# Cost-Effectiveness Analysis of Unmanned Aircraft Systems Use by Nongovernmental Organizations for Post-Disaster Needs Assessments

Nathan Scott Tilton

Middle Tennessee State University

Author Note: The author is currently pursuing the Bachelor of Science in Aerospace Maintenance Management, for which the current work constitutes the honors thesis.

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by
Nathan S. Tilton

APPROVED:

Dr. Mark Callender, Advisor
Assistant Professor, Department of Aerospace

Dr. Wendy Beckman
Chair, Department of Aerospace

Dr. Anthon Eff
Professor, Department of Economics and Finance
Honors Council Representative

Dr. John R. Vile
Dean, University Honors College

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## Abstract

Increasing use of Unmanned Aircraft Systems (UAS) in the commercial sector is forecasted to have significant economic impact. However, the economic impact of UAS in the humanitarian sector is largely unknown. One UAS application with economic promise in the humanitarian field is providing aerial data for post-disaster needs assessment (PDNA). The author applied financial cost-effectiveness analysis to examine the economic competitiveness of using small UAS for PDNA by humanitarian non-governmental organizations (NGO). Results showed that UAS have economic advantages in small-scale PDNA conducted by NGOs.

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# I. Introduction and Background

## General

Several recent natural disasters have a surprising similarity: the 2005 Hurricane Katrina (Pratt, Murphy, Stover, & Griffin, 2009), the 2010 Haiti earthquake (United Nations Institute for Training and Research, 2012), and the 2011 Japan nuclear meltdown (Hodge, 2011). For all three of these events unmanned aircraft were used in the immediate disaster response or in the long-term humanitarian rebuilding effort. Unmanned aircraft, also known as unmanned aerial vehicles (UAVs), remotely piloted aircraft (RPA), or drones, are a rapidly developing segment of the aviation industry. The broader term, unmanned aircraft systems (UAS), have been adopted in the industry as the designation for these aircraft and their accompanying systems. UAS is already beginning to transform many different industries around the world, with perhaps none more critical than humanitarian aid.

UAS have significant economic implications. In 2013, the Association for Unmanned Vehicle Systems International (AUVSI) predicted that the economic impact of UAS in the United States alone between 2015 and 2025 would be $82.1 million and would create 103,776 new jobs (Jenkins & Vasigh, 2013). Humanitarian efforts, though not driven by economic considerations, are certainly affected by them. Global Humanitarian Assistance (GHA) estimated that there was $24.5 billion spent in international humanitarian assistance in 2014, of which non-governmental organizations (NGO) constituted $4 billion (Global Humanitarian Assistance, 2015). The premise of this thesis research project was that UAS are an underutilized, affordable resource for international humanitarian non-governmental organizations. Through cost-effectiveness analysis (CEA), this project focused on one specific humanitarian application for UAS, post-disaster needs assessment (PDNA).

Beyond economic considerations, UAS integration faces significant challenges for NGOs. These challenges include varying or nonexistent government regulations, privacy and security concerns, public perception, and lack of standardization or infrastructure (Kim & Davidson, 2014). This project did not seek to address these issues, but instead investigated some of the possible economic implications of the use of UAS in the humanitarian sector.

## Unmanned Aircraft Systems (UAS)

**UAS history.** Unmanned aviation existed before manned aviation. Unmanned balloons and gliders were used for reconnaissance, bombing, and experimental research long before the Wright Brothers flew in 1903. The first modern UAS can be traced back to the radio-controlled Curtis N-9 Aerial Torpedo in 1918; it was designed to fly 1,000 yards and then dive towards its target (Barnhart, Hottman, Marshall, & Shappee, 2012). Military research has continued to be the driving force for UAS development throughout the twentieth and twenty-first centuries. One of the most advanced UAS currently in use is the US Air Force RQ-4 Global Hawk. The RQ-4 has a 130-foot wingspan, costs $222 million, has a service ceiling of 60,000 feet, and can survey over 40,000 square nautical miles in a day (Northrop Grumman, 2008).

UAS components and operating software continue to become more affordable and widely available. As a result, applications for UAS continue to grow. UAS applications are currently being researched and used for agriculture (Hunt, Hively, Fujikawa, Linden, Daughtry, & Mccarty, 2010), archeology (Lin, Novo, Har-Noy, Ricklin, & Stamatiou, 2011), law enforcement (Straub, 2014), wildlife management (Jones, Pearlstine, & Percival, 2006), and humanitarian aid. UAS research for humanitarian aid is particularly varied. UAS research has been conducted for post-disaster damage assessment and mapping (Xu, et al., 2014), research and rescue efforts (Dohetry & Rudol, 2008), monitoring nuclear radiation levels (Hodge, 2011), and delivering medical supplies (Raptopoulos, 2013).

According to the Federal Aviation Administration (FAA), UAS is defined as, "the unmanned aircraft (UA) and all of the associated support equipment, control station, data links, telemetry, communications and navigation equipment, etc., necessary to operate the unmanned aircraft" (Federal Aviation Administration, n.d.). The International Civil Aviation Organization (ICAO) adopted a similar definition.

> "An unmanned aerial vehicle is a pilotless aircraft, in the sense of Article 8 of the Convention on International Civil Aviation, which is flown without a pilot-in-command on-board and is either remotely and fully controlled from another place

(ground, another aircraft, space) or programmed and fully autonomous." (International Civil Aviation Organization, 2011)

These definitions give a framework, by which to understand the different components of UAS.

**Unmanned aircraft.** There are three basic types of unmanned aircraft based upon design characteristics: fixed-wing, rotor-wing, and lighter-than-air.

***Fixed-wing.*** Fixed-wing aircraft rely upon air flowing over a fixed wing to generate lift. This aerodynamic design allows fixed-wing aircraft to have extended flight duration, payload, and range. Disadvantages for fixed-wing aircraft include limited maneuverability and more complicated logistics for launch and recovery, such as a runway or a catapult launch and net recovery system.

***Rotor-wing.*** Rotor-wing aircraft, which are sometimes known as vertical takeoff and landing (VTOL) aircraft use rotors to generate lift. This design characteristic allows rotor-wing aircraft to be very maneuverable, to stay in a fixed location, and to have few launch and recovery requirements. However, rotor-wing aircraft have limited flight duration, payload, and range. Rotor-wing aircraft can also be named according to the number of rotors they use. For example, a four-rotor rotor-wing is called a quadcopter.

***Lighter-than-air.*** Lighter-than-air aircraft generate lift because they are lighter than the air that they displace. Advantages for lighter-than-air aircraft include extended flight duration and range. Disadvantages for lighter-than-air aircraft include limited payloads, airspeed, and complicated launch and recovery. There are fewer lighter-than-air aircraft than fixed-wing and rotor-wing aircraft used for unmanned operations, though there is promise in future development. Lighter-than-air unmanned systems were not featured in this project.

**Command and control.** One of the most important concepts for UAS is the level of autonomy. Fully autonomous UAS utilize an autopilot and a preprogrammed mission to complete flights without human intervention. On the other end of the spectrum there are UAS that are operator-controlled by an external pilot for the entire flight. Most UAS operate somewhere between full autonomy to operator controlled.

***Autopilots.*** Autopilot systems are one of the most rapidly developing components of the UAS industry. These systems utilize a preprogrammed flight plan with designated waypoints. Autopilots can be used in conjunction with an external pilot, simplifying pilot controls or allowing the external pilot to conduct high-risk maneuvers such as takeoff and landing. Autopilots also include a lost-link function that controls the aircraft in case of lost communication with the operator. Lost-link procedures vary but can include: return to the starting waypoint, loiter or circle in place until communication has been reestablished, remain on current heading for a certain amount of time, or conduct an immediate landing. Commercially available autopilots include the Procerus Kestrel (Lockhead Martin, n.d.), the Cloud Cap Piccolo (Cloud Cap Technology, n.d.), and the MicroPilot MP series (MicroPilot, n.d.).

***Ground control stations.*** Ground control stations (GCSs) are the means for human control of UAS. GCSs vary in location and scale. Large-scale military GCSs operate multiple UAS with supporting personnel and can be located halfway around the world from the operational site. Small-scale GCSs can be as simple as a laptop computer or smart phone and can be operated on-site by a small team or individual. GCSs are often developed alongside an UAS, but an example of a commercially available GCS platform is the open source software ArduPilot Mission Planner (ArduPilot, 2016).

***Communication data links.*** GCSs require a communication data link with the UAS. Data links are generally considered to be of two categories: line-of-sight (LOS) and beyond-line-of-sight (BLOS). LOS operations operate using high frequency radio waves. Considerations for LOS operations include limited range, radio frequency congestion, and regulations concerning the use of radio frequencies. BLOS use either a satellite connection or relay aircraft. There are legal and safety concerns with operating UAS in BLOS operations, so this project focused on LOS operations only (Morgan, 2015).

**Payloads.** Payload is the term used for any materials that are carried by a UAS and are not required for flight operation. UAS are typically designed around a particular payload and mission. Due to their small size, most commercial UAS have limited payloads. Payloads in this project consisted of small aerial sensing platforms.

***Aerial sensing platforms.*** Aerial sensing platforms that are available for UAS include electro-optical (EO) cameras, infrared (IR) cameras, synthetic aperture radar (SAR), and Light Detection And Ranging (LIDAR). EO cameras utilize the visible light spectrum and can be used for still imagery, video, or a blended composition. EO cameras can be used to create orthomosaic maps that are dimensionally corrected and can be use for measuring true distances. An example of an inexpensive, commercially available EO camera is a GoPro Hero 4. Infrared cameras utilize the infrared portion of the electromagnetic spectrum (1-400 THz) (Barnhart, Hottman, Marshall, & Shappee, 2012). Infrared cameras are used for thermal imaging and are generally more expensive than EO cameras. An example of a commercially available infrared camera is the FLIR Vue, (FLIR). SAR uses radar signatures and LIDAR utilizes laser scanning to create two or three-dimensional images. They are both significantly more expensive than EO cameras, but are able to operate through cloud cover.

**Launch and recovery.** Launch and recovery procedures for UAS range from elaborate to virtually nonexistent. Large scale UAS can require the same infrastructure as commercial airliners. Most of the launch and recovery procedures discussed in this project will be on a smaller scale, but also vary significantly depending on the UAS. Common launch procedures for UAS include hand thrown, catapult, vertical takeoff, and self-launch utilizing a small clearing. Common recovery procedures for UAS include net system, parachute, vertical landing, and short clearings.

**Human operators.** Even at the highest level of autonomy, UAS require some level of human operation and observation. The amount of human operators and tasks that they perform depend upon the scale, objectives, and type of platform used for the operation. Small teams or individuals conducted most of the case studies found in this project.

**Non-Governmental Organizations (NGOs)**

**NGO history.** The term "non-governmental organization" (NGO) came into existence with the United Nations (UN) in 1945. Article 71 of the UN Charter to the Economic and Social Council (ECOSOC) referenced ECOSOC's ability to consult with "with non-governmental organizations" (United Nations, 1945). A more modern definition of a NGO is, "a private, self-governing, nonprofit organization dedicated to advancing an objective or objectives such as alleviating human suffering; promoting education, health care, economic development, environmental protection, human rights, and conflict resolution; and encouraging the establishment of democratic institutions and civil society" (United States Institute of Peace, 2011). NGOs are not consistently defined around the world and may go by different terms, such a non-profit organization (NPO) or private voluntary organization (PVO) among others (Vakil, 1997)

The above definition given before outlines some common characteristics among most NGOs. First, NGOs are generally started and run by private individuals. Second, most NGOs are by definition non-profit enterprises and have special tax and legal status. Third, NGOs are commonly founded around a particular cause or purpose. It is difficult to determine how many NGOs there are around the world. According to the US Department of State, there are approximately one and a half million NGOs that operate in the United States (Bureau of Democracy Human Rights and Labor, 2016). The number of NGOs also seems to be increasing. For example, there are some researchers that have shown that number of international NGOs has risen from about 400 in 1909 to 25,000 in the twenty-first century (Davies, 2014). NGOs have a unique position to impact positive change throughout the world.

**NGO distinct characteristics.** Because of the broad understanding of NGOs around the world, the term can be used to describe very different organizations. In order to understand the scope of these organizations there are some distinct characteristics of NGOs to consider.

***Objectives.*** The first characteristic is the cause or objective of the NGO. These can be very diverse. For example, though an organization such as the World Wide Fund for Nature (WWF) and an organization such as Cooperative for Assistance and Relief Everywhere (CARE) might have some overlap in common interests, their objectives are generally very different. Many NGOs have a humanitarian aid orientation, and they are the focus of this project. Humanitarian aid, though another elusive term, can be defined as actions that "save lives, alleviate suffering and maintain human dignity during and in the aftermath of man-made crises and natural disasters, as well as to prevent and strengthen preparedness for the occurrence of such situations" (Good Humanitarian Donorship, 2003).

***Scale.*** Another characteristic to consider is the scale of an NGO. NGOs can range from local, regional, national, and international organizations. Scale has a significant impact on both the resources and need to purchase technological capital, such as UAS. This project will address technology in such a price range that it could be implemented across a wide spectrum of NGOs.

***Operational activities.*** One last characteristic of NGOs is operational activities. NGOs can generally be categorized as either service NGOs, which focus upon relief or developmental work, or advocacy NGOs, which focus upon political change (Davies, 2014). Though these two categories often overlap, this project will focus upon operational NGOs.

**NGO aviation operations.** Though UAS and manned aircraft can have different applications, it is important to have an understanding of the role that manned aviation currently plays in NGO operations. NGO aviation comes in various forms, but is generally conducted in one of three forms. First, an NGO may own and operate its own fleet of aircraft, which is rare. Second, the NGO may utilize another aviation-oriented NGO. Examples of this include Air Serv International, Wings of Hope, Angel Flight, and Missionary Aviation Fellowship (MAF). Third, the NGO may utilize a private company or government resource. The United Nations, through the World Food Programme (WFP), created the United Nations Humanitarian Air Service (UNHAS). In 2010, UNHAS served 870 humanitarian agencies, flew 350,534 passengers, and delivered 14,833 tons of cargo (Cole, 2011),

**NGO perceptions of UAS.** Though NGOs are increasingly utilizing UAS, perceptions of UAS are varied in the NGO community. In a 2014 Occasional Policy Paper, the United Nations Office for the Coordination of Humanitarian Affairs (OCHA) discussed some of the potential uses and limitations for UAS in the humanitarian sector. OCHA noted that humanitarian organizations are already using UAS in the realm of "real time information and situation monitoring, public information and advocacy, search and rescue, and mapping" (Gilman, 2014). However, OCHA also noted that there are significant legal, ethical, privacy, and social engagement issues surrounding the humanitarian use of UAS. OCHA mentions the humanitarian UAV network, UAViators, as an example of the humanitarian community seeking to address these issues. Started by the Qatar Computing Research Institute in 2014, UAViators is a network created to "catalyze research, information sharing and collaboration in order to build the evidence base, document lessons learned and disseminate best practices" for UAS in the humanitarian sector (Meier, 2016). The Humanitarian UAV Network has developed several resources, such as a UAS best practices document, a database of international humanitarian UAS research and laws, and training seminars held around the world. The network also operates as a means to quickly mobilize UAS operators in the event of a humanitarian crisis.

Funded by the European Commission Humanitarian Aid and Civil Protection Department (ECHO), UAViators partnered with the Swiss Foundation for Mine Action (FSD), CartONG, and the Zoi Environment Network to complete a survey of 196 humanitarian aid workers on the use of UAS in 2015 (CartONG, EC Humanitarian Aid and Civil Protection Departmen, Swiss Foundation for Mine Action, UAViators, & Zoi Environment Network, 2015). The results from this survey provide insight into the perception and use of UAS by the humanitarian community. Several of the results from that survey are provided below. A breakdown of survey participants, which shows that over 50% or respondents came from NGOs, is shown Figure 1.

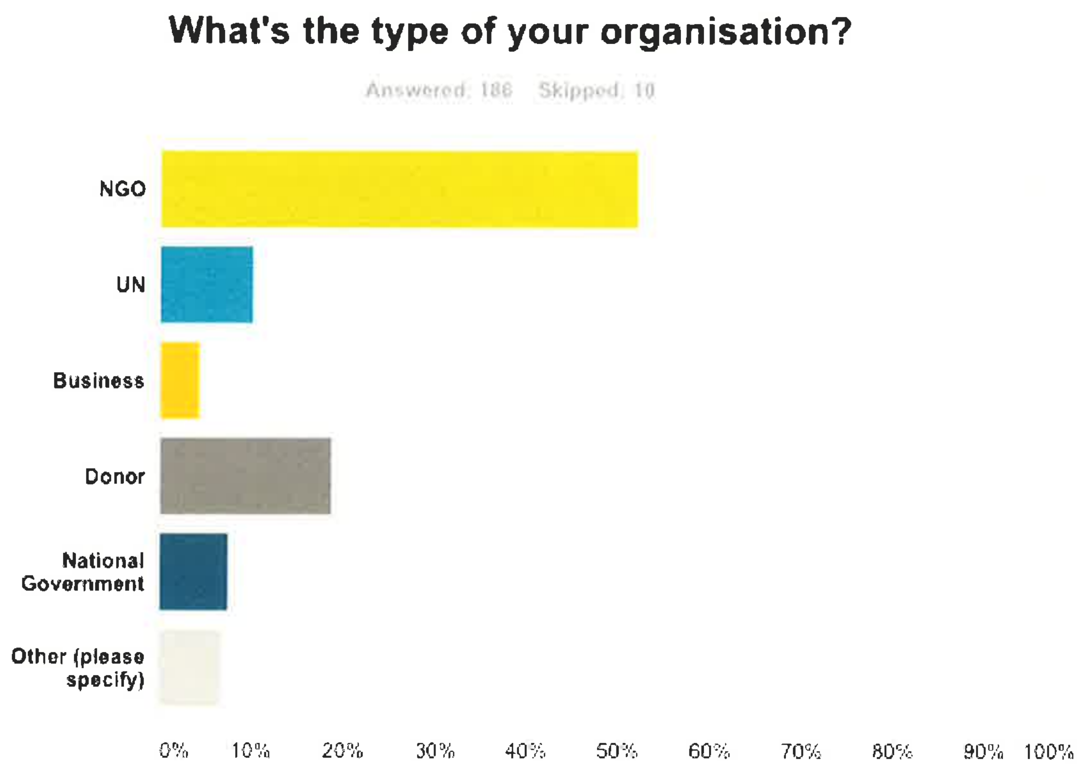


*Figure 1.*Humanitarian UAS survey: "What's the type of your organization?" (CartONG, EC Humanitarian Aid and Civil Protection Departmen, Swiss Foundation for Mine Action, UAViators, & Zoi Environment Network, 2015).

The survey showed a generally favorable, but still mixed, perception of UAS in the humanitarian sector. When asked how respondents generally view the use of UAS for humanitarian work, nearly 22% responded very or somewhat unfavorable, 18% responded neutrally, and nearly 60% responded somewhat or very favorable. Though it seems that most humanitarians are generally favorable towards UAS, there are still those with significant reservations. Figure 2 shows the results from the question, "In general, how do you view the use of drones (UAVs) for humanitarian work?"

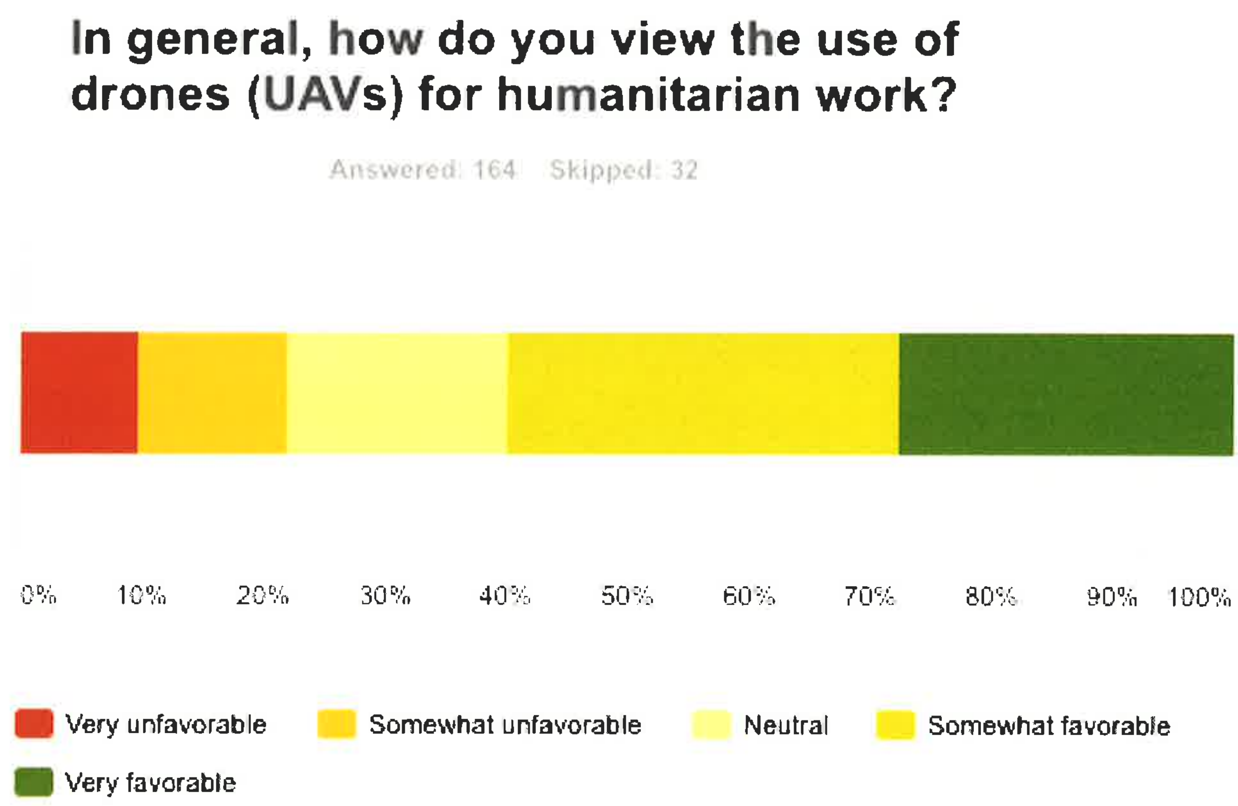


*Figure 2.* Humanitarian UAS survey: "In general, how do you view the use of drones (UAVs) for humanitarian work? (CartONG, EC Humanitarian Aid and Civil Protection Departmen, Swiss Foundation for Mine Action, UAViators, & Zoi Environment Network, 2015).

The survey also reveals that most participants had very little experience with UAS. Only 12.65% of participants had used UAS as part of their organizational activities, though nearly 60% of participants indicated either a passive or active interest in using UAS as part of their organizational activities. Figure 3 shows the results from the question, "What is your experiences with drones (UAVs)?"

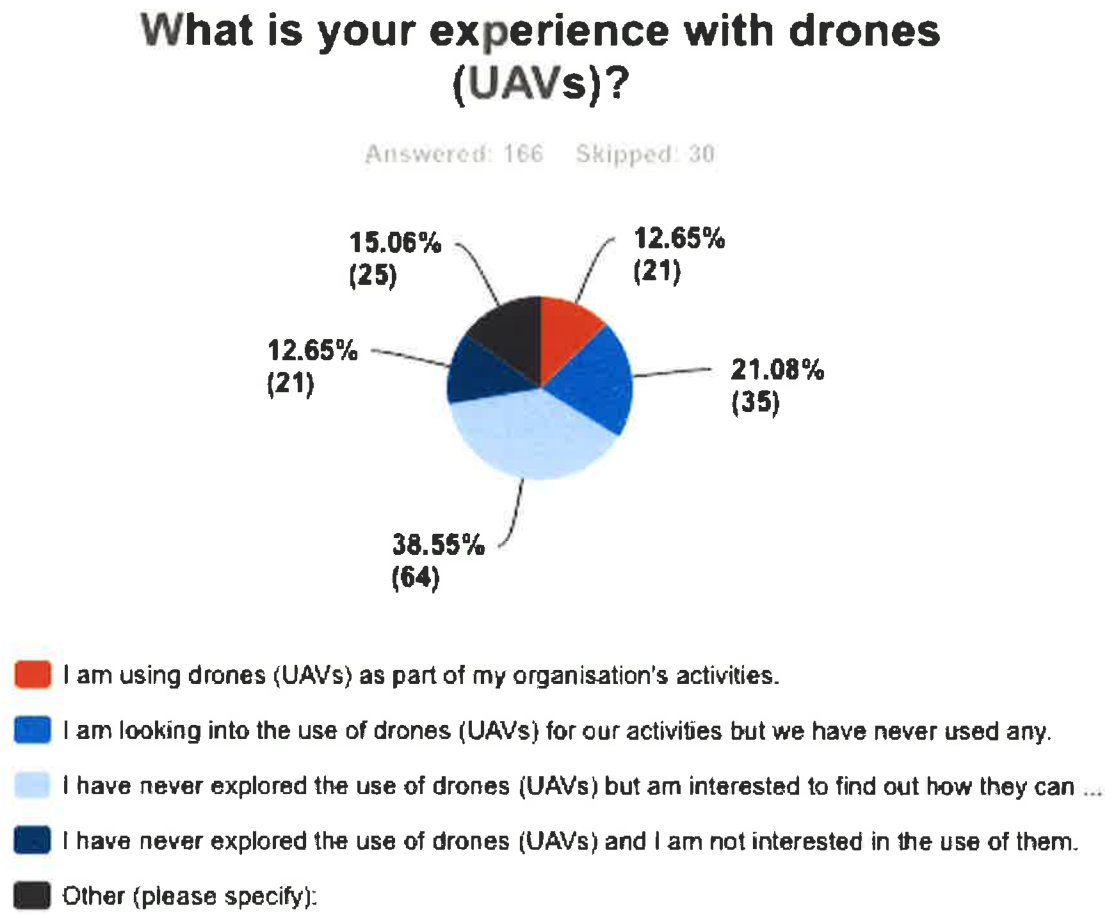


*Figure 3.*Humanitarian UAS survey: "What is your experiences with drones (UAVs)?" (CartONG, EC Humanitarian Aid and Civil Protection Departmen, Swiss Foundation for Mine Action, UAViators, & Zoi Environment Network, 2015).

When participants were asked which UAS application they were most personally interested in, the most popular response from aid workers, at 88.51%, was mapping. This response supports the impression that at the present time mapping is one of the most applicable UAS applications for humanitarian operations. Monitoring and search and rescue were also two popular responses. Figure 4 shows the results from the question, "What purpose of drones (UAVs) are or would be of most interest to you?"

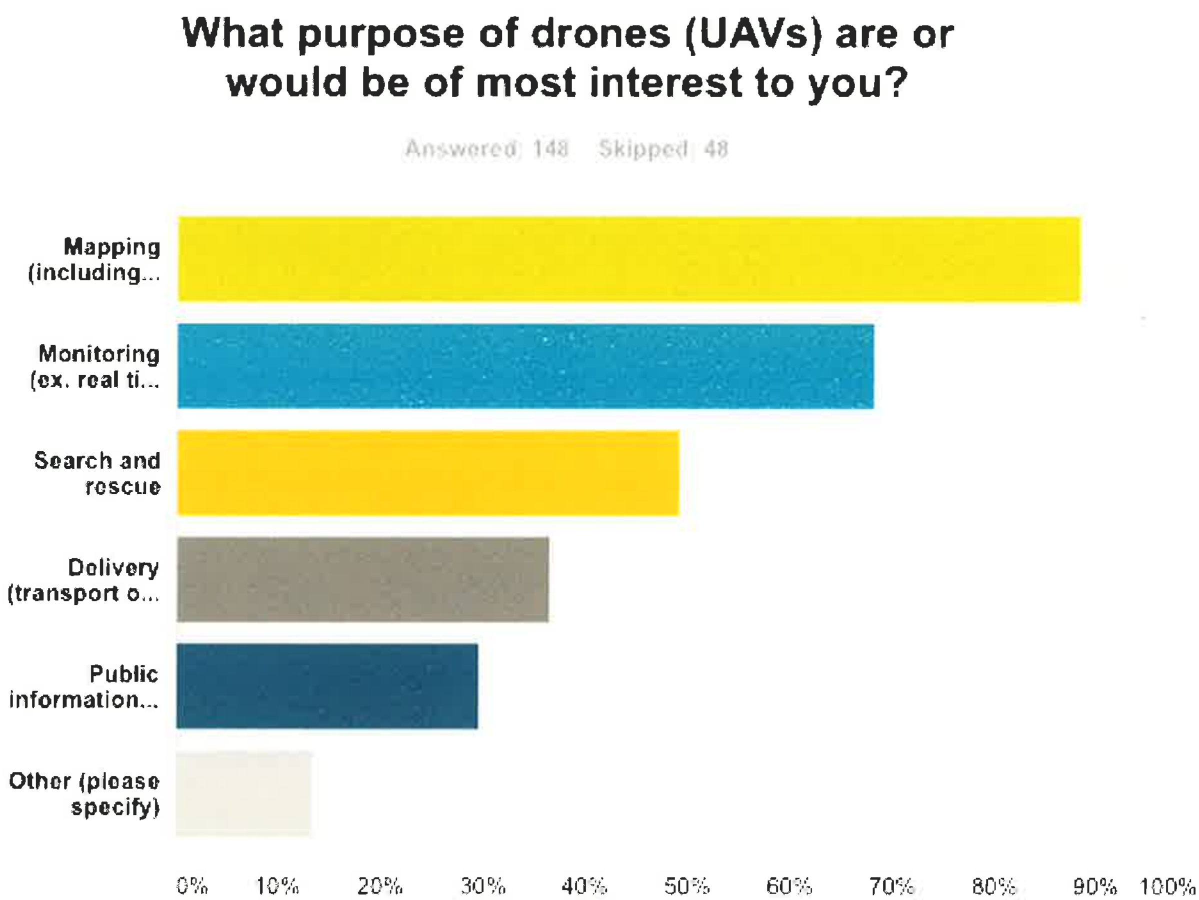


*Figure 4.* Humanitarian UAS survey: "What purpose of drones (UAVs) are or would be of most interest to you?" (CartONG, EC Humanitarian Aid and Civil Protection Departmen, Swiss Foundation for Mine Action, UAViators, & Zoi Environment Network, 2015).

With high interest levels but little experience in the humanitarian community, there is an apparent need for more humanitarian-focused UAS research and education. In an attempt to help address this need, this economic research project focused on the most popular humanitarian UAS application, mapping–or more specifically mapping used post-disaster needs assessment.

### Post-Disaster Needs Assessment (PDNA)

**General.** On April 25, 2015 a 7.8 magnitude earthquake struck the country of Nepal, which was followed by a 7.3 magnitude earthquake on May 12, 2015. It was the worst natural disaster to strike Nepal since 1934; the devastation was catastrophic. With over half the country affected by the earthquakes, there were more than 600,000 houses destroyed and 290,0000 damaged across the country. Almost 9,000 people were killed with over 22,000 people injured (European Commision Humanitarian Aid and Civil Protection Department, 2015). The humanitarian response to this catastrophe involved over 450 humanitarian agencies and was able to provide aid to 3.7 million affected people between the months of April and September (United Nations Office for the Coordination of Humanitarian Affairs, 2015).

One of the most immediate needs in such a catastrophe is precise and prompt post-disaster needs assessment (PDNA). Within 24 hours of the first earthquake there were over 100 international search and rescue and medical teams in Nepal. Coordinating and directing these teams to the areas they are needed most is a significant challenge. This section examines the advantages and disadvantages of both traditional PDNA and PDNA that utilizes UAS.

**Field-based surveys.** The most traditional method of PDNA assessment is field-based surveys. There are several common PDNA guidelines for conducting field-based surveys. The United Nations developed the Multi-Cluster/Sector Initial Rapid Assessment (MIRA) (United Nations Inter-Agency Standing Committee, 2012). The World Bank developed the Post-Disaster Needs Assessments (PDNA) (World Bank, 2015). The International Committee of the Red Cross (ICRC) and the International Federation of Red Cross and Red Crescent Societies (IFRC) developed the Guidelines for Assessments in Emergencies (International Committee of the Red Cross and International Federation of Red Cross and Red Crescent Societies, 2008). These assessments typically focus on determining the status of buildings and transportation infrastructure.

A closer assessment of the ICRC and IFRC model gives a clearer understanding of how these field-based surveys are conducted. The ICRC and IFRC specify three types of PDNA: rapid, detailed, and continual (International Committee of the Red Cross and International Federation of Red Cross and Red Crescent Societies, 2008). Rapid assessments are conducted within a week of the crisis with limited access to information and rely highly on assumptions. Detailed assessments are conducted within a month of the crisis with more access to information and evaluate the assumptions made during the rapid assessment phase. Continual assessments are conducted on a recurring, long-term basis and are used to determine how humanitarian efforts are progressing.

At the beginning of the PDNA process, certain preliminary parameters must be established such as the intended data to be collected, areas to be surveyed, and the specific questions to be used. Individuals or small teams are sent to conduct surveys on either a random or purposeful sampling basis. Surveys are completed through observation and interviews. Survey questions are prioritized to establish the situation of the following sectors: relief, health, livelihoods, water, sanitation, hygiene, food, nutrition, safety, security, protection, and shelter. After the surveys are taken they are analyzed and synthesized into a published report.

**Remote sensing.** In 1906 San Francisco, California, USA was ravaged by an earthquake and ensuing fire. George Lawrence, a photographer, used a 49-pound camera mounted on a series of kites to take photographs of San Francisco from 2,000 feet in the air (Baker, 1989). This was one of the first instances of remote sensing. Remote sensors are defined as sensors that "collect data by detecting the energy that is reflected from Earth" (National Oceanic and Atmospheric Administration, n.d.). Humanitarian PDNA has increasingly utilized remote sensing as a method to supplement the data from field-based surveys. Remote sensing provides objective, hard data that can be used in the PDNA process.

**Remote sensing data.** Remote sensing data can either be real-time or static. Real-time data, such as video, is useful for immediate inspection or monitoring. This study decided to focus on static data, such as still imagery, because this is what is used to create different kinds of maps, which provide useful data for PDNA analysis. These maps include two-dimensional maps, three-dimensional maps, digital elevation models, and thermal maps (Kakaes, Greenwood, Lipincott, Dosemagen, Meier, & Wich, 2015).

***Two-dimensional maps.*** Two-dimensional maps are created by combining multiple images through photo-stitching computer software. Through this process these images are orthorectified, which removes the perspective distortion that results from combining multiple images. Orthorectified two-dimensional maps can then be combined with a geographic information system (GIS) to create geographically accurate maps. A GIS is a "a computer system for capturing, storing, checking, and displaying data related to positions on Earth's surface" (Rutledge, et al., 2011). Figure 5 depicts visually how images are combined to make a cohesive map, and Figure 6 depicts a two-dimensional map created after the 2013 Typhoon Haiyan in the Philippines.

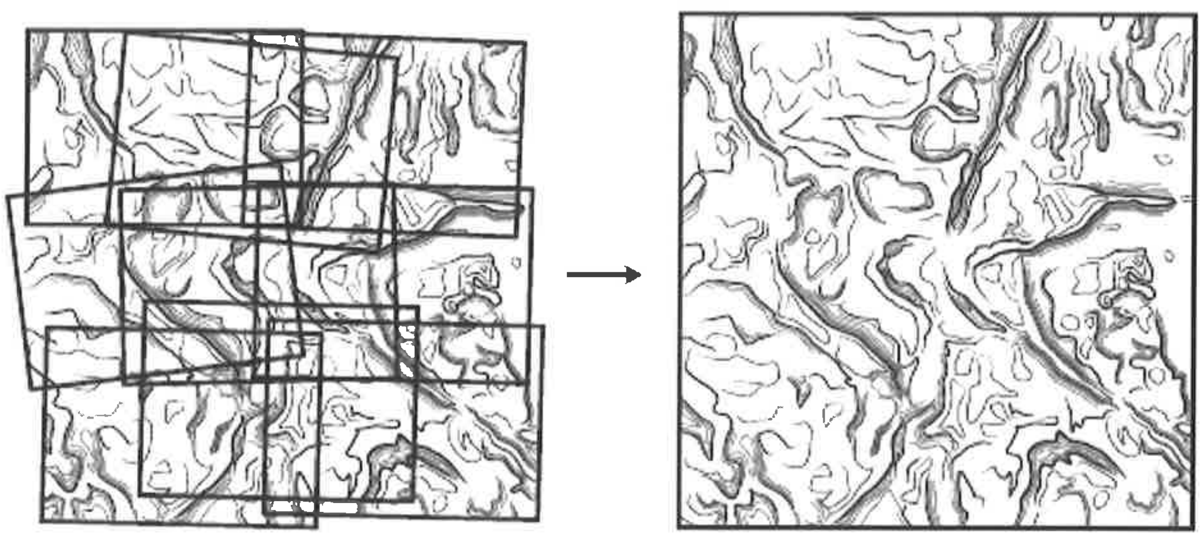

*Figure 5.* Orthorectified geographically accurate two-dimensional map. (Kakaes, Greenwood, Lipincott, Dosemagen, Meier, & Wich, 2015)

*Figure 6.* Two-dimensional map of Barangay Cabacongan, Leyte, Philippines. (Meier, 2014a).

***Three-dimensional maps.*** Three-dimensional maps are similar to two-dimensional maps except that they produce digital maps with volume. Three-dimensional maps typically combine nadir imagery, which is shot straight down, and oblique imagery, which is shot at angle. Using both types of imagery adds more detail to the final three-dimensional map. Computer software finds similar points from hundreds of different still images to create a set of points in a three-dimensional space and then fills in the space in between with data from the images. Pix4D and Agisoft PhotoScan are two popular photo processing software programs for creating three-dimensional maps. These programs are relatively expensive and require computers with significant processing power. Another alternative is open-source software such as Public Lab's MapKnitter, OpenDroneMap, and VisualSFM's Visual Software from Motion. Open-source software can be more difficult to work with and may require an internet connection, but can create accurate three-dimensional maps. Figure 7 depicts the software process in order to create a three-dimensional model and Figure 8 depicts a three-dimensional map created using Pix4D after the 2015 earthquakes in Nepal.

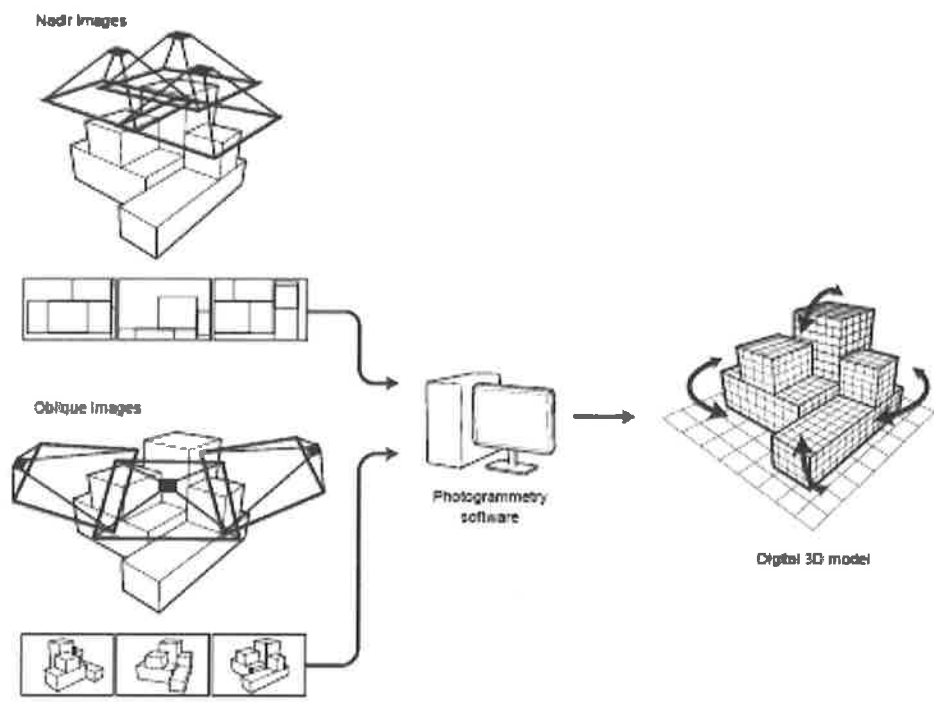


*Figure 7.* Three-dimensional model software creation process (Kakaes, Greenwood, Lipincott, Dosemagen, Meier, & Wich, 2015).

*Figure 8.* Three-dimensional model of a neighborhood in Kathmandu, Nepal (Meier, 2015b).

***Digital elevation models.*** Digital elevation models have similarities to three-dimensional maps, but are distinct in that that they represent only the underlying terrain. Buildings, trees, and other surface features are removed. Elevation is typically depicted by different colors. Digital elevation models are useful when trying to determine the underlying terrain of an area, such as in a flood. Figure 9 depicts a digital elevation map created after the 2014 Tropical Cyclone Ita caused flooding on the Solomon Islands.

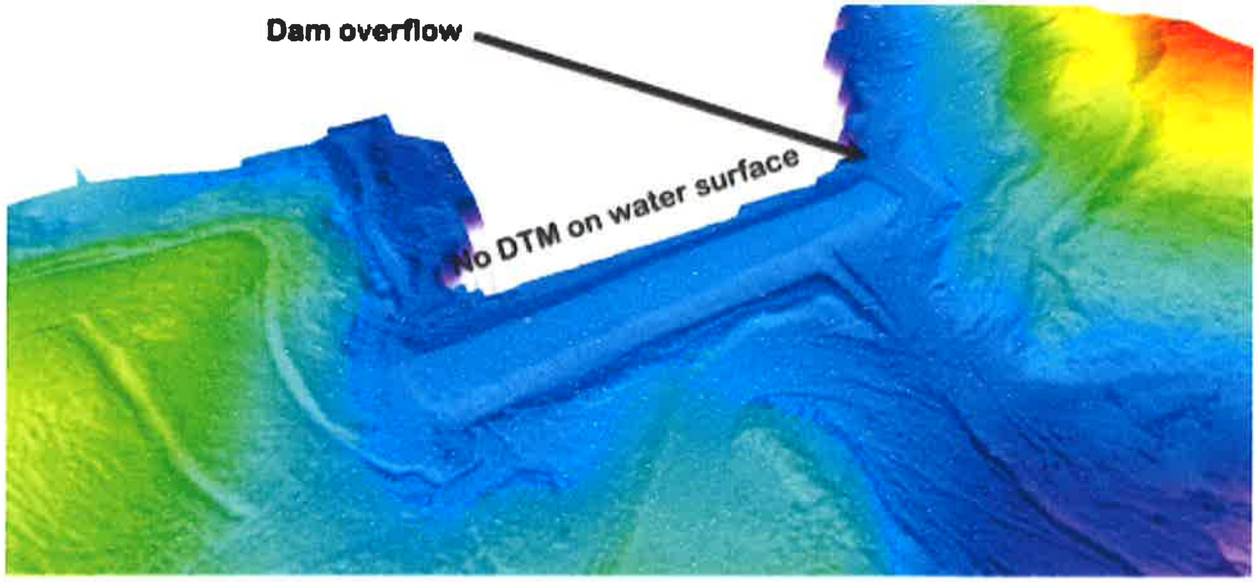


*Figure 9.* Digital elevation map of a dam on the Solomon Islands. (Meier, 2014b)

***Thermal maps.*** Thermal maps capture the temperatures of the mapping area. Applications for thermal maps include detecting damage to roads, fire fighting, and search and rescue. Temperature ranges are depicted with either a color scale or gray scale. Thermal imaging cameras can be expensive and subject to export restrictions. Figure 10 is thermal imaging of a wildfire in Alberta, Canada in 2011.

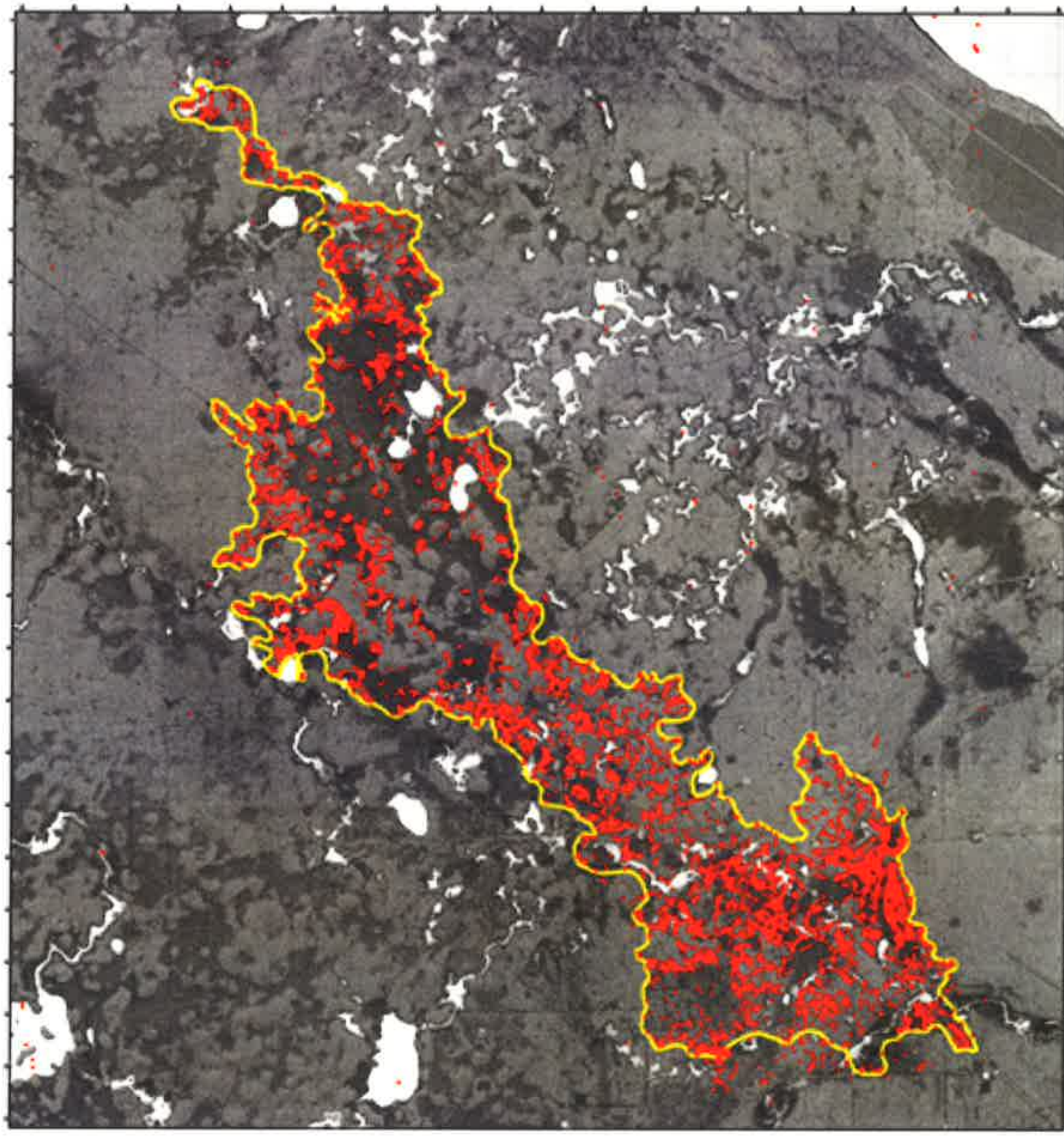

*Figure 10.* Thermal imaging of wildfire in Alberta, Canada 2011 (ITRES Research Limited, 2012).

**Remote sensing principles.** There are some basic principles to remote sensing that must be understood before an economic comparison of different platforms can be analyzed. Most of these principles will apply more directly to planning aerial photography missions, manned and unmanned, though a few apply to satellite imagery as well. The following principles are discussed: image quality, image overlap, georeferencing, and flight planning.

***Image quality.*** Aerial photography resolution is measured in ground sampling distance (GSD). GSD designates "the length on the ground corresponding to the side of one pixel in the image, or the distance between pixel centers measured on the ground (these are equivalent). A larger GSD (10 cm) means that fewer details will be resolvable in the image and it will be of lower quality, while a smaller GSD (5 cm) means the exact opposite." (Kakaes, Greenwood, Lipincott, Dosemagen, Meier, & Wich, 2015). When an image sensor is used to capture an image two similar isosceles triangles are created: one triangle between the camera lens and the object being captured and another triangle between the camera lens and the camera's detecting surface. the height of the first triangle is the altitude of the aerial platform and the height of the second triangle is the focal length of the camera. Figure 11 shows this geometric relationship.

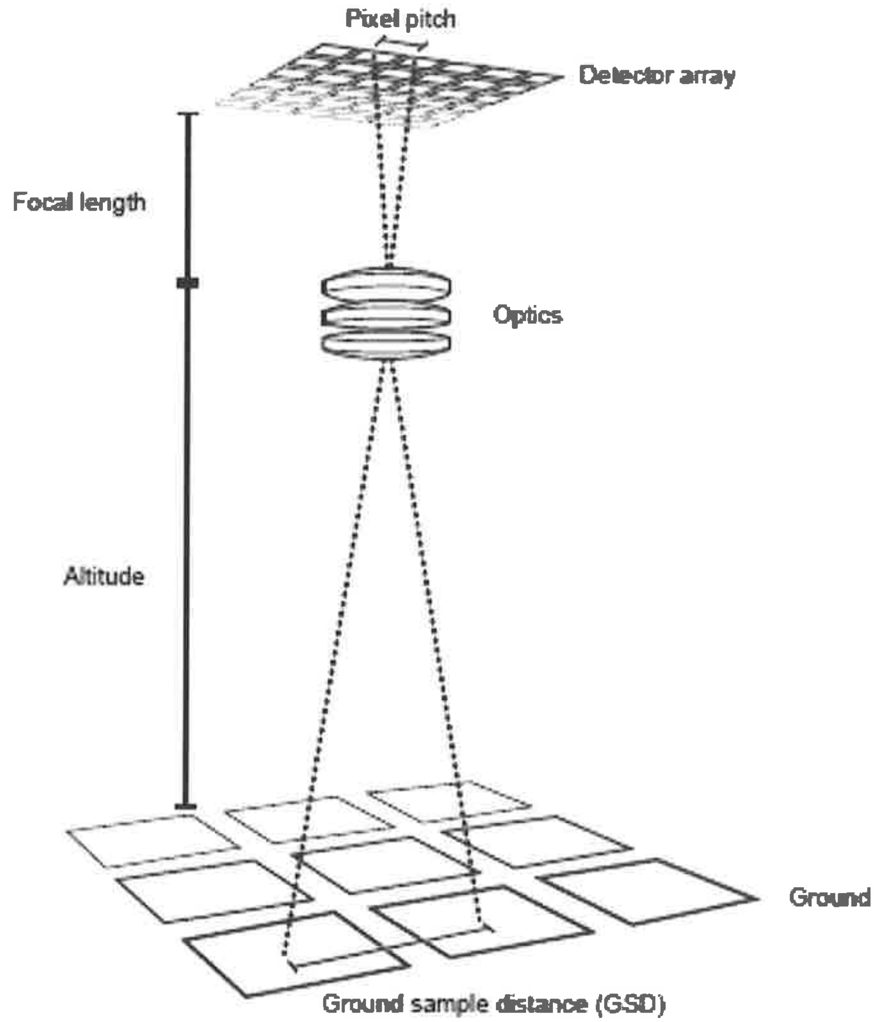


*Figure 11.* Ground sample distance (GSD) (Kakaes, Greenwood, Lipincott, Dosemagen, Meier, & Wich, 2015).

Calculating GSD depends on the pixel size, the height of the camera above the ground, and the focal length. Thus changing any of these factors, the focal length of the camera (through zoom), the altitude at which the aircraft is flying, or the pixel density of the camera's sensor will alternate GSD. The equation for GSD is given in Equation 1.

$$GSD = \frac{Pixel\ Size\ x\ Height\ above\ ground\ level}{Focal\ length} \quad (1)$$

***Image overlap.*** Mapping software requires a certain amount of image overlap in order to find common points between images. This overlap must be in both forward and lateral directions. There is no universal overlap standard as terrain features can influence how much overlap is required. Most mapping companies recommend anywhere from 80%-60%, with higher overlap for terrain that has less distinct features, such as agricultural fields. Figure 12 shows how image overlap affects flight planning; though Figure 12 depicts a UAS the same principle applies to manned aircraft.

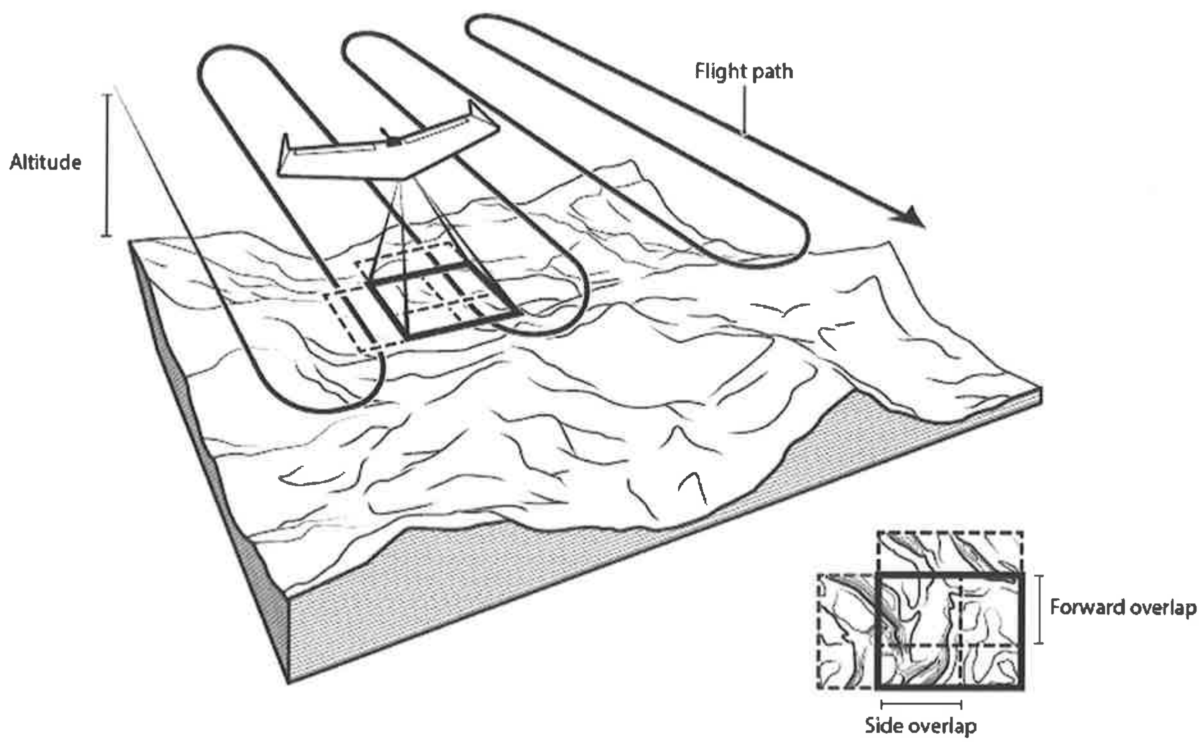


*Figure 12.* Image overlap (Kakaes, Greenwood, Lipincott, Dosemagen, Meier, & Wich, 2015).

***Georeferencing.*** Georeferencing means that "the internal coordinate system of a map or aerial photo image can be related to a ground system of geographic coordinates" (United States Geological Survey, 2016). Without georeferencing, maps will have real-world scale and cannot be used for measurement. Image-processing software requires the real-world Global Position System (GPS) coordinates of a few identifiable features on the map in order to georeference it. Finding these coordinates can be done through a number of means. The most basic and time-consuming method is through the use of ground control points (GCPs) that are placed prior to the surveying images are taken. The coordinates of each GCP are found using a professional-grade global navigation satellite system (GNSS), which include GPS, the Russian GLONASS, European Galileo, or Chinese Beidou. The more GCPs there are the more accurate the map will be; this has to be weighed against the added time and money used to implement more GCPs. Though there is no accepted standard amount for GCPs, most software programs require around five minimum GCPs. Figure 13 shows a simple GCP and how GCPs would be placed for a UAS surveying mission.

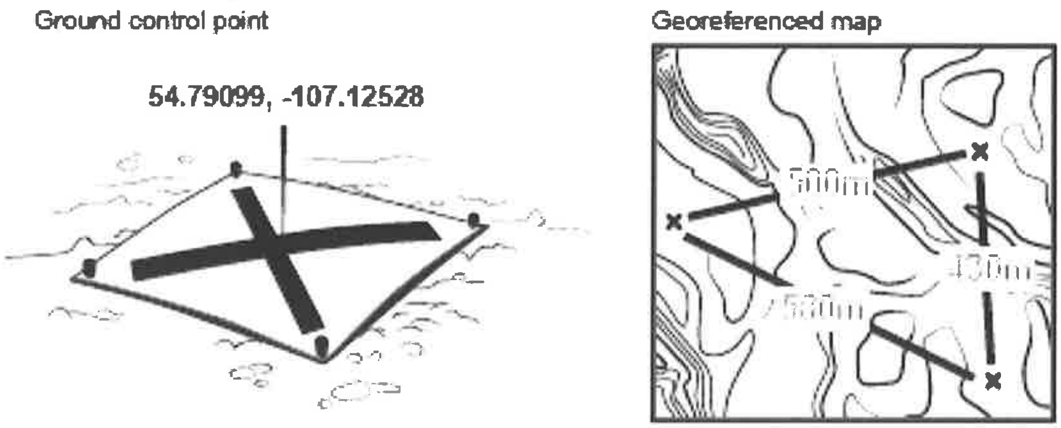


*Figure 13*. Ground control point (GCPs) (Kakaes, Greenwood, Lipincott, Dosemagen, Meier, & Wich, 2015).

Georeferencing can also be completed through comparing remote sensing data to other georeferenced data, such as another map or digital source such as Google Earth. Another method is for the aircraft or camera to record GPS location when the image is taken. Small-scale UAS will not generally have this capability, but there are exceptions. The senseFly eBee Real Time Kinematic (RTK) model produces survey-grade maps by measuring radio wave phase from GPS satellites and the Micro Aerial Projects V-Map system creates precision measurements through dual-frequency GPS.

***Mission planning.*** It can be a daunting task to consider image quality, image overlap, and georeferencing when planning an aerial surveying mission. However, most aerial surveying platforms come equipped with mission planning software that will calculate flight parameters based on camera, aircraft, and desired image quality specifications. In the UAS industry, these programs are often developed specifically for

UAS aircraft or a free open software GCS, like ArduPilot Mission Planner mentioned earlier, can be utilized. Though programs decrease expertise required of UAS operators, an operational understanding of remote sensing is helpful.

***Remote sensing platforms.*** Remote sensing can be conducted through three primary methods: manned aircraft (helicopters and airplanes), satellite, and UAS. Each platform has its advantages and disadvantages. Data collected from all three of these platforms is usually analyzed and processed by a geographic information system (GIS). GIS allows remote sensing data to georeferenced to existing maps and can produce different types of data, such as multi-spectral imaging and three-dimensional models.

*Satellites.* There are two basic types of satellites, polar and geostationary. Geostationary satellites orbit at an altitude of about 22,000 miles above the surface of the earth and orbit the earth at the same speed as its rotation, effectively staying stationary in relationship to the earth (Lewis, 2009). Polar-orbiting satellites operate at lower altitudes, about 10,000 miles above the surface of the earth, and thus provide higher resolution data than geostationary satellites. However, they are only over same point every few days. Sensors on satellites are similar to the ones described for UAS systems earlier in this project, except generally on a larger and more sophisticated scale.

Satellite data has become more widely available for NGO operations around the world over the past few decades. In 1999, the International Charter on Space and Major Disasters, with almost 20 space agencies and organization, was created to provide free data for disaster-stricken countries around the world. However, access to this data can only be requested by approved governmental organizations, and as such would only be available to NGOs in the case of a major catastrophe. The United States releases free satellite data from Landsat 8, but it is at a resolution of 30 meters per pixel. Commercially available satellite imagery is available with resolutions in to 50 centimeter per pixel range, though it is usually sold in minimum sizes of $100km^2$ to $500\ km^2$ (DroneApps, 2016). NGOs with the financial means, such as the UN, Human Rights Watch, and Amnesty International, partner with commercial satellite companies in order to supply large amounts of satellite data to smaller NGOs in the event of a catastrophe (Nerenberg, 2010). For example, in 2007 Amnesty International and the American Association for the Advancement of Science partnered on a $100,000 project called "Eyes on Darfur" which compared past satellite data with current data from 13 at-risk villages ($94\ km^2$) in Darfur, Sudan. Also, the United Nations Institute for Training and Research (UNITAR) through the Operational Satellite Applications Programme (UNOSAT) created the Humanitarian Rapid Service in 2003 as a platform to provide two dimensional orthomosaic maps on world-wide catastrophes (United Nations Institute for Training and Research Operational Satellite Applications Programme, 2013). Organizations can request UNOSAT to acquire and analyze data for a particular humanitarian crisis.

*Manned aircraft.* Another option for NGOs for remote sensing data is through manned aircraft such as helicopters and airplanes. This is very common in environmental and conservation efforts (Jachmann, 1991). Airplanes offer generally lower operating costs than helicopters, but are required to fly at higher altitudes. Manned aircraft provide higher resolution data than satellite imagery and are flexible to specific mission needs. However, manned aircraft are expensive to operate and may not be safe to operate in certain parts of the world. Sensors on manned aircraft are similar to both UAS and satellites.

*UAS.* UAS have increasingly been utilized for humanitarian operations around the world. All three UAS unmanned aircraft types, fixed-wing, rotor-wing, and lighter-than-air, have been used for humanitarian remote sensing. A hand-launched fixed-wing UAS, the HoverWings 18, was used to survey about 16 square miles after the Ms7.0 Lushan earthquake in 2013 (Xu, et al., 2014). Two types of rotor-wing UAS, Lockheed Martin's Indago and the Allign 690L were used after a category 5 cyclone on the pacific island of Vanuatu in 2015 (Kakaes, Greenwood, Lipincott, Dosemagen, Meier, & Wich, 2015). UAS offer high-resolution data, down to one centimeter, but current UAS do not have the capability to cover vast amounts of area such as with satellites or manned aircraft.

# II. Method

## Data Collection

Data collection for this project was completed primarily through online resources. Technical data was either directly obained from manufacturers or derived from manufacturer specifications. Case studies in the humanitarian sector provided realistic background for the hypothetical scenarios represented in this study. Because NGOs operate all around the world, making financial estimates was difficult. For the purposes of this project, it was decided to base costs on market rates found in the United States.

**Economic Analysis**

In order to research the possible economic implications of UAS for the humanitarian community, it was necessary to determine which financial decision-making metrics the humanitarian community utilizes. A traditional business determines success in terms of profits or loss. NGOs are by definition non-profit and thus must determine success through a different framework. A report by the UK-based Humanitarian Policy Group (HPG) outlines some of the practical and ideological difficulties in measuring the impact of humanitarian assistance.

> There are, of course, many good reasons why it is difficult to measure the impact of humanitarian interventions, including difficult issues of causality and attribution and a lack of basic data, such as population figures. Relief interventions are often of short duration, capacity and resources are stretched, insecurity may limit access to populations and the space for analysis and research is constrained. Nor is the new emphasis on results without costs of its own: within the humanitarian sector, a focus on measurement could reduce operational effectiveness and lead to the neglect of issues such as protection and dignity because they are difficult to measure. Focusing on what is measurable risks reducing humanitarian aid to a technical question of delivery, rather than a principled endeavour in which the process as well as the outcome is important. (Hofmann, Roberts, Shoham, & Harvey, 2004)

These factors add many layers of complexity to measuring NGO effectiveness. However, as the HPG report also states, "As the overall volume of humanitarian assistance has increased, so there has been greater scrutiny of how this money is spent" (Hofmann, Roberts, Shoham, & Harvey, 2004). As stated earlier, an estimated $24.5 billion was used in international humanitarian aid in 2014. Both for accountability to investors and effective management of resources, NGOs need financial tools to evaluate all viable alternative methods for accomplishing their objectives.

Two economic methods for determining the strengths and weaknesses of alternative options in business have also been used in the humanitarian sector: cost-benefit analysis (CBA), which is also referred to as benefit-cost analysis (BCA), and cost-effectiveness analysis (CEA). These two methods rely on similar principles and processes, but have distinct differences that lend themselves to different applications. Though CEA was selected for this project, both methods are explained to provide context.

**Cost-benefit analysis (CBA).** CBA was first used in the realm of public projects in the 1930s. The Flood Control Act of 1939 required that "the benefits to whomever they accrue [be] in excess of the estimated costs" (Farnham & Guess, 2000). This principle, that the benefits of an endeavor should outweigh its accompanying costs, led to the creation of cost-benefit analysis. In order to compare costs and benefits of a project, a cost-benefit analysis interprets each cost and benefit on a financial scale, or in other words, "attempting to compare costs with the dollar value of all (or most) of a programs many benefits" (Newcomer, Hatry, & Wholey, 2015). The mathematical form of CBA is represented in Equation 2.

$$Net\ Benefits\ or\ Costs = Total\ Benefits - Total\ Costs \tag{2}$$

**Cost-effectiveness analysis (CEA).** CEA is the same as CBA, but does not convert benefits into a monetary value (Newcomer, Hatry, & Wholey, 2015). The reason for this lies in the difficulty in placing monetary value on certain benefits, such as a human life. CEA is commonly used in the medical field for this reason, and consequently lends itself to humanitarian applications. Instead of benefits, CEA compares costs to units of effectiveness, a predetermined measure of outcome. Examples of units of effectiveness are numbers of lives saved or number of goods delivered. Total cost is divided by units of effectiveness to create a cost-effectiveness ratio (CER). Equation 3 gives the mathematical expression of CER:

$$CER = \frac{Total\ Cost}{Units\ of\ Effectiveness} \tag{3}$$

**Comparison of CBA and CEA.** CBA allows for the integration of all possible costs and benefits, as long as accurate financial equivalencies can be made. CEA can only depict costs in relationship to one particular kind of benefit, and thus is one-dimensional. CBA then is suited for a holistic project analysis, whereas CEA is more suited for projects where a particular outcome is being evaluated.

**Basic CBA/CEA process.** There are many different approaches to conducting a CBA or a CEA, but the basic process for both generally stays the same. The following process comes from the *Handbook of Practical Program Evaluation* (Newcomer, Hatry, & Wholey, 2015).

***Set the framework for the analysis.*** The first question is to determine whether to use CBA or CEA. This depends on a variety of factors, such as the number of programs to be evaluated and the objectives of the analysis.

***Decide whose costs and benefit/effects should be recognized.*** In the business world costs and benefits to a particular group of people are examined, whereas public or humanitarian programs examine the overall impact to society.

***Identify and categorize costs and benefits/effects.*** There are several considerations in this step of the process. First, it is important to consider real benefits/effects and costs versus transfers. Real benefits/effects and costs measure net gains or losses to society, whereas transfers are merely redistribution of resources within a society. For example, deciding to provide aid one area over another is not a net benefit or loss to the society as a whole, but simply a transfer. Second, it must be determined if these are direct or indirect benefits/effects and costs. Direct effects could be the number of supplies delivered, versus an indirect effect such as better health resulting from the supplies delivered. Third, it must be determined if the benefits/effects and costs are tangible or intangible. An intangible effect in humanitarian aid could an increased sense of security or well-being. It is difficult to depict intangible benefits and costs in CBA and CEA, but they should still be addressed.

***Project costs and benefits/effects over the life of the program, if applicable.*** This part of the project examines how benefits and costs may change over the time of a program. For example, certain upfront costs may be short-lived and not continue throughout the entire program.

***Monetize (place a dollar value on) costs.*** Both CBA and CEA require that costs be stated in monetary form. Even intangible costs must be converted to a financial framework. Though this has obvious disadvantages, it provides easier comparison and addition. Typical costs for humanitarian organizations can include salaries, materials, capital, and other expenditures. Another important aspect of this step is to spread the cost of capital expenses, those used over the entire lifespan of the program, evenly throughout the lifespan of the program. This is done by accounting for depreciation and the loss of opportunity cost tied up in the asset. An annual cost for capital investments was calculated by using the PMT function in excel, with five annual payments at a 6% interest rate.

***Quantify benefits in terms of units of effectiveness (for CEA), or monetize benefits (for CBA).*** For CBA this process is similar to the previous step, except it is applied to the benefits of the program. For this reason, this step is more nuanced than for CEA. Some of the benefits that CBA is able to capture can include time saved, increased productivity, and cost avoidance. For CEA, this step selects the most important benefit in order to get units of effectiveness. In the humanitarian context, common CEA benefits include the number of lives saved, number or weight of goods delivered, and number of homes rebuilt.

***Discount costs and benefits to obtain present values.*** A basic economic principle is that people value present day costs and benefits more than future costs and benefits. To account for this, CBA and CEA incorporate a social discount rate (typically about 3%) to account for the opportunity cost lost in the selection of a certain option. In CEA, the present value of costs (PVC) is an aggregate of the costs in each year converted to their first year equivalent. This can be done by the following formula. *T* is the last year of the analysis, *t* is the year being evaluated, *r* is the social discount rate, and *Cr* is the total cost per year. PVC calculation is shown by Equation 4.

$$PVC = C_1 + \frac{C_2}{(1+r)^1} + \frac{C_3}{(1+r)^2} + \cdots + \frac{C_r}{(1+r)^{r-1}} = \sum_{t-1}^{T} \frac{C_r}{(1+r)^{t-1}} \quad (4)$$

For CBA, the process is similar, except that it includes a benefits portion to the equation and calculated net present value (NPV). Equation 5 shows the calculation of NPV.

$$NPV = \sum_{t-1}^{T} \frac{(B_t)}{(1+r)^{t-1}} - \sum_{t-1}^{T} \frac{(C_t)}{(1+r)^{t-1}} \quad (5)$$

***Compute a cost - effectiveness ratio (for CEA) or a net present value (for CBA).*** For CEA, this step in the process creates the cost-effectiveness ratio (CER). The only difference between this formula and the formula mentioned in the description of CEA is that the PVC replaces total costs. Alternatively, the reciprocal of the equation can be used, providing the units of effectiveness per dollar. However, this ratio tends to be so small that it is not used. Equation 6 shows the calculation of CER.

$$CER = \frac{PVC}{Units\ of\ Effectiveness} \quad (6)$$

For CBA, this step involves the calculation of NPV explained earlier. However, NPV can be supplemented by two other calculations. The first calculation is the benefit-cost ratio (BCR). This is found by dividing the present value of benefits (PVB) by the present value of costs (PVC). The BCR, similar to the CER, allows for easy comparison of alternative programs. A BCR with a value higher than one signifies that the program has greater overall benefits than costs. Equation 7 shows the calculation of BCR.

$$BCR = \frac{PVB}{PVC} \tag{7}$$

The second calculation that can be used to supplement NPV is the return on investment (ROI). This is a private sector practice that has been used in non-profit sector, where it has been termed the social return on investment (SROI). The Roberts Enterprise Development Fund, a philanthropic fund based in US, first introduced the SROI model in 2000 (Mil13). Several UK-based organizations conducted research on SROI during the early 2000s that culminated in a methodology guideline published by the Cabinet Office of the Third Sector in the UK in 2009 with updates in 20102 (Nicholls, Lawlor, Neitzert, & Goodspeed, 2012). SROI is found similarly to BCR, except that it subtracts PVC from PVB in the numerator. The difference between SROI and BCR is that SROI is a focus on additional benefit generated from invested costs. A positive SROI would indicate that benefits exceed the costs, a negative SROI would indicate that the costs exceed the benefits, and a SROI of zero would indicate that benefits and costs are equal. Equation 8 shows the calculation of SROI.

$$SROI \frac{PVB - PVC}{PVC} \tag{8}$$

***Perform sensitivity analysis.*** Both CEA and CBA must rely on some assumptions. To account for these assumptions, a sensitivity analysis is used. There are two kinds used: partial and extreme case. A partial sensitivity analysis varies one assumption while keeping everything constant. For example, in the humanitarian world one fluctuating assumption could be the speed of aid delivery, which is dependent on many different factors such as technological, logistical, structural, and environmental issues. A partial sensitivity analysis would vary the rate of aid delivery while keeping all other factors constant. An extreme case sensitivity analysis assigns the values for each assumption for both a worst-case and best-case scenario. The partial sensitivity analysis is more applicable in a stable environment where only a few variables are likely to vary, whereas an extreme case sensitivity analysis is more applicable in vary unstable or uncertain environments. With so many variables for NGO humanitarian operations, it was decided to apply a 15% increase to CER to calculated a worst-case scenario and subtract 15% of CER to calculate a best-case scenario.

***Make a recommendation where appropriate.*** This is the final step in the CEA/CBA process where a final recommendation should be made. At the most basic level, the alternative with the highest BCR, SROI, or CER should be selected. However, reality is rarely this simple. The researcher should resist the temptation to minimize the nuanced nature of CBA/CEA. It is highly possible for two different researchers with the same data to reach different conclusions based different sets of assumptions. Also, it is important at this stage to address intangible or unquantifiable costs and benefits.

Juxtaposing these items alongside the BCR or CER can help decision-makers to understand the full impact of each alternative.

**Project selection of CEA.** The process for conducting CBA and CEA are very similar, however CEA was selected for this project. CEA provides more of an objective comparison in the context that a particular output is desired. For PDNA, UAS is primarily used as a data collection platform. CEA gives the ability to directly compare the cost of different outputs based on the data that they produce.

## Cost-Effectiveness Analysis Applied to PDNA

**Framework.** The purpose of this analysis is to examine where it is financial advantageous to use UAS for remote sensing data for PDNA. Current UAS models that are available to the NGO community are small in scale, so most of the their possible applications are for small, highly detailed data that would be useful for PDNA. With their current technical limitations, UAS cannot replace other remote sensing platforms. However, they provide economic advantages in certain situations. Thus this analysis is not a comprehensive financial analysis of remote sensing platforms PDNA, but rather designed to determine when it is economically advantageous to use UAS. With these purposes in mind, it was determined to use a cost-effectiveness analysis. The costs for remote sensing data can be compared on the amount of area that they cover, if the resolution is comparable. Therefore, the CER selected was US dollars per square kilometer covered.

Remote sensing data and data collected from field-based surveys are complimentary but different. It was determined that a direct financial comparison of the two methods would be an inaccurate comparison. Also, through programs such as UNOSAT, 50-centimeter resolution two-dimensional maps with damage analysis can be provided to NGOs in case it is needed. Instead, this project focused on aerial platforms that can provide high-resolution data (GSD 15cm and smaller), a need for PDNA which has substantiated by recent research. Following the Haiti Earthquake in 2010, research was conducted comparing 15cm GSD remote sensing data from aerial with 50cm GSD satellite data. This study reached the conclusion that "damage derived from satellite imagery was underestimated by a factor of eight, compared to the damage derived from aerial imagery. These results suggest that despite the fast availability of very high resolution satellite imagery… the spatial resolution of 50 cm is not sufficient for an accurate interpretation of building damage" (Corbane, Lemoine, Louvrier, & Kauffman, 2013).

**Selected aircraft.** Three aircraft were selected, one manned and two UAS: the single-engine aircraft Cessna 172 Skyhawk, the fixed-wing senseFly Ebee RTK, and the rotor-wing UAS DJI Phantom 3 Pro.

***Cessna 172.*** The Cessna 172 Skyhawk is a small, single-engine aircraft that has been used for aerial surveying. Though there are many different types of aircraft used for aerial surveying around the world, the Cessna 172 is one of the most numerous light aircraft around the world. A helicopter option was not considered because most are cost-prohibitive for all but the largest of NGOs. Figure 14 depicts a Cessna 172 Skyhawk.


*Figure 14.* Cessna 172 Shyhawk (Goyer, 2012).

***senseFly eBee RTK.*** The senseFly eBee was developed specifically for aerial mapping. Like the DJI Phantom 3, it is relatively easy to use and has been used for humanitarian surveying operations, namely by an organization known as Drone Adventures (Klaptocz, 2014). For these reasons, it was selected for this project as the representative of the light fixed-wing UAS alternative. The RTK model of the eBee utilizes the Real Time Kinematic technology described earlier, which eliminates the need for GCPs. The RTK model is about double the price of the regular Ebee, but it was chosen because of the operational advantage of not having to deploy GCPs. The eBee RTK model comes with its own version of the Pix4D photo analysis software. This UAS is hand-launched, flies entirely autonomously, and conducts an autonomously controlled belly landing after a completed flight. Figure 15 depicts a senseFly Ebee RTK.


*Figure 15.* senseFly Ebee RTK (Ball, 2014).

***DJI Phantom 3 Pro.*** The DJI phantom is a UAS on the border of the commercial and recreation markets. It is a good representative of the small, rotor-wing UAS market and is relatively affordable and easy to use. It has also been used for humanitarian PDNA, in particular by the Humanitarian UAV Network, UAViators (Meier, 2015a). For these reasons, it was selected as a representation of the light rotor-wing UAS alternative. The Pro version of the DJI Phantom 3 offers a higher quality camera, and for this reason the Pro model was selected. Figure 16 depicts a DJI Phantom 3 Pro.

*Figure 16.* DJI Phantom 3 Pro (DJI, n.d.).

*Technical specifications.* Table 1 compares some of the important technical specifications for the Cessna Skyhawk 172, senseFly Ebee RTK, and DJI Phantom 3 Pro.

Table 1.

*Technical specifications of three aerial remote sensing platforms*

| Platform | Cessna Skyhawk 172 | senseFly Ebee RTK | DJI Phantom 3 Pro |
|---|---|---|---|
| Weight (kg) | 1,157 | 0.69 | 1.216 |
| Wingspan (m) | 11 | 0.96 | 0.59* |
| Endurance (minutes) | 300 | 40 | 23 |
| Max speed (m/s) | 63 | 11-25 | 16 |
| Price (USD) | 300,000 | 25,000 | 1,000 |
| References | (DJI, n.d.) | (senseFly, n.d.) | (Cessna Aircraft Company, n.d.) |

*DJI Phantom 3 Pro wingspan is the diagonal length including propellers

**Selected cameras.** It was important to identify which cameras would be used for each platform. The following three cameras were selected, Waldo Air XCAM-B, Canon S110, and DJI FC300X. All three of these cameras are electro-optical (EO) cameras. Other cameras, such as thermal or infrared cameras, are available for each of aircraft, but it was decided to limit cost considerations to EO cameras for simplicity.

Waldo Air, a company based in Nashville, TN, created the XCAM-B as an affordable and easily mounted aerial surveying camera for several aircraft types, including the Cessna 172 Skyhawk. The camera is attached in a pod on the wing strut. It is a comparably affordable camera for manned aircraft, and the package includes the camera system, Pix4D photo analysis software, and a mission planner. The Waldo Air XCAM-B camera pod and accompanying mission planner are shown in Figure 17. The XCAM-B mounted on a Diamond DA-40 single-engine aircraft is shown in Figure 18.

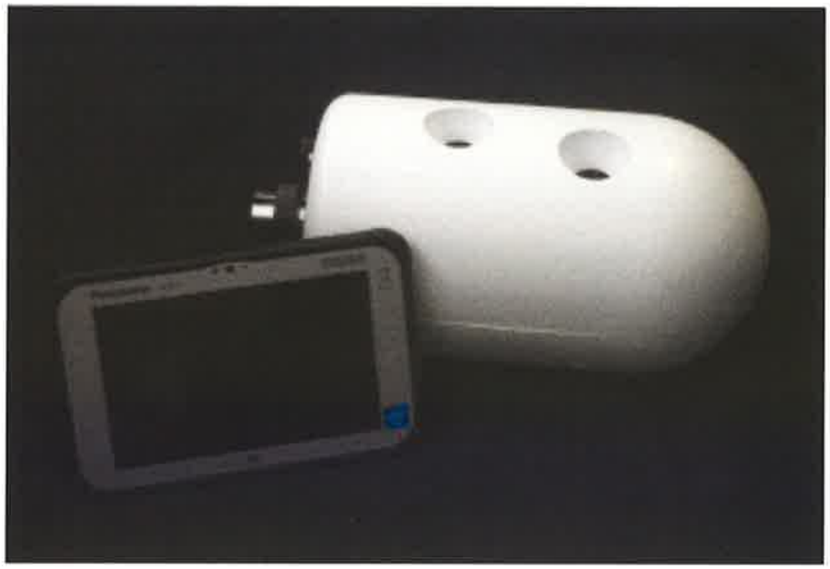

*Figure 17.* Waldo Air XCAM-B (Geosense, n.d.).

*Figure 18.* Waldo Air XCAM-B mounted on a Diamond DA-40 (Geosense, n.d.).

The senseFly eBee series is designed to work with a series of different cameras, including the Canon S110. The Canon S110 series is small digital camera frequently used in UAS aerial mapping missions. It is relatively cheap, lightweight, and produces high-definition photos. The Canon S110 is shown in Figure 19.


*Figure 19.* Canon S110.

The FC300X is a Sony camera provided in the purchase price of DJI Phantom 3 Pro. This camera is designed more specifically for video and aerial photography instead of mapping, but can still be used effectively for aerial surveying. The FC300X can be seen mounted on a series of gimbals below the DJI Phantom 3 Pro in Figure 3, which was included earlier.

Table 2 lists some of the specifications for the Waldo Air XCAM-B, Canon S110, and FC300X. Pixel size is the size of single pixel on the camera sensor in micrometers, focal length is the distance from the lens sensor in millimeters, the sensor size is measured in millimeters in width times height, image size is the dimensions of the photographs captured by the camera measured in pixels in width times height, and price is in US dollars. FC300X's price is included in the overall cost of the DJI Phantom 3 Pro and its weight is not listed in the aircraft's specifications.

Table 2.

*Camera Specifications*

| Camera | Waldo Air XCAM-B | Canon S110 | FC300X |
|---|---|---|---|
| Pixel Size (µm) | 4.3 | 1.9 | 1.56 |
| Focal Length (mm) | 40 | 5.2-26 | 3.5 |
| Sensor (mm x mm) | 43x15 | 7.44x5.58 | 6.17x4.55 |
| Image Size (pixels) | 10,200 x 3,506 | 4,000 x 3,000 | 4,000 x 3,000 |
| Price ($) | 32,500 | 299 | - |
| Weight (g) | 2700 | 198 | ? |
| Refernces | (Waldo Air, n.d.) | (Canon, n.d.) | (DJI, n.d.) |

*This data was not provided on the manufacturer's website, but was derived from given parameters

*Data Analysis Software.* Another major consideration for an aerial mapping mission is the post-flight data analysis. According to Pix4D, the time that it takes to process images into a comprehensive two-dimensional or three-dimensional map relies on several different factors: the number of images used, image size, image content, computer used, area covered, and resolution (Pix4D). Calculating time for data analysis was one of the most difficult aspects of this project, but on average from case studies data analysis took about 80% of total project time for UAS surveying missions.

Though free photogrammetry (photo analysis) software is available, Pix4D was selected as the data analysis software for all three aircraft. Pix4D provides more functionality than free software and is either included or discounted for all three platforms. Pix4D is included with the Waldo Air XCAM-B and a version of it is included with the eBee RTK. A discounted version of Pix4D, Pix4Dmapper Mesh, has been developed for DJI systems and includes a mission planner.

**Typical surveying mission.** In order to provide a financial comparison, aerial surveying parameters for each of the three platforms were calculated. Calculations were based on GSD data in 10cm, 5cm, and 3cm. The thought behind this approach is based on case study testimonials, Data with 10cm GSD seems to be used for two-dimensional orthomosaic maps used quickly identifying damage after a catastrophe (Testing the utility of mapping drones for early recovery in the Philippines, 2016). 5cm GSD data seems to be used for detailed damage assessment (Rapid damage assessments of Tabarre and surrounding communities in Haiti following Hurricane Sandy, 2016). 3cm GSD seems to be used for highly detailed three-dimensional models (Small-scale mapping with consumer drones in Nepal, 2016).

Flight altitude and area per flight were calculated by using the free mission planner Maps Made Easy which is available online (Maps Made Easy, n.d.). Parameters for mission planning an aerial survey were a 70% forward and lateral overlap grid pattern, maximum range, average surveying speed, and a small time allowance for climbing to altitude and then descending. The senseFly eBee RTK and DJI Phantom 3 Pro included fifteen minutes in between each flight to account for transitions in between each flight and Cessna 172 included 60 extra minutes to account for flight time from airport and required minimum fuel upon landing. DJI Phantom 3 Pro area per hour was also included 15 minutes to place GCPs for increased accuracy in between each flight. Area per hour calculations used all the time considerations to calculate how much area would be covered per hour of overall operation at the stated GSD. Average post-flight image processing time was also provided. This parameter is the most subjective of all the other parameters, and constitutes best guess figures based on case studies. Typical surveying mission specifications are listed in Table 3.

*Table 3.*

Typical surveying mission specifications

| Platform | Cessna 172 | senseFly eBee RTK | DJI Phantom 3 Pro |
|---|---|---|---|
| Average surveying speed (m/s) | 45 | 10 | 8 |
| Flight duration (minutes) | 300 | 40 | 23 |
| | | | |
| GSD 10cm flight altitude (m) | 865 | 275 | 230 |
| GSD 10cm area covered per flight ($km^2$) | 200 | 1.5 | 0.5 |
| GSD 10cm area covered per hour ($km^2$/hr) | 40 | 1.5 | 0.5 |
| GSD 10cm processing time ($km^2$/hr) | 0.5 | 0.5 | 0.5 |
| | | | |
| GSD 5cm altitude (m) | 430 | 135 | 115 |
| GSD 5cm area per flight ($km^2$) | 110 | 0.9 | 0.3 |
| GSD 5cm area per hour ($km^2$/hr) | 22 | 0.9 | 0.3 |
| GSD 5cm processing time ($km^2$/hr) | 0.25 | 0.25 | 0.25 |
| | | | |
| GSD 3cm flight altitude (m) | 260 | 82 | 70 |
| GSD 3cm area per flight ($km^2$) | 70 | 0.6 | 0.2 |
| GSD 3cm area per hour ($km^2$/hr) | 14 | 0.6 | 0.2 |
| GSD 3cm processing time ($km^2$/hr) | 0.1 | 0.1 | 0.1 |

**Selected scenarios.** In order to conduct CEA, two hypothetical humanitarian PDNA scenarios were selected to highlight the economic advantages of the senseFly eBee and DJI Phantom 3 Pro. The first scenario is a NGO that provides aid at a series of refugee camps. This NGO is considering aerial surveys as an alternative to satellite data due to the rapidly fluctuating nature of refugee camps and relatively small surveying size. The second scenario is a NGO that responds frequently to large-scale natural disasters. This NGO is considering aerial surveys as a means to acquire three-dimensional models of heavily damaged buildings or transportation infrastructure. Severely damaged buildings are a serious safety concern to both aid workers and residents, and this NGO would like to be able to assess building integrity with minimal risk and in a timely manner.

**Common considerations.** There are several common considerations for both scenarios. UAS and manned aircraft have a few distinct characteristics that affect operational use and costs. UAS technology is changing at a rapid rate and current systems can become outdated within a few years. Manned aircraft, such as Cessna 172, have traditionally long life spans due to intensive maintenance procedures, pilot certification requirements, and the expense of a new aircraft. For example, there was a 1959 model Cessna 172 that was known to be still be flying in the United Kingdom in 2007 (Williams, 2007). Also, infrastructure exists around the world to rent manned aircraft, whereas that capability for UAS is still developing or nonexistent, especially in third world countries. To account for these differences, time frames for both scenarios were considered over a five-year period. At the end of this period it is assumed that the NGO would desire to replace their current UAS or it would require replacement due to a crash. Also, resale value for manned aircraft was considered to be much higher than for UAS.

Other common considerations include insurance, storage, and government approval. With the high dependability of manned aircraft, liability insurance for a Cessna

172 can be less expensive than for a much cheaper UAS such as the eBee RTK or the DJI Phantom 3 Pro. However, storage for a small UAS is significantly cheaper than for a manned aircraft. Both the eBee RTK and DJI Phantom 3 can easily be stored anywhere you can fit a small suitcase-sized container, whereas a manned aircraft requires either a hangar or ramp space at a local airport. Whether operating with manned or unmanned aircraft, aerial surveying missions typically require government approval because of safety and security concerns. A small monetary amount was accounted for legal fees associated with obtaining government approval, though this would vary significantly from country to country.

**Scenario one: refugee camps.** An NGO delivers aid to a series of refugee camps every year. The NGO is considering aerial surveying as a means to conduct periodic PDNA. Its main concerns are identifying population changes and infrastructure needs. This organization is also concerned about conducting aerial surveys in a manner that would not disrupt or frighten refugees. These refugee camps are located in the same country, but are 100km apart. For this hypothetical scenario, this NGO conducts monthly surveys of three different refugee camps with an average size of 2.5 $km^2$. The NGO determines that it would like aerial data with a GSD of 10cm. It believes that this resolution would allow the organization to identify refugee camp size, structures, and problem areas. The NGO would like the data within 24-48 hours timeframe each month.

***Cessna 172.*** As the first option the NGO considers purchasing a Cessna 172 and keeping it in country. There are additional costs associated with owning an aircraft, such as maintenance, fuel, storage, and insurance, but owning an aircraft gives the NGO increased flexibility with regular aerial surveys. The NGO also purchases the Waldo Air XCAM-B camera system and pays a local mechanic to install it on the aircraft. The NGO pays yearly to train one of its employees on Pix4D in order to analyze data and hires a local pilot for each aerial survey. Other expenses include obtaining government approval and data analysis computer. The Cessna 172, XCAM-B camera system and computer should retain resale value over the five-year period.

***eBee RTK.*** As a second option the NGO considers purchasing a single eBee RTK and keeping it in country. In this scenario they train one of their employees as both an eBee RTK operator and data analyst. The employee will travel by car to each refugee camp once a month and operate the eBee RTK from the perimeter of the camp. Other expenses include storage, annual recurrent training on both the eBee RTK and Pix4D, government approval, data analysis, and insurance. Cost for recharging eBee RTK and computer battery is so small that it is considered negligible. At the end of five years, the eBee RTK and computer should have resale value.

***DJI Phantom 3 Pro.*** As a third option the NGO considers purchasing three DJI Phantoms Pro models. In this scenario they train three of their employees as both a DJI Phantom 3 Pro operators and Pix4D data analysts. Each employee will travel by car to one of the refugee camps once a month and operate the DJI Phantom 3 Pro. Unlike the eBee RTK option, the limited range of the DJI Phantom 3 Pro requires the operator to change location throughout the camp as they complete the survey. Other expenses include storage, annual recurrent training on both the Phantom 3 Pro and Pix4D, government approval, data analysis, and insurance. Costs for recharging the DJI Phantom

3 Pro and computer battery are so small that they are considered negligible. At the end of five years, DJI Phantom 3 Pro and computer should have resale value.

**Scenario two: urban structures.** This NGO provides aid after natural disasters such as flood, earthquakes, and fire. This NGO is considering aerial surveying as a means for obtaining three-dimensional models of severely damaged urban structures. These structures can be residential buildings, transportation infrastructure such as bridges, or manufacturing plants. These models would be used to determine the integrity of these structures. This organization's main concerns are quickly determining safety hazards to residents and aid workers and community engagement. For this hypothetical scenario, this NGO has on average five highly damaged urban structures each year with an average size of 10 hectares (0.1 $km^2$) around the world. The NGO determines that they would like to acquire remote sensing data with a resolution of 3cm GSD. This data would provide highly accurate three-dimensional models.

***Cessna 172.*** Because of the global nature of the emergencies that this NGO responds too, it is determined that it would be more economical and quicker to rent a local aircraft and pilot in the affected country than to buy an aircraft and fly it to the country. There are drawbacks to this approach, since after any natural disaster rental rates will be high and aircraft availability will be limited. The NGO will bring its own camera system, Waldo Air XCAM-B, and pay a local mechanic to install it on the aircraft. The NGO will also bring its own data analyst who will ride in the aircraft during surveying and process data afterwards. The XCAM-B system transportation cost is included as checked baggage with the data analyst. Other expenses include upfront and annual recurring training of data analyst, transportation of camera and data analyst in and out of country, obtaining government approval, and storage of camera and laptop system. Also, the XCAM-B camera system and computer should retain resale value over the five-year period.

***senseFly eBee RTK***. As a second option, the NGO considers purchasing a senseFly eBee RTK. The NGO would pay for initial or recurrent training one of its employees as both a UAS operator and data analyst annually. The employee will travel by airline to each location and the senseFly eBee RTK can be transported as checked baggage by the employee. Other expenses include storage, data analysis computer and time, insurance, and government approval. The eBee RTK and computer should retain resale value over the five year period.

***DJI Phantom 3 Pro.*** As a third option, the NGO considers purchasing a DJI Phantom 3 Pro. Operational considerations for the DJI Phantom 3 Pro are almost identical to the eBee RTK, especially on such a small scale. It can also be easily transported as checked backage.

## III. Results

### Scenario One: Refugee Camps

**Time.** The first parameter that was calculated was the time it would take to complete one full survey of the three refugee camps using each platform. Flight and processing time were calculated using *GSD 10cm area covered per hour* and *GSD 10cm* *processing time* found in Table 3. Two total times were calculated: paid time and mission time. Paid time was used to calculate the total financial cost and mission time to calculate the total time the entire operation would require to complete. The reason that the two times were calculated is because the DJI Phantom 3 Pro option utilizes three operators simultaneously to achieve the 24-48 hour window. Tables 4, 5, and 6 show the time calculations for the Cessna 172, eBee RTK, and DJI Phantom 3 Pro, respectively.

*Table 4.*

Scenario one: Cessna 172 time calculations

| Segments | Estimate and Method of Valuation | Mission Time | Paid Time |
|---|---|---|---|
| Flight | Assume 0.1 hours for each of the three refugee camps for surveying (2.5km$^2$ at 40km$^{2/}$/hr) with 0.5 hour transit in between each location (100 km at 63 m/s) and 1.0 additional transit. | 2.8 hours | 2.8 hours |
| Processing | Assume data analysis time of 0.5km$^2$/hr for the total area of 7.5 km$^2$ | 15 hours | 15 hours |
| Total | | 17.8 hours | 17.8 hours |

*Table 5.*

Scenario one: eBee RTK time calculations

| Segments | Estimate and Method of Valuation | Mission Time | Paid Time |
|---|---|---|---|
| Flight | Assume 1.7 hours for each of the three refugee camp (2.5 $km^2$at 1.5 $km^2/hr$) | 5.1 hours | 5.1 hours |
| Driving | Assume 1.0 hour driving to the first location, 2.0 hour of driving time driving to each of the other locations, and 1.0 hour to drive back. | 4.0 hours | 4.0 hours |
| Processing | Assume data analysis time of 0.5$km^2/hr$ for the total area of 7.5 $km^2$ | 15 hours | 15 hours |
| Total Time | | 24.1 hours | 24.1 hours |

Table 6.

*Scenario one: DJI Phantom time calculations*

| Mission Segments | Estimate and Method of Valuation | Mission Time (hours) | Paid Time (hours) |
|---|---|---|---|
| Flight | Assume 5 hours for each of the three refugee camp (2.5 $km^2$at 0.5 $km^2/hr$) | 5.0 | 15.0 |
| Driving | Assume 2.0 hour of driving time to and from each location | 2.0 | 6.0 |
| Data Analysis | Assume data analysis time of 0.5$km^2/hr$ for total area of 7.5 $km^2$ | 15 | 15 |
| Total Time | | 22 hours | 36 hours |

**Operational costs:** Cost breakdowns for each platform were calculated using US market estimates. Each individual cost was then extrapolated to an annual cost. Explanations for how each cost was defined and calculated for the Cessna 172, eBee RTK, and DJI Phantom 3 Pro are shown in Tables 7, 8, and 9.

Table 7.

*Scenario one: Cessna 172 operational expenses*

| Financial Costs | Estimate and Method of Valuation |
|---|---|
| Cessna 172 | Cost of $300,000 for Cessna 172 out over useful life (Annual cost: $71,218.92 at 6% interest). |
| Waldo XCAM-B Camera | Waldo XCAM-B cost of $32,500 spread out over useful life (Annual cost: $7,715.38 at 6% interest). |
| Computer | High-speed $2,000 data analysis computer cost spread out over useful life. (Annual cost: $474.79 at 6%). |
| Maintenance | Assume annual maintenance of Cessna 172 at $2,500. |
| Hangar | Assume annual hangar cost of $250/month (Annual cost: $3,000) . |
| Insurance | Assume annual insurance cost of $1,500. |
| Fuel | Assume $40/hr for fuel at 2.8 hours per month (Annual cost: $1,344) |
| Pilot | Assume pilot rate of $35/hr at 2.8 hours per month (Annual cost: $1,176) |
| Data Analyst | Assume $35/hr for data analyst at 17.8 hours per month (Annual cost: $7,476) |
| Pix4D Training | Assume annual cost of $500 for either recurrent or new Pix4D training |
| Waldo XCAM-B Installation | Assume $100 in first year to have mechanic install Waldo Air XCAM-B camera system. |
| Government Approval | Assume $100 for legal fees for acquiring government approval per year. |
| Storage | Assume $100 annual storage fee of camera system. |
| Resale | Assume resale value of 80% for the Cessna 172 and 50% resale value for both XCAM-B and computer as resale value spread out over the five year period (Annual cost: -$51,450). |

Table 8.

*Scenario one: eBee RTK operational expenses*

| Financial Costs | Estimate and Method of Valuation |
|---|---|
| eBee RTK | Cost of $25,000 for eBee RTK out over useful life (Annual cost: $5,934.91 at 6% interest) |
| Computer | High-speed $2,000 data analysis computer cost spread out over useful life (Annual cost: $406.73 at 6% interest) |
| Insurance | Assume annual liability insurance cost of $2,500 for eBee RTK. |
| Travel Cost | Assume cost of car rental to be $100 per month (Annual cost: $1,200) |
| Employee | Assume $35/hr for NGO employee at 24.1 hours per month (Annual cost: $10,122) |
| Pix4D Training | Assume annual cost of $500 for either recurrent or new Pix4D training |
| eBee RTK Training | Assume annual cost of $500 for either recurrent or new eBee RTK training |
| Government Approval | Assume $100 for legal fees for acquiring government approval per year. |
| Storage | Assume annual storage cost of $100 for eBee RTK. |
| Resale | Assume resale value of 50% for the eBee RTK and computer as spread out over the five year period (Annual cost: -$2,700) |

*Table 9.*

Scenario one: DJI Phantom 3 Pro operational expenses

| Financial Costs | Estimate and Method of Valuation |
|---|---|
| eBee RTK | Cost of $3,000 for three DJI Phantom 3 Pros out over useful life (Annual cost: $$712.19 at 6% interest) |
| Computer | High-speed $2,000 data analysis computer cost spread out over useful life (Annual cost: $406.73 at 6% interest) |
| Insurance | Assume annual liability insurance cost of $1,500 for each DJI Phantom 3 Pro (Annual cost: $4,500). |
| Travel Cost | Assume cost of car rental to be $100 per month for each of the three cars (Annual cost: $3,600) |
| Employee | Assume $35/hr for NGO employees at 36 hours per month (Annual cost: $15,120) |
| Pix4D Training | Assume annual cost of $1500 for three NGO employees to receive either recurrent or new Pix4D training |
| Pix4D Mapper Mesh | Annual cost of $499 for Pix4D Mapper Mesh mission planning and data analysis program per DJI Phantom 3 Pro (Annual cost: $1497) |
| DJI Phantom 3 Pro | Assume annual cost of $1500 for three NGO employees to receive either recurrent or new DJI Phantom 3 Pro training |
| Government Approval | Assume $100 for legal fees for acquiring government approval per year. |
| Storage | Assume annual storage cost of $300 for storing three DJI Phantom 3 Pros. |
| Resale | Assume resale value of 50% for each of the DJI Phantom 3 Pros and one computer as spread out over the five year period (Annual cost: -$500) |

**Lifetime costs.** Annual operational costs were considered over a five-year period. Total costs were calculated by adding together all costs; PVC was calculated by using Equation 4; area given is the total area covered in a one year period; CER was calculated by dividing PVC by area; for a sensitivity analysis, 15% of CER, both positive and negative, was calculated. Tables 10, 11, 12 show the lifetime costs of the Cessna 172, eBee RTK, and DJI Phantom 3 Pro, respectively.

Table 10.

*Scenario one: Cessna 172 lifetime costs*

| Costs | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 | Total |
|---|---|---|---|---|---|---|
| Cessna 172 | $71,218.92 | $71,218.92 | $71,218.92 | $71,218.92 | $71,218.92 | $356,094.60 |
| XCAM-B | $7,715.38 | $7,715.38 | $7,715.38 | $7,715.38 | $7,715.38 | $38,576.90 |
| Computer | $474.79 | $474.79 | $474.79 | $474.79 | $474.79 | $2,373.95 |
| Mainteance | $2,500.00 | $2,500.00 | $2,500.00 | $2,500.00 | $2,500.00 | $12,500.00 |
| Isurance | $1,500.00 | $1,500.00 | $1,500.00 | $1,500.00 | $1,500.00 | $7,500.00 |
| Fuel | $1,344.00 | $1,344.00 | $1,344.00 | $1,344.00 | $1,344.00 | $6,720.00 |
| Pilot | $1,176.00 | $1,176.00 | $1,176.00 | $1,176.00 | $1,176.00 | $5,880.00 |
| Data Analyst | $7,476.00 | $7,476.00 | $7,476.00 | $7,476.00 | $7,476.00 | $37,380.00 |
| Pix4D Training | $500.00 | $500.00 | $500.00 | $500.00 | $500.00 | $2,500.00 |
| Mechanic | $100.00 | $0.00 | $0.00 | $0.00 | $0.00 | $100.00 |
| Government | $100.00 | $100.00 | $100.00 | $100.00 | $100.00 | $500.00 |
| Storage | $100.00 | $100.00 | $100.00 | $100.00 | $100.00 | $500.00 |
| Resale | -$51,450.00 | -$51,450.00 | -$51,450.00 | -$51,450.00 | -$51,450.00 | -$257,250.00 |
| Total Costs | $42,755.09 | $42,655.09 | $42,655.09 | $42,655.09 | $42,655.09 | $213,375.45 |
| PVC | $42,755.09 | $41,412.71 | $40,206.51 | $39,035.45 | $37,898.50 | $201,308.26 |
| Area | 90 | 90 | 90 | 90 | 90 | 450 |
| **CER** | | | | | | **447.35** |
| Best Case (-15%) | | | | | | 380.25 |
| Worst Case (+15%) | | | | | | 514.45 |

Table 11.

*Scenario one: eBee RTK lifetime expenses*

| Costs | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 | Total |
|---|---|---|---|---|---|---|
| eBee RTK | $5,934.91 | $5,934.91 | $5,934.91 | $5,934.91 | $5,934.91 | $29,674.55 |
| Computer | $474.79 | $474.79 | $474.79 | $474.79 | $474.79 | $2,373.96 |
| Insurance | $2,500.00 | $2,500.00 | $2,500.00 | $2,500.00 | $2,500.00 | $12,500.00 |
| Travel | $1,200.00 | $1,200.00 | $1,200.00 | $1,200.00 | $1,200.00 | $6,000.00 |
| Employee | $10,122.00 | $10,122.00 | $10,122.00 | $10,122.00 | $10,122.00 | $50,610.00 |
| Pix4D Training | $500.00 | $500.00 | $500.00 | $500.00 | $500.00 | $2,500.00 |
| eBee RTK Training | $500.00 | $500.00 | $500.00 | $500.00 | $500.00 | $2,500.00 |
| Government | $100.00 | $100.00 | $100.00 | $100.00 | $100.00 | $500.00 |
| Storage | $100.00 | $100.00 | $100.00 | $100.00 | $100.00 | $500.00 |
| Resale | -$2,700.00 | -$2,700.00 | -$2,700.00 | -$2,700.00 | -$2,700.00 | -$13,500.00 |
| Total Costs | $18,731.70 | $18,731.70 | $18,731.70 | $18,731.70 | $18,731.70 | $93,658.51 |
| PVC | $18,731.70 | $18,186.12 | $17,656.43 | $17,142.16 | $16,642.88 | $88,359.29 |
| Area | 90 | 90 | 90 | 90 | 90 | 450 |
| **CER** | | | | | | **196.35** |
| Best Case (-15%) | | | | | | 166.90 |
| Worst Case (+15%) | | | | | | 225.81 |

Table 12.

*Scenario one: DJI Phantom 3 Pro lifetime expenses*

| Costs | $1.00 | $2.00 | $3.00 | $4.00 | $5.00 | Total |
|---|---|---|---|---|---|---|
| DJI Phantom 3 Pro | $712.19 | $712.19 | $712.19 | $712.19 | $712.19 | $3,560.95 |
| Computer | $474.79 | $474.79 | $474.79 | $474.79 | $474.79 | $2,373.96 |
| Insurance | $4,500.00 | $4,500.00 | $4,500.00 | $4,500.00 | $4,500.00 | $22,500.00 |
| Travel | $3,600.00 | $3,600.00 | $3,600.00 | $3,600.00 | $3,600.00 | $18,000.00 |
| Employee | $15,120.00 | $15,120.00 | $15,120.00 | $15,120.00 | $15,120.00 | $75,600.00 |
| Pix4D Training | $1,500.00 | $1,500.00 | $1,500.00 | $1,500.00 | $1,500.00 | $7,500.00 |
| Pix4D Mapper Mesh | $1,497.00 | $1,497.00 | $1,497.00 | $1,497.00 | $1,497.00 | $7,485.00 |
| DJI Training | $1,500.00 | $1,500.00 | $1,500.00 | $1,500.00 | $1,500.00 | $7,500.00 |
| Government | $100.00 | $100.00 | $100.00 | $100.00 | $100.00 | $500.00 |
| Storage | $300.00 | $300.00 | $300.00 | $300.00 | $300.00 | $1,500.00 |
| Resale | -$500.00 | -$500.00 | -$500.00 | -$500.00 | -$500.00 | -$2,500.00 |
| Total Costs | $28,803.98 | $28,803.98 | $28,803.98 | $28,803.98 | $28,803.98 | $144,019.91 |
| PVC | $28,803.98 | $27,965.03 | $27,150.52 | $26,359.72 | $25,591.96 | $135,871.22 |
| Area | 90 | 90 | 90 | 90 | 90 | 450 |
| **CER** | | | | | | **301.94** |
| Best Case (-15%) | | | | | | 256.65 |
| Worst Case (+15%) | | | | | | 347.23 |

**Scenario one: Analysis and recommendation.** The CER and operational time results from these nine tables are synthesized in Figure 20.

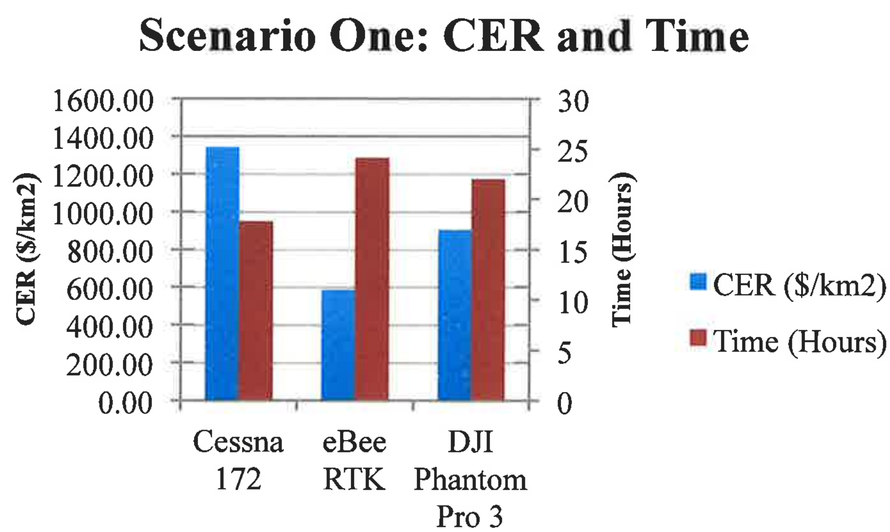


*Figure 20.* Scenario one: CER and time

The Cessna 172 option is the fastest option and the eBee RTK is the most cost-effective. Using three DJI Phantoms 3 Pros provides a medium between both platforms. However, with such a small difference in time to accomplish the same mission, the eBee RTK solution seems to be the most logical solution. It also has the added advantage of only utilizing one NGO employee versus three NGO employee with the DJI Phantom 3 Pro option.

**Scenario Two: Urban Structures**

**Time.** The first parameter that was calculated was the time it would take to complete one survey of one of the buildings. Flight and processing time were calculated using *GSD 3cm area covered per hour* and *GSD 3cm processing time* found in Table 3. T. In this scenario paid time and mission time are the same. Tables 13, 14, and 15 show the time calculations for the Cessna 172, eBee RTK, and DJI Phantom 3 Pro, respectively.

Table 13.

*Scenario two: Cessna 172 time calculations*

| Segments | Estimate and Method of Valuation | Mission Time |
|---|---|---|
| Transit | Assume 24 hours for international travel back and forth for data analyst | 24 |
| Flight | Assume 0.05 hours for surveying (0.1km$^2$ at 14km$^{2/}$/hr with additional time to capture oblique imagery for three-dimensional model) with 1.0 hour transit to and from the site. | 1.05 hours |
| Processing | Assume data analysis time of 1.0 hour (0.1 km$^{2/}$/hr) for the total area of 0.1 km$^2$ | 1 hours |
| Total | | 26.05 hours |

Table 14.

*Scenario two: eBee RTK time calculations*

| Segments | Estimate and Method of Valuation | Mission Time |
|---|---|---|
| Transit | Assume 24 hours for international travel back and forth for NGO employee | 24 |
| Flight | Assume 0.2 hours for aerial survey (0.1 km$^2$at 0.6 km$^2$/hr) | 0.2 hours |
| Processing | Assume data analysis time of 1.0 hour (0.1 km$^{2/}$/hr) for the total area of 0.1 km$^2$ | 1 hours |
| Total Time | | 25.2 hours |

Table 15.

*Scenario two: DJI Phantom time calculations*

| Mission Segments | Estimate and Method of Valuation | Mission Time (hours) |
|---|---|---|
| Transit | Assume 24 hours for international travel back and forth for NGO employee | 24 |
| Flight | Assume 5 hours for each of the three refugee camp (0.1 $km^2$at 0.2 $km^2$/hr) | 0.5 |
| Processing | Assume data analysis time of 1.0 hour (0.1 $km^{2/}$/hr) for the total area of 0.1 $km^2$ | 1 hours |
| Total Time | | 25.5 hours |

**Operational costs.** Cost breakdowns for each platform were calculated using US market estimates. Each individual cost was then extrapolated to an annual cost. Explanations for how each cost was defined and calculated for the Cessna 172, eBee RTK, and DJI Phantom 3 Pro are shown in Tables 16, 17, and 18.

Table 16.

*Scenario two: Cessna 172 operational expenses*

| Financial Costs | Estimate and Method of Valuation |
|---|---|
| Waldo XCAM-B | Waldo XCAM-B cost of $32,500 spread out over useful life (Annual cost: $7,715.38 at 6% interest) |
| Computer | High-speed $2,000 data analysis computers cost spread out over useful life. (Annual cost: $474.79 at 6%) |
| Aircraft/Pilot Rental | Assume $165/hr rental rate for pilot and aircraft rental for 1.05 per operation, at 5.25 hours per year (Annual cost: $866.25) |
| Transit | Assume $1,000 per operation for round-trip airline tickets for analyst (Annual cost: $5,000) |
| Data Analyst | Assume $35/hr for data analyst at 26.05 per operation, at 130.25 hours per year (Annual cost: $4558.75) |
| Pix4D Training | Assume annual cost of $500 for either recurrent or new Pix4D training |
| Waldo XCAM-B Installation | Assume $200 in to have mechanic install and remove Waldo Air XCAM-B per operation (Annual cost: $1000) |
| Government Approval | Assume $100 for legal fees for acquiring government approval per operation (Annual cost: $500). |
| Storage | Assume $100 annual storage fee of camera system. |
| Resale | Assume 50% resale value for both XCAM-B and computer as resale value spread out over the five year period (Annual cost: -$3,450) |

Table 17.

*Scenario two: eBee RTK Operational Expenses*

| Financial Costs | Estimate and Method of Valuation |
|---|---|
| eBee RTK | Cost of $25,000 for eBee RTK out over useful life (Annual cost: $5,934.91 at 6% interest) |
| Computer | High-speed $2,000 data analysis computer cost spread out over useful life (Annual cost: $406.73 at 6% interest) |
| Insurance | Assume annual liability insurance cost of $2,500 for eBee RTK. |
| Transit | Assume $1,000 per operation for round-trip airline tickets for analyst (Annual cost: $5,000) |
| Employee | Assume $35/hr for NGO employee at 24.1 per operation, at 120.5 hours per year (Annual cost: $4217.50) |
| Pix4D Training | Assume annual cost of $500 for either recurrent or new Pix4D training |
| eBee RTK Training | Assume annual cost of $500 for either recurrent or new eBee RTK training |
| Government Approval | Assume $100 for legal fees for acquiring government approval per operation (Annual cost: $500). |
| Storage | Assume annual storage cost of $100 for eBee RTK. |
| Resale | Assume resale value of 50% for the eBee RTK and computer as spread out over the five year period (Annual cost: -$2,700) |

Table 18.

*Scenario two: DJI Phantom 3 Pro operational expenses*

| Financial Costs | Estimate and Method of Valuation |
|---|---|
| eBee RTK, | Cost of $1,000 for one DJI Phantom 3 Pro spread out over useful life (Annual cost: $237.40 at 6% interest) |
| Computer | High-speed $2,000 data analysis computer cost spread out over useful life (Annual cost: $406.73 at 6% interest) |
| Insurance | Assume annual liability insurance cost of $1,500 DJI Phantom 3 Pro. |
| Transit | Assume $1,000 per operation for round-trip airline tickets for analyst (Annual cost: $5,000) |
| Employee | Assume $35/hr for NGO employee at 25.5 hours per operation, at 127.5 hours per year (Annual cost: $4462.50) |
| Pix4D Training | Assume annual cost of $500 for either recurrent or new Pix4D training |
| Pix4D Mapper Mesh | Annual cost of $499 for Pix4D Mapper Mesh mission planning and data analysis program |
| DJI Phantom 3 Pro Training | Assume annual cost of $500 for either recurrent or new DJI Phantom 3 Pro training |
| Government Approval | Assume $100 for legal fees for acquiring government approval per operation (Annual cost: $500). |
| Storage | Assume annual storage cost of $100 for storing DJI Phantom 3 Pro. |
| Resale | Assume resale value of 50% for each of the DJI Phantom 3 Pros and one computer as spread out over the five year period (Annual cost: -$300) |

**Lifetime costs.** Annual operational costs were considered over a five-year period. Total costs were calculated by adding together all costs; PVC was calculated by using Equation 3, area given is the total area covered in a one year period; CER was calculated by dividing PVC by area; for a sensitivity analysis ,15% of CER, both positive and negative, was calculated. Tables 19, 20, 21 show the lifetime costs of the Cessna 172, eBee RTK, and DJI Phantom 3 Pro, respectively.

Table 19.

*Scenario two: Cessna 172 lifetime expenses*

| Costs | 1 | 2 | 3 | 4 | 5 | Total |
|---|---|---|---|---|---|---|
| XCAM-B | $7,715.38 | $7,715.38 | $7,715.38 | $7,715.38 | $7,715.38 | $38,576.92 |
| Computer | $474.79 | $474.79 | $474.79 | $474.79 | $474.79 | $2,373.96 |
| Transit | $5,000.00 | $5,000.00 | $5,000.00 | $5,000.00 | $5,000.00 | $25,000.00 |
| Aircraft/Pilot | $911.25 | $911.25 | $911.25 | $911.25 | $911.25 | $4,556.25 |
| Data Analyst | $4,558.75 | $4,558.75 | $4,558.75 | $4,558.75 | $4,558.75 | $22,793.75 |
| Pix4D Training | $500.00 | $500.00 | $500.00 | $500.00 | $500.00 | $2,500.00 |
| Mechanic | $1,000.00 | $1,000.00 | $1,000.00 | $1,000.00 | $1,000.00 | $5,000.00 |
| Government | $500.00 | $500.00 | $500.00 | $500.00 | $500.00 | $2,500.00 |
| Storage | $100.00 | $100.00 | $100.00 | $100.00 | $100.00 | $500.00 |
| Resale | -$3,450.00 | -$3,450.00 | -$3,450.00 | -$3,450.00 | -$3,450.00 | -$17,250.00 |
| Total Costs | $17,310.18 | $17,310.18 | $17,310.18 | $17,310.18 | $17,310.18 | $86,550.88 |
| PVC | $17,310.18 | $16,806.00 | $16,316.50 | $15,841.26 | $15,379.87 | $81,653.80 |
| Area ($km^2$) | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 2.5 |
| **CER** | | | | | | **32661.52** |
| Worst Case (+15%) | | | | | | 37560.75 |
| Best Case (-15%) | | | | | | 27762.29 |

Table 20.

*Scenario two: eBee RTK lifetime expenses*

| Costs | 1 | 2 | 3 | 4 | 5 | Total |
|---|---|---|---|---|---|---|
| eBee RTK | $5,934.91 | $5,934.91 | $5,934.91 | $5,934.91 | $5,934.91 | $29,674.55 |
| Computer | $474.79 | $474.79 | $474.79 | $474.79 | $474.79 | $2,373.96 |
| Insurance | $2,500.00 | $2,500.00 | $2,500.00 | $2,500.00 | $2,500.00 | $12,500.00 |
| Transit | $5,000.00 | $5,000.00 | $5,000.00 | $5,000.00 | $5,000.00 | $25,000.00 |
| Employee | $4,217.50 | $4,217.50 | $4,217.50 | $4,217.50 | $4,217.50 | $21,087.50 |
| Pix4D Training | $500.00 | $500.00 | $500.00 | $500.00 | $500.00 | $2,500.00 |
| eBee RTK Training | $500.00 | $500.00 | $500.00 | $500.00 | $500.00 | $2,500.00 |
| Government | $100.00 | $100.00 | $100.00 | $100.00 | $100.00 | $500.00 |
| Storage | $100.00 | $100.00 | $100.00 | $100.00 | $100.00 | $500.00 |
| Resale | -$2,700.00 | -$2,700.00 | -$2,700.00 | -$2,700.00 | -$2,700.00 | -$13,500.00 |
| Total Costs | $16,627.20 | $16,627.20 | $16,627.20 | $16,627.20 | $16,627.20 | $83,136.01 |
| PVC | $16,627.20 | $16,142.92 | $15,672.73 | $15,216.25 | $14,773.05 | $78,432.15 |
| Area ($km^2$) | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 2.5 |
| **CER** | | | | | | **31372.86** |
| Worst Case (+15%) | | | | | | 36078.79 |
| Best Case (-15%) | | | | | | 26666.93 |

Table 21.

*Scenario two: DJI Phantom 3 Pro lifetime expenses*

| Costs | 1 | 2 | 3 | 4 | 5 | Total |
|---|---|---|---|---|---|---|
| DJI Phantom 3 Pro | $237.40 | $237.40 | $237.40 | $237.40 | $237.40 | $1,186.98 |
| Computer | $474.79 | $474.79 | $474.79 | $474.79 | $474.79 | $2,373.96 |
| Insurance | $1,500.00 | $1,500.00 | $1,500.00 | $1,500.00 | $1,500.00 | $7,500.00 |
| Travel | $5,000.00 | $5,000.00 | $5,000.00 | $5,000.00 | $5,000.00 | $25,000.00 |
| Employee | $4,462.50 | $4,462.50 | $4,462.50 | $4,462.50 | $4,462.50 | $22,312.50 |
| Pix4D Training | $1,500.00 | $1,500.00 | $1,500.00 | $1,500.00 | $1,500.00 | $7,500.00 |
| DJI Training | $1,500.00 | $1,500.00 | $1,500.00 | $1,500.00 | $1,500.00 | $7,500.00 |
| Government | $100.00 | $100.00 | $100.00 | $100.00 | $100.00 | $500.00 |
| Storage | $300.00 | $300.00 | $300.00 | $300.00 | $300.00 | $1,500.00 |
| Resale | -$500.00 | -$500.00 | -$500.00 | -$500.00 | -$500.00 | -$2,500.00 |
| Total Costs | $14,574.69 | $14,574.69 | $14,574.69 | $14,574.69 | $14,574.69 | $72,873.45 |
| PVC | $14,574.69 | $14,150.18 | $13,738.04 | $13,337.91 | $12,949.42 | $68,750.24 |
| Area ($km^2$) | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 2.5 |
| **CER** | | | | | | **27500.10** |
| Worst Case (+15%) | | | | | | 23375.08 |
| Best Case (-15%) | | | | | | 31625.11 |

*Scenario two: Analysis and recommendation.* The CER and mission time calculation from these nine tables are synthesized in Figure 2.

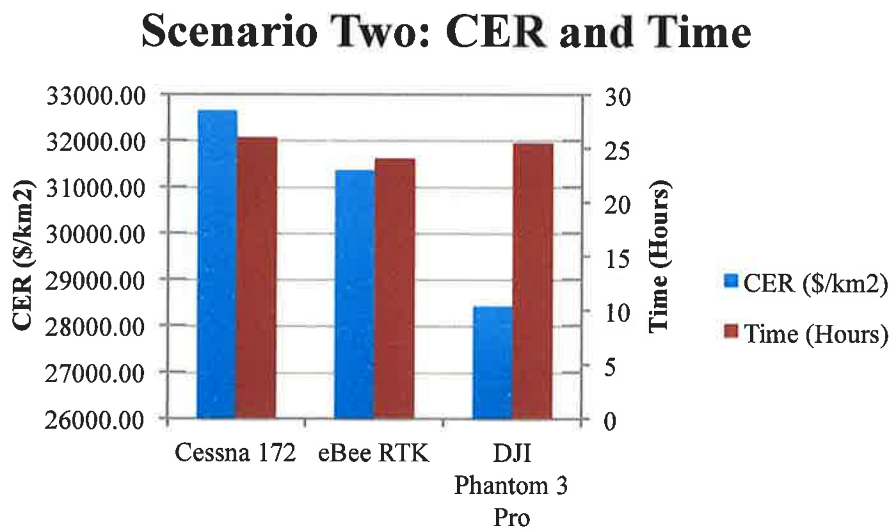


*Figure 21.* Scenario two: CER and time

The Cessna 172 is the least cost-effective and slowest option available. The eBee RTK option provides the fastest alternative, though not by much. The DJI Phantom 3 Pro alternative provides the most cost-effective option by a significant factor, and is not significantly slower than the eBee RTK. This is because of the lower overhead required to operate a DJI Phantom 3 Pro. The DJI Phantom 3 Pro also provides greater maneuverability in an urban setting.

## Conclusion

Effectiveness is a key concern for NGOs in the international humanitarian sector. Lives often hinge on the operational effectiveness of aid delivery. As a developing technological field, UAS offer another useful tool for humanitarian NGOs. It is not without its limitations. This project examined only one possible application for UAS in the humanitarian sector: post-disaster needs assessments. Even within this application, UAS is best suited for small-scale, high-resolution projects. However, this project did seek to show that NGOs could increase effectiveness with readily available UAS. As UAS continue to develop, their relative effectiveness will only continue to increase.

**References**


ArduPilot. (2016). *Mission planner overview*. Retrieved March 5, 2016, from http://ardupilot.org/planner/docs/mission-planner-overview.html

Baker, S. (1989, Summer). San Francisco in ruins. *Landscape Magazine , 30 (2)* .

Ball, M. (2014, June 11). *senseFly announces eBee RTK Survey-grade mapping drone*. Retrieved March 10, 2016, from Informed Infrastructure: https://informedinfrastructure.com/9061/sensefly-announces-ebee-rtk-survey-grade-mapping-drone/

Barnhart, R. K., Hottman, S. B., Marshall, D. M., & Shappee, E. (2012). *Introduction to unmanned aircraft systems.* Bacon Raton, FL, USA: CRC Press.

Bureau of Democracy Human Rights and Labor. (2016, January 16). *Fact sheet: Non-governmental organizations (NGOs) in the United States*. Retrieved March 1, 2016, from http://www.humanrights.gov/dyn/2016/01/fact-sheet-non-governmental-organizations-ngos-in-the-united-states/

Canon. (n.d.). *Canon S110*. Retrieved March 10, 2016, from https://www.usa.canon.com/internet/portal/us/home/products/details/cameras/point-and-shoot/advanced-cameras/powershot-s110

CartONG, EC Humanitarian Aid and Civil Protection Departmen, Swiss Foundation for Mine Action, UAViators, & Zoi Environment Network. (2015). *Survey: The perception and use of drones (UAVs) in humanitarian activities.*

Cessna Aircraft Company. (n.d.). *Cessna 172 Skyhawk*. Retrieved March 12, 2016, from http://cessna.txtav.com/en/single-engine/skyhawk

Cloud Cap Technology. (n.d.). *Picollo autopilots*. Retrieved 15 2016, March, from http://www.cloudcaptech.com/products/auto-pilots

Cole, A. (2011). WFP aviation: Meeting the air transport needs of the humanitarian community. *ICAO Journal , 66* (6).

Corbane, C., Lemoine, G., Louvrier, C., & Kauffman, M. (2013). Intercomparison and validation of building damage assessments based on post-Haiti 2010 earthquake imagery using multi-source reference data. *Natural Hazards Earth System Sciences Discussions , 1*, 1445-1486.

Davies, T. (2014). *NGOS: A new history of transnational civil society.* New York, NY, USA: Oxford University Press, Inc.

DJI. (n.d.). *Phantom 3 Professional*. Retrieved March 10, 2016, from http://www.dji.com/product/phantom-3-pro

Dohetry, P., & Rudol, P. (2008). Human body detection and geolocalization for UAV search and rescue missions using color and thermal imagery. *Aerospace Conference* (pp. 1-8). Big Sky, MT: IEEE.

DroneApps. (2016, March 9). *Price wars: counting the cost of drones, planes and satellites*. Retrieved from https://droneapps.co/price-wars-the-cost-of-drones-planes-and-satellites/

European Commision Humanitarian Aid and Civil Protection Department. (2015). *Nepal earthquakes, April and May 2015 ECHO Fact Sheet.* Brussels.

Farnham, P. G., & Guess, G. M. (2000). *Case in public policy analysis.* Washington, DC, USA: Georgetwon University Press.

Federal Aviation Administration. (n.d.). *Unmanned Aircraft Systems (UAS) Frequently Asked Questions*. Retrieved March 7, 2016, from https://www.faa.gov/uas/faq

FLIR. (n.d.). *FLIE Vue*. Retrieved March 15, 2016, from http://www.flir.com/suas/content/?id=68335

Geosense. (n.d.). *Hi-Res city modeling with small manned aircraft*. Retrieved March 10, 2016, from Geosense.gr: http://geosense.gr/assets/pdf/Pix4D/Showcase_3D%20City%20Modeling_US.pdf

Gilman, D. (2014). *Unmanned aerial vehicles in humanitarian response.* Policy Paper, United Nations Office for the Coordination of Humanitarian Affairs.

Global Humanitarian Assistance. (2015). *Global humantiarian assistance report.* Bristol, UK: Development Initiatives.

Good Humanitarian Donorship. (2003). *23 Principles and Good Practice of Humanitarian Donorship*. Retrieved March 3, 2016, from ghdinitiative.org: http://www.ghdinitiative.org/ghd/gns/principles-good-practice-of-ghd/principles-good-practice-ghd.html

Goyer, R. (2012, January 19). *Cessna 172: Still relevant.* Retrieved March 10, 2016, from Flying Magazine: http://www.flyingmag.com/aircraft/pistons/cessna-172-still-relevant

Hodge, N. (2011, March 17). *U.S. drone surveying Japan's damaged nuclear complex.* Retrieved February 15, 2015, from The Wall Street Journal: http://www.wsj.com/articles/SB10001424052748703818204576206531927079212

Hofmann, C.-A., Roberts, L., Shoham, J., & Harvey, P. (2004). *Measuring the impact of humanitarian aid.* Humanitarian Policy Group. London: Overseas Development Institute.

Hunt, R. E., Hively, D. W., Fujikawa, S. J., Linden, D. S., Daughtry, C. S., & Mccarty, G. W. (2010). Acquisition of NIR-green-blue digital photographs from unmanned aircraft for crop monitoring. *Remote Sensing , 2* (1), 290-305.

International Civil Aviation Organization. (2011). Circular 328: unmanned aircraft systems (UAS). Montreal, Quebec, Canada.

International Committee of the Red Cross and International Federation of Red Cross and Red Crescent Societies. (2008, March). *Guidelines for assessment in emergencies.* Retrieved March 5, 2016, from ifrc.org: http://www.ifrc.org/Global/Publications/disasters/guidelines/guidelines-for-emergency-en.pdf

International Committee of the Red Cross and International Federation of Red Cross and Red Crescent Societies. (2008). *Guidelines for assessment in emergencies.* Retrieved March 17, 2016, from http://www.ifrc.org/Global/Publications/disasters/guidelines/guidelines-for-emergency-en.pdf

ITRES Research Limited. (2012, June 27). *ITRES begins second season of wildfire hotspot mapping using TABI-1800.* Retrieved March 10, 2016, from http://www.itres.com/itres-begins-second-season-of-wildfire-hotspot-mapping-using-tabi-1800-2/

Jachmann, H. (1991). Evaluation of four survey methods for estimating elephant densities . *African Journal of Ecology , 29* (3), 188-195.

Jones, G. P., Pearlstine, L. G., & Percival, F. H. (2006). An assessment of small unmanned aerial vehicles for wildlife research. *Wildlife Society Bulletin , 34* (3), 750-758.

Kakaes, K., Greenwood, F., Lipincott, M., Dosemagen, S., Meier, P., & Wich, S. (2015). *Drones and aerial observation: New technologies for property rights, human rights, and global development. A primer.* New America.

Kim, K., & Davidson, J. (2014). *Using unmanned aircraft for disaster management.*

Klaptocz, A. (2014, May). *Mapping the Philippines after Typhoon Haiyan.* Retrieved March 10, 2016, from Drone Adventures: http://blog.droneadventures.org/post/85863359885/mapping-the-philippines-after-typhoon-haiyan

Lewis, S. (2009, November 11). *Remote sensing for natural disasters: Facts and figures.* Retrieved March 9, 2016, from SciDev.Net: http://www.scidev.net/global/earth-science/feature/remote-sensing-for-natural-disasters-facts-and-figures.html

Lin, A. Y.-M., Novo, A., Har-Noy, S., Ricklin, N. D., & Stamatiou, K. (2011). Combining GeoEye-1 satellite remote sensing, UAV aerial imaging, and geophysical surveys in anomaly detection applied to archaeology. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing , 4* (4), 870-876.

Lockhead Martin. (n.d.). *Kestrel flight systems & autopilot*. Retrieved March 15, 2016, from http://www.lockheedmartin.com/us/products/procerus/kestrel-autopilot.html

Maps Made Easy. (n.d.). *Point Estimator*. Retrieved March 10, 2016, from https://www.mapsmadeeasy.com/flight_planner

Meier, P. (2014a, June 25). *Humanitarians in the sky: Using UAVs for disaster response.* Retrieved March 10, 2016, from iRevolutions: http://irevolutions.org/2014/06/25/humanitarians-in-the-sky/

Meier, P. (2014b, September 25). *Humanitarian UAVs in the Solomon Islands*. Retrieved March 10, 2016, from iRevolutions: http://irevolutions.org/2014/09/25/humanitarian-uavs-in-the-solomon-islands/

Meier, P. (2015a, November 4). *Aerial robotics in the land of the Buddha.* Retrieved March 10, 2016, from National Geographic: http://voices.nationalgeographic.com/2015/11/04/aerial-robotics-land-of-buddha/

Meier, P. (2015b, November 4). *Video: Crisis mapping nepal with aerial robotics.* Retrieved March 10, 2016, from iRevolutions: http://irevolutions.org/2015/11/04/crisis-mapping-nepal-aerial-robotics/

Meier, P. (2016). *UAViators: Introduction.* Retrieved March 22, 2016, from UAViators: http://uaviators.org/introduction

MicroPilot. (n.d.). *Integrated autopilots*. Retrieved March 15, 2016, from https://www.micropilot.com/products-mp2128lrc.htm

Millar, R., & Hall, K. (2013). Social return on investment (SROI) and performance measurement. *15* (6), 923-941.

Morgan, D. (2015, May 1). *FAA considers beyond-line-of-sight operations.* Retrieved March 5, 2016, from http://www.reuters.com/article/us-usa-drones-faa-idUSKBN0NM4HE20150501

National Oceanic and Atmospheric Administration. (n.d.). *What is remote sensing?* Retrieved March 9, 2016, from http://oceanservice.noaa.gov/facts/remotesensing.html

Nerenberg, J. (2010, December 29). *Satellites for good: The NGO's ultimate tool.* Retrieved March 21, 2016, from http://www.fastcompany.com/1713015/satellites-good-ngos-ultimate-tool

Newcomer, K. E., Hatry, H. P., & Wholey, J. S. (2015). *Handbook of practical program evaluation* (4 ed.). Hoboken, NJ, USA: John Whiley & Sons Inc.

Nicholls, J., Lawlor, E., Neitzert, E., & Goodspeed, T. (2012). *A guide to social return on investment.* UK Cabinent Office of the Third Sector.

Northrop Grumman. (2008). *RQ-4 Global Hawk fact sheet.* Retrieved from http://www.northropgrumman.com/capabilities/rq4block20globalhawk/documents/hale_factsheet.pdf

Pix4D. (n.d.). *How to estimate processing time?* Retrieved March 27, 2016, from https://support.pix4d.com/hc/en-us/articles/202558819-How-to-estimate-Processing-Time-#gsc.tab=0

Pratt, K., Murphy, R., Stover, S., & Griffin, C. (2009). CONOPS and autonomy recommendations for VTOL small unmanned aerial system based on Hurricane Katrina operations. *Journal of field robotics , 26* (8), 636-650.

Raptopoulos, A. (2013, June). No roads? There's a drone for that. *TEDGlobal* .

Rutledge, K., McDaniel, M., Boudreau, D., Ramroop, T., Teng, S., Costa, H., et al. (2011, March 26). *GIS (geographic information system)*. (National Geographic) Retrieved March 8, 2016, from http://education.nationalgeographic.org/encyclopedia/geographic-information-system-gis/

senseFly. (n.d.). *eBee*. Retrieved March 12, 2016, from https://www.sensefly.com/drones/ebee.html

Straub, J. (2014). Unmanned aerial systems: Consideration of the use of force for law enforcement applications. *Technology in Society* , *39*, 100-109.

Swiss Foundation for Mine Action. (2016, March). *Rapid damage assessments of Tabarre and surrounding communities in Haiti following Hurricane Sandy* . Retrieved March 25, 2016, from http://drones.fsd.ch/wp-content/uploads/2016/03/Case-Study-Haiti-Final2-1617046.pdf

Swiss Foundation for Mine Action. (2016, March). *Small-scale mapping with consumer drones in Nepal* . Retrieved March 25, 2016, from http://drones.fsd.ch/wp-content/uploads/2016/03/Case-Study-Nepal-Final.pdf

Swiss Foundation for Mine Action. (2016, March). *Testing the utility of mapping drones for early recovery in the Philippines.* Retrieved March 25, 2016, from http://drones.fsd.ch/wp-content/uploads/2016/03/Case-Study-Philippine-Final.pdf

Tilton, J. S. (1986). *Tip leakage flow in a linear turbine cascade.* MS Thesis, Virginia Polytechnic Institute and State University.

United Nations. (1945, October 24). *Chapter X: UN charter.* Retrieved March 8, 2016, from http://www.un.org/en/sections/un-charter/chapter-x/

United Nations Institute for Training and Research Operational Satellite Applications Programme. (2013, February). *10 years on, UNOSAT humanitarian rapid mapping is a leading standard.* Retrieved March 21, 2016, from http://www.unitar.org/unosat-latest-reports-show-state-art-satellite-analysis

United Nations Institute for Training and Research. (2012, February 17). *UNOSAT carries out first UAV mission for IOM in Haiti*. Retrieved March 7, 2016, from unitar.org: https://www.unitar.org/unosat-carries-out-first-uav-mission-iom-haiti

United Nations Inter-Agency Standing Committee. (2012, March). *Multi-cluster/sector initial rapid assessment.* Retrieved March 17, 2016, from https://docs.unocha.org/sites/dms/Documents/mira_final_version2012.pdf

United Nations Office for the Coordination of Humanitarian Affairs. (2015). *Nepal earthquake humanitarian response April to September*.

United States Geological Survey. (2016, February 24). *USGS FAQ*. Retrieved March 16, 2016, from http://www.usgs.gov/faq/node/3545

United States Institude of Peace. (2011). *Glossary of terms for conflict management and peacebuilding.* Retrieved March 1, 2016, from http://glossary.usip.org/resource/nongovernmental-organization-ngo

Vakil, A. C. (1997). Confronting the classification problem: Toward a taxonomy of NGOs. *World Development , 25* (12), 2057-2070.

Waldo Air. (n.d.). Retrieved March 10, 2016, from http://www.waldoair.com/

Williams, D. (2007, March 17). *Cessna 172 G-BSEP*. Retrieved March 20, 2016, from http://www.dmjwilliams.co.uk/gbsep.htm

World Bank. (2015, March). *Post-disaster needs assessments: Volume A guidelines.* Retrieved March 17, 2016, from http://www.undp.org/content/dam/undp/library/Environment%20and%20Energy/Climate%20Strategies/PDNA%20Volume%20A%20FINAL%2012th%20Review_March%202015.pdf

Xu, Z., Yang, J., Peng, C., Wu, Y., Jiang, X., Li, R., et al. (2014). Development of an UAS for post-earthquake disaster surveying and its application in Ms7.0 Lushan earthquake, Sichuan, China. *Computers & Geosciences , 68*, 22-40.