual inspections may be required due to heavy winds or corrosive salty air. Tower and mast owners can verify inspection frequency from manufactures but this is only if no protocol has been established. Some of the prevalent factors affecting tower and mast inspection frequency include:

- Historical records – towers with good history
- Age – end-of-life cycle
- Loads – towers or masts with more loads
- Location – urban densely populated areas, rural areas, or coastal areas
- Environment –exposure to heavy wind, rain, snow etc. (Participant 5, 2020)

The general process starts with a visual inspection of the tower from the ground. This is done to observe any obvious structure faults or hazards before the initial climb to protect tower climbers. After the visual inspection, the tower inspector ascends upwards inspecting every step. However, depending on the level of inspection, a thorough climb may consist of hundreds of different points of interest. This level of inspection should be accomplished regularly. The climb process includes pictures and recording heights of any defects. The structural inspection of any tower should consist of tower legs, cross members, climbing points, tensions arms, platforms and walkways. For self-supporting and monopole towers, rappelling down the tower side opposite of the climb is may also be necessary. After the completion of inspection, a report should be complied detailing that the tower and surrounding area is structurally and integrally sound at the time of examination. A structural engineer should be consulted on the results for final recommendations (Isola and McCrumm, 1996).

A theoretical inspection model was created in order to understand the scenario at different activity levels along with stakeholders involved when the conventional method is used for inspections. This model is presented below in figure 13.

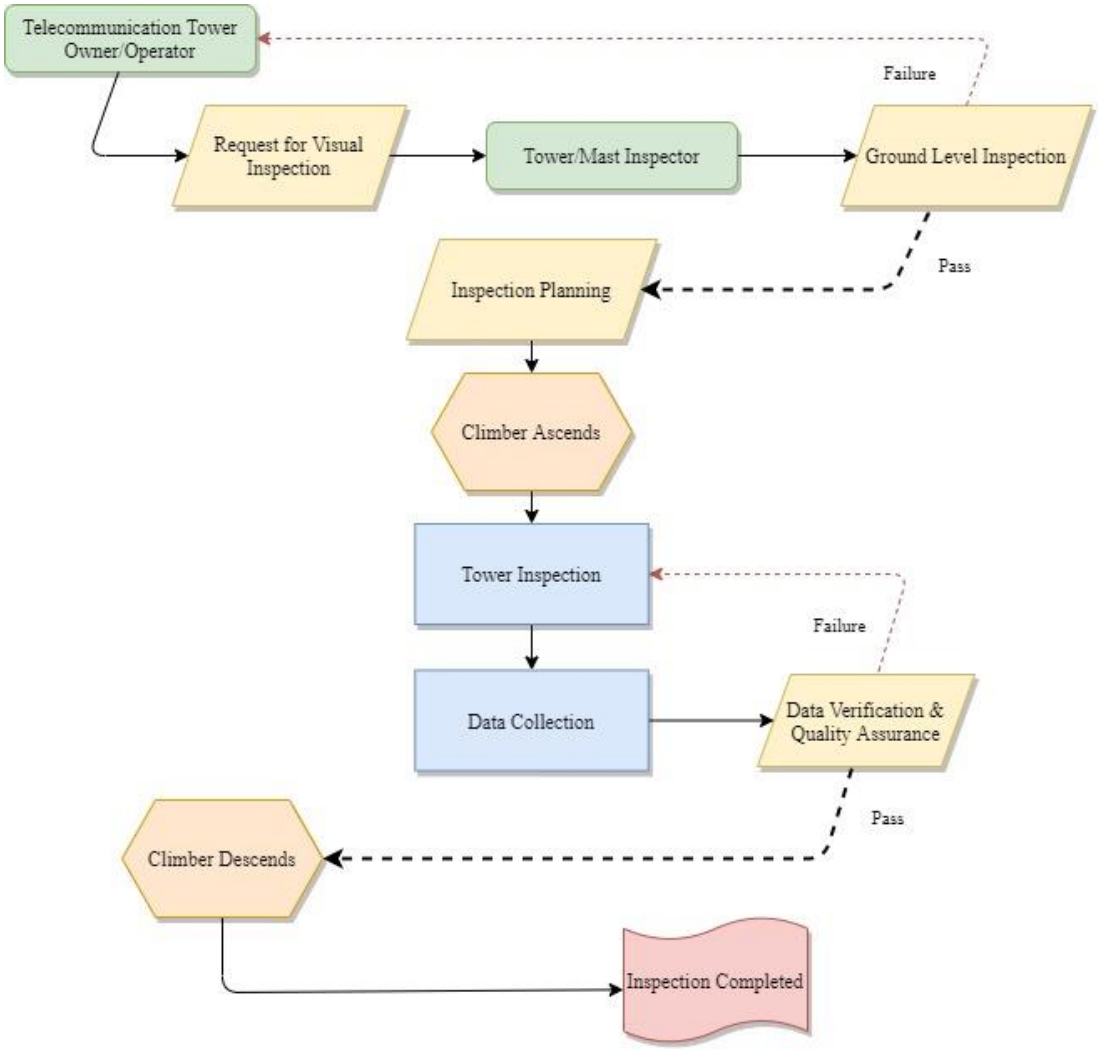


Figure 13. Theoretical Conventional Tower Inspection Process Flowchart

4.1.2 Drone Structural Inspection Scenario

The purpose of this section is to present and illustrate a scenario that will utilize a drone for routine tower/mast visual inspections. Under the most ideal operational scenario possible, the operation would take place during normal working hours, preferably in daylight with good visibility that is deemed acceptable by tower inspector and drone operator. The inspection team can consist of tower inspector, drone pilot, UAS operators and structural engineer. The tower inspector begins the ground level inspection of the surrounding site and visual observation of the tower. If passed the initial tower inspection planning can begin. If it is deemed a failure, the tower owner and or operator are responsible for corrective actions. The tower inspector and drone pilot records the GPS coordinates, type, air temperature, weather conditions and time. The UAS operators begins any and necessary drone related setups including payload mounted cameras, sensors, base station and user interfaces. Before the drone takes off, a UAS operator checks the battery level and status while also verifying a stable connection has been established to the base station. The drone can either follow a programmed path or flown manually depending on conditions (Participant 2, 2020). The drone operator beings by flying to the coordinates of the tower and starts the examination. The drone operator is advised by the tower inspector as to what are the specific points of interest such as rust areas, crack, faults, defective hardware systems, and lighting fixtures which is all streamed in real-time back to the base station. During the course of the inspection, the drone operator is continuously verifying the remaining flight time and battery capacity. In the event of a battery change during an inspection, the drone will fly to the recharging station and the battery will be replaced. At the time of battery replacement, the tower inspector has the opportunity to verify the visual data for quality purpose. If the data is sufficient the drone can continue its flight path or land. If the data is insufficient, the process repeats itself until the tower inspector is satisfied and the inspection can be completed. A conceptual inspection model was created in order to understand the scenario at different activates levels and stakeholders involved when using a drone for inspections. Figure 14 shows that the process can be initiated by either the tower owner or operators. Operators in this context refers to those who have components or hardware on the tower.

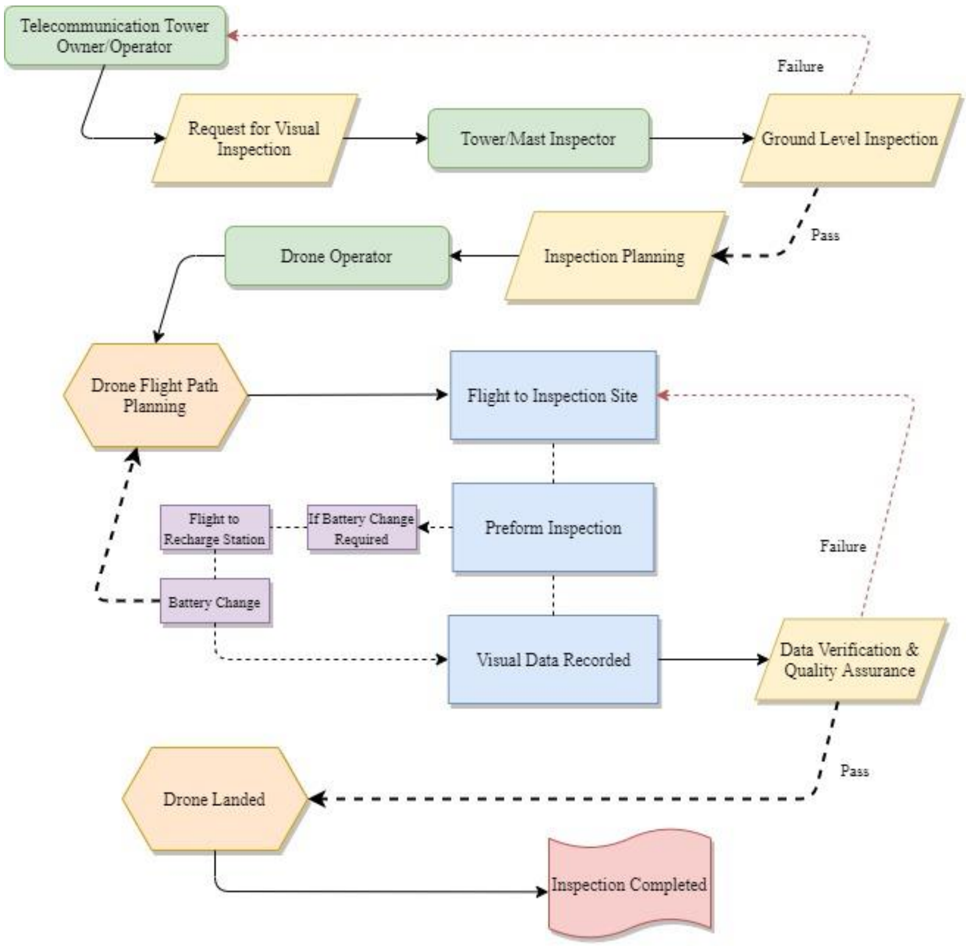


Figure 14. Conceptual Drone Tower Inspection Process Flowchart

4.2 Simulation of Inspection Scenario

Due to the nature of the study, a simulation was created using actual masts from Finland's Air Navigation Services (ANS). This was done to protect all interviewees and third parties involved from data infringement along with preserving the non-disclosure agreement in place between the researcher and Nokia. ANS is responsible for all aeronautical information documentation in Finland and is publically accessible. ANS publishes obstacle data on a yearly basis that are in accordance with the Aeronautical Information Regulation and Control (AIRAC) guidelines. ANS's most recent Area 1 obstacle data sheet was used to identify all obstacles 100m above ground level in Finland's airspace. Total obstacles were 1317 of which included masts, towers, chimneys, poles, pylons, buildings, structures and wind turbines (ANS Finland, 2020). For the purpose of the simulation only masts were selected totaling 401 of which five were chosen at random. Table 8 is a legend in order to better comprehend the obstacle data sheet and table 9 presents the five masts that were used for the study.

FIELD	INFORMATION	EXAMPLE
OBST ID	Obstacle Identification	EFINOB 10031
TYPE	Type	Mast
LAT	Latitude as degrees	61.93083059
LONG	Longitude as degrees	25.73175845
HGT AGL (FT)	Height above ground level (AGL) in FT	355
ELEV MSL (FT)	Elevation above mean sea level (MSL) in FT	982
LGT TYPE	Type of top light	F R
LGT HR	Hours of light	HN
MARKINGS	Markings	Yes

Table 8. Legend for Obstacle Data sheet (ANS Finland, 2020)

OBST ID	TYPE	LAT	LONG	HGT AGL (FT)	ELEV MSL (FT)	LGT TYPE	LGT HR	MARKINGS
EFINOB 10241	Mast	60.80882	21.42678	329	385	F R	HN	Yes
EFINOB 36023	Mast	60.73292	21.55308	460	517	FLG R	HN	Yes
EFINOB 46754	Mast	62.47694	21.53088	591	749	FLG W	HN	Yes
EFINOB 11526	Mast	67.02106	27.21524	863	2419	FLG W	H24	Yes
EFINOB 11014	Mast	60.17771	24.64009	1070	1214	FLG W	H24	Yes

Table 9. List of Masts for Simulation (ANS Finland, 2020)

The simulation model was used to simulate visual inspection conditions to estimate the total of work hours needed for a completed inspection using a drone versus conventional method. When it came to simulating inspection points, the length of the masts were separated into sections by multiples of fifties until it was rounded to the nearest hundredth. If the length of the mast was not a round number, the remaining feet were inspected in one single section. Each section contained ten points of interest for inspection (rust areas, crack, faults, defective hardware systems, and lighting fixtures etc.). Table 10 below, illustrates the masts data including sections that were ran against the simulation in order to achieve the total mast inspection time.

OBST ID	TYPE	LAT	LONG	HGT AGL (FT)	NO. OF 50FT SECTIONS	REMAINING SECTIONS (FT)
EFINOB 10241	Mast	60.80882	21.42678	329	6	29
EFINOB 36023	Mast	60.73292	21.55308	460	8	60
EFINOB 46754	Mast	62.47694	21.53088	591	10	91
EFINOB 11526	Mast	67.02106	27.21524	863	18	63
EFINOB 11014	Mast	60.17771	24.64009	1070	20	70

Table 10. List of Masts (ANS Finland, 2020)

4.2.1 Drone Simulation Inspection

Before the simulation was ran for a drone inspection, a few conditions were assumed including the following:

- Masts were inspected in sections and each section was equal to the maximum flight time of the drone
- Flight time between mast sections and drone base station was negligible
- Triangular distribution estimate with ±10% high and lows for process time
- Recorded visual data was always accepted

With these assumptions in place the simulation was carried out. Under the circumstances that the simulation was meant to test the hypothesis that average inspection time will vary if the battery change and data verification processes are carried out one after the other. The initial drone related setup and planning was twenty minutes until the drone was ready to ascend up the mast assuming the different estimated factors. The flight time of the drone was assumed to be forty minutes (Participant 1, 2020) which was equal to capacity of one charged battery. The speed of the drone was assumed to be 0.3 feet per second from which an estimate was calculated of the maximum length the drone could inspect through one battery cycle. With the simulation setup in place, the drone began its flight and iterated through the mast inspection loop. When all point of interest were recorded and a section was completed the drone returned to the base station for a battery change. During the battery change, the data was verified with a mast inspector for quality purposes. The battery change process had an estimated duration time of two minutes (Participant 1, 2020) and data verification was one-tenth of the drones total flight time. In total, the battery change and data verification process had a duration of six minutes. Once the battery change and data verification were completed, a decision node was prompted asking if data quality was accepted or not with a double probability outcome. If no, the drone re-inspected the section. If yes, another decision node was prompted asking if there were any more sections remaining in the inspection. If yes, the flight plan was updated and the drone resumed the inspection. If no, the mast inspection was considered to be completed and this halted the simulation. The simulation was reconfigured and the process was repeated with a different mast configuration.

The simulation was setup in a way to understand the difference between both the battery replacement and data verification processes separately. From a cost standpoint, this could have beneficial by adding an extra UAS operator to facilitate these two processes in parallel to save time. For the simulation to be adequate, inspection scenarios were first carried out using the baseline conditions that were presented in the beginning of this section. Each process time was triangularly distributed with a ±10% high and lows estimate as sample data was limited. In figure 15 below, the simulation is duplicated once the drone requires a battery change. The time needed for both data verification and battery change were combined at the end of each simulation accumulating only the slowest process times which were then added to the total inspection time. Hence, the time to complete each process was represented in the overall inspection time.

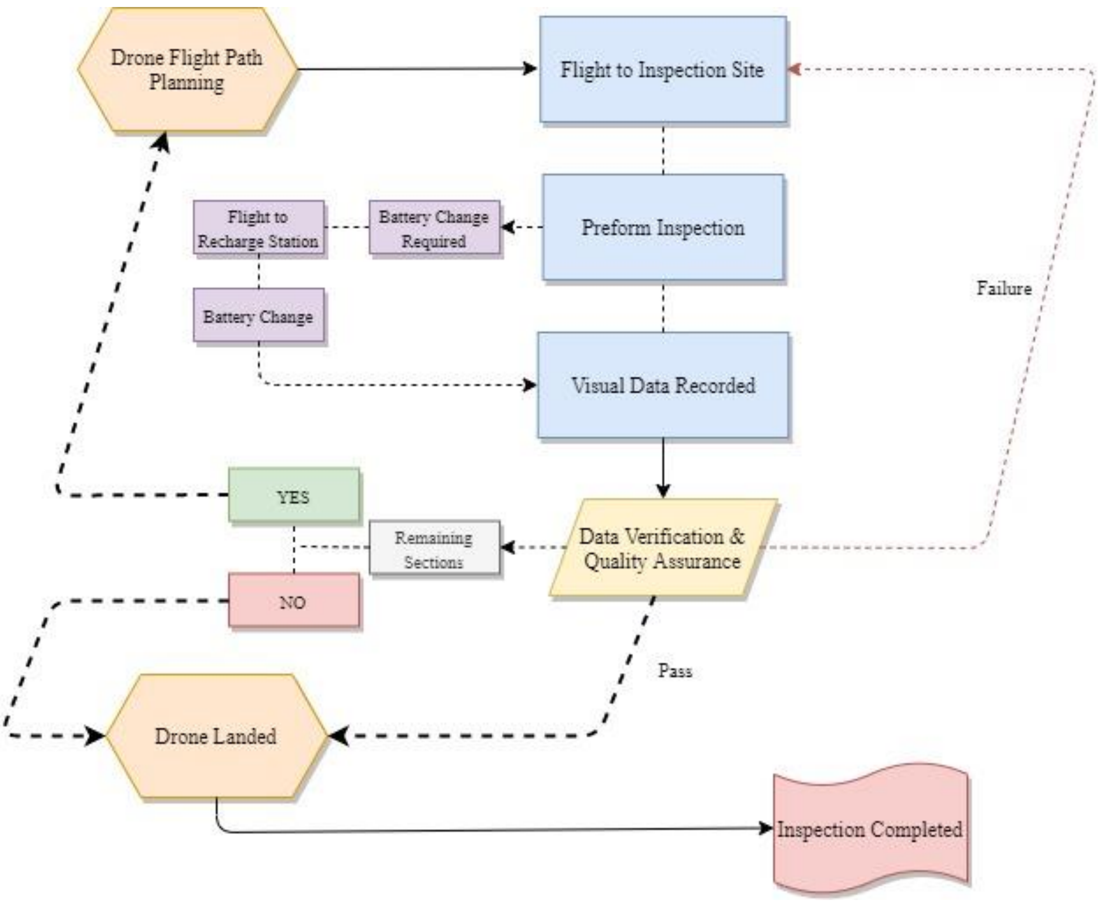


Figure 15. Conceptual Drone Tower Inspection with Data Verification Node

4.2.2 Conventional Simulation Inspection

The simulation for conventional inspection was run in a similar fashion in comparison to the drone simulation. The major difference between the two was the conditions and the battery change process time was removed. Before the conventional simulation was ran the following conditions were assumed:

- Visual inspection was always passed
- Climbing speed was constant
- Triangular distribution estimate with ±10% high and lows for process time
- Recorded visual data was always accepted

With these assumptions in place the simulation was carried out. The initial setup time for conventional method was deemed to take sixty minutes to complete before the mast could be climbed for inspection. The reasoning behind the difference in setup times is to take into account the visual inspection of the mast that must take place from the ground and surrounding area. Due to the lack of satisfactory data from primary sources concerning conventional method, the climbing speed of the mast climber was referenced from the journal of Applied Ergonomics, vol. 66. A study was conducted on the ergo-metrics of ladder climbing from seventy-five and ninety degree pitches. The aim of the study was to understand the effects of climb speed and pitch against oxygen level, heart rates and level of exertion on the body. The study determined the slowest climbing speed at ninety degree pitch to be were 9.5m per minute (Baron et al., 2017). Ninety degree pitch climbing speed was selected because this roughly replicated the environment of the conventional simulation inspection climb. Thus, the speed of the mast climber was calculated by assuming the 9.5m per minute climb speed divided by two. This was done to factor in equipment and harness weight of the climber. The total climbing speed was 15ft per minute. With the simulation parameters in place the mast climber began the inspection, inspecting each section including the ten points of interest per section. When are sections were completed the climber descending down the mast and the data was verified completing the inspection. The simulation was reconfigured and the process was repeated with a different mast configuration. Much like the drone simulation, the baseline conditions were accepted before the simulation took place. All processing times were triangularly distributed with a ±10% high and lows estimate as sample data was limited.

4.3 Simulation Results

With the simulation established, the next logical step would be to understand how beneficial and cost effective the drone inspection would be over conventional mast inspections. This will help tower owners and operators understand the feasibility whether to opt for drone of conventional method for visual inspections. The working hours were calculated by multiplying the number of crew members by the completed inspection time in hours. Table 11 below, demonstrates the results of the simulation calculated for inspection time with drone scenario. The simulation results discovered total number of batteries with respect to the height of the mast. The completed inspection time also included the time (hours) needed for editing and reporting. Editing included the process of obtaining still photo images from the video data to include into the final inspection report. Video editing included color correction, video segmenting, and cropping. The editing process was estimated to take half the time of the mast inspection (Participant 1, 2020). The number of crew members for drone inspection consisted of a project manager, mast inspector, drone pilot, and UAS operator. Based on the results of the simulation, the total numbers of batteries was deduced from the TBC. The number of batteries used per mast will be carried over into the cost analysis portion of the research for the drone inspection. The most relevant figures are those columns highlighted in orange (completed inspection time in hours) and green (working hours).

The conventional method included the same editing and reporting process time estimation. The inspection time hours included inspection planning, climbing time, point of interests, and descend time. The number of mast climbers was dependent on the mast height. If the mast more than 500ft in height, two mast climbers were required. This is similar to the batteries required in the drone inspections, which will also be taken into account for the cost analysis portion of the conventional method. The crew members of the conventional inspection included a project manager, mast inspector, and mast climbers. Table 12 below, demonstrates the results of the simulation calculated for inspection time for conventional method. By the numbers based on the parameters set up in the simulation, the conventional method is marginally faster for completed inspection time which also means total working man hours needed.

MAST ID (EFINOB)	HGT AGL (FT)	NO. OF BATTERIES	INSPECTION TIME (HRS)	EDITING & REPORT TIME (HRS)	COMPLETED INSPECTION TIME (HRS)	NO. OF CREW	WORKING HOURS
10241	329	4	3.5	1.7	5.2	4	20.9
36023	460	6	4.7	2.4	7.1	4	28.4
46754	591	7	6.0	3.0	9.0	4	35.9
11526	863	11	8.6	4.3	12.9	4	51.6
011014	1070	13	10.6	5.3	15.9	4	63.5

Table 11. Simulation Results for Mast Inspection with Drone

MAST ID (EFINOB)	HGT AGL (FT)	NO. OF MAST CLIMBERS	INSPECTION TIME (HRS)	EDITING & REPORT TIME (HRS)	COMPLETED INSPECTION TIME (HRS)	NO. OF CREW	WORKING HOURS
10241	329	1	3.6	1.8	5.3	3	16.0
36023	460	1	4.6	2.3	6.9	3	20.6
46754	591	2	5.6	2.8	8.4	4	33.5
11526	863	2	7.7	3.9	11.6	4	46.3
011014	1070	2	9.3	4.7	14.0	4	55.8

Table 12. Results for Conventional Mast Inspection

5 ACTIVITY BASED COSTING FOR MAST INSPECTION

An ABC framework is able to support the notion of using a drone for mast inspections over the conventional method. Any financial endeavors or conquests start with the requirements of stakeholders involved, scope of information needed to make a decision and understanding the resources and time involved. The ability to scale the economy with investments is achieved with minimum value in the performance of mast inspections when the resources and costs become the primary focus. The purpose of this section is to use ABC to identify costs from activity level for mast inspections.

5.1 Defining Activities

The activities for the ABC model are taken from the flowcharts for the drone (figure 15) and conventional (figure 13) mast inspection from sections 4.2.1 and 4.2.2 of this thesis. The process of each activity derives from the necessary resource in the form of working hours and equipment. The ultimate goal is to gain insight into all activities required to complete an inspection. In order to define the resources needed, the equipment related to each drone activity must be identified. From a stakeholder's perspective, the resources needed for a successful mast inspection must presented and accepted. The resources should be presented in manner that exemplify the resource's level of consumption through its activity. This is caused by a cost driver, or the costs associated with that activity. The activities and cost drivers for a drone and conventional mast inspection are presented below in tables 13 and 14.

Resources Level	**Cost Activity**	**Cost Driver**
Inspection Team	Project Manager	Number of Project Managers
	Mast Inspector	Number of Mast Inspectors
	Drone Pilot	Number of Drone Pilots
	UAS Operator (Trainee)	Number of UAS Operators
Drone Equipment	Drone +payload attachment	Manufacturing Costs
	Editing +reporting	
	Battery module	Number of Batteries

Table 13. ABC of Drone Mast Inspection

Resources Level	**Cost Activity**	**Cost Driver**
Inspection Team	Project Manager	Number of Project Managers
	Mast Inspector	Number of Mast Inspectors
	Mast Climber	Number of Mast Climbers
Equipment	Harness +Camera	Manufacturing Costs
	Editing + Reporting	

Table 14. ABC of Conventional Mast Inspection

The ABC is used to understand the cost optimization and provide the opportunity to compare the cost differences between both inspections types helping stakeholders make smarter business decisions. The resources are deduced to their cost activity and cost driver which in this case equate to labor and equipment costs. Labor refers to the required working hour and equipment refers to tool or hardware needed for a mast inspection. Hardware means the absolute necessary materials costs needed to keep the drone operational such as motors, electronic speed controller (ESC), frame, propellers and cost for payload attachments including mounted cameras and sensors. Costs are conceptualized at the rate of resource consumption. For drone inspections, the number of batteries used should also be factored into the total costs. Editing and reporting times should also be considered. The level of variability is dependent on the resource to time consumption ratio for inspection time hourly. Overall, the idea is to compare the costs of drone and conventional method. Cost can be direct (e.g. processes times, material, working hours) and indirect (e.g. setup times, material handling, inventorying processing) and production activities.

5.2 Cost Breakdown

On the basis of the simulation, the costs for the mast inspection can be identified to their exact values based on the corresponding height of the mast that was inspected. Table 15 illustrates the necessary resources for a drone mast inspection and table 16 shows the resources required for a conventional mast inspection.

Resources Level	**Cost Activity**	**No.**
Inspection Team	Project Manager	1
	Mast Inspector	1

	Drone Pilot	1
	UAS Operator (Trainee)	1
Drone Equipment	Drone +payload attachment	1
	Editing +reporting	
	Battery module	1

Table 15. Resources for Drone Mast Inspection

Resources Level	**Cost Activity**	**No.**
Inspection Team	Project Manager	1
	Mast Inspector	1
	Mast Climber	1
Equipment	Harness +Camera	1
	Editing + Reporting	

Table 16. Resources for Conventional Mast Inspection

In a practical sense, drone mast inspection is a feasible concept and mildly easy to implement but from a business standpoint costs are always the primary concern. The costs for drone include the manufacturing costs, pilot training, inspection crew members, and total batteries used. The manufacturing costs include the drone platform, payload attachment, and battery module.

- **Drone Platform –** Depending largely on the type of drone and intended use, the total price may vary. A small rugged drone with top-mountable sensors and no payload attachment could cost up to €1,500. A standard multi-rotor drone with bottom payload attachment capable of dual operative controls with either autonomous or manual flight modes is estimated to cost up to €4,000. The lifecycle of a drone is difficult to estimate considering regular maintenance, flying conditions and potentials crashes. Thus, the hourly cost per drone will be determined by the amount of training hours required to become a drone pilot equaling fifty hours (Participant 1, 2020). Additionally, consumable operating costs should be taken into account. These costs can include the hardware or supplies necessary to keep the drone operational. These components include drone motors, ESC, and propellers with average lifecycle lasting up to 150 hours (Participant 2, 2020). Table 17 below displays the hourly cost per component.

Component Level	Cost per €	Hourly Cost €
Motor	€85.60	€0.57
ESCs	€70.00	€0.46
Propellers	€93.40	€0.62

Table 17. Component Cost per Hour

- **Payload Attachment** – Payload attachments can include the costs needed for gimbals, high-definition cameras and imaging sensors. The estimated costs for payload attachment is €4,000 (Participant 1, 2020). This estimation includes a bottom mounted stabilizing gimbal with HD camera and image sensor optical zoom.

- **Battery Module –** In order to estimate the complete battery module costs, the battery lifecycle or in this case the drone flight time (forty minutes) must be factored into the costs. As the batteries are rechargeable, the general recommendation for drone battery charge cycles is 200 charges and the cost for one battery equals €185.60 (Participant 2, 2020). The number of batteries was contingent on the height of the mast for the inspection. Thus, the battery costs should be realized through actual hourly costs. Table 18 below shows the hourly costs equivalent to the mast height and batteries needed for a complete inspection.

MAST ID (EFINOB)	HGT AGL (FT)	No. of batteries	Cost per €	Hourly Costs €
10241	329	4	€742.40	€3.71
36023	460	6	€1,113.60	€5.56
46754	591	7	€1,299.20	€6.49
11526	863	11	€2,041.60	€10.20
011014	1070	13	€2,412.80	€12.06

Table 18. Battery Cost for Masts per Hour

- **Editing and Reporting –** Editing and reporting includes all processes of obtaining still photo images from the video data to include into the final inspection report. Video editing included color correction, video segmenting, and cropping. The cost per hour varies but is estimated to be upwards to €30 an hour (Participant 2, 2020).

- **Inspection Crews –** The crew's members for inspections should be trained and certified and also familiar with the processes needed to inspect tower or masts. Drone pilot and UAS operator training costs should include twenty hours of supervised and twenty hours of unsupervised total flight time along with ten hours of takeoff and landings. The hourly costs for UAS training costs €25 on average (Participant 2, 2020). Salary figures for each role of the inspection team were not disclosed but were generated based on Statistics Finland structure of earnings based on occupation. The salary levels are averages of private and public sector employees for both men and women. Table 19 blow explains the salaries calculated based on the 2019 total earrings by occupation for forty working hours a week (Statistics Finland, 2019).

Position	Avg. Monthly Earnings €	Hourly Cost €
Project Manager	€6,199.00	€35.76
Mast Inspector	€4,299.00	€24.80
Mast Climber	€2,964.00	€17.10
Drone Pilot	€4,102.00	€23.67
UAS Operator (Trainee)	€2509.00	€14.46

Table 19. Salaries for Inspection Crew (Statistics Finland, 2019)

5.3 Cost Consolidation

Based on the ABC of mast inspections and the hourly costs for all identified cost drivers in section 5.2, the costs can consolidated based on the value of the resources. This is done to calculate the overall costs for a mast inspection. Table 20 below shows the consolidated total costs a multi-rotor drone with bottom payload attachment and single battery.

Equipment	Quantity	Total Cost €
Multi-rotor Drone	1	€4,000
Motor	6	€85.60
ESCs	6	€70.00
Propellers	6	€93.40

Stabilizing gimbal with HD Camera	1	€4,000
Battery module	1	€185.60
TOTAL		€9,679.60

Table 20. Consolidate Drone Equipment Costs

The total consolidated costs for drone with the above configuration would cost €9,679.60. Although lifecycle assessment of the drone was not part of the scope of this research, the drone hourly costs were calculated based on the total lifetime flight hours a single drone was allowed to accumulate or 800 hours (Participant 2, 2020). The total consolidated costs was then divided by the total lifetime flight hours in order to calculate the hour costs. This yielded an hour rate of €12.09 for the drone. The unit cost per hour for drone inspection is displayed in table 21 and table 22 shows the total inspection costs for the masts used in the drone simulation with the inclusion of total batteries used for each mast.

Crew	**Quantity**	**Hourly Cost €**
Project Manager	1	€35.76
Mast Inspector	1	€24.80
Drone Pilot	1	€23.67
UAS Operator (Trainee)	1	€14.46
Equipment		
Drone + Stabilizing gimbal with HD Camera + battery module	1	€12.09
Editing + Reporting		€30.00
Miscellaneous Costs		€10.50
Regular Daily Allowance		€21.50
TOTAL		€172.78

Table. 21 Unit Cost for Drone Mast Inspection per Hour

MAST ID (EFINOB)	**HGT AGL (FT)**	**NO. OF BATTERIES**	**BATTERY HOURLY COST**	**COMPLETED INSPECTION TIME (HRS)**	**UNIT COST PER HOUR**	**TOTAL COST**
10241	329	4	€3.71	5.2	€ 176.49	€ 917.75
36023	460	6	€5.56	7.1	€ 178.34	€ 1,266.21
46754	591	7	€6.49	9.0	€ 179.27	€ 1,613.43
11526	863	11	€10.20	12.9	€ 182.98	€ 2,360.44

011014	1070	13	€12.06	15.9	€ 184.84	€ 2,938.96

Table 22. Total Cost for Drone Mast Inspection

For the conventional inspection, the majority of the unit costs consist of manpower hours including climbing, project and inspection times. The number of mast climbers was dependent on the height of the mast and was factored into the overall costs. On-site labor costs accounted for the labor needed to perform a visual inspection before the actual inspection took place. The unit cost per hour for conventional inspection is displayed in table 23 and table 24 shows the total inspection costs for the masts used in the conventional simulation.

Crew	**Quantity**	**Hourly Cost €**
Project Manager	1	€35.76
Mast Inspector	1	€24.80
Mast Climber	1	€17.10
Equipment		
Editing + Reporting		€30.00
On-Site Labor		€150.00
Miscellaneous Costs		€10.50
Regular Daily Allowance		€21.50
TOTAL		€289.66

Table. 23 Unit Cost for Conventional Mast Inspection per Hour

MAST ID (EFINOB)	HGT AGL (FT)	NO. OF MAST CLIMBERS	BATTERY HOURLY COST	COMPLETED INSPECTION TIME (HRS)	UNIT COST PER HOUR	TOTAL COST
10241	329	1	€17.10	5.3	€289.66	€1,535.19
36023	460	1	€17.10	6.9	€289.66	€1,998.65
46754	591	2	€17.10	8.4	€306.76	€2,576.78
11526	863	2	€17.10	11.6	€306.76	€3,558.41
011014	1070	2	€17.10	14.0	€306.76	€4,294.64

Table 24. Total Cost for Conventional Mast Inspection

6 RESULTS

In this the chapter, the results of the study will be displayed which were derived from the methods applied to gather and analyze data. The purpose is to state the findings of the research and present them in a logical sequence without bias or interpretation. Thus this section will only include the findings of the research and a contextual analysis of the results. The primary findings are presented from the results of the simulation which sought to compare the two different inspections methods through three main benchmarks:

1. The time it takes to complete a mast inspection
2. The total number of man-hours to complete inspection
3. The total costs for a single inspection

6.1 Time Comparison for Drone and Conventional Method

The comparison shown is based on time taken for inspection in figure 16. These values correspond to the height of the mast, number of sections per mast, and calculating the time taken to complete one iteration of a section with interest points plus the time needed for editing and reporting. The grey points and power line represents the drone inspection times by tower height while the same is represented for the convention method in black. Both methods show a positive linear correlation meaning that as the length of the tower in feet increases, the duration of the time needed to complete an inspection will also increase. The average completed inspection time for drone based on the masts used in the simulation was ten hours. The average completed inspection time for conventional method was nine hours. The total average difference between both methods was two hours or 8% differential. This translates to the conventional method being 8% more efficient than the drone inspection in terms of completed inspection time.

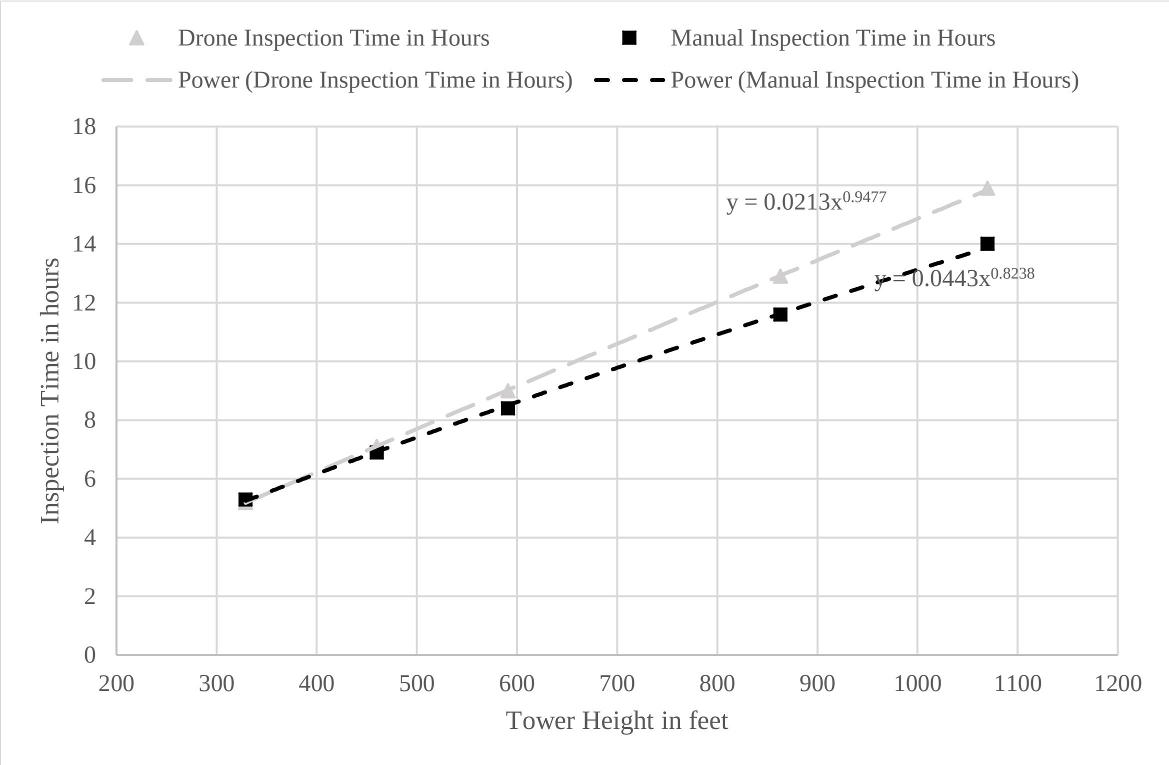


Figure 16. Inspection Time for Drone and Conventional Methods

Figures 17 below is stacked bar chart that present the absolute total inspection times in minutes. Each bar has been segmented by processes including the setup time, total inspection time for 50ft sections, total inspection time for remaining sections (ft) and total battery change time which only pertained to drone processes. The purpose here is visually understand the relative decomposition in minutes per mast inspection where the total bar length represents time not including report and editing times. By cross-referencing against the scale of the axes, the length of the masts influences the time as a whole. When comparing the actual segments, setup times were constant throughout the simulation. Drone setup time was a third faster than conventional method. The average inspection time for 50ft and remaining section using drone was 331 minutes and 309 minutes for conventional method having a 6.9% differential. This shows that on average conventional method sections times were faster 6.9% than the drone. The average time for battery change is fifty minutes. For drone inspections, the battery change equates to 17% of the entire process. However, if the battery change process was discarded and set up times were included into the averages, drone inspection time would be 18 minutes faster than conventional method.

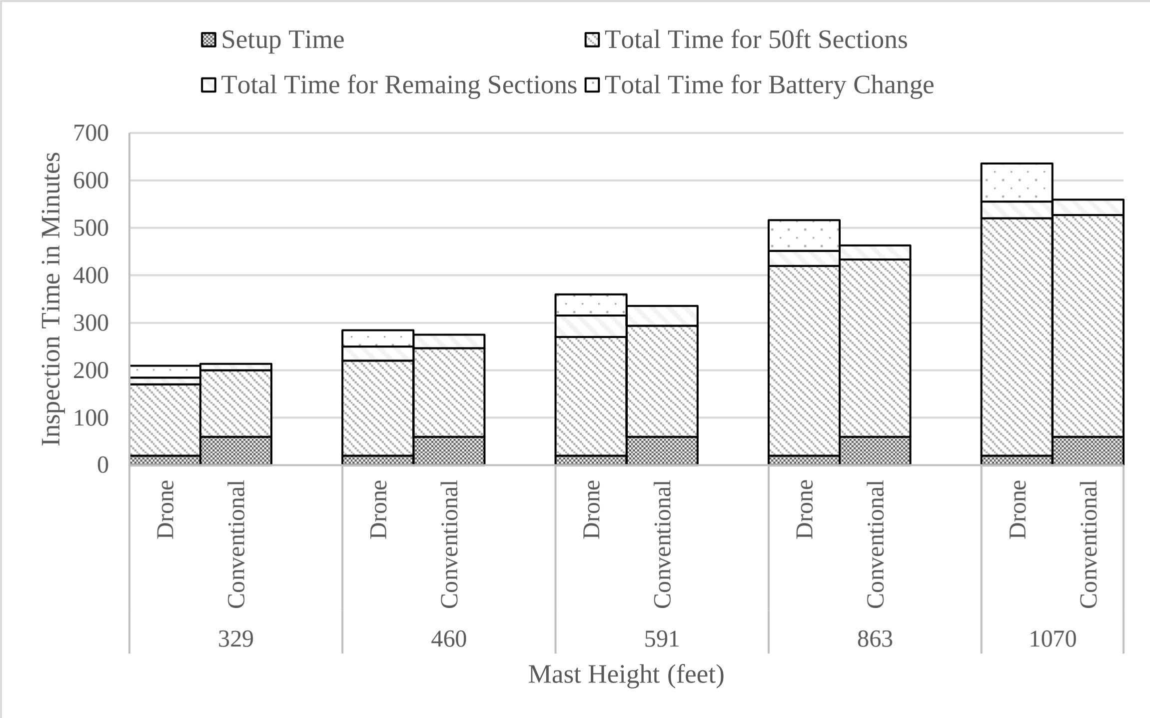


Figure 17. Inspection Time Breakdown for Drone and Conventional Method

6.2 Working Hours for Drone and Conventional Method

The comparison below in figure 18 is based on total working hours by number of crew members for inspection. Much like the total inspection time, the total working hours needed for inspection corresponds to the height of the mast, number of sections per mast, and calculating the time taken to complete one iteration of a section with interest points plus the time needed for editing and reporting multiplied by the numbers of crew members. The crew members in drone inspection was set to four including project manager, mast inspector, drone pilot, and UAS operator. The number of crew members for conventional method consisted of project manager, mast inspector, and mast climber. The number of mast climbers was increased to two if the height of the mast was more than 500ft, thus increasing the total crew members needed. Figure # is a plot graph. The grey points and power line represents the drone working hour needed for inspection by tower height while the same is represented for the convention method in black. Positive linear correlation is present meaning mast height is the leading variable. The average working time for drone based on the masts used in the simulation was forty hours. The average completed working time for conventional method was thirty-four hours. The total average difference between both methods was six hours or 16.2% differential. This implies that the conventional method required 16.2% less working hours than the drone inspection.

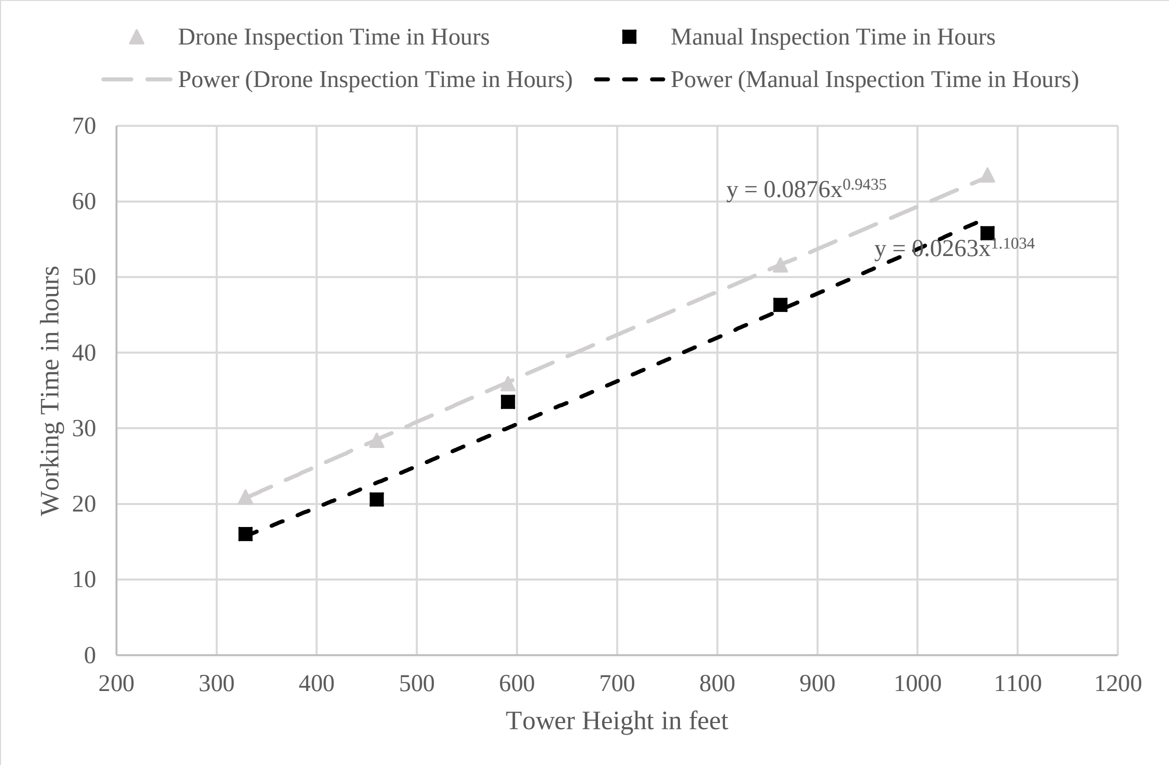


Figure 18. Working Time Drone and Conventional Methods

6.3 Cost Comparison for Drone and Conventional Method

Figure 19 below provides a summary of the cost benefit analysis of drone and conventional method alternatives for mast inspections. This reports the respective estimated costs of the resources identified from the ABC. Figure # is a plot graph, the grey points and power line represents the drone inspection times by tower height while the same is represented for the convention method in black. Much like the comparisons made between working hours and inspection time, mast length is the dominating variable for costs progression. The taller the mast the more time and costs are required regardless of method inspection. The purpose of this comparison is to analyze which method of inspection, either drone or conventional, is most cost beneficial. Considering the aggregate costs for each mast, the drone method for mast inspection is the most cost beneficial. The average costs for drone inspection was €1,819.36

while the average costs for the conventional method was €2,792.73. The costs between each method of inspection had a 42.2% differential. In translation, on average the drone method is 42.2% more cost effective that conventional mast inspections.

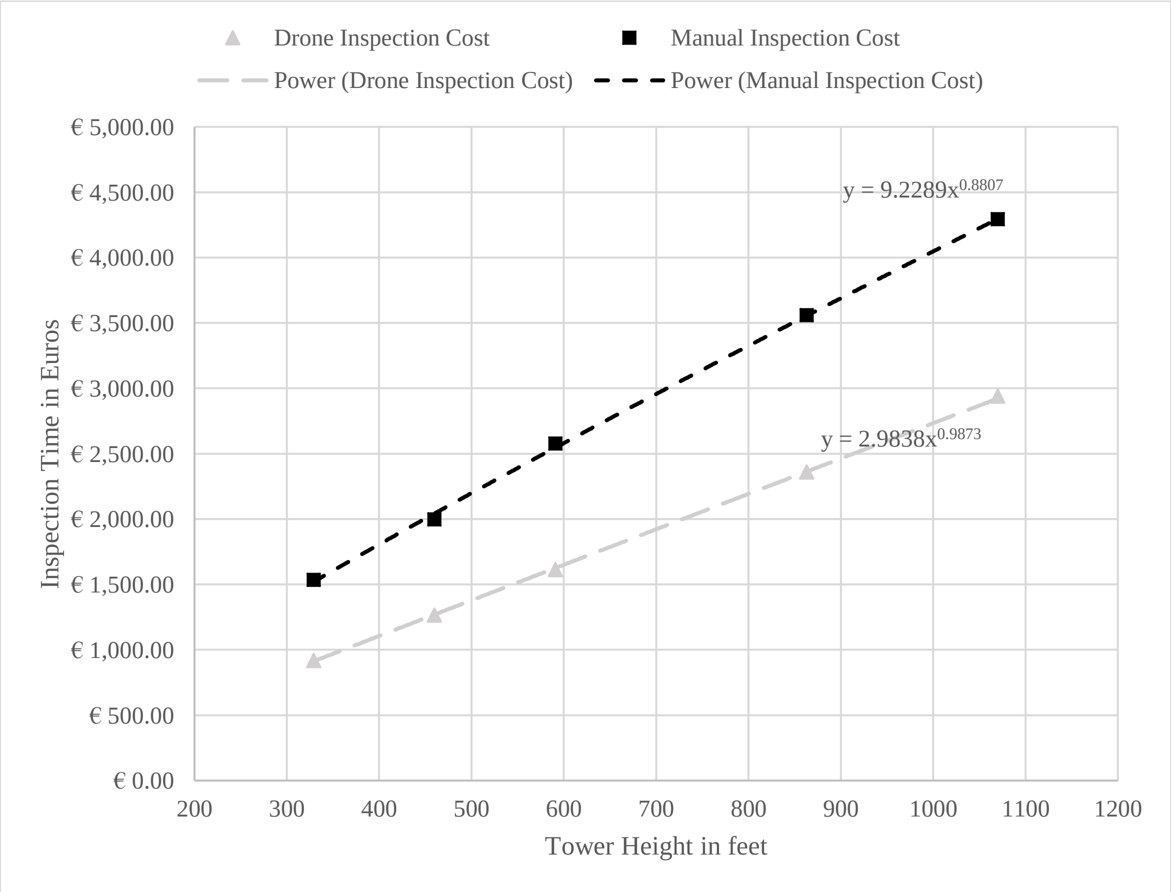


Figure 19. Inspection Cost for Drone and Conventional Methods

7 CONCLUSIONS AND DISCUSSION

In this chapter, the major findings will be outlined by the sub-questions and summarized. Following this summarization, the main research question will be addressed. This chapter also suggests the managerial implications of the study. Finally, this chapter acknowledges the limitations of the simulation affecting overall outcome of the research. The purpose of this chapter is to draw a conclusion based on the results of the study and address the problems stated in the introduction.

7.1 Major Findings

The first sub-question, *'what are the possible drone applications',* pertained to the case study of the research and was supported by drone theoretical literature and interview responses. The purpose of the sub-question was to provide a brief market overview of all potential industries that could benefit from a drone or UAS solution with the intention of selecting an industry and application with the highest monetary value. The major industries were analyzed through the scope of using a drone over conventional methods to understand the technologies commercial purpose. The theoretical findings were cohesive for all major industries. From a commercial use standpoint, a drone or UAS solution can create value-adding work as a disruptive technology. Drones can provide business new opportunities and operations models to achieve a competitive advantage. Specific uses cases ranged from safe, cost beneficial solutions of data collection, delivery services, humanitarian aid and disaster relief. However beneficial, drone challenges were also analyzed to understand the technologies short comings. Several key issues were observed. Legislation is still far behind the technology meaning that its implementation will take some time. Job displacement was also a negative effect of drones, however, through the market analysis the majority of the jobs in danger were associated with being the most dangerous and in some cases costly. Based on the results from the interviews the top performing industries for drone solution were narrowed down for selection. The top three industries included infrastructure/construction, security/surveillance and photography/aerial imagery. The theoretical background supported the findings from the interviews concerning industry. Infrastructure was observed for having a potential of nearly forty-five billion estimated value. Security was valued at eleven billion and media and entertainment valued at nine billion for drone powered solutions (PwC, 2016). Interviewees also gave drone application suggestions based on their previous industry selection. As the infrastructure industry as whole was still too wide for speculation of the value captured by a drone solution, the focus needed to be narrowed down. Interviewees identified drones for exceptional use in structural integrity inspections and data collection in particular for high structure evaluation. High structures were defined as telecommunication masts, TV or radio towers, and antennas. Thus the choice of application was high structure evaluation/inspection.

The second sub-question was *'what are drone characteristics and associated costs?'*. Naturally, after identifying the industry and application by drone capabilities, the next logical step was to understand the types of drone and operating costs in order to prove feasibility. Theoretical background was used to define the drone types and their characteristics while the interviews provided estimates needed for the drones cost structure. In theory, the type of the drone was classified by powertrain and flying style. Fixed wing drones were battery operated and shared a similar design to airplanes having a fixed flight path. Multi-rotor drones, also battery operated, were capable of a multitude of flights maneuvers. The same was observed for hybrid drones but the difference was that the powertrain was a combination of fixed wing and multi-rotor drones. Based on the drone classification, the multi-rotor was selected as the focus of the analysis for the case study. The interviews and data collected from company materials were able to provide the general costs breakdown and overview for a single multi-rotor drone. The main components consisted of the drone, motors, propellers, ESCs, payload attachment and battery module. These were considered to be the absolute bare minimum components necessary for operation making them relevant to include for costs. An ABC analysis was used to identify each component at a base unit cost per hour. The costs were then consolidated and divided by the lifetime flight hours of single drone which yielded the hourly operational costs for drone per hour. Thus, the drone costs were conceptualized and could be used to calculate total inspection costs.

The third sub-question was *'what are the processes for mast inspection and their associated costs?'*. This question is a byproduct of the results from the first sub-question. After identifying the operative industry and narrowing the scope of the drone application to inspection of telecommunication masts, it was imperative to understand the actual mast inspection from a conventional standpoint. Conventional in this context referred to the manual inspection process. The interviews provided a general overview to the actual mast inspection that is carried out in Finland. There is no legislation currently in existence that can stipulate the accuracy of the mast inspection or the frequency, therefore, opinions were gathered from industry experts only. The general consensus was that masts needed frequent inspections due to age or extreme weather conditions. The responsibility of these inspections were carried over to the mast or tower owners or operators. A mast owner was identified as the entity who constructed the mast or tower. A mast operator was identified as a party who leased space on the mast for components or hardware installation. The process itself was very straightforward and easily comprehendible starting with a request of a mast inspection initiated by the owner or operator. This action was passed on to a third party responsible for carrying out the inspection and reporting either a structural failure or pass. The mast was climbed and inspected and results were examined by a mast inspector. In some cases, a structural engineer was consulted with to verify results. ABC was used to identify the operational costs of the conventional mast inspection per hour. This was done at resource based level identifying the main cost driver to be labor in working hours. Salary figures were used from Statistics Finland to understand the hourly wage of each necessary crew member involved in the inspections.

7.2 Conclusions

The main research question for this study was *'To what extent are drones beneficial and cost-effective to operate?'*. The answer to all the sub-questions were compiled to generate a simulation to answer the main research question. A simulation was used as an alternative to understand exactly just how beneficial and costs-effective a drone solution can be in comparison to its counterpart. An activity-based cost analysis was carried out to estimate the costs for a mast inspection using a drone or by means of conventional method. The mast inspection process was conceptualized to select the exact resource incurred at every level of the inspection. There were separate scenarios for drone and conventional mast inspection.

Each resources was broken down by activity level to identify its appropriate cost driver. In this case the main cost drivers of the mast inspections were labor and equipment costs. A simulation protocol was created for each of the mast inspection scenarios in order predict the total inspection time and costs needed for such an inspection. The protocol was ran against five randomly selected masts located in Finland. The results of the simulation were compared in order to answer the main research questions. To comprehend the results of the main research question, benefits and cost-effective must be separated as two driving factors in determining whether or not a drone is the right solution. Benefits in this context refers to time or total working hours saved or and cost-effectiveness refers to the economic relief.

The results of the simulation showed that, given the estimated cost configuration for drone and assuming the process for mast inspection was standardized, the results showed variations. Strictly from a financial standpoint, the drone out performs the conventional method significantly regardless of mast height. According to the results of the simulation for total inspection time and total working hours, the conventional method marginally out preforms the drone. This is contrary to belief, considering much of the previous research into drone feasibility studies claim that drones always out preform man powered tasks (Mailey, 2013). These studies are almost always government funded or operated meaning that resources are plentiful. This research intended to explore drone cost effectiveness from commercial sector point of view. Despite what research has shown, under the pretense of mast simulation inspections in this research, the predominant variable in and throughout the results of the simulation was mast height. As the mast became taller in size, the inspection cost and time increased. The conventional method was 8% faster than the drone inspection. When analyzing the time breakdown by process for both scenarios, it becomes clear that a drone would be optimal for use if the battery change process was minimized. This contradicts what was prescribed in the literature, in particular for the infrastructure and construction drone applications, with claims that drones can help speed the completion of the project (Choa, 2015). When assessing the costs, the drone is more cost effective and affordable than conventional inspection by 42.2%. The approach that was used in this research relied on simulation based time estimates of mast inspections using activity-based costing to determine whether drone would be beneficial and cost-effective. From a numerical comparison point of view for mast inspection, the drone was determined cost-effective but not as beneficial as the conventional method. However, the results of this study are not applicable for cross-industry assessment. Neither does the results of the research in any way represent the other possible drone applications or use cases. The findings from the simulation in particular, do seem to challenge a lot of the theoretical background on drone applications. Mediating variables that were assumed under the simulation should be taken into consideration.

7.3 Managerial Implications

The managerial implications for the results of the research help to understand, to an extent, the factors that affect overall resource consumption level from both inspections. This implicates service providers and customers to understand when the drone is a beneficial cost-effective solution for investment. For service providers or customers looking to invest into a UAS platform or drone solution it is important to evaluate two or more alternatives against its conventional method using the same unit of effectiveness. In this research, the level of effectiveness was measured through time and costs. The method with the lowest consumption values should be adopted with the assumption that the investment alternatives are of the same size. For example, the drone hourly unit cost in this simulation was €12.09, while the standalone drone configuration costs were €9,679.60. Depending on its usefulness and deprecation value over time, it is up to management to decide when it is smarter to purchase rather than lease a drone solution or UAS platform. Although this research was not intended to include component level design or costs which are more suited for an engineering research paper, some costs could not be ignored as they were necessary for drone operation. From a manufacturing perspective, the research highlights the actual unit cost per hour at a component level which could be an arguing point. As a customer, the ultimate goal would be to drive that unit cost down. In theory this is only achieved by establishing and developing long-term trusting relationships with manufactures. The results in this research should not serve as rules but rather considerations aimed at helping the decision making process.

7.4 Limitations and Future Research

The results of this research are meant to bring into question the benefits and cost-effectiveness of drones relative to the value created as a disruptive technology for mast inspections. By no means do the results from this study represent the benefits and cost effectiveness of drones as a whole. There are multiple limitations to the study that must be accounted for when interpreting the results. The cost-effective analysis of the study using ABC method is incomplete. There are many resource level costs from both inspection scenarios, either drone or conventional method, that are not included due to uncertainty and data scarcity. This has resulted into an underestimation of the consolidated costs which would ultimately affect the cost-effectiveness outcomes. Another limitation to the study is the scope, which only explores mast inspections as the application. Based on the market overview for drone business applications this only a percentage of the total possibilities. The simulation used for the scenarios is also a limiting factor. A simulation is not capable for re-creating real-life situations. The simulation is only responsible for creating a set of systems responses under specific operating conditions. This does not account for human error or environmental factors that could be experienced during an actual mast inspection.

Future research should focus on the evaluation of the drone application by industry in order to identify those opportunities that are most suitable for drone or UASs. Research could use this study as a framework for quick analysis of the feasibility of drone implementation based on costs and time needed. From a hardware perspective, technology could be a driving factor for drone performance. Improvements in lighter weight materials, battery, and motor efficiency could result in longer flight times for drones.

REFERENCES

Abbott, R. M. 2004. “Temporal assessment of urban forest patch dynamics using medium scale aerial photography and GIS.” PhD diss., 2004.

Adams, Stuart & Friedland, Carol. 2011. A Survey of Unmanned Aerial Vehicle (UAV) Usage for Imagery Collection in Disaster Research and Management.

Anderson, C. 2014. “Agricultural drones.” *Technology Review* 117 (3): 58-60.

Anderson, K., and K.J. Gaston. 2013. “Lightweight unmanned aerial vehicles will revolutionize spatial ecology.” *Frontiers in Ecology and the Environment* 11 (3): 138-46

ANS Finland. 2020. AIS products and services. [online document]. [Accessed 10 November 2020]. Available at https://www.ais.fi/en/products-and-services

Anwar, A. 2019. Strategy Analytics: Commercial UAS Market has $15.1 Billion Potential. [online document]. [Accessed 20 June 2019]. Available at https://www.businesswire.com/news/home/20190110005423/en/Strategy-Analytics-Commercial-UAS-Market-15.1-Billion

Bamburry, D. 2015. "Drones: Designed for Product Delivery." Wiley Online Library. The Design Management Institute. [online document]. [Accessed 20 June 2020]. Available at http://onlinelibrary.wiley.com/doi/10.1111/drev.10313/full

Barron, P.J., Burgess, K., Cooper, K., & Stewart, A. 2018. The effect of pitched and vertical ladder ergometer climbing on cardiorespiratory and psychophysical variables Applied Ergonomics, 66, 172-176.

Bedord, L. 2013. “Drones evolve into a new tool for ag.” <https://www.agriculture.com/farm-management/technology/drones-evolve-into-a-new-tool-f-ag_322-ar31423> retrieved 20.06.2019

Boardman, A., Greenberg, D., Vining, A., and Weimer, D. 2006. Cost-Benefit Analysis: Concepts and Practice, 3rd edition. Upper Saddle River, N.J.: Prentice Hall.

Campbell, J. B., and R.H. Wynne. 2011. *Introduction to remote sensing*. Fifth Ed. New York, NY: The Guilford Press

Cellini, S. R. & Kee, J. E. 2015. Cost-Effectiveness and Cost-Benefit Analysis. 10.1002/9781119171386.ch24.

Chabot, D. 2018. Trends in drone research and applications as the Journal of Unmanned Vehicle Systems turns five. Journal of Unmanned Vehicle Systems, 6, vi–xv.

Cho, J., Lim, G., Biobaku, T., Kim, S., & Parsaei, H. 2015. Safety and Security Management with Unmanned Aerial Vehicle (UAV) in Oil and Gas Industry Procedia Manufacturing, 3, 1343-1349.

Choi-Fitzpatrick, Austin & Chavarria, Dana & Cychosz, Elizabeth & Dingens, John & Duffey, Michael & Koebel, Katherine & Siriphanh, Sirisack & Tulen, Merlyn & Watanabe, Heath & Juskauskas, Tautvydas & Holland, John & Almquist, Lars. 2016. Up in the Air: A Global Estimate of Non-Military Drone Use: 2009-2015.

Clarke, R. 2014a. Understanding the drone epidemic. *Computer Law & Security Review*, *30*(3), 230-246.

Clarke, R. 2014b. What drones inherit from their ancestors? *Computer Law & Security Review*, *30*(3), 247-262.

Clarke, R., & Moses, L. B. 2014. The regulation of civilian drones' impacts on public safety. *Computer Law & Security Review, 30*(3), pp.263-285.

Clinch, J. 2004. Cost–Benefit Analysis Applied to Energy Encyclopedia of Energy.

Cook, K. 2007. The Silent Force Multiplier: The History and Role of UAVs in Warfare. In Aerospace Conference pp. 1 - 7.

DHL. 2014. Unmanned Aerial Vehicles in Logistics: A DHL perspective on implications and use cases for the logistics industry. [online document]. [Accessed 20 June 2020]. Available at http://www.dhl.com/content/dam/downloads/g0/about_us/logistics_insights/DHL_TrendReprt_UAV.pdf

Dreze J. and Stern, N. 1987. The theory of cost-benefit analysis. [online document]. [Accessed 20 June 2020]. Available at http://personal.lse.ac.uk/sternn/040NHS.pdf

Drone onDemand. 2020. [online document]. [Accessed 20 June 2020]. Available at https://www.droneondemand.shop/products/its-a-bird-its-a-plane-its-a-birdseye-view-fixed-wing-drone

Drummond, Michael F., Mark J. Sculpher, Karl Claxton, Greg L. Stoddart, and George W. Torrance. 2015. Methods for the Economic Evaluation of Health Care Programmes. (4th ed.). Oxford: Oxford University Press.

Eder, T. 2017. Nokia Saving Lives Project Wins the UAE Drones for Good Award 2017 [Humanitarian Technology]. IEEE Robotics & Automation Magazine, 24(2), pp. 91-92.

Elcosh. 2011. Types of telecommunication towers. [online document]. [Accessed 24 Sep 2020]. Available at http://www.elcosh.org/index.php

Eriksson, P. and Kovalainen, A. 2008. Qualitative methods in business research. SAGE Publications Ltd. London, UK.

Eskola, J. and Suoranta, J. 1998. Johdatus laadulliseen tutkimukseen. Vastapaino. Tampere, Finland.

FAA. 2016. “FAA Aerospace Forecast Fiscal Years 2016-2036.” Federal Aviation Administration, 24 Mar. 2016. [online document]. [Accessed 20 June 2020]. Available at http://www.faa.gov/data_research/aviation/aerospace_forecasts/media/FY2016 36_FAA_Aerospace_Forecast.pdf

Falkner, E., and D. Morgan. 2002. “Chapter 17 project planning and cost estimating.” In *Aerial mapping methods and applications.* Second ed., 161-172 CRC Press LLC.

Fraser, R., Olthof, I., Maloley, M., Fernandes, R., Prevost, C., & Sluijs, J. 2015. UAV Photogrammetry for Mapping and Monitoring of Northern Permafrost Landscapes ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XL1, pp. 361-361.

Gademer, A., F. Mainfroy, L. Beaudoin, L. Avanthey, V. Germain, C. Chéron, S. Monat, and J.P. Rudant. 2009. “Solutions for near real time cartography from a mini-quadrotor UAV.” In *SPIE Europe Remote Sensing*, pp. 74781G-74781G. International Society for Optics and Photonics, 2009.

Garamone, J. 2002). “From the US civil war to Afghanistan: A short history of UAVs.” *Defend America.* [online document]. [Accessed 20 June 2020]. Available at http://www.defense.gov/news/newsarticle.aspx?id=44164

Glaive Store. 2020. [online document]. [Accessed 20 June 2020]. Available at https://www.glaive.store/GCL3_Hybrid_Composite_wing_VTOL_UAV/p6038704_19629 893.aspx

Gunasekaran, A., Sarhadi, M. 1998. Implementation of activity-based costing in manufacturing. *Internal Journal of Production Economics*, Vol. 56, No. 57. pp. 231 – 242.

Hanley, N. and Spash, C. 1993. Cost-Benefit Analysis and the environment, Cheltenham UK and Northampton MA, USA: Edward Elgar Publishing Ltd.

Hirsjärvi, S. and Hurme, H. 2004. Tutkimushaastattelu: Teemahaastattelun teoria ja käytäntö. Helsinki University Press. Helsinki, Finland.

Horngren, C., Datar, S., Foster, G., Rajan, M. & Ittner, C. 2009. Cost Accounting A Managerial Emphasis. 9th Edition. New Jersey: Pearson Education

Johansson, P. O. 1993. Cost-benefit analysis of environmental change. Great Britain: Cambridge University Press.

Joshi, D. 2017. Exploring the latest drone technology for commercial, industrial and military drone uses. [online document]. [Accessed 20 June 2020]. Available at http://www.businessinsider.com/dronetechnology-uses-2017-7?IR=T

Kaplan, R. & Atkinson, A. 1998. Advanced management accounting. 3rd edition. New Jersey: Pearson Education.

Karwatka, D. 2002. "*The Montgolfier brothers and the first hot air balloon*." Vol. 62 H.W. Wilson - Education Abstracts

Levin, H. M., and McEwan, P. 2001. Cost-Effectiveness Analysis, 2nd edition. Thousand Oaks, CA: SAGE Publications, Inc.

Lippi, G., and Mattiuzzi, C. 2016. "Annals of Translational Medicine." *Biological Samples Transportation by Drones: Ready for Prime Time?* 4(5) : 92. *National Center for Biotechnology Information*. [online document]. [Accessed 20 June 2020]. Available at https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4791341/

M. C. Isola and R. L. McCrum, 1996. "Inspection and Repair of High-Mast Luminaires (HML),"

Mailey, C. 2014. "Small UAS are effective remote sensing tools at low altitudes." In *Association for Unmanned Vehicle Systems.* [online document]. [Accessed 20 June 2020].

Available at http://www.auvsi.org/HamptonRoads/blogs/chrismailey/2014/02/20/small-uas-are-effective-remote-sensing-tools-at-low-altitudes

Mark, S., Philip, L. and Adrian, T. 2009. Research methods for business studies

McEwan, P. J. 2012. Cost-effectiveness analysis of education and health interventions in developing countries. Journal of Development Effectiveness, 189–213.

McGonigle, S. A. J, A. Aiuppa, G. Giudice, G. Tamburello, A. J. Hodson, and S. Gurrieri. 2008. “Unmanned aerial vehicle measurements of volcanic carbon dioxide fluxes.” *Geophysical Research Letters.* [online document]. [Accessed 20 June 2020]. Available at http://onlinelibrary.wiley.com/doi/10.1029/2007GL032508/full

McKellar, K. 2015. “Utah Agencies share high-resolution map data.” *Deseret News*, February 1, 2015. Sec Utah.

Merriam, S.B. 1998. Qualitative Research and Case Study Applications in Education. Jossey-Bass Publishers, San Francisco.

Nokia (2019a). About Nokia - Our history. [online document]. [Accessed 20 June 2020]. Available at https://www.nokia.com/en_int/about-us/who-we-are/our-history

Nokia (2019b). Nokia Drone Networks. [online document]. [Accessed 20 June 2020]. Available at https://www.dac.nokia.com/applications/nokia-drone-networks/

Nokia (2019c). Nokia Saving Lives an innovative non-profit initiative. [online document]. [Accessed 20 June 2020]. Available at https://www.nokia.com/networks/use-cases/nokia-saving-lives/

Participant 1. 2020. Drone R&D Lead. Espoo. Interview 25.05.2020

Participant 2. 2020. UAV Operations Specialist. Espoo. Interview 15.06.2020

Participant 3. 2020. Customer Executive. Espoo. Interview 28.09.2020

Participant 4. 2020. CFO. Espoo. Interview 30.10.2020

Participant 5. 2020. Systems Manager. Espoo. Interview 22.10.2020

Polinder, S., Toet, H., Panneman, M., and van Beeck, E. 2011. Methodological approaches for cost–effectiveness and cost–utility analysis of injury prevention measures. Copenhagen: WHO Regional Office for Europe.

Popper, B. 2015. These are the companies allowed to fly drones over the US, *Welcome to the next generation of aviation*. [online document]. [Accessed 20 June 2020]. Available at <https://www.theverge.com/2015/7/7/8883821/drone-search-engine-faa-approved-commercial-333-exemptions

PwC. 2016. Clarity from above: PwC global report on the commercial applications of drone technology. [online document]. [Accessed 20 June 2020]. Available at https://www.pwc.pl/pl/pdf/clarity-from-above-pwc.pdf> retrieved 20.06.2019

Quah, E. and Toh, R.(2012. Cost-benefit analysis: Cases and materials. New York, USA: Routledge.

R. J. Dobson, C. Brooks, C. Roussi, & T. Colling. 2013. Developing an unpaved road assessment system for practical deployment with high-resolution optical data collection using a helicopter UAV. In 2013 International Conference on Unmanned Aircraft Systems (ICUAS) (pp. 235-243).

Raiborn, C. & Kinney, M. 2010. Cost Accounting Principles. 8th Edition. Hampshire: Cengage Learning.

Rakhra, S. A. 1991. Benefit cost-analysis of investment in public infrastructure: a review. [online document]. [Accessed 20 June 2020]. Available at http://www.chba.ca/uploads/policy%20archive/1988/1991-10%20 Investment%20in%20Infrastructure.pdf

Schmid, A. A. 1989. Benefit-Cost Analysis: A Political Economy Approach, Boulder, CO: Vestview Press.

Statistics Finland. 2019. Wages, Salaries and Labour Costs. [Accessed 10 November 2020]. Available at https://www.stat.fi/tup/suoluk/suoluk_palkat_en.html#Total%20earnings%20by%20occupation

Terdiman, D. 2014. “The history of the predator, the drone that changed the world (Q&A).” *Cnet.* [Accessed 20 June 2020]. Available at https://www.cnet.com/news/the-history-of-the-predator-the-drone-that-changed-the-world-q-a/

Tsai, W. H. 1996. Activity-based Costing Model for Joint Products. *Computers & Industrial Engineering*, Vol 31, No 3–4, pp. 725 – 729.

Tuominen, P., Reda, F., Dawoud, W., Elboshy, B., Elshafei, G., & Negm, A. 2015. Economic appraisal of energy efficiency in buildings using cost-effectiveness assessment. *Procedia Economics and Finance 21*, 422 – 430.

Turney, P. 2005. Common Cents. New York: McGraw-Hill.

Wall, K., & MacKenzie, C. 2013. Multiple objective decision making. DRMI, Naval Postgraduate School.

Wang, U. 2014. “The good drones: Industries eagerly await FAA rules to allow them to fly”. *The Guardian*. [Accessed 20 June 2020]. Available at https://www.theguardian.com/sustainable-business/2014/nov/26/drones-quadcopoters-farms-drilling-utilities

Wegner, G. and Pascual, U. 2011. Cost-benefit analysis in the context of ecosystem services for human well-being: A multidisciplinary critique. Global Environmental Change, volume 21, issue 2, 492-504.

Yin, R. K. 2014. *Case study research: Design and methods* (5th ed.). Los Angeles, Calif.: Sage Publications.

Yin, R.K. 1994. Case Study Research – Design and Methods, 2nd Editions, Applied Social Research Method Series, Sage Publications Inc., Thousand Oaks

Zaloga, S. J. 2008. *Unmanned aerial vehicles: Robotic air warfare 1917-2007*. Vol. 144 Osprey Publishing.

Zhu, Jinxia, Ke Wang, Jinsong Deng, and Tom Harmon. 2009. “Quantifying Nitrogen Status of Rice Using Low Altitude UAV-Mounted System and Object-Oriented Segmentation Methodology.” *ASME 2009 International Design Engineering Technnical Conferences and Computers and Information in Engineering Conference.* ASME. Vol. 3, 2009. 603-609.

Zikmund, W. 2000. Business Research Methods, Sixth Edition. The Dryden Press.

APPENDIX 1.

INTERVIEW QUESTIONS FOR CASE STUDY: NDN

Name:
Role: (E.g. title or position)
Company or Organization:
List of Drone Industries based on theoretical background

- Photography/Aerial Imagery
- Infrastructure/Construction
- Security/Surveillance
- Agriculture
- Emergency/Health Care
- Other

Out of the list of possible drone applications, based on your own experiences and knowledge, can you select an industry with highest drone application potential?

Within this industry, can you suggest a possible drone application?

In what way can the drone solution be of assistance or beneficial?

INTERVIEW QUESTIONS FOR CASE STUDY: TELECOMMUNCAITON

Name:
Role: (E.g. title or position)
Company or Organization:

Can you briefly describe the role in your current company or organization?

APPENDIX 1. (CONTINUES)

In what way can the drone solution be of assistance or beneficial?

What is the type of data that you are collecting and how?

Can you describe the operational processes involved that the drone solution would be replacing?

Can you describe under ideal conditions how these processes would be undertaken?

What are the necessary costs involved for this conventional method?

What are the necessary costs involved the drone solution?