UNMANNED AERIAL SYSTEMS FOR SURVEYING AND MAPPING: COST COMPARISON OF UAS VERSUS TRADITIONAL METHODS OF DATA ACQUISITION

by

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DEDICATION

I dedicate this document to First Lieutenant Amos "Camden" R. Bock, U.S. Army. As fellow GIS undergraduate students at West Point, Amos sacrificed many hours to help me with several projects over the course of our studies. He was always there when I needed help, never asking for any in return. As with our undergraduate studies, any success in graduate level academia I've achieved would be viewed as utter mediocrity compared to what his performance would've been, had he been given the chance to continue his education.

Sadly, Amos gave the last full measure of devotion to his country on October 23rd, 2006, when he was killed in action in Baghdad, Iraq. He will be missed by more people than he ever imagined, and will never realize the impact he had on the lives of others.

Well Done, Amos. Be thou at peace.

ACKNOWLEDGMENTS

I am indebted to my fellow Geographic Information Science and Technology (GIST) students and instructors who’ve been there to help me along the way. Most importantly, thank you to my wife and children for being a constant motivation for continued self-improvement.

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LIST OF ABBREVIATIONS

AUVSI	Association for Unmanned Vehicle Systems International
COA	Certificate of Waiver or Authorization
FAA	Federal Aviation Administration
FRMA	FAA Reform and Modernization Act of 2012
GPS	Global Positioning System
GIST	Geographic Information Science and Technology
LiDAR	Light Detection and Ranging
RPLS	Registered Professional Land Surveyor
SSI	Spatial Sciences Institute
TFR	Temporary Flight Restriction
UAS	Unmanned Aerial System
USC	University of Southern California

ABSTRACT

Commercial, government and private use of Unmanned Aerial Systems (UAS) are rapidly expanding in the United States. Although commercial use of UAS is still limited to a case by case basis, the Federal Aviation Administration began allowing companies to petition for use of UAS for commercial purposes. As of October 30th, 2015, 2020 exemptions have been granted to companies in various industries. Those companies approved to use UAS for surveying see a need for the technology, but must also weigh the capabilities and limitations of UAS to acquire and process survey data against those of more traditional methods. This study sought to answer the question of whether or not using UAS for topographic mapping and volumetric surveying can lower the cost and time to complete the same task using land surveying and manned aircraft systems while still achieving acceptable accurate results. This study compares the use of UAS within the surveying and mapping industry with traditional and accepted methods and provides a comparison of their use. Specifically, this thesis reports on tests comparing UAS data acquisition and processing for volumetric calculation and topographic mapping. Time, accuracy, and cost were compared between UAS and traditional survey methods. The results of this study showed that using UAS for topographic mapping and calculating volumes is more time and cost efficient than land surveying, with no loss in accuracy, but only when performed over bare earth terrain. The results also showed UAS to be more time and cost effective than using terrestrial Light Detection and Ranging (LiDAR), but with less accurate results. The author is currently employed as the Flight Operations Manager for a large surveying and mapping firm, and the position involves the day-to-day remote acquisition of survey data through the use of aerial LiDAR and aerial photography, as well as the establishment of a UAS department within the

company. In addition, flight of all kinds, both manned and unmanned, has been a passion of the author since becoming an aviator in the United States Army in 2004.

CHAPTER 1: INTRODUCTION

1.1 Unmanned Aerial Systems in Land Surveying

In the profession of Land Surveying, new technologies, such as the Total Station (Moffit and Bouchard, 41), Light Detection and Ranging (LiDAR) devices (Campbell and Wynne, 243), and Global Positioning Systems (GPS) (Campbell and Wynne, 393), are appropriately met with some level of skepticism. When first introduced, accuracy and precision are often compared to previously used and accepted technologies and practices to determine their scientific validity. Likewise, the introduction of Unmanned Aerial Systems (UAS) has undergone serious scrutiny regarding precision, accuracy, and therefore validity in surveying by surveyors and their clients alike. This skepticism is often countered by the claims of versatility and capability of UAS by their manufacturers and proponents. Nevertheless, studies are emerging that show that UAS is a viable alternative to traditional more costly surveying methods. For example, a recent study by McKim and Creed (2016) tested UAS to conduct UAS landfill surveys, and found that the data could be collected quickly, results were accurate to about 5cm, with less accuracy in vegetated areas.

The purpose of this study is to compare using UAS for surveying against traditionally accepted methods, so see if advantages exist in cost, time, and accuracy. One advantage of UAS that is universally acknowledged is the level of safety it can bring to the hazardous profession of aerial data acquisition. From 2003 to 2013, the Occupational Safety and Health Administration (OSHA) recorded 258 fatalities in the electric utility industry alone[1], many of which involved visual inspections of electrical towers that could have been accomplished utilizing UAS. In 2014, there were five fatalities from accidents in manned rotorcraft, conducting similar visual inspection work.

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[1] "Data and Statistics", accessed October 2015, www.osha.gov

Establishing the ability of new surveying technology to provide accurate and precise data is just the first step in UAS technology's widespread use. The high cost of systems such as LiDAR must be offset by the benefit of time and money saved from their utilization. UAS is no different in this respect.

At the most recent Association for Unmanned Vehicle Systems International (AUVSI) conference in April 2015, there were more than 600 companies in attendance[2], and hundreds of UAS were on display. These systems ranged in price from the consumer grade level (less than $10,000) to the professional and military grade levels of seven figures.

1.2 Research Statement

Acquiring survey grade data, either remotely through aerial LiDAR, or through traditional methods of land surveying, is a time consuming and financially burdensome endeavor. Utilizing UAS for data acquisition has three unique advantages: low initial investment cost, low mobilization cost, and decreased time required to complete acquisition. This study provides a comparison of using UAS to acquire land surface survey data. The scope of this study is limited to using UAS under $10,000 and to two common tasks of surveying; topographic mapping and volumetric calculation. In the context of this study, volumetric calculation is defined as obtaining the fill between two surfaces, determining the average of the two areas, and multiplying the average by the vertical separation or the contour interval (Moffitt and Bouchard, 701). If the topographic lines generated using UAS are within 0.2 feet in all three axes compared to those generated using traditional survey methods, then the accuracy of the UAS method is considered to be as good as tradition survey methods. The *Manual of Practice for Land Surveying in the State of Texas* states that contour accuracy must be plus or minus one-half of the contour interval. For one-foot contour mapping, this would mean that the lines

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[2] "Unmanned Systems 2015", last accessed May 2015, www.auvsi.org

generated from both methods would need to be within 0.5 feet of each other[3]. However, the use of UAS also falls under the discipline of photogrammetry, accuracy standards of which are governed by the American Society for Photogrammetry and Remote Sensing (ASPRS). Their standards manual states that vertical accuracy for surveying using photogrammetry must meet a 95% confidence level. Statistically, in non-vegetated terrain when elevation errors follow a normal distribution, 68.27% of errors are within one standard deviation of the mean error, (ASPRS, page A6), and 88.27% of 0.5 feet is 0.34 feet. To ensure "good" data, the industry generally rounds this down to 0.2 feet. Additionally, the accepted industry standards, such as the use of GPS, might also have an error, and choosing a standard of 0.2 feet will also help ensure that all data meets the 0.5 feet accuracy standard for topographic mapping. Topographic mapping is commonly known as the process of determining the positions, on the earth's surface, of the natural and man-made features of a given locality and determining the configuration of the terrain (Moffitt and Bouchard, 615).] For volumetric calculations, two-foot contour mapping is often used. According to the TSPS standard of accuracy, this would mean that the measurements would need to be plus or minus one foot. Dirt volumes in the construction industry are measured in cubic yards. One cubic foot is just over 3% of a cubic yard. Thus, for a volumetric calculation, the UAS data must be within 3% of the calculation derived from traditional methods.

Four study areas for this thesis work were selected throughout the state of Texas, shown in Figure 1, in order to compare results from locations with different terrain. Locations were chosen which met Federal Aviation Administration (FAA) requirements for distance from airports as well as vegetation coverage and battery life per flight for the UAS's tested. For example, a recent study by McKim and Creed (2016) showed that UAS technology is not efficient in highly vegetated areas.

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[3] "TSPS Manual of Practice for Land Surveying in Texas", 2006 Revised Eleventh Edition, page101.

Figure 1: Test Areas (airplane symbols) in Texas.

In order compare the use of UAS to traditional land surveying methods the following hypotheses were tested in this study:

- Alternative Hypothesis 1: Using UAS for topographic mapping will take less time than traditional surveying methods.
- Null Hypothesis 1: Using UAS for topographic mapping will take more time than with traditional surveying methods.
- Alternative Hypothesis 2: Using UAS for volumetric calculation will take less time than with traditional surveying methods.

- Null Hypothesis 2: Using UAS for volumetric calculation will take more time than with traditional survey methods.
- Alternative Hypothesis 3: Using UAS for topographic mapping will cost less money than with traditional survey methods.
- Null Hypothesis 3: Using UAS for topographic mapping will cost more money than with traditional survey methods.
- Alternative Hypothesis 4: Topographic lines generated using UAS will be within 0.2 feet, in all three axes of those generated using traditional survey methods.
- Null Hypothesis 4: Topographic lines generated using UAS will not be within 0.2 feet, in all three axes of those generated using traditional survey methods.
- Alternative Hypothesis 5: UAS and traditional survey methods for volumetric calculations will produce volumes that differ by 3% or less.
- Null Hypothesis 5: UAS and traditional survey methods for volumetric calculations will produce volumes that differ by more than 3%.
- Alternative Hypothesis 6: Using UAS for volumetric calculations will cost less than using traditional survey methods.
- Null Hypothesis 6: Using UAS for volumetric calculations will cost the same or more than using traditional survey methods.

Another goal of this work is to advance the application of UAS in the profession of surveying. Additionally, this thesis will allow for dissemination of lessons learned regarding best practices for their implementation to the surveying community.

The base of knowledge for this study was achieved through attending industry conferences, and by exploring the following topics: UAS regulations in the United States, UAS technology, automated photogrammetric technology, project management, and standard survey practices.

1.3 Thesis Organization

Chapter 2 provides detailed background on the systems and methods used during the testing portion of this study. Technical descriptions of the UAS used, the LiDAR sensor used, and the GPS and other equipment used during land surveying are presented. Chapter 3 describes the testing methodology, is divided into subchapters covering volumetric calculation and topographic mapping. Chapter 4 then describes the results of this study in detail. Likewise divided into two subchapters, Chapter 4 compares the data acquired through all methods, the relative accuracy, costs, and the time involved associated with each method of acquisition. Lastly, Chapter 5 includes a discussion of the outcomes of this thesis work and recommendations for future investigations. Two sections describe the limitations of UAS discovered in this study, and the final conclusions provide suggestions for the best path forward using UAS based on the results of the study.

CHAPTER 2: SYSTEMS USED IN TESTING

This chapter describes the aircraft, sensors, software, LiDAR, Photogrammetry, GPS, and survey tools used in the testing conducted in the study. Different testing systems were used for volumetric calculation and topographic mapping. A rotary wing system and a fixed wing system were used in order to study the physical limitations and capabilities associated with these types of aircraft. The UAS used for volumetric calculation was the 3DRobotics Iris, and the UAS used for topographic mapping was the 3DRobotics Aero-M, shown in Figure 2.

Figure 2: Aircraft Used in the Study: Aero-M (Top), Iris+

2.1 Traditional Survey Methods and Systems

2.1.1 Topographic Mapping and Volume Calculation by Cross Section

Cross sections created through manual surveying in the field are one of several traditional survey methods used in this study. A cross section is a profile of the earth taken at right angles to the centerline of an area to be surveyed (Harbin, 2001). Cross sections are established by noting latitude, longitude, and elevation of a series of points along a line perpendicular to the survey area. In modern surveying, those latitudes, longitudes, and elevations are established using Global Positioning Systems (GPS). Cross sections are shot (measured) at regular intervals so as to cover the entire survey area. The size of the interval between cross sections differs depending on the goal of the particular project and is dependent on the ground measurement accuracy required. Topographic lines are then drawn by interpolation based on common points of elevation within the survey area. Volumes are calculated by comparing two sets of topographic lines, or by comparing the difference in elevations at the top and bottom of an enclosed area, such as a ditch or dirt pile.

One of the study areas chosen for this thesis work was a small drainage ditch in Fate, Texas, discussed in detail in this thesis. This ditch was chosen because it was devoid of vegetation, was in an area that met all regulatory requirements for UAS, is representative of all four study locations investigated in this thesis work, and because it was representative of a majority of volumetric calculations conducted within the survey industry.

2.1.2 Topographic Mapping by Terrestrial LiDAR

Topographic mapping by terrestrial LiDAR is well documented and recognized as a highly accurate method for conducting ground surveys (Campbell and Wynne, 2011). A LiDAR is a device that emits up to 300,000 pulses each second, depending on the design of the device. These laser pulses reflect off the objects they encounter then return to the LiDAR device. Through a series of calculations, provided in detail in Campbell and Wynne (2011), involving time of laser return, the angle the laser, and the strength of the return signal, the LiDAR device assigns a latitude, longitude, and height value to each return point. The use of LiDAR generates a much larger amount of data than using the cross-sectional method and provides a very accurate, detailed representation of terrain, and direct measurement of surface elevation. It's use in the context of this study is showed how the point cloud generated from LiDAR compared to that derived from photogrammetry using UAS. Data was acquired from both systems using the same control points for georeferencing the data.

2.1.3 Topographic Mapping by Photogrammetry

As defined by the American Society of Photogrammetry, photogrammetry is "the art, science, and technology of obtaining reliable information about physical objects and the environment through processes of recording, measuring and interpreting photographic images and patterns of recorded radiant electromagnetic energy and other phenomena" (Wolf, 1983). Although photogrammetry with manned aircraft was not performed as part of this study, the UAS data was compared to a manned aircraft flight that occurred prior to UAS testing in the same test area, and thus comparable data was acquired.

2.1.3.1 Traditional Photogrammetry with Manned Aircraft

Elevations and topographic lines are traditionally determined from measurements in parallax difference between photographs (Wolfe, 1983). This is done only after an orthomosaic, or a set of individual images put together in a correct geographic coordinate system, is created.

2.1.3.2 Automated Photogrammetry using UAS

Modern software, such as Pix4D and Agisoft, use a different approach to creating orthomosaics and generating topographic lines. When images are loaded into automated photogrammetric software, each image is divided into a set of pixels. The software then determines pixels from each photograph that match each other and creates automated tie points, generating an orthomosaic. This orthomosaic is based on the GPS position of the camera taking each photograph. Automated aerial triangulation and parallax measurements are calculated to generate an elevation for each point. To draw accurate topographic lines, ground control points must be used. Ground control points are set down within view of the planned coverage area, and each 3D location is measured using a GPS (Figure 3). The longitude, latitude, and elevation value for each ground control point are then manually assigned using the software to the corresponding pixel where the GPS shot was taken. The software can then assign the remaining pixels in the orthomosaic a 3D location based on their relative location to a known point. The results can include thousands of 3D D\data points, similar to LiDAR (Figure 4).

Figure 3: Example of Ground Control Points Viewed from a UAS, October 13th, 2015, Houston Texas

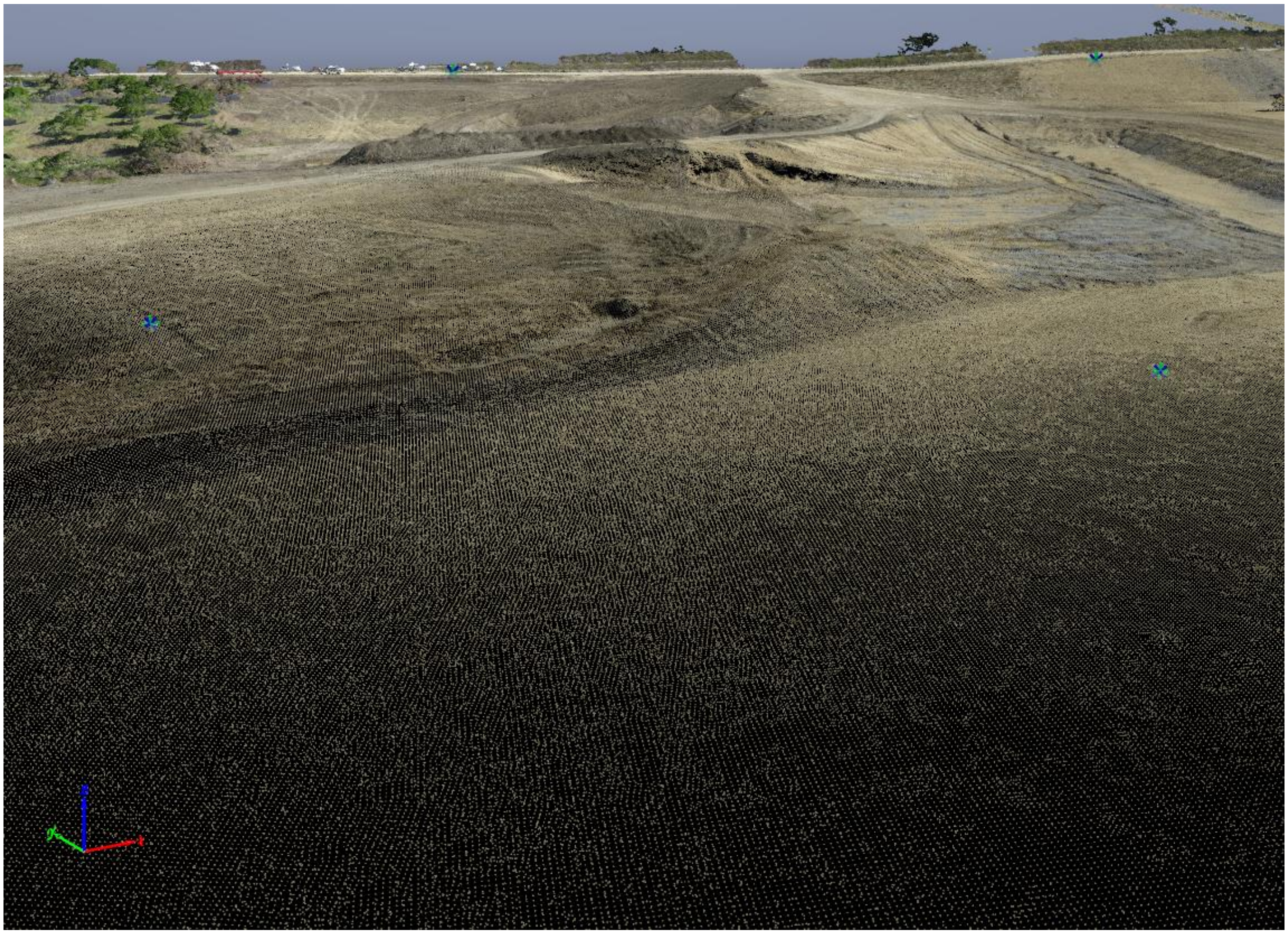

Figure 4: 3D Point Cloud from UAS Flight, August 2015, Austin Texas

2.2 Testing Systems

2.2.1 Volumetric Calculation Testing Systems

One traditional land survey test was conducted to compare the results with volumetric calculations obtained using UAS. The traditional test was conducted on the 25th of February 2015. The total area surveyed was approximately 8 acres. The land surveyor utilized a Trimble R10 Rover GPS to record 50-foot cross sections in the study area, as shown in Figure 5[4]. The R10 was linked to a virtual reference station run by the Texas Department of Transportation.

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[4] http://www.trimble.com/Survey/TrimbleR10.aspx

The GPS data was processed using AutoCAD Civil 3D 2012. The same software was used to calculate the volume of the canal.

The UAS used was the Iris, manufactured by 3DRobotics (footnote for the iris & 3D Robotics URL). The Iris is a remotely piloted, four bladed small UAS. The sensor used with the Iris was the Sony SteadyShot, an 11.9-megapixel camera with a 120-degree fisheye lens (footnote for SteadyShot URL). The sensor was mounted to the front of the aircraft, with the lens pointed downward toward the ground. The camera was not stabilized on a gimbal, but rather hard mounted to the aircraft using after-market hardware. The flight was planned using Mission Planner software, version 1.3.28. The images taken from the sensor mounted on the aircraft and the top of slope points taken from the ground survey were processed using Pix4D photogrammetric software, and the same software was used to calculate the volume of the ditch, previously defined above. Both Mission Planner and Pix4D are open source software, free software, and the total cost of the UAS and sensor was $950 USD.

2.2.3 Topographic Mapping Testing Systems

Three tests were conducted to compare different methods of Topographic Mapping. The first test conducted on the 23rd of July 2015 compared the point cloud generated by the UAS to that of a terrestrial LiDAR scanner. Ground control points were set using the Trimble R10 Rover GPS, linked to a virtual reference station run by the Texas Department of Transportation. The LiDAR data was collected using a Leica C10 Terrestrial LiDAR Scanner. The same ground control points were used to georectify the data in both the UAS and the LiDAR tests. The software used to calibrate the point cloud was Agisoft, and the software used to classify and colorize the LiDAR points was PLS-CADD 2014. The UAS used was the Iris+, manufactured by 3DRobotics. The Iris+ is remotely piloted, four bladed aircraft, similar to the Iris used during the volumetric calculation. The sensor used was a GoPro Hero-4 Black, which contains a 12-megapixel lens with a 120-degree field of view (footnote for GoPro, i.e., URL). The sensor was externally mounted on the aircraft using a two-axis gimbal for stabilization. The sensor was set to take a picture every one second. Mission Planner software was used to plan the flight. Pix4D software was used to process the photos and export a .las file, an AutoCAD drawing file format used for LiDAR processing. PLS-CADD software was used to generate one-foot interval contour lines in .las format.

The second test conducted on 21 August 2015 compared the cross sectional method of topographic mapping with the use of UAS. The total area surveyed was approximately 21 acres. The land surveyor used a Trimble R10 GPS to shoot 100-foot cross sections. AutoCAD software was used to interpolate topographic lines based on the GPS shots taken using the cross-sectional method (footnote for AutoCAD software, URL). The UAS used was the Aero-M, manufactured by 3DRobotics (footnote for Aero-M, URL). The Aero-M is a 2.7 pound fixed wing, remotely piloted aircraft. The Aero-M uses a Canon S100 camera, a 12-megapixel point and shoots using a digital camera (footnote for Canon, URL). The sensor was internally mounted on the Aero-M. The Trimble R10 GPS was used to record the horizontal and vertical position of ground control points. Mission Planner software was used to plan the flight. Pix4D software was again used to process the photos, create an orthomosaic, and create 1-foot interval contour lines.

The third test conducted on 25 August 2015 compared the use of Manned aircraft Photogrammetry to UAS for topographic mapping, described previously. The total area surveyed was approximately 14 acres. The UAS used was the Aero-M. The Trimble R10 GPS was used to identify the position of ground control points. Mission Planner software and Pix4D were again used to plan the flight and process the imagery and create 1-foot contour lines. Due to confidentiality reasons, the type of manned aircraft, sensor, or processing software used during the manned aircraft flight and subsequent topographic mapping is not reported in this thesis. Nevertheless, the final topographic data, lines, generated by the manned aircraft flight in an AutoCAD drawing file format were obtained for analysis as part of this thesis work.

As evident from this discussion above, several different systems were used during this thesis study. To make the author’s work repeatable, a detailed testing methodology was needed before showing the results of the study. Chapter 3 presents this methodology.

CHAPTER 3: TESTING METHODOLOGY

This chapter describes the thesis work testing methodology. This chapter is divided into four subchapters; UAS Vs. Cross-Sectional Method for Volumetric Calculation, UAS Vs. Terrestrial LiDAR for Topographic Mapping, UAS Vs. Cross-Sectional Method for Topographic Mapping, and UAS Vs. Manned Aircraft Photogrammetry for Topographic Mapping. Chapter 3 describes the method of comparing traditional survey practices with the use of UAS. To conduct a comparison, of the two survey methods, the accuracy of data acquired through the use of UAS was determined, and the costs of acquiring that data using traditional land surveying and UAS were compared. As a control, the field collection and data processing completed for each method were conducted by the same researchers.

3.1 Test 1: Comparison of UAS to Cross Sectional Method for Volumetric Calculation

The accuracy of data acquired using UAS was determined by comparing the volume calculated using UAS to the volume calculated using land surveying. The total acreage of the area mapped was approximately 8 acres. To calculate the volume of the test site using UAS, a digital elevation model was created in Pix4D. A volume polygon was then drawn around the ditch (Figures 5 and 6). The polygon was drawn by connecting top of slope GPS points, to create a controlled comparison. In the context of this study, top of slope refers to the point on the ground at which the depressed area begins, separating it from the surrounding terrain. To be deemed accurate, the total volume calculated using UAS had to be within three percent of the volume calculated using land surveying (Per. Comm.). In addition to the standards of accuracy described in chapter one, this standard of accuracy, plus or minus three percent, was confirmed through interviews with Project Managers with a combined 20 years of experience in conducting land surveys for the construction and transportation industries. These industries regularly commission land surveyors to calculate cut and fill volumes, with an excepted error of up to 3% (Shropshire and Cox, 2015).

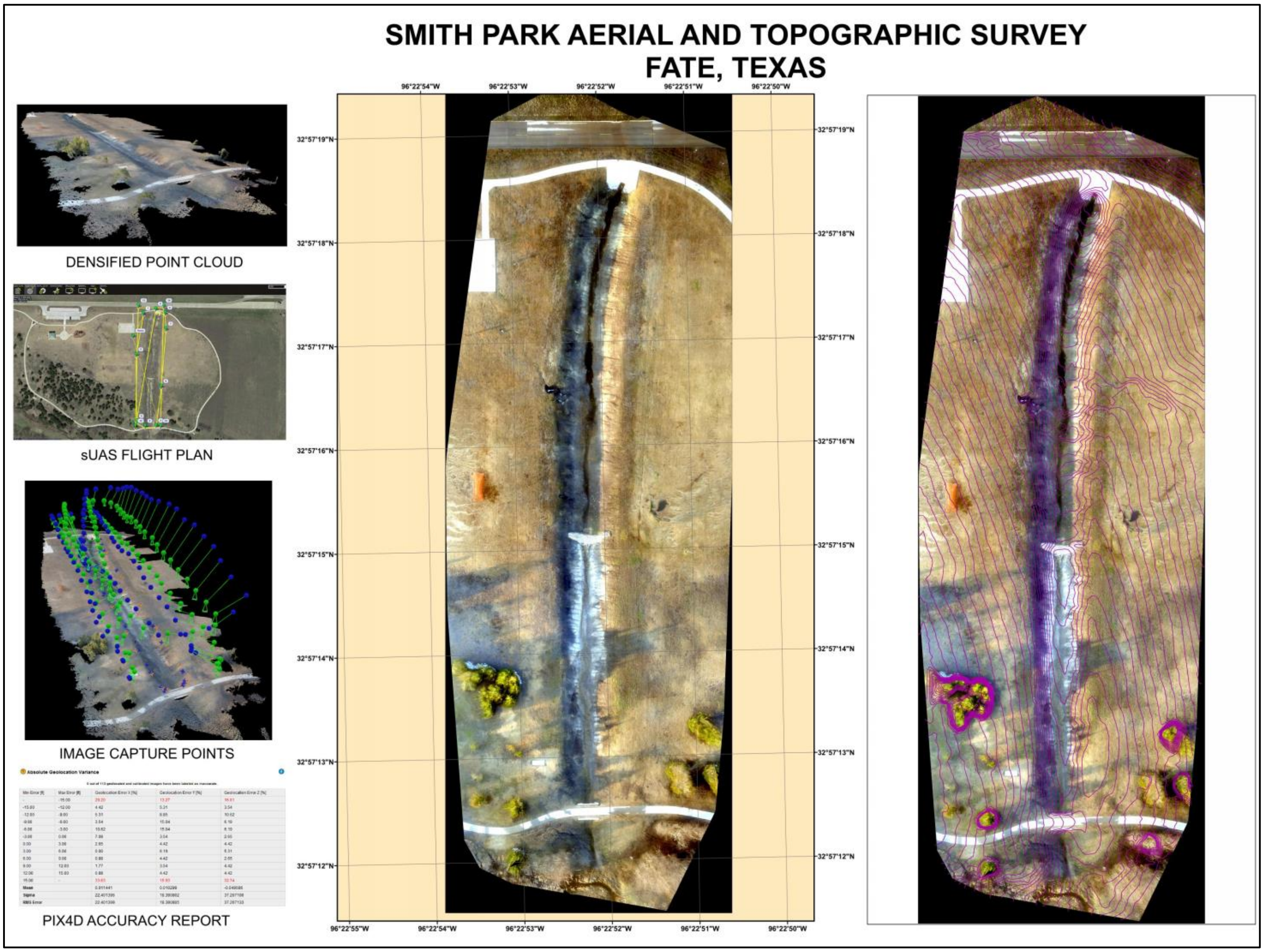


Figure 5: Map of Ditch Survey Area, February 2015, Fate Texas.

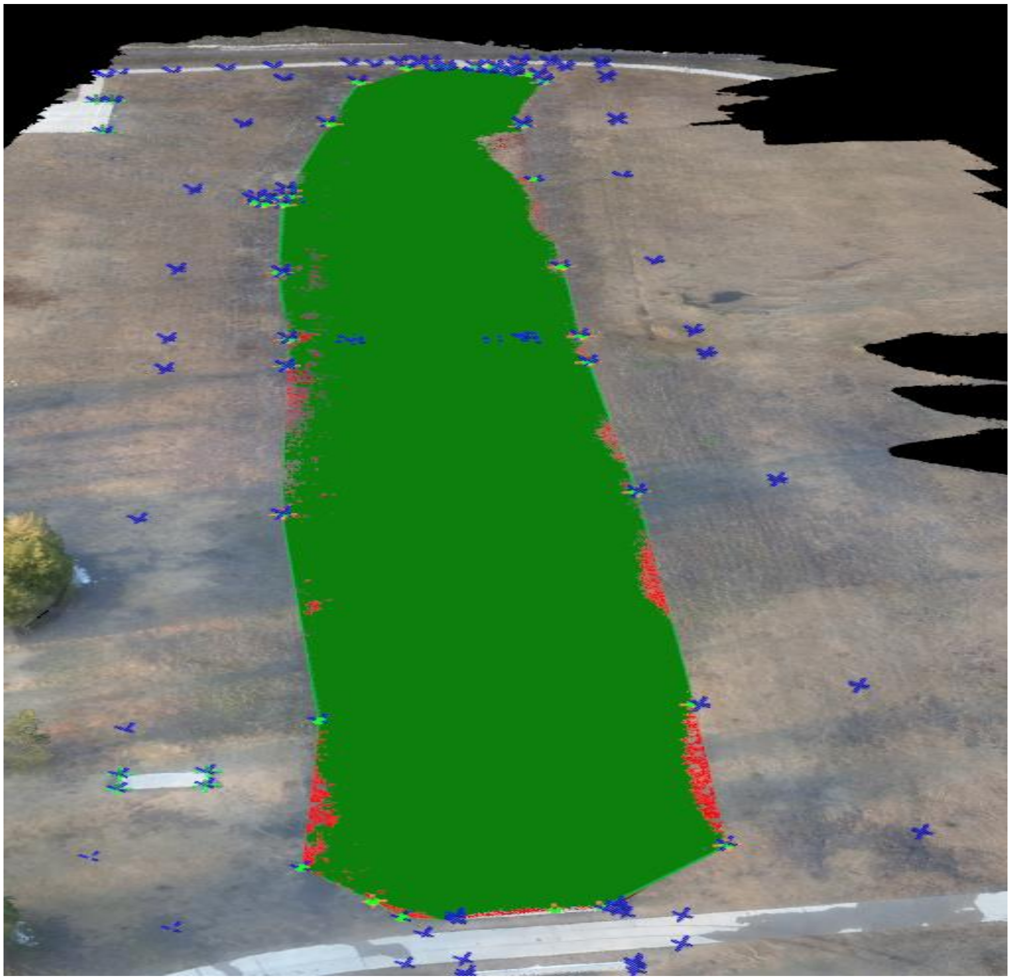


Figure 6: Volume polygon of ditch, drawn using Pix4D.

The cost comparison was performed by calculating the total time spent by each person involved in the test, and multiplying that time by their hourly charge rate, the amount of money billed for associated services. The persons involved in the test included a UAS Pilot and observer, a two-person field crew taking GPS shots for the cross-sectional method, and a project manager in the office to process the data. The time to conduct each method of testing was determined the summing the time spent planning in the office, mobilizing to the test site, collecting the data, mobilizing back to the office, processing the data and calculating the volumes. The time to record the top of slope GPS shots was used in the time calculation for both methods since those points were used in both types of volumetric calculations.

3.2 Test 2: Comparison of UAS to Terrestrial LiDAR for Topographic Mapping

The accuracy of data acquired using UAS was determined by comparing the point clouds created by the LiDAR and the UAS methods, as illustrated in Figure 7. The total area mapped during this test was approximately 10 acres. To be deemed accurate points determined using UAS had to be within 0.2 feet, both horizontally and vertically, of the data acquired using the LiDAR methodology. Although the Texas Administrative Code only requires that measurements be recorded with equipment and methods of practice capable of attaining the accuracy and tolerances required by the professional land surveying services being performed (Texas Code, 2015), the standard of 0.2 feet is a widely held standard of accuracy in surveying, based on the discussion in Chapter 1.

The cost of each method was determined by calculating the total time spent by each person involved in the test, and multiplying that time by their hourly charge rate, the amount of money billed for associated services. The labor rates were then added to hourly rates for the use of the equipment involved, in this case, a Trimble R10 GPS. The time to conduct each method of testing was determined by summing the time spent planning in the office, mobilizing to the test site, collecting the data, mobilizing back to the office, and processing the data. The images shown in Figure 8 illustrate the comparison of a cross section of the two point clouds.

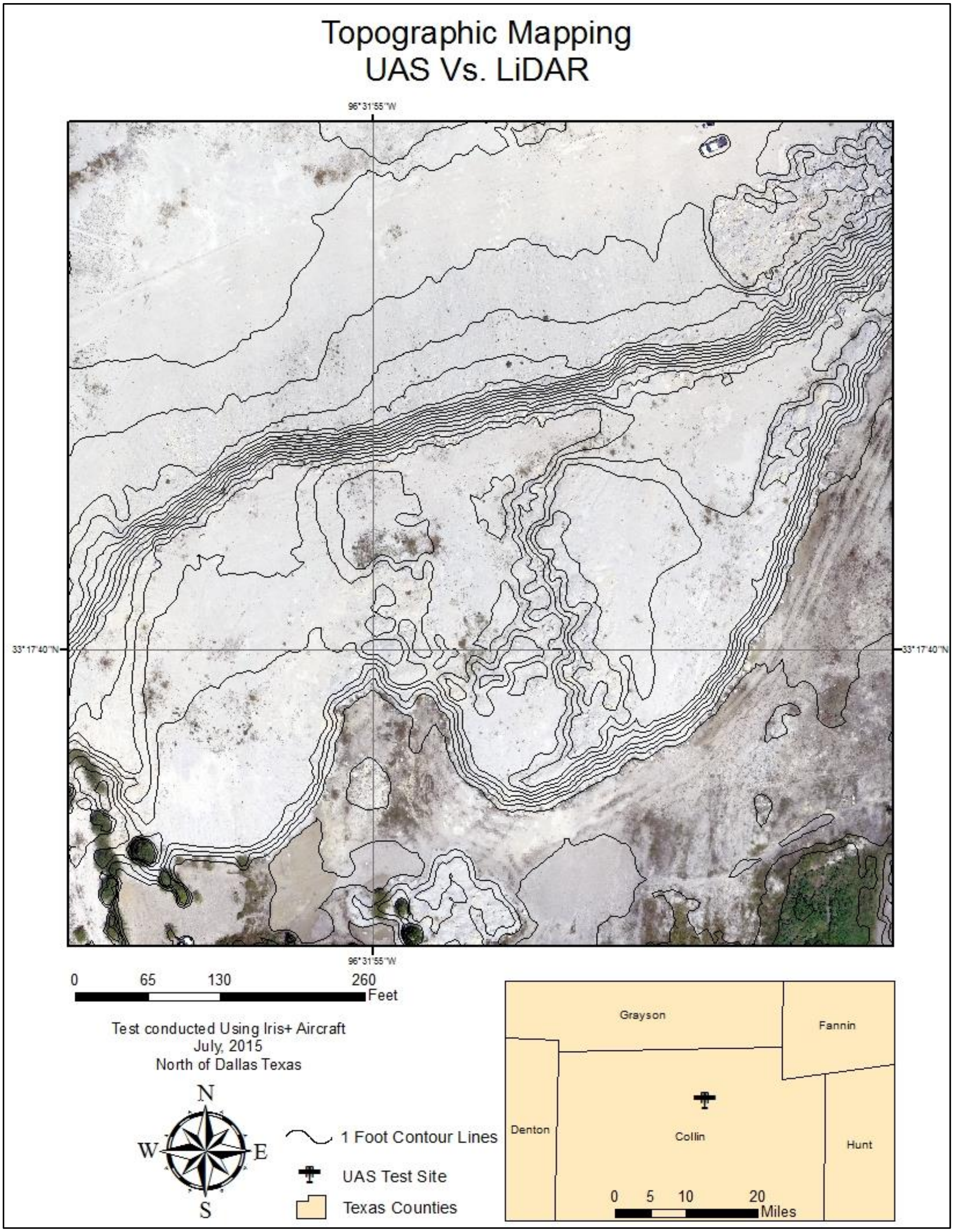


Figure 7: LiDAR Comparison Test Area, July 2015, Melissa Texas.

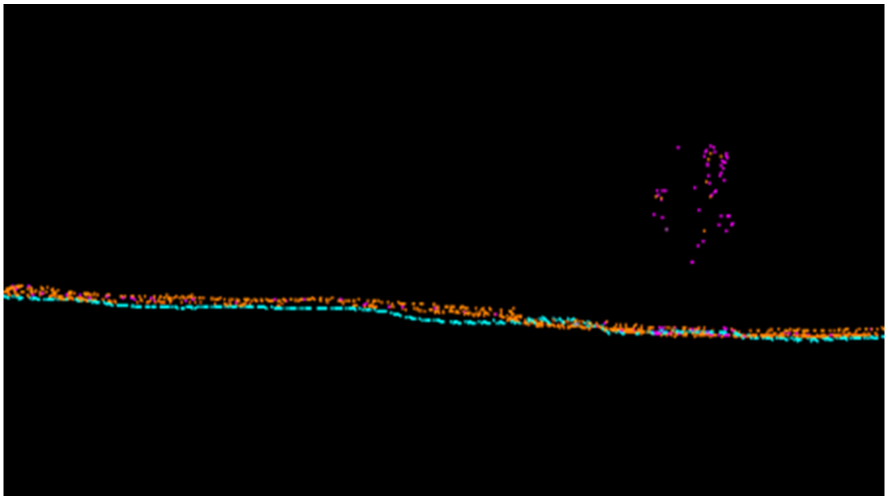


Figure 8: Cross section of point clouds. Orange and Purple Are LiDAR, Green and Cyan Are UAS.

Regarding the cross section in Figure 8, if data sets are within 0.2 feet of each other vertically, all points would overlap. Since these points do not overlap perfectly, meaning there are cross sections that do not precisely overlap, this means that the UAS and LiDAR data are not within 0.2 feet of each other in those locations.

3.3 Test 3: Comparison of Cross-sectional Method and UAS Method for Topographic Mapping

Both the cross-sectional method and the UAS method were conducted on the same day. The accuracy of the topographic lines created using the UAS method was determined by comparing their location and elevation to the topographic lines created using the cross-sectional method (Figures 9 and 10). The total area mapped for this test was approximately 23 acres. Elevation readings were noted on both sets of contour lines where they appeared to cross. The cost of each method was obtained by calculating the total time spent by each person involved in the test, and multiplying that time by their hourly charge rate, the amount of money billed for associated services. The labor rates were then added to hourly rates for the use of the equipment involved, in this case, a Trimble R10 GPS and the Aero-M software. The time to conduct each method of testing was determined as the sum of time spent planning in the office, mobilizing to the test site, collecting the data, mobilizing back to the office, processing the data and creating the topographic lines. The total cost of the Aero-M software, associated planning, and other equipment was $5,400.

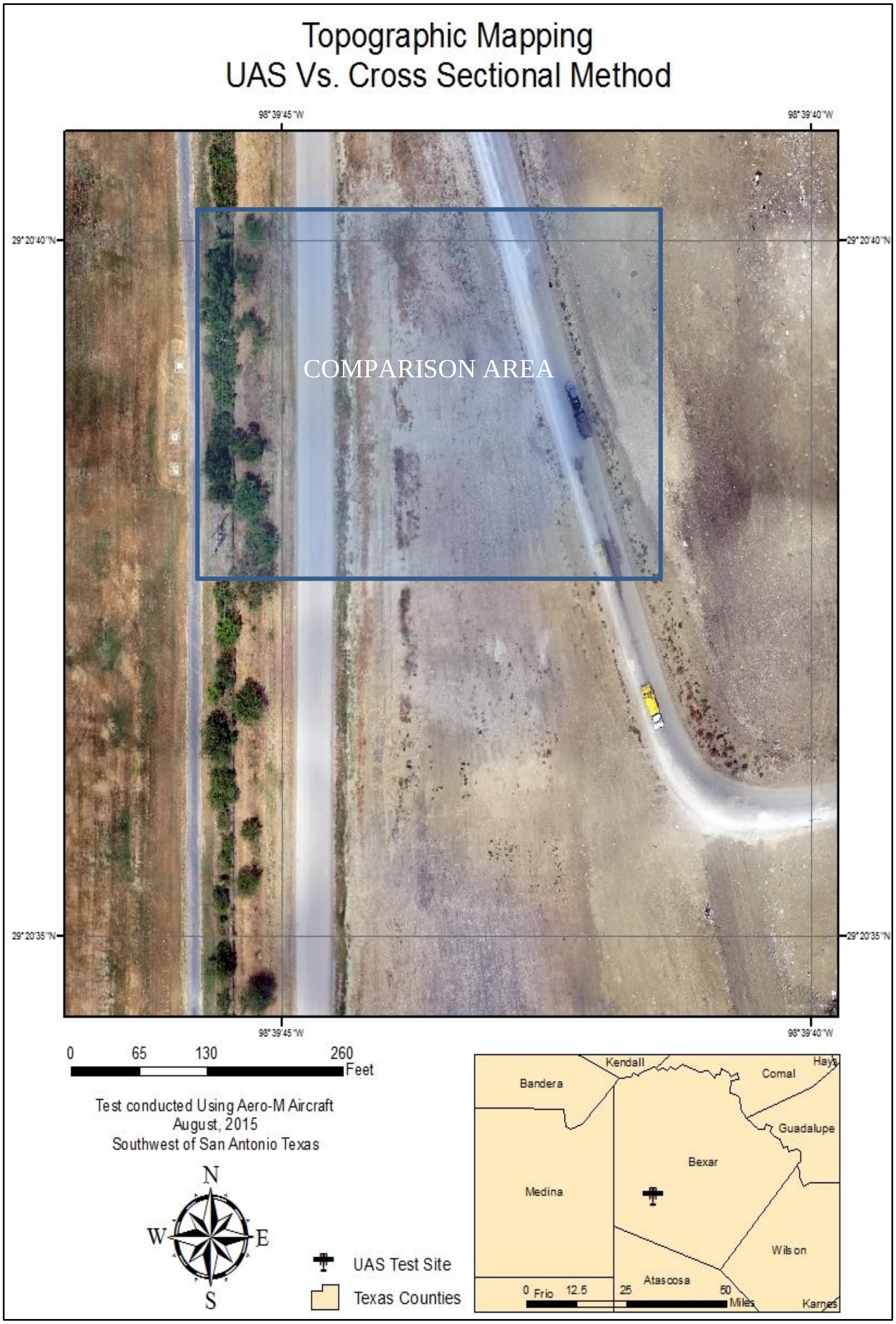


Figure 9: Cross Sectional Method Testing Site

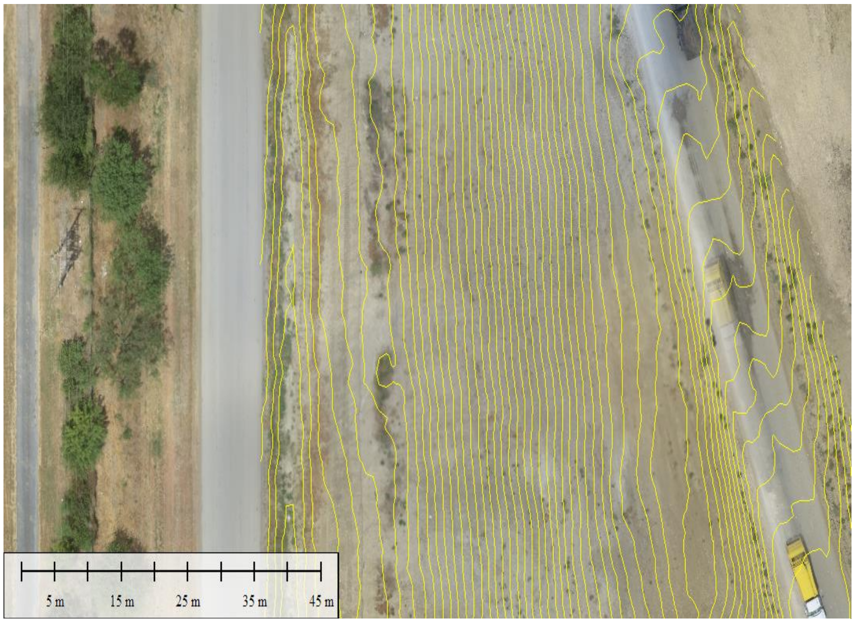


Figure 10: Topo Lines Generated by UAS

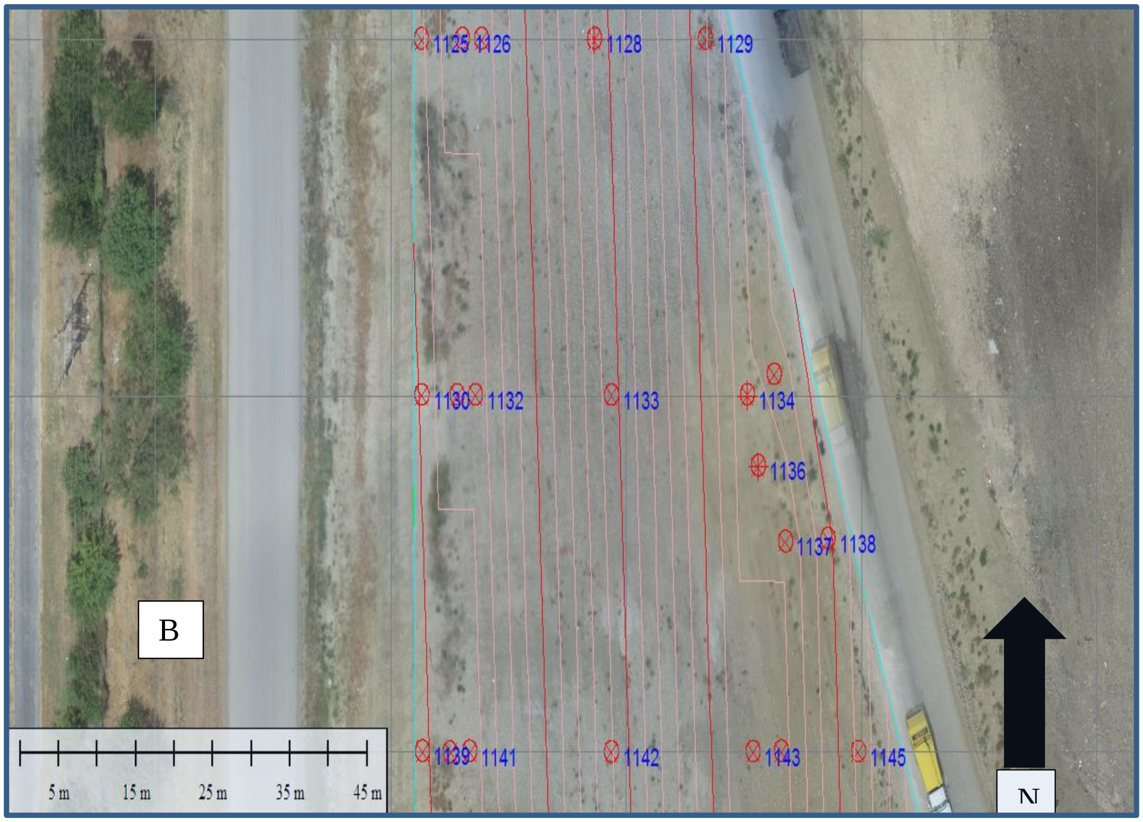


Figure 11: Topo Lines Generated by Cross-Sectional Method. Numbers indicate Unique ID for each GPS shot

3.4 Test 4: Comparison of UAS Method and Manned Aircraft Photogrammetry for Topographic Mapping

The UAS method and Manned Aircraft Method were conducted in 2015 during different times of the year (Figure 12). The 14-acre test site underwent excavation during the time between the manned aircraft flight and the UAS flight. To best compare the accuracy of the two different topographic line sets, an area was chosen to analyze where no excavation had taken place. The time to conduct the UAS flight was calculated by adding the time to mobilize from the office to the site, establish ground control points, fly the mission, return to the office, and process the data and create the topographic lines. The time for the manned aircraft to fly the study areas and subsequent data processing steps is unknown. The cost of the UAS method was calculated by multiplying the time spent by each person involved in the test by their hourly charge rate. The total cost of the manned aircraft flight was $5,000 (Hanson, 2015).The traditional survey methodologies described in this chapter are widely held throughout the survey industry. The methodologies for UAS are not, however, as the technology is new and evolving. The comparison of results, detailed in the next chapter, is one way to determine the validity of both the technology described in Chapter 2 and the methodology presented in Chapter 3.

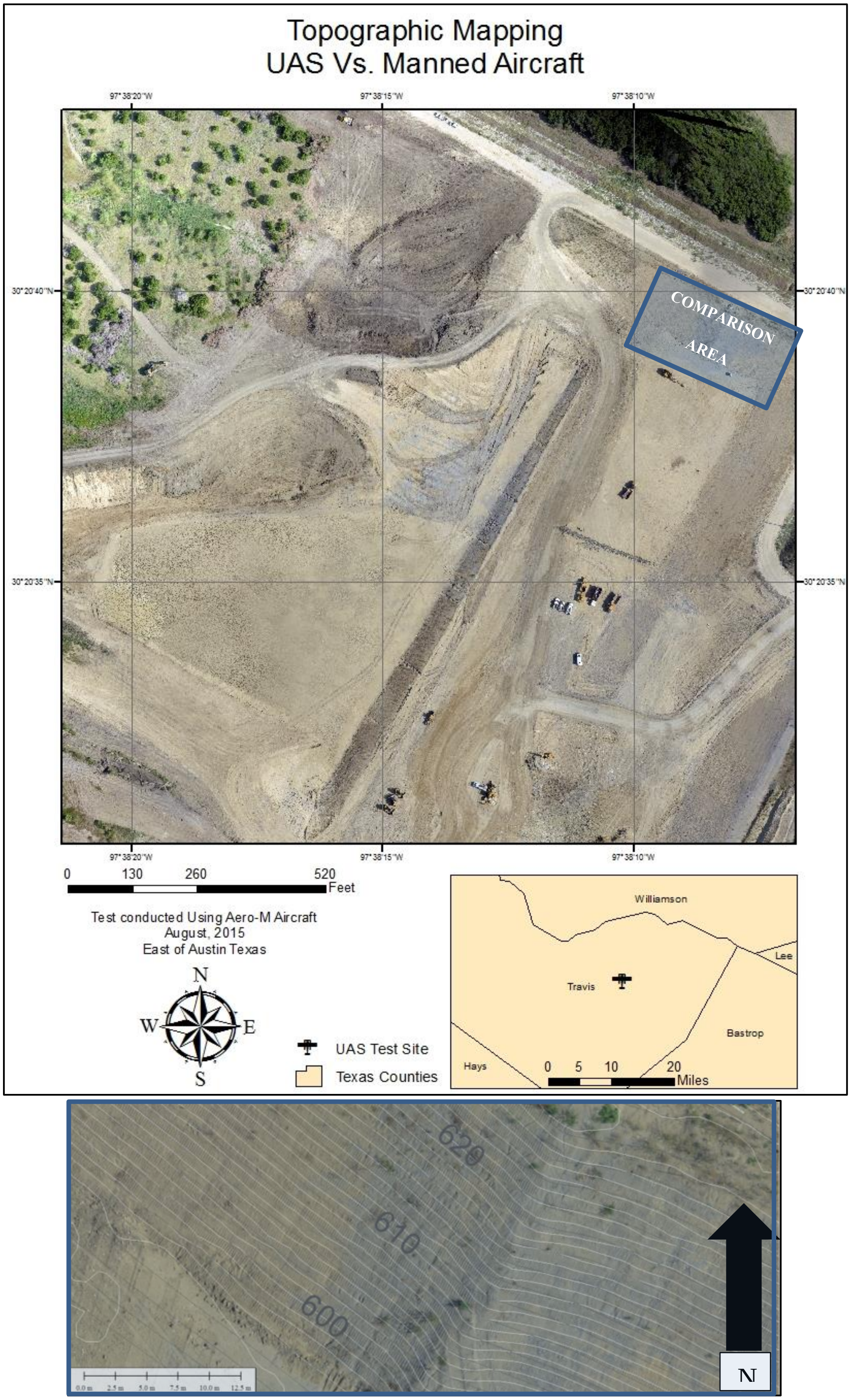


Figure 12: Top: Test Location. Bottom: Comparison of UAS and Manned aircraft Topo Lines (Lines shown in gray are from manned aircraft, lines in white are from UAS)

CHAPTER 4: RESULTS

This chapter details the results of the testing in regards to the time required to accomplish each task for each method, the cost associated with each method, and the comparison of accuracy between methods used in each test. Overall the UAS method proved to be more beneficial than using the cross-sectional method for both volumetric calculation and topographic mapping. The UAS method took less time and cost less money with no loss in accuracy of the results. The UAS method could not be proven to be more or less beneficial compared to the use of manned aircraft for photogrammetry because time of flight data was not available for the latter, thus assumptions of total time and thus cost had to be made. It is assumed that the UAS method for topographic mapping took less time and cost less than using terrestrial LiDAR or manned aircraft, and it was determined that it is a less accurate method for topographic mapping. Table 1 summarizes these results.

Test	**Traditional Method**	**Traditional Method Time**	**UAS Method Time**	**Traditional Method Cost**	**UAS Method Cost**	**Accuracy Comparison**
Volumetric Calculation	Cross Sectional Method	11 Hours	5 Hours	$2,235	$1,316.50	0.09% Difference between calculation results
Topographic Mapping	Terrestrial LiDAR	10 Hours	7 Hours	$4,600	$2,450	41% Accurate
Topographic Mapping	Cross Sectional Method	16 Hours	8 Hours	$3,200	$1,944	Less than 0.1' difference between contour lines
Topographic Mapping	Manned Aircraft Photogrammetry	Unknown	8 Hours	Unknown	$1,011	Less than 0.1' difference between contour lines

Table 1: Summary of results

The cost was calculated by multiplying the number of hours to complete each method of surveying by the charge rate for the individuals conducting the surveying. The charge rate is the individual or team salary multiplied by a pre-designated multiplier. Equipment, health insurance, and a 20% markup (for profit) are factored into the multiplier. Table 2 is a breakdown of the charge rates.

Personnel	Salary	Overhead Multiplier	Charge Rate
2 Person Survey Crew with GPS	$70	3.2	$225
UAS Pilot	$35	4.1	$145
Observer	$24	4.1	$98
Office Technician	$35	4.1	$145

Table 2: Breakdown of Charge Rates

4.1 Test 1: Comparison of UAS to Cross Sectional Method for Volumetric Calculation

4.1.1 Comparison of Time

The UAS method was accomplished in a total of six hours. Two hours were spent mobilizing to and from the test site. A total of 20 minutes were spent planning the flight, which lasted 8 minutes. One hour of time was included in this total for the cross-sectional method, accounting for the time necessary to acquire the top of slope locations used in the volumetric calculations. Two and a half hours were spent processing the data in the office planning and calculating the volume results.

The cross-sectional method was accomplished in a total of 11 hours. Two hours were spent mobilizing to and from the site, six hours to acquire the GPS locations using the cross-sectional method, and three hours were required in the office to create the surface model in AutoCAD, then to calculate the final volume.

The UAS method took five fewer hours, or 46% less time to calculate the volume than using he cross-sectional method. In regards to time spent, Alternative Hypothesis 2 proved to be true: using UAS for volumetric calculation took less time than the cross-sectional method.

4.1.2 Comparison of Cost

The charge rate for the Pilot In Command who flew the mission was $145 per hour, who billed 3 hours to the project. The charge rate for the observer who assisted with the flight was $98 per hour, who billed 3 hours to the project. The charge rate for the two-person survey crew with the Trimble R10 GPS was $225 per hour, who billed eight hours to the project. The charge rate for the persons conducting the processing in the office was $145 per hour, for both methods.

The results were determined using the UAS method for a total cost of $1,316.50. Using the traditional cross-sectional method, the total cost was $2,235. Thus, the UAS method cost $918 less than the cross-sectional method. In regards to cost, Alternative Hypothesis 6 proved to be true: Volumetric calculation using UAS cost less than the cross-sectional method.

4.1.3 Accuracy Results

The volume calculated using the UAS method was 5,276 cubic yards. The volume calculated using the cross-sectional method was 5,271 cubic yards. The difference in volume between the two calculations was five cubic yards, a 0.09% difference. In this test, Alternative Hypothesis 5 proved to be true: Volumetric calculation using UAS was as accurate as using the cross-sectional method.

4.2 Test 2: Comparison of UAS to Terrestrial LiDAR for Topographic Mapping

4.2.1 Comparison of Time

The UAS method required a total of 7 hours to complete the tasks of data acquisition and analysis. Two hours were spent mobilizing to and from the test site, 30 minutes were spent planning the flight, which lasted 15 minutes. Two hours were spent establishing ground control points, and the remaining time was spent processing the data and creating a point cloud.

The traditional method of using Terrestrial LiDAR took a total of 10 hours to accomplish. Two hours were spent mobilizing to and from the test site, an additional two hours to establish ground control points, three hours to scan the test area, and lastly three hours to process the data in the office.

In the end, the UAS method took three fewer hours to than using Terrestrial LiDAR to complete the testing. In this case, Alternative hypothesis 1 proved to be true: Topographic mapping using UAS took less time than using traditional methods.

4.2.2 Comparison of Cost

Utilizing the UAS method the testing was completed for a total cost of $2,450. Whereas the traditional method using LiDAR cost $4,600. Thus, the UAS method cost $2,150 less than the traditional method. In this case, Alternative Hypothesis 3 proved to be true: Using UAS for topographic mapping cost less than using traditional methods.

4.2.3 Comparison of Accuracy

When the point clouds generated by the UAS method and the terrestrial LiDAR method were compared, 41% of the points were within 0.1 feet of each other in the vertical axis, 81% of the points were within 0.25 feet of each other, and 95% of the points were within 0.5 feet of each other. In this case, Null Hypothesis 4 proved to be true: topographic lines created using UAS were less accurate than those using traditional methods. It is important to note, however, that from a business standpoint, having 95% of the points fall within 0.5 feet of the LiDAR is acceptable for many applications. Not all clients require 0.2 foot accuracy, and may prefer a less costly and time-consuming survey that can achieve 0.5 foot accuracy.

4.3 Test 3: Comparison of Cross-sectional Method and UAS Method for Topographic Mapping

4.3.1 Comparison of Time

The UAS method for topographic mapping in this test required a total of 8 hours to complete. Three hours were spent mobilizing to and from the test site, while planning the flight and preparing the aircraft took 30 minutes. The total flight time was 28 minutes long. One hour was spent establishing ground control points, and the remaining time was spent coordinating the flight with the U.S. Airforce (flight took place within the confines of airspace operated by Lackland Air Force Base), processing the data in the office and creating the 1-foot interval contour lines.

The cross-sectional method took a total of 16 hours to complete. Three hours were spent mobilizing to and from the test site. Eight hours were spent collecting the topographic data using the cross-sectional method, and the remaining five hours were spent creating the topographic lines from the cross sections and conducting quality control of the data.

Using the UAS method required eight fewer hours to complete the data collection and analysis than the traditional cross-sectional method. In this case, Alternative Hypothesis 1 proved to be true: Topographic mapping using UAS took less time than using the cross-sectional method.

4.3.2 Comparison of Cost

To conduct the topographic mapping, the UAS method cost a total of $1,944 based on a charge rate of $145 per hour for the pilot and $98 per hour for the observer, each of whom spent 8 hours completing the project.

The total cost of using the cross-sectional method was $3200, based on an hourly charge rate of $225 for the survey crew (3 hours of mobilization and 8 hours of surveying) and $145 per hour for the office technician to process the data. In this case, Alternative Hypothesis 3 proved to be true: Topographic mapping using UAS cost less than using traditional ground survey.

4.3.3 Comparison of Accuracy

Where the topographic lines from the UAS method and the cross-sectional method cross, there is less than a 0.1-foot difference in all three axes as measured using AutoCAD. In this test, Alternative Hypothesis 4 proved to be true.

4.4 Test 4: Comparison of UAS Method and Manned Aircraft Photogrammetry for Topographic Mapping

4.4.1 Comparison of Time

The UAS method took 4 hours to complete the topographic mapping. A total of 30 minutes were spent mobilizing to and from the job site, one hour was spent setting ground control points, one hour total was required to plan the flight and fly the aircraft, and the remaining 90 minutes were spent processing the data.

As previously stated in Chapter 3, it is unknown how long the manned aircraft flight required to complete the data collection task. In this test, the validity of Alternative Hypothesis 1 and Null Hypothesis 1 cannot be determined.

4.4.2 Comparison of Cost

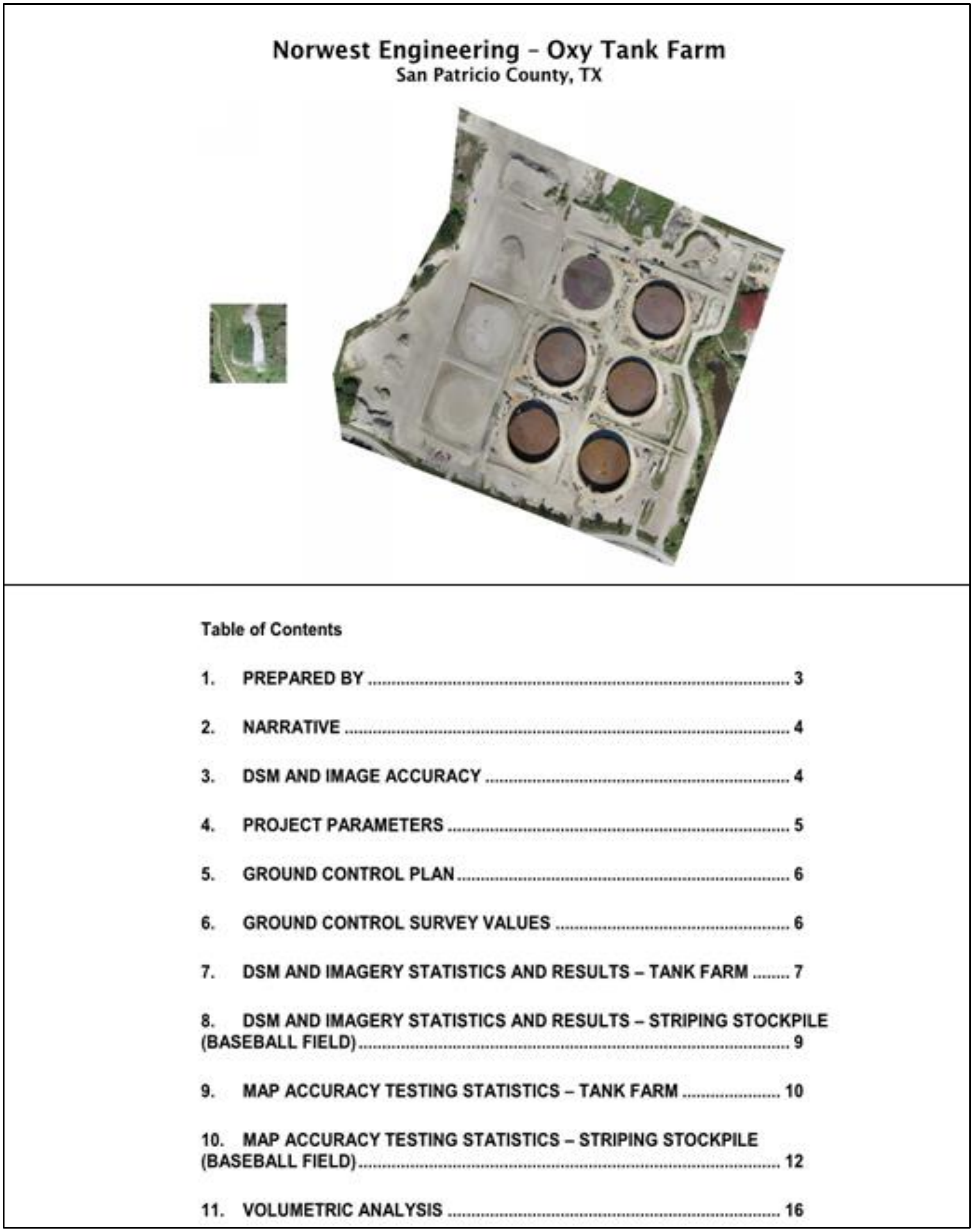
As previously stated, the total cost of the UAS Method was $1,960. Although the total cost of the manned aircraft flight cannot be determined, it was estimated based on conversations with the owner of the test flight who paid for the manned aircraft flight approximately $5,000. Assuming true cost, then this test would prove Alternative Hypothesis 3 to be true: Topographic Mapping using UAS costs less than using manned aircraft.

4.4.3 Comparison of Accuracy

There was less than 0.1 foot of difference in all three axes between the topographic lines acquired using the UAS method when compared to those obtained using the manned aircraft flight. Figure 11 illustrates that the 1-foot contour lines created by the UAS method line up fairly close to those topographic lines generated by the manned aircraft flight. In this test, Alternative Hypothesis 4 proved to be true: Topographic mapping using UAS is as accurate as using manned aircraft.

4.5 Business Results

This study resulted in the broadened use of UAS by the author's employer. Accuracy and cost savings proven through testing, the author's employer is now using UAS on a regular basis for topographic mapping and volumetric calculations. After acquiring and processing data, and creating either topographic maps or volumetric calculations, this company prepares and sends a detailed report to its clients. This report not only gives the requested figures, such as the volume of a surface, but also details how that data was obtained, and to what degree of accuracy the data can reasonably be stated as true. The first two pages from such a report, prepared after a UAS Survey, are shown below in Figure 13.



Norwest Engineering – Oxy Tank Farm
San Patricio County, TX

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Figure 13: Cover page and Table of Contents of UAS Volumetric survey conducted by the author in November 2015

Chapter 4 of this document provided a discussion of the results of this study. From this discussion, many questions were raised as to why these particular results were obtained. Chapter 5 discusses in more detail some of the causes of error and expands on legal and technology limitations and potential future uses of UAS.

CHAPTER 5: DISCUSSION AND CONCLUSIONS

In this thesis study, alternative hypothesis 1, 2, 3, and 5 proved to be true. The UAS methods proved to cost less, take less time, and be as accurate in all but one case, when compared to traditional survey methods.

5.1 Discussion of Results

In conclusion, nearly all traditional survey methods required more time and money to complete compared with using the UAS method. Test 4, comparison of UAS methods to manned aircraft for topographic mapping, remains an exception since the necessary flight time information for the manned aircraft flight could not be gathered. Test 2, comparing the point clouds generated from UAS and LiDAR, was the only test in which the null hypothesis proved true, though the UAS method is less accurate by only approximately 0.5 feet compared to the traditional LiDAR method. Based on the testing conducted as part of this thesis work, it can be determined that the use of UAS for topographic mapping is more cost efficient than traditional methods, with limitations, as noted in the following discussion.

5.2 Limitations of UAS

As limitations were discovered when projects increased in size due to the regulatory requirement of maintaining visual line of sight with UAS, it is recommended that future work in this area be done after the FAA allows for commercial use of UAS beyond visual line of sight. The need to de-regulate the industry and allow for beyond visual line of sight UAS flight continues to be a subject of much debate[5]. In speaking before a House Oversight and Government Reform Committee in June of 2015, Association for Unmanned Vehicle Systems International (AUVSI) President Brian Wynne broached the subject, saying that, “Despite these

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[5] http://www.uasmagazine.com/articles/1281/uas-house-committee-debates-drone-rules-regs-risks

positive steps, we need to permit expanded uses that pose no additional risk to the airspace system. Whether within the context of the rule, through the reauthorization or by other means, we need to allow for beyond-visual-line-of-sight, nighttime operations and operations over congested areas. Otherwise, we risk stunting a still-nascent industry (AUVSI Weekly). Although this appears to be the next step in civil UAS use in the United States, in reality, this is probably at least two years away, as UAS technology continues to outpace our government's ability to regulate its use.

There are several limitations of UAS, some regulatory, some not, that affect the cost of using UAS for surveying, and were avoided during this testing. These tests were very limited in the areal coverage of the project study areas. No mapping project greater than 25 acres was attempted. Also, all testing was done over bare earth surfaces, due to the testing aircraft using passive sensors and automated photogrammetry (McKim and Creed, 2016).

5.2.1 Regulatory Limitations

The FAA Reform and Modernization Act of 2012 (FRMA) included several sections regarding the use of UAS, and how private companies can go about using them for commercial use (FAA Reform Act). Ultimately, what is needed by the FAA is an approved Certificate of Waiver or Authorization (COA). Before the FRMA, only government entities were allowed to receive a COA. Section 333 of the FRMA called for the FAA to establish a process by which private companies could apply for a COA. In 2014, the FAA began issuing something known as a Section 333 Exemption, which allows companies to apply for a COA (H.R.658, 2012). The FAA has also begun issuing a "blanket COA" when they approve a Section 333 Exemption for a company. There are many regulatory limitations imposed by the FAA on those companies approved to use them for commercial use. The author's employer received a Section 333 exemption, which included more than 30 restrictions. FAA (FAA, 2015). In November of this year, The University of Southern California received their Section 333 Exemption, which carried 32 restrictions, and further restrictions were placed on them in the COA they received (Duncan, 2015).

Local regulations also pose limitations on those seeking to use UAS for surveying. Texas, for example, passed House Bill 1481, which took effect in September of 2015 and further limits the areas in which people may lawfully operate UAS. The bill made an offense of the use of UAS near critical infrastructure without the owner's consent, giving a specific list of what qualified as critical infrastructure (H.B. 1491, 2015). Other states have similar regulations that further limit the use of UAS.

Perhaps the most limiting restriction is the requirement to maintain line of sight with the aircraft at all times. For example in a recent mapping assignment following a natural disaster, the author used UAS to map 2.6 miles of transmission line that had been hit by a tornado[6]. The pilot's visual contact with small UAS was lost much faster than with the larger manned counterparts, and the aircraft could only be seen approximately one-half to three-quarters of a mile away against the backdrop of a hazy sky. Even with a launch point in the middle of each set of flight lines, flying in bad weather resulted in three separate takeoffs and landings, a total of 8 hours work for two people to fly the aircraft and set ground control. In this particular example the work could have been accomplished much faster with a manned aircraft, and most likely at a lower cost.

The line of site restriction is the best example of a regulation that, if changed, will affect the time and cost of using UAS. Linear surveying and mapping projects, such as Electric Transmission Line mapping, will be done at a much faster pace and lowered cost. In the author's

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[6] http://www.12newsnow.com/story/30392984/tornado-reported-in-san-marcos-damage-in-floresville-dhanis

experience during testing, small UAS could be seen only when one-half mile or closer to the operator, limiting operations to around 1 mile of corridor mapping without re-positioning the operator. The battery life and airspeed of the systems used during this testing allow the aircraft to fly up to 15 miles in a single flight. If the line of sight restriction is lifted, linear mapping will require far less time, due to a drastic reduction in time to re-position the observer and repeatedly set up and tear down equipment. This lowered time will translate to a reduction in cost as well.

Because the FAA considers UAS to be aircraft, operators of unmanned aircraft must also follow all restrictions placed on manned aircraft, unless specifically exempted from doing so in their Section 333 Exemption and associated COA. An example of a common regulatory hindrance to flight for all aircraft is the presence of Temporary Flight Restrictions or TFRs. The FAA defines a TFR as "an area restricted to air travel due to a hazardous condition, a special event, or a general warning for the entire FAA Airspace." Large wildfires, the Super Bowl, and presidential travel are examples of events and hazards that can trigger a TFR to be put up. TFRs must be checked for before flight for all aircraft, including UAS. Although no TFRs interfered with the testing for this study, it is highly likely that TFRs could disrupt commercial UAS operations.

5.2.2 Physical Limitations

The majority of UAS in use today utilize automated photogrammetry for data acquisition and processing, rather than LiDAR. While LiDAR systems do exist and are commercially available, they are, in many cases, cost-prohibitive. Moreover, the increased weight of such systems can severely limit the flight time of the aircraft.

Generating volume calculations and topographic mapping is a perfect task for automated photogrammetry over bare earth. But the limitations of passive sensors of old remain in the UAS era, mainly vegetation (McKim and Creed, 2016)). If the true ground or bare earth is not present in the image, the software will not map the true ground, but will instead map the top of trees, grass, vehicles, buildings, and other objects obstructing the view of the true ground level.

Flight time is another limiting factor. While this is improving every day, the majority of commercially available UAS can fly fewer than 90 minutes at a time, and thus cover much less ground than a manned aircraft. This limitation is primarily due to the use of battery powered engines. As battery technology improves in the future, so too will UAS flight time.

5.3 Conclusions

UAS can be more cost effective than traditional survey methods, but this is not necessarily a cost-effective tool for every aspect of surveying and mapping. The limited flight time and requirement to maintain line of site with the aircraft requiring multiple launches and recoveries, and subsequent repositioning of aircrews, make the mapping of large regions less effective than with manned aircraft. This study was not able to determine at what point an area is too large for UAS to be cost effective when compared to manned aircraft. This would be an excellent goal for future study.

UAS can also be less cost effective than the traditional cross-sectional method for small surveying jobs, such as 1 to 5 acres in area. The regulatory requirement to have a certificated airman flying the aircraft requires personnel with formal training and certification, unlike a typical field survey crew with a GPS. Although using UAS was faster in all three test scenarios, it is reasonable to assume that at some point on smaller projects the use of UAS could take as much time as the traditional method. Since personnel with formal training and certifications typically have a higher cost to business, the time may be equal, but the cost would, in theory, be higher.

This study determined that using UAS for volumetric calculation and topographic mapping is as accurate as traditional survey methods and most cost and time effective when mapping areas 10 to 200 acres in size, in survey locations with little to no vegetation. When shared with the author’s employer, these test results led to a decision by the employer to invest heavily, both in time and money, in growing a UAS surveying program. At the time of this thesis, this program had earned over $40,000 in revenue in its first four months. This work, along with the study detailed in this thesis, resulted in the creation of a general decision matrix shown in Figure 12 below. This decision matrix has now become a tool to help project managers not familiar with the capabilities of UAS. This matrix shows the general point where it becomes more cost effective to use UAS for surveying of Land Surveying methods.

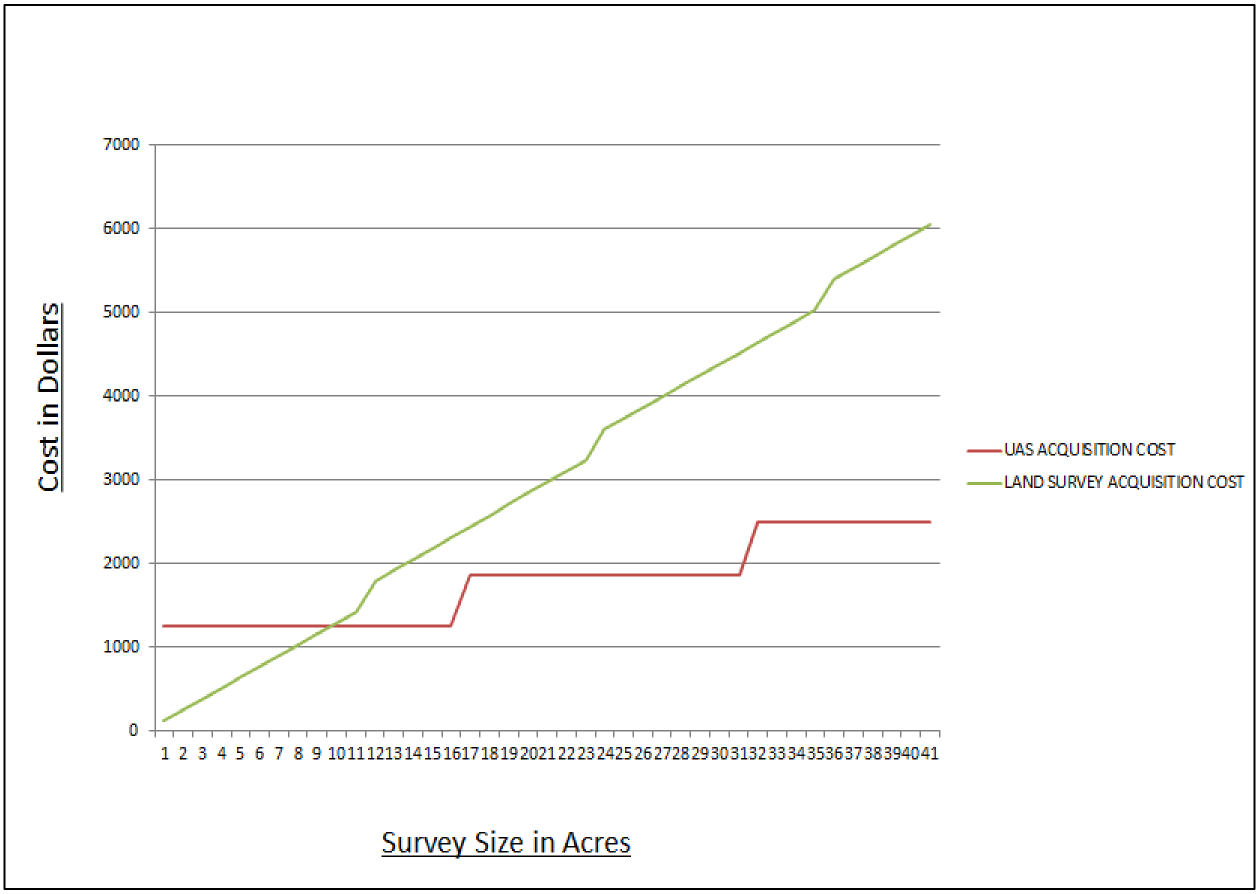

Figure 14: Decision Matrix

Finally, UAS should not be considered a replacement for traditional methods of surveying and mapping, but rather viewed as another tool in the toolbox, to be used only when the situation warrants.

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