Airport Imagery and Geospatial Data Collection Through the use of UAS

Figure 1: Members of the team and advisers at Kit Carson County Airport

Design Category:
Airport Operation and Maintenance

Design Challenge:
Innovative ways to collect, verify, distribute or use geospatial data to benefit safety or efficiency impacting airport operations

University:
Kansas State University Polytechnic Campus

Undergraduate Team Members:
Hsin Huang, Ryan Thomas, Preston Renfro, Ian Bonsall, & Elliot Rogers

Faculty Advisers:
Tara Harl Ed.D, Michael Most Ph.D., David Burchfield, Christopher Senn, & Durant Bridges Ed. D

Executive Summary

To address a current airport industry issue as a submission to the Airport Cooperative Research Program (ACRP) University Design Competition, an interdisciplinary team from Kansas State University Polytechnic Campus analyzed the need for a supplement to current methodologies in airport imagery and geospatial data collection. To accomplish this, the team has developed and tested an innovative Unmanned Aircraft System (UAS)-based methodology.

Airport consulting firms currently work with third party contractors to update aerial mapping or an Airport Layout Plan (ALP). The introduction of a supplementary UAS methodology to solve the problems of high costs is a viable and more economical option for airport geospatial data acquisition.

Costs and benefits were analyzed with industry reference and real world application to comprehensively vet the team's proposed solution. The team conducted a successful test flight operation at a small Colorado airport and produced sample data at a $23,228.68 cost reduction demonstrating the potential use of UAS in airport imaging operations.

Safety risk assessment and mitigation descriptions were created for the team's proof-of-concept and explained to fit data collection applications. The software and UAS platforms used were publicly available and could be purchased by airports to reduce conventional aerial mapping costs significantly. In addition, the usable and maintainable technology is a novel step in an economical sustainable airport model.

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Table of Acronyms

ACRP – Airport Cooperative Research Program

ALP – Airport Layout Plan

CFR – Code of Federal Regulations

DSM – Digital Surface Model

FAA – Federal Aviation Administration

DJI - Dà-Jiāng Innovations Science and Technology Co. 大疆创新

GBA – GB Architecture Engineers

GCP – Ground Control Point

GIS – Geographic Information System

GPS – Global Positioning System

LiDAR – Light Detection and Ranging

MTZ – Martinez Geospatial

NAS – National Airspace System

OSS – Obstacle Sensing System

RPIC – Remote Pilot-In-Command

RTH – Return-To-Home

RTK—Real-Time Kinematic

SMS – Safety Management System

TRB- Transportation Research Board

UAS – Unmanned Aircraft System

UAV – Unmanned Aerial Vehicle

VO – Visual Observer

3DR – 3D Robotics

Problem Statement and Background

Aerial imagery and geospatial data acquisition are vital components of many airport operations, planning, and construction projects. Current methodologies for acquiring this data are aerial imagery, Light Detection and Ranging (LiDAR), and satellite imagery per Federal Aviation Administration (FAA), Advisory Circular 150/5300-17C (FAA, 5 May 2009). Research and correspondence with several airport managers and airport consulting firms have shown that one of the most expensive and problematic aspects of projects such as airport master planning or ALP updates is the collection of aerial images and geospatial data. The high cost associated with current aerial photography practices has led some airport operators to use images many years out of date for future planning and development (S. Swanson, K. Bieker, Salina Airport Authority, personal communication, Feb. 2017).

Contact with industry has shown there are advantages to be gained through more affordable and timely aerial imaging. For example, while imaging has been a critical component in the initial stages of master planning and ALP projects, image collection timelines tend to be rigid. Pilot availability and the high cost of conducting aerial photography with manned aircraft have been barriers for on-demand aerial imaging and data collection. The possibility of more flexible image collection operations would provide better timing and planning efficiencies needed for airport projects such as master planning and ALP updating (T. Kahmann, E. Pfeiffer, Coffman Associates, personal communication, Nov. 2016). New remote sensing techniques have the potential to improve the aerial component of geospatial data collection. The goal of this project is to present a UAS-based methodology, intended to serve as an alternative for traditional aerial imagery data collection and other geospatial data types needed by airport management and airport contractors for a variety of airport projects.

Literature Review

Recent developments in the regulatory structure governing the UAS industry have led to a rapid expansion in the commercial application of unmanned aerial technology. On August 1, 2016, the FAA implemented 14 Code of Federal Regulation (CFR) Part 107, which outlined federal rules for the “operation and certification of small unmanned aircraft systems," in a commercial capacity within the National Airspace System (NAS) of the United States (FAA, 2016). The partial opening of the NAS to UAS commercial operations has the potential to create an industry sector generating in excess of $13 billion within the first three years of integration (AUVSI 2013).

Recent research has shown a growing focus on UAS technology applications in aerial imaging and surveying across multiple industries. This research included a 2014 study which evaluated UAS as imaging and surveying platforms in civil engineering applications. This revealed the potential of UAS to solve some of the monumental issues involved in conducting surveys and imaging projects in civil engineering, such as high costs and time consumption (Siebert & Teizer, 2014).

Additionally, a 2008 study used an open-source, consumer-grade UAS, and a consumer-grade digital camera system to gather aerial imagery of the Super-Sauze landslide in the Southern French Alps. The goal was to investigate UAS as a low-cost alternative remote sensing method (Niethammer *et al.*). From the data gathered using the unmanned aircraft, the research team used photogrammetric processing and a structure-from-motion algorithm to deliver high-quality ortho-mosaics and Digital Surface Models (DSMs).

UAS were used to acquire aerial imagery which was photogrammetrically processed to yield high-quality ortho-mosaics and surface data in each of these studies. Based on the successful results of using UAS to gather aerial imagery and geospatial data in other fields, the team hypothesized that similar success might be attained if UAS were introduced as a supplementary aerial photography and geospatial data collection tool within the airport environment.

Investigation of published literature revealed a demand for research into UAS with regards to airport operations. ACRP, The National Academies of Sciences, Engineering, and Medicine, and the Transportation Research Board (TRB), are currently awarding grants for research regarding “Airports and UAS” (Transportation Research Board 2016). This demand further solidified the notion that a solution involving the interaction between UAS and airports would be relevant.

The team decided to focus on applying UAS technology in a remote sensing role at airports, due to the published research findings. Information gleaned from the literature and from industry advisers convinced the team that UAS have the potential to make a positive impact on airport planning—specifically, the cost and efficiency of airport surveying and aerial imagery collection for airport planning and for generating or updating airport master plans, and ALPs.

Problem Solving Approach

The team objective was to develop a solution that would introduce UAS as an additional tool for airport geospatial data and imagery collection processes. The team's goal was to supplement, rather than replace, the current aerial imaging and data collection methodologies. One focus was flexibility concerning the platforms and sensors that are used in this methodology. For the purposes of this submission, the team elected to test a platform and a sensor readily available for testing. However, there are currently numerous options available on both the UAS and sensor markets, which could be substituted during implementation.

Platform

The platform chosen to demonstrate the team's methodology is the Phantom 4 quadcopter manufactured by Dà-Jiāng Innovations Science and Technology Co. (DJI). Three Phantom 4 systems were made available to the team during project execution by the team's sponsoring institution, Kansas State University Polytechnic Campus. These afforded the opportunity to do a practical, proof-of-concept exercise to vet the theory. The team conducted research on the Phantom 4 platform to ensure that it had all the attributes needed. Critical aircraft specifications included size, obstacle avoidance capability, and payload capacity. The weight of the aircraft when ready-to-fly is 3.04 pounds (DJI, 2016). This attribute is critical because it allows the aircraft to operate under 14 CFR Part 107 as a small UAS (FAA 2016). Additionally, the aircraft has an operation Obstacle Sensing System (OSS) which enhances safety by reducing the likelihood of collisions. Finally, the Phantom 4 carries a natural-color

Figure 2: Phantom 4 by DJI

imaging sensor as a payload which allows for aerial imagery collection and geospatial analysis through photogrammetric processing.

One drawback of the Phantom 4 in remote sensing applications is that it does not possess interchangeable payload capabilities. The sensor carried by the Phantom 4 cannot be swapped-out for another sensor such as a thermal imaging sensor or a LiDAR sensor (DJI, personal communication, Feb. 2017).

By making flexibility a key point of the project, the team ensured feasibility, should photogrammetrically processed aerial imagery become an unacceptable means of data acquisition, due to regulatory constraints or additional data requirements. However, digital photogrammetry and LiDAR measurement systems often produce comparable results (Stal *et al.*, 2013). Therefore, the team felt comfortable in recommending the Phantom 4. But, if the situation dictates that LiDAR data is required, an alternate aircraft possessing an interchangeable payload capability may be substituted. An alternate platform could easily be outfitted with a LiDAR sensor such as the RIEGL “miniVUX-1UAV” which is designed to be carried on a UAS (Riegl Laser Measurement Systems Gmbh, 2017).

Sensor

The sensor used in the proposal is a natural-color imaging sensor that is integrated into the Phantom 4 airframe by the manufacturer. The make and model of the sensor is proprietary to DJI. However, the necessary specifications are found in the Phantom 4 User Manual. A 12-megapixel camera system capable of capturing still images and video in either 1080p or 4K resolution is installed on the aircraft. The camera system has a 3-axis stabilizing gimbal with a 120° range of motion. The stabilizing gimbal enables the system to capture clear and stable imagery despite airframe motion and vibration in flight (DJI 2016). This hardware was critical, as post-processing and product generation are dependent on the quality and clarity of captured imagery.

Software

Post-processing software is required to turn the raw images into data products. The team selected Esri ArcGIS, a Geographic Information System (GIS) software package, and Pix4Dmapper, used for converting aerial imagery into professional maps and models. Use of the two professional software packages in concert allowed for the generation of geo-rectified ortho-mosaics and DSMs from captured images (Pix4D), plus facilitated the manipulation of created models to render useful data products (ArcGIS). Both software packages are professional-grade licensed programs that were available to the team through the on-campus processing lab.

Proof-of-Concept

The team sought to complete a proof-of-concept operation at an active airport to verify the adequacy of the selected platform, sensor, and software package in a real-world situation. A partnership was established with the management of Kit Carson County Airport (KITR) in Burlington, Colorado, through the industry connections of one of the team’s faculty advisors. This location served as the site of the team’s proof-of-concept demonstration.

Summary

After a partnership with Mr. Daniel Melia, the manager of KITR, was established and permission to test the methodology was obtained from the city of Burlington, the governing entity of KITR, the team planned and executed a test mission in mid-February of 2017. Significant details of the operation are:

- Location: Burlington Kit Carson County Airport (KITR) (with permission and assistance from the Kit Carson Airport manager and the city of Burlington)

- Date: 18 February 2017.
- Time: 8:30 AM – 2:00 PM (includes mission setup, execution, and breakdown)
- Airspace: Class G (no supplementary FAA authorization was required to operate under Part 107).
- Approximate Area of Data Acquisition: 550 acres.
- # of Ground Control Points (GCPs): 41
- Aircraft Used: DJI Phantom 4.
- Governing Regulations: 14 CFR Part 107.
- Flight Crews (x3): Licensed Remote Pilot-In-Command (RPIC), Visual Observer (VO)
- Data Acquired: 2943 natural color images.
- Post-Processing Location: Kansas State University Polytechnic Campus UAS Data Processing Lab
- Post Processing Software: Pix4D and Esri ArcGIS

Operation

The initial task was to capture coordinates of pre-selected GCP locations using a Real-Time Kinematic (RTK) Global Positioning System (GPS). Flight operations were initiated at approximately 9:30 AM, after GPS capture concluded. The 550-acre operations area (Figure 3), was flown in its entirety. All flying was conducted under manual control by the RPIC with the onboard camera set to capture images at a two-second interval. As mentioned previously, the reasons for conducting the operation manually are addressed in the feasibility section of the cost-benefit analysis. Flight concluded at 1:00 PM. Final tasks included equipment breakdown and data verification.

Figure 3: KITR Operations Area

Data Processing

The image processing was conducted in the UAS data processing lab located on the Kansas State University Polytechnic Campus. The imagery was stitched together into an ortho-mosaic (Figure 4). The

Figure 4: KITR Ortho-mosaic

next processing steps included GCP rectification of the ortho-mosaic, point cloud, and DSM generation. The team shared the data with industry partners Mr. Tim Kahmann and Mr. Erik Pfeiffer of Coffman Associates, Kansas City, MO, during a video conference. The objective of sharing data was to determine how the data captured using the team’s methodology compared to data sets obtained by manned aircraft which Coffman Associates utilized on a regular basis. Through this exchange, Mr. Kahmann and Mr. Pfeiffer verified the quality and applicability of the captured imagery as it pertains to their requirements as airport consultants, and indicated that it compared favorably based on resolution and coverage with imagery acquired using traditional methods.

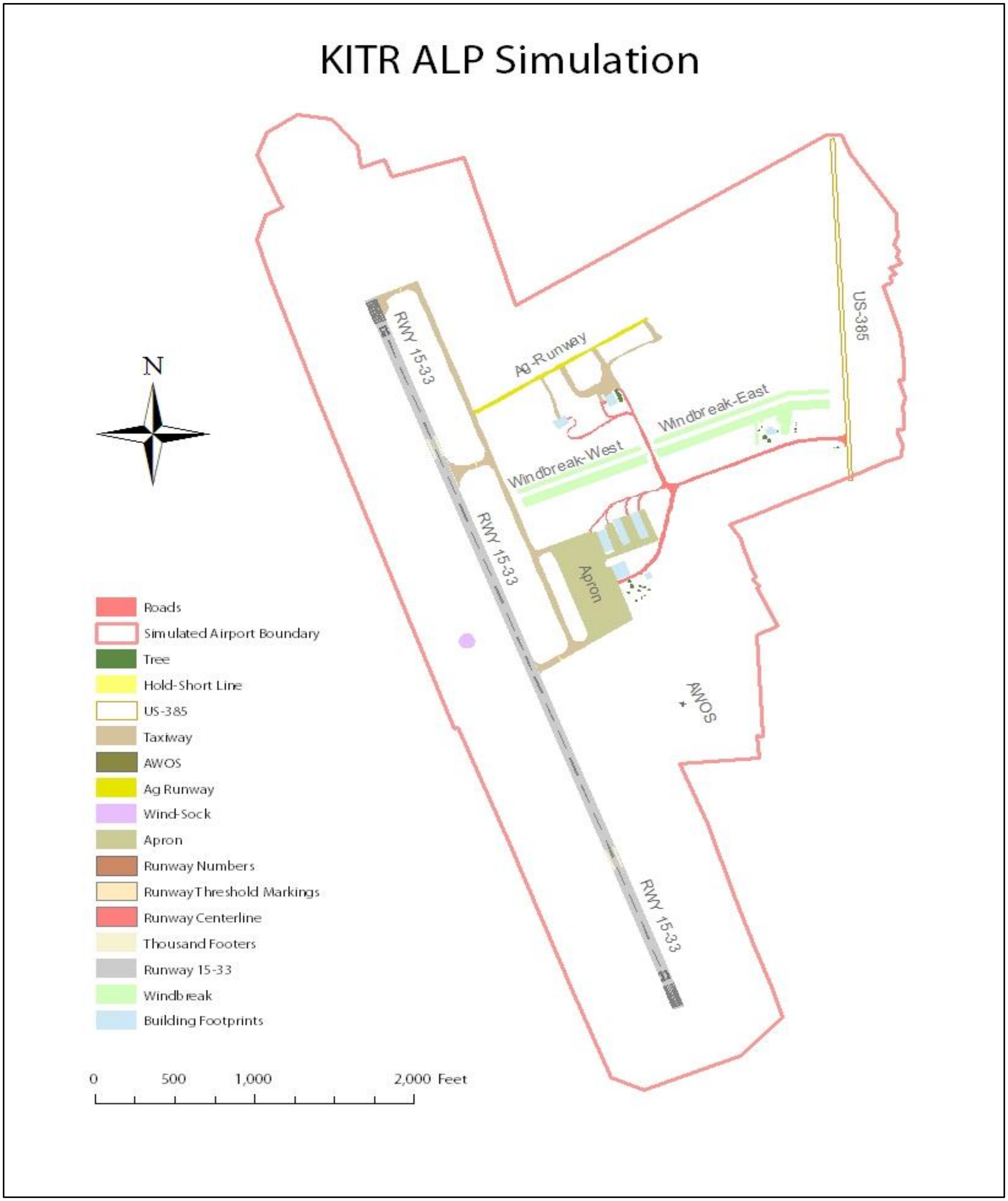

Figure 5: Simplified ALP Simulation (ArcGIS)

The team requested traditional sample project data from industry partner Coffman Associates during the video conference. With permission from the Salina Regional Airport, Coffman Associates was able to release sample data from a Salina ALP project they had previously completed. Referencing this industry example, the team created a simplified ALP using the data acquired from KITR (Figure 5). Completion of this step finalized the demonstration of the applicability of data gathered by the team in a real-world scenario.

Safety Risk Assessment

The team conducted a safety risk assessment on the proposal, which integrates UAS-based remote sensing missions into airport operations, referencing the SMS Safety Management System Manual, the FAA System Safety Handbook, and ACRP resources. While many hazards and risks would be consistent regardless of location, others would vary between airports based on traffic, location, and environmental factors. Thus, a thorough safety risk assessment must be conducted before implementation at each airport. With this in mind, the safety risk assessment conducted below has been tailored to reflect the implementation of this methodology at KITR where the team conducted the proof-of-concept operation. The safety risk assessment process is comprised of five components identified in the SMS Safety Management System Manual, and the ACRP resource, “ACRP Design Competition - Wes Timmons - Completing a Safety Risk Assessment.”

System Description

The first component of the assessment process is a system description for the safety risk assessment to be conducted. For this methodology, the system involves conducting low-altitude remote sensing operations utilizing UAS at KITR.

Hazard Identification and Risk Analysis

This segment focused on the hazards associated with conducting low-altitude UAS operations at KITR. Each hazard was identified and the associated risk was determined in reference to the severity and likelihood of outcomes. The terms used to express likelihood, severity, and their associated definitions are from the SMS Safety Management System Manual and the FAA Safety Systems Handbook (Figures 6 and 7). The identified hazards and pre-mitigation severities, and likelihoods are depicted in Figure 8.

	Hazard Severity Classification *Note: Severities related to ground-based effects apply to movement areas only*				
	Minimal	Minor	Major	Hazardous	Catastrophic
	CONDITIONS RESULTING IN ANY ONE OF THE FOLLOWING				
Unmanned Aircraft Systems	Discomfort to those on the ground Loss of Separation leading to a Measure of Compliance greater than or equal to 66 percent	Low Risk Analysis Event severity, two or fewer indicators fail Non-Serious injury to three or fewer people on the ground	Medium Risk Analysis Event Severity, three indicators fail Non-serious injury to more than three people on the ground A reduced ability of the crew to cope with adverse operating conditions to the extent that there would be a significant reduction in safety margins Manned aircraft making an evasive maneuver, but proximity from Unmanned Aircraft remains greater than 500 feet	High Risk Analysis Event severity, four indicators fail Incapacitation to Unmanned Aircraft System crew Proximity of less than 500 feet to a manned aircraft Serious injury to persons other than the Unmanned Aircraft System crew	A collision with a manned aircraft Fatality or fatal injury to persons other than the Unmanned Aircraft System crew Fatality or fatal injury to persons other than the Unmanned Aircraft System crew

Figure 6: Hazard Severity Classification

Likelihood of Occurrence Definitions	
Probable	Qualitative: Anticipated to occur one or more times during the entire system/operational life of an item
Remote	Qualitative: Unlikely to occur to each item during its total life. May occur several times in the life of an entire system or fleet.
Extremely Remote	Qualitative: Not anticipated to occur to each item during its total life. May a few times in the life of an entire system or fleet.
Extremely Improbable	Qualitative: So unlikely that it is not anticipated to occur during the entire operational life of an entire system or fleet.

Figure 7: Likelihood of Occurrence Definitions

Hazard Identification Number	Hazards	Severity	Likelihood
#1	Frequency Interference	Hazardous	Extremely Remote
#2	Lost Link	Major	Remote
#3	Lost GPS Signal	Minor	Remote
#4	Manned Aircraft Traffic	Catastrophic	Extremely Remote
#5	Unmanned Aircraft Traffic	Major	Extremely Remote
#6	Ground Obstacles/Terrain	Hazardous	Extremely Improbable
#7	Weather	Minor	Extremely Remote
#8	Loss of Line of Sight	Major	Remote

Figure 8: Hazard Identification Table

Risk Assessment

In the third stage, the team calculated the initial risk associated with each hazard and plotted the value on a risk assessment matrix (Figure 9). Note: Hazards are labeled in this risk assessment matrix according to the hazard identification numbers assigned in Figure 8.

Severity Likelihood	Minimal	Minor	Major	Hazardous	Catastrophic
Probable	Low	Medium	High	High	High
Remote	Low	Medium **(#3)**	Medium **(#2),(#8)**	High	High
Extremely Remote	Low	Low **(#7)**	Medium **(#5)**	Medium **(#1)**	High **(#4)**
Extremely Improbable	Low	Low	Low	Medium **(#6)**	High Medium

Figure 9: Pre-Mitigation Risk Assessment Matrix

Risk Control

During the fourth step of risk assessment development, the team identified appropriate measures, to mitigate risks associated with potential hazards to the maximum practical level. According to the SMS Safety Management System Manual, a high-risk level is considered unacceptable and “the NAS change cannot be implemented unless the hazard’s associated risk is mitigated to medium or low.” To accomplish this reduction of risk, the team devised risk mitigation strategies and controls for each of the potential hazards associated with the operation. After mitigation, the hazards were again plotted on a risk assessment matrix (Figure 9) based on the post-mitigation risk levels.

Hazard #1: Frequency Interference

Risk Mitigation:

- Take credit for frequency hopping feature present on aircraft transmitter. Frequency hopping reduces the likelihood of frequency interference.

Hazard #2: Lost Link

Risk Mitigation:

- During the operation, the team would be in constant radio contact with local air traffic via the KITR UNICOM frequency (122.8) to reduce the likelihood of an accident resulting from a lost link situation.
- Take credit for aircraft safety features including the lost link Return-To-Home (RTH) failsafe. This failsafe reduces both the likelihood and severity of a lost link situation.

Hazard #3: Lost GPS Signal

Risk Mitigation:

- In the event of a loss of GPS signal, the PIC would toggle the aircraft into attitude (non-positioning) mode, and return the aircraft to land. This procedure would reduce the severity of a lost GPS situation

Hazard #4: Manned Aircraft Traffic

Risk Mitigation:

- A minimum of one visual observer is included in every crew. In addition to maintaining line of sight with the aircraft during flight, the visual observer is responsible for spotting traffic, including manned aircraft that present a hazard, and reporting it to the (PIC), so that corrective action may be taken as necessary. This procedure would reduce the likelihood of a collision, or emergency actions being taken as a result of traffic conflict.

- Take credit for 14 CFR Part 107 regulation requiring unmanned aircraft to yield right of way to other aircraft. Following this regulation would reduce the likelihood of a collision.
- During the operation, each crew would be in constant radio contact with local air traffic via the KITR UNICOM frequency (122.8). This contact would allow coordination and communication between the unmanned crew(s) and manned traffic also operating in the vicinity; further reducing the likelihood of a collision.
- If manned traffic becomes a factor, the PIC would take manual control of the UAS, adjust altitude and/or heading as necessary, and land as soon as practical; flight operations would be temporarily halted until traffic becomes a non-factor. This action would reduce the likelihood of a collision with manned traffic.

Hazard #5: Unmanned Aircraft Traffic (during simultaneous operations):

Risk Mitigation:

- During simultaneous operations the altitudes of unmanned aircraft would be staggered, reducing the likelihood of a collision.
- A minimum of one visual observer would be included in every flight crew. In addition to maintaining line of sight with the aircraft during flight, the visual observer is responsible for spotting traffic, including other unmanned aircraft, and reporting it to the PIC, so that corrective action may be taken as necessary. This action would reduce the likelihood of a collision, or emergency actions being taken because of traffic conflict with other unmanned aircraft.

Hazard #6: Ground Obstacles/Terrain

Risk Mitigation:

- Take credit for aircraft safety features including the OSS built into the DJI Phantom 4. This system reduces the likelihood of a collision with an obstacle or terrain.

- All normal aircraft operations would be performed in position mode where the OSS is active. Ensuring normal operations are conducted in position mode with the OSS active further reduces the likelihood of a collision with obstacles/terrain.

Hazard #7: Weather

Risk Mitigation:

- Flight operations would not be permitted when current or forecast winds exceed 15 MPH. This limit would reduce the severity of wind effects on aircraft flight characteristics, and reduce the likelihood for a wind-related accident.
- Take credit for 14 CFR Part 107 regulations, which permit flight only when flight visibility is at least 3 miles. This restriction would reduce the likelihood of lost line-of-sight situations, and weather-related accidents.
- Flight operations would not be permitted in known icing conditions. This limitation would reduce the likelihood for a weather-related accident.

Hazard #8: Loss of Line of Sight

Risk Mitigation:

- A minimum of one visual observer would be included in every crew. The primary responsibility of the visual observer(s) would be maintaining visual line-of-sight with the aircraft. This measure would reduce the likelihood of losing line-of-sight with the aircraft.
- In the event of a loss of line-of-sight during flight operations, the aircraft RTH failsafe would be activated. This failsafe would reduce the severity of a lost line-of-sight situation.

Severity / Likelihood	Minimal	Minor	Major	Hazardous	Catastrophic
Probable	Low	Medium	High	High	High
Remote	Low	Medium	Medium	High	High
Extremely Remote	Low **(#3)**	Low **(#2)**	Medium **(#8)**	Medium **(#1)**	High
Extremely Improbable	Low	Low **(#7)**	Low **(#5), (#6)**	Medium	High / Medium **(#4)**

Figure 10: Post-Mitigation Risk Assessment Matrix

Industry Interaction

To ensure viability of our proposal, industry contacts established in prior academic work were contacted to provide feedback concerning the applicability of UAS operations at airports. As referenced, the team contacted Mr. Kahmann of Coffman and Associates for input regarding the use of UAS in the airport maintenance and planning industry. This input confirmed the team's initial considerations. With a broad understanding of current airport geospatial data collection and associated challenges obtained from Mr. Kahmann and his associate Mr. Pfeiffer, the team contacted Dr. Chester Young, an instructor of airport law and environmental studies at Kansas State University Polytechnic Campus, for his industry contacts in construction. Via those contacts, Mr. Ben Lindner from GB Architects Engineers (GBA), provided specific answers to team-developed questions concerning methodology.

The team maintained close contact with multiple faculty advisers throughout the entirety of the process. The university advisers gave input on the process used by the students and aided in resource acquisition required to complete a proof-of-concept with industry standard equipment.

The team deemed it necessary to contact airport administration to conduct a proof-of-concept operation, even though there was no need for additional authorization when flying UAS missions under the current regulations for commercial use of UAS (FAA, 2016). As previously addressed, KITR Manager Daniel Melia was receptive to the concept as well as the prospect of our test flights at KITR. Mr. Melia's input was valuable in adapting the mission as well as the identification of feasibility issues.

The team shared the developed data and images with the industry contacts at Coffman Associates, following the data collection phase. Mr. Kahmann and Mr. Pfeiffer were enthusiastic about the team's methodology, both in concept and execution with the given equipment and timeframe. Mr. Kahmann and Mr. Pfeiffer discussed the applicability of the team's methodology and helped the team establish another industry connection in Martinez Geospatial to compare costs with traditional aerial photography methods using manned aircraft. Throughout the project, the team gained extensive insight from industry advisers' knowledge and experience with geospatial subjects, as well as their reactions, questions, and suggestions based on the team's progress. The opportunity to provide a completed example of how UAS geospatial data collection can be used in and applied to airport work through an industry contact and adviser managing the Kit Carson County Airport was a definitive foundation for visualizing and completing the project.

Technical Design Description

The geospatial data collection of an airport changes on a case-by-case basis, depending on the airports, equipment, and applications of the data collected. The team developed a solution for this study that could fulfill a simple data collection need of an airport looking to update a master plan or an ALP.

The team utilized the low costs of UAS aerial imaging to create an alternative geospatial data collection method, cutting costs and creating a more on-demand source to meet the needs of industry, as

Figure 11: KITR Operation Flight Path and GCP Layout

communicated by industry advisers. The team planned and executed six flights, referenced by forty-one GCPs over KITR, as a demonstration of a specific mission applying the team's methodology. Figure 10 highlights the GCPs (yellow points) and the flight paths detailed by the location from which each aerial image was taken (red points).

Based on the solar elevation angle during the operation performed in mid-February, the flights were planned for an approximate four-hour operation window from late morning to early afternoon, with a one-hour time window beforehand to lay out necessary targets for additional GCPs, which could not be acquired from terrain or ground markings. Each flight was planned to require less than 15 minutes (averaging at 11 minutes due to wind) to provide for a safety margin of at least five minutes on the approximately 20-minute flight time allowed by the Phantom 4 battery.

The specific operation requirements can vary widely based on the various aspects involved. Thus, these variations may alter the platform technical design needs for the operation at hand. An individual operator or consultant may have unique specifications regarding the platform or sensors they need, which can determine the GCP layout, image development software, or other aspects of the methodology. However, reviewing current best practices involving the application of contracted aerial photography, the literature and data have shown that using UAS as demonstrated would offer the same, if not better results in economically acquiring geospatial data.

Cost-Benefit Analysis

Through industry contacts, the team obtained an overview of the actual costs incurred by airports and contractors in current airport aerial image data collection methods. The team gained more insight on the risks and time needed in gathering and utilizing geospatial data, beyond prices of data collection and processing. Although specific figures became available from industry contacts, which can be compared directly, the commercial potential can be analyzed more objectively with a critical consideration of the fundamentals used in both traditional procedures and the demonstrated UAS method.

Operationally, the team's methodology is a more streamlined and efficient process producing lower financial costs and a faster completion time. Although the original goal of providing alternative methods through UAS operations was to reduce costs and increase efficiency, the team also found tangential benefits impacting airport managers and contractors. For example, enabling airports and related contractors to perform certain data collection operation duties without the need for third party companies for flyovers and image development is an additional benefit (T. Kahmann, Coffman Associates, D. Melia, KITR, personal communication, Feb. 2017).

To evaluate actual costs incurred, an estimate from Martinez Geospatial (MTZ), a geospatial service provider, was compared against the results of the team's methodology (T. Kahmann, Coffman Associates, personal communication, Mar. 2017). Ryan Flicek, Aviation Director of MTZ stated ". . . [an] estimated fee based on a theoretical ALP Mapping Project at Kit Carson County Airport. . . It is understood that this project would support a standard paper ALP . . ." This quote applies the following data to the team's performed proof-of-concept and demonstrates a specific comparison. The estimate from Director Flicek is provided in Figure 12 to outline the specific costs.

Task	Fee
Project Planning/Project Management	$3,461.40
Imagery Acquisition (Flight Mission)	$6,000.00
Aerotriangulation	$1,944.00
Planimetric Mapping, Topographic Mapping, Digital Terrain Model	$7,324.68
Orthophoto Production (0.25’ GSD)	$2,520.00
Quality Assurance, Mapping Edit & Formatting	$3,262.56
Field-Survey Services (10 Targets)	$8,000.00
TOTAL	$32,512.64

Figure 12: MTZ Fee Schedule

Through the team’s proof-of-concept testing and collaboration with the UAS program of Kansas State University Polytechnic Campus, the team incurred a minimal cost of under $100.00 for the demonstrated operation. The team reached out for quotes from professional UAS operators to determine a realistic comparison for industrial use. With assistance from Mr. Trevor Witt, a professional in the UAS industry, the team was quoted the costs detailed in Figure 13 for performing geospatial data collection at KITR (T. Witt, Witt Technologies LLC, personal communication, Feb. 2017).

Task	Fee
UAS Image Collection Mission	$2,000.00
Image Development at $35/Hour for 16 Hours of Development	$560.00
TOTAL	$2,560.00

Figure 13: Proof-of-Concept Fee Schedule

These total costs compared leave a base difference of $29,952.64. Due to the academic nature of the team’s proof-of-concept, costs such as quality assurance, planning and management, editing, and formatting were non factors to the team’s operation. Professional UAS operations are likely to incur similar costs to the industry quote, when again performed by industry. A more accurate estimate for industry operators is expected to provide a difference of closer to $23,228.68, as shown in Figure 14.

Task	Fee
UAS Image Collection Mission	$2,000.00
Image Development at $35/Hour for 16 Hours of Development	$560.00
Project Planning and Management	$3,461.56
Quality Assurance, Formatting, and Editing	$3,262.56
Total	***$9,283.96***
Total Cost Reduction from Traditional Industry Quote	**$23,228.68**

Figure 14: Adjusted Proof-of-Concept Fee Schedule

In addition, lower cost analysis can be drawn through an understanding of the necessary steps in operations of each mission type. For example, Director Flicek listed their utilized aircraft to be a Cessna 210N, a single engine piston aircraft. According to Aircraft Cost Calculator LLC, a company providing an online tool for estimating aircraft operating costs, the Cessna 210N incurs an average hourly cost of $220.69, which means a five-hour flight would compare to the total cost of acquiring the aircraft used in the team's proof-of-concept. This cost difference is easily understood when considering the indirect costs associated with operating a manned aircraft. For example, Aircraft Cost Calculator lists an annual expense of $13,747.50 as hangar expenses for safe-keeping of manned aircraft used in current best practices. Conversely, the UAS used in the team's solution can be easily stored in a small space (DJI, 2016).

Another demonstrated benefit is that the sensor system used in the team's proof-of-concept is integrated into the Phantom 4 and is a part of the approximately $2,000.00 original aircraft cost. Conversely, Director Flicek lists the current methods using an UltraCam Falcon from Vexcel Imaging; different systems from Vexcel Imaging are resold for prices ranging between $10,000.00 and $200,000.00 (New Tech Services Inc., personal communication, Mar. 2017).

Communication with industry professionals has shown other notable benefits to applying UAS to airport geospatial data collection besides reduced costs. Benefits such as simplifying the process with the use of UAS, shorter development time, fewer risks, *etc.* would be far from insignificant to airport administrations and contractors (T. Kahmann, E. Pfeiffer, Coffman Associates, Personal communication, Nov. 2016). Mr. Kahmann and Mr. Pfeiffer explained how image data is necessary in document development such as airport master plans and typically must be completed as one of the first objectives. The use of UAS to expedite geospatial data collection would be ideal to ensure timely availability of all relevant images and information, preventing unforeseen delays early in a project due to challenges with image acquisition.

However, many airport administrators and contractors find that the simplicity of employing an external pilot outweighs the potential increase of costs, notwithstanding that the use of most commercially available unmanned systems is undeniably cheaper and less complicated. While these contracts to private operating pilots or crews may be less complicated in each individual operation, it is important to note that private contractors operating unmanned systems, collecting geospatial data are also available.

To further analyze benefits not associated with financial cost, the team also considered technical capabilities of the project compared to current industry practices. The team found better data resolution collected at lower altitudes using UAS and the integrated sensor systems, than traditional methods associated with manned aircraft. Director Flicek described the imaging overview as depicted in Figure 15.

Resolution	0.25’ Ground Sample Distance
Map Scale/Interval	1” = 40’, 1-foot Contour Interval
Map Accuracy	ASPRS Class II Standards

Figure 15: MTZ Ortho Imaging Overview

These specifications can be significantly improved by the using of UAS for data collection. Despite the lower quality of sensor system, the lower altitude of flight (400’ vs 2700’) affords for an advantageous opportunity for precise data collection and development, resulting in 1.1 inches of resolution improvement.

Manned Aircraft Geospatial Imagery Resolution	3” (.25’)
Proof-of-Concept UAS Geospatial Imagery Resolution	1.9” (.228’)

Figure 16: Imaging Comparison

UAS implementation for geospatial data collection can provide an expedited acquisition and development timeline. For example, aerial data being used to help with wildlife control on an airport may be required promptly, which could more likely be provided through UAS operations than manned aircraft. Due to the versatility and flexibility of UAS, the most notable commercial potential of involving UAS in the collection of geospatial data may be the diversity of uses and applications for on demand and more affordable data.

Feasibility

The team identified a series of challenges to address in order to bring the proposal to full-scale implementation. The first issue was identified during the literature review. One document reviewed during this process was the 14 CFR Part 107 regulations for the operation and certification of UAS. 14 CFR Part 107 places restrictions on the operation of UAS in controlled airspace (FAA 2016). Because of these confines, requests to waive the airspace restrictions would need to have been submitted to and approved by the FAA in order to integrate the methodology at airports located in controlled airspace.

Obtaining approval to operate UAS at controlled airports is a complex issue with many safety implications that increase with higher traffic. However, there is precedent for receiving FAA permission to operate UAS for imaging and data collection purposes at high traffic controlled airports. UAS company 3D Robotics (3DR), was able to obtain a waiver to fly imaging missions as part of a new non-aviation construction project on a parking structure at Atlanta's Hartsfield-Jackson International Airport in January of 2017 (3DR 2017). This actual case demonstrated that approval for the operations of UAS may be attained for even the most complex airport environments when appropriate safety assurance measures are demonstrated.

An additional challenge making the project fully feasible was found during the team's proof-of-concept operation at KITR. The team was required to conduct all flight operations during data collection without autonomous flight capabilities. The root cause of this issue was that DJI, the aircraft manufacturer, placed restricted "no fly" zones around a multitude of areas including many airports. DJI created a process to allow consumers to temporarily disable these restrictions in the "DJI GO" flight application. However, DJI has not given this capability to third party flight software developers who create the various applications that allow for generation and execution of automatic (autopilot controlled) flight plans. Current circumstances dictate that the only way to perform operations with UAS at airports located in these restricted areas is via manual control.

The success of the proof-of-concept operation demonstrated that quality data may be obtained with this methodology while flying the UAS manually. However, in order to maximize efficiency, and to mitigate the risk of gaps in coverage due to operator error or imprecision, this inability to fly UAS automatically using current flight applications must be rectified in some form.

Conclusion

Geospatial data collection is a vital component of many airport improvement and development projects for all airports. Airports rely heavily on data sets such as the ALP, and routinely require quick access to an aerial view of the airport facilities and property for mockups, short and long term planning, feasibility studies, and other projects involved in day-to-day operation. Airport operators perpetually run into difficulties due to the high costs associated with aerial photography and data collection using traditional methodologies. The difficulties associated with these high costs often result in the use of outdated ALPs, lack of accurate planning in airport improvements, and slow turnaround times on many other projects dealing with airport space or facilities (T. Kahman, Coffman Associates, E. Pfeiffer, S. Swanson, K. Bieker, Salina Regional Airport Administration, personal communication).

Industry professionals have identified a need to supplement current methodologies with a potential lower-cost option, especially for quick and small area projects. Aerial mapping and ALP updates are often delayed or cancelled due to the prohibitive costs associated with data acquisition flights. As seen in the cost-benefit analysis on pages 31 through 35, the current costs of aerial photography alone are often a limiting factor for updating imagery for airfield improvements (R. Flecik, MTZ, S. Swanson, Salina Regional Airport Administration, personal communication).

UAS are quickly becoming a viable and advantageous method of collecting quality aerial geospatial data. The literature definitively shows a success in integrating UAS technology in a variety of geospatial uses where a cost effective, lower risk, on demand option was necessary (Immerzeel, *et al.*, 2014; Molina, 2014; Stal, Tack, Maeyer, Wulf, & Goossens, 2013; Tonkin, 2014). While the airport setting can be a complicated environment with additional stipulations and guidance on acceptable data collection methods, the team found the literature to support method adaptation and even provide directions for performing airport survey remote sensing (FAA, 5 May 2009; FAA, 21 May 2009; FAA, 2009; FAA, 2011).

Using UAS to solve geospatial data cost problems is a viable option for airport managers and consultants. The team's proof-of-concept study demonstrates the applicability and reliability of using UAS for airport operations. The team demonstrated the feasibility of reliable and safe UAS operations at an airport in accordance with FAA regulations, through mitigation. The team demonstrated a $23,228.68 cost reduction in comparison to currently used techniques for geospatial data collection suitable for the needs of airport operators and consultants.

Appendix A: Team Information

Undergraduate Team Members:

Elliot Rogers

Email: pleocoma@gmail.com

Phone: 530-979-0314

Mailing Address: P.O. Box 1987, Lawrence KS 66044

Preston Renfro

Email: prestonrenfro73@gmail.com

Phone: 214-226-8615

Mailing Address: 11220 Flamingo Lane Dallas, TX 75218

Ian Bonsall

Email: ibonsall@outlook.com

Phone: 785-728-7375

Mailing Address: 402 E 12th St, Goodland, KS 67735

Hsin Huang

Email: hhsin@ksu.edu

Phone: 785-320-0225

Mailing Address: 2300 Centennial Road, Salina, KS 67401

Ryan Thomas

Email: ryan.thomas.2@hotmail.com

Phone: 913-426-0202

Mailing Address: 2214 Millwood Drive, Atchison, KS 66002

Faculty Advisors:

Dr. Tara Harl

Email: tlharl@ksu.edu

Dr. Michael Most

Email: mtmost@ksu.edu

David Burchfield

Email: burchfie@ksu.edu

Christopher Senn

Email: chrissenn@ksu.edu

Dr. Durant Bridges

Email: durantbridges@ksu.edu

Appendix B: University Description

Kansas State University's Polytechnic Campus provides a small, personalized atmosphere where the experience matters and learning isn't just confined to a textbook and classroom. Applied discipline is emphasized, so programs encompass lab time, in-the-field education, competitions, internships and business connections. With this hands-on approach, students are given valuable opportunities that would prepare them for their future careers and help them stand out amongst others in their field.

Kansas State Polytechnic offers 14 undergraduate programs and a Professional Master of Technology, with an approximate 90 percent placement rate of its students in either employment or higher education after graduation. For aviation students, the campus is located on a 12,000-foot runway and is home to one of the largest enclosed unmanned flight facilities in the nation. Suite-style residence halls, all-you-can-eat meal plans, a state-of-the-art recreation center and more than 20 clubs and organizations provide students with big university benefits in an easy to navigate environment.

Located in Salina, the Polytechnic Campus is one of four in the Kansas State University system. The city has a population of about 50,000 residents and offers a variety of local and national restaurants, shopping, arts and entertainment. It is about an hour from the Manhattan campus, making it convenient to cheer on the Wildcats at home games.

Appendix C: Non-University Partner Description

Coffman Associates Airport Consultants

Coffman Associates is a specialized airport planning firm comprised of 25 professional and technical staff members whose work is focused exclusively on airport planning and associated environmental and noise studies. Therefore, the entire firm, its capabilities, and experience are directed at producing the most valuable master plans, noise compatibility studies, and environmental documentation obtainable in the industry. Coffman Associates has earned a reputation for excellence since its founding in 1979 and has been awarded the American Association of Airport Executives Corporate Cup of Excellence Award and the FAA Partnership Award.

Over the past 38 years, Coffman Associates has completed over 1,000 planning assignments, including more than 500 airport master plans, 100 airport noise compatibility studies, and over 200 airport environmental studies. As an extension of these three primary services, Coffman Associates has also prepared specific services focusing on wildlife hazard issues, airport financial analysis, rates and fee assessments, minimum standards, airport rules and regulations, airport business and strategic planning, obstruction analysis, and airport zoning and land use planning. Furthermore, Coffman Associates has been involved with the FAA Airports-GIS program since its inception, including being one of a few firms selected to complete a Phase One pilot eALP. The firm continues to be involved with Airports-GIS projects, as well as developing web-based applications to make GIS more useful to airports.

Mr. Kahmann and Eric Pfeifer represented the firm serving as industry representatives. Tim has over 9 years with Coffman Associates and serves as the geospatial manager. Eric has more than 10 years with the firm and is an airport planner and LEED certified sustainable development coordinator. They participated in conference calls, providing sample data, and connecting the team with other industry contacts.

GB Architecture Engineers (GBA)

GBA provides innovative engineering and architectural solutions for high-profile projects. GBA and its subsidiaries, GBA Builders, LLC, GBA Systems Integrators, LLC, and ViroCon, Inc. serve primary markets including transportation, water environment, building design, site development, commissioning, systems integration and construction management.

GBA and its subsidiaries employ a staff of 200 headquartered in Lenexa, Kansas, and with regional offices in Missouri, Colorado, Nebraska, Iowa, Texas and Illinois. Members of GBA's multi-disciplined staff work closely with clients to accomplish the firm's core purpose – "creating remarkable solutions for a higher quality of life."

GBA's Core Purpose and Core Values characterize our commitment to the firm's Core Ideology. They represent the fundamental nature of the company's vision. We are committed to living our Core Purpose and Core Values by utilizing them as the guiding principles of our business.

GBA's Core Purpose is creating remarkable solutions for a higher quality of life.

GBA's Core Values are:

- Committed to the highest standards of fairness and integrity.
- Dedicated to providing innovative and quality services.
- Be honest in our business practices.
- Provide exceptional service to our clients, profession, and community.
- Foster a learning environment.
- Promote compassion and teamwork with clients and employees.

Kit Karson County Airport (KITR)

The test flight to demonstrate the team’s proof-of-concept occurred at the Kit Carson County Airport in February of 2017. The Kit Carson County Airport is located 5 miles south of the city of Burlington, Colorado. The airport is owned and operated by the City of Burlington and offers flight services through Meliaire Aviation. The airport utilizes a single asphalt runway. The airport manager, Daniel Melia, permitted the team to perform test flights at this location and was interested in the prospects of how the design concept would be valuable to UAS in the future. Mr. Melia also aided with adapting the test flight and identifying feasibility issues.

Martinez Geospatial (MTZ)

Martinez Geospatial is a firm that utilizes aerial imagery, airborne LiDAR, and/or other conceptual ideas to develop innovative geospatial solutions tailored to the unique requirements of each individual project. Martinez Geospatial was founded as a private aerial mapping firm in 1974 and over the past four decades have transitioned from being primarily a photogrammetry specialist into a full-service geospatial services provider. Martinez Geospatial specializes in creating geospatial data for projects that include: architectural/structural, roadway, railway, aviation, energy resources, land use analysis, and site development.

Mr. Ryan Flicek represented Martinez Geospatial for the duration of the research paper. Mr. Flicek assisted the team with estimates on how the current industry would react and charge for the new research. He also provided sample data to the team.

Appendix E: Evaluation of Educational Experience

Students:

1. **Did the Airport Cooperative Research Program (ACRP) University Design Competition for Addressing Airports Needs provide a meaningful learning experience for you? Why or why not?**

    The ACRP competition was a meaningful learning experience for all members of our group. As an interdisciplinary team, we came into this project with different knowledge bases to draw from (airport management and UAS operations). By completing a project that integrated the worlds of airports and UAS, each team member was able to acquire a much better understanding of an area where our pre-project knowledge was lacking. The applicability of the solution we chose, and the rigor of polishing a document for submission to ACRP was a meaningful way to develop each member's understanding of working in the airport or UAS industry.

2. **What challenges did you and/or your team encounter in undertaking the competition? How did you overcome them?**

    The team encountered and overcame multiple challenges throughout the course of this project. One of the more major ones was the limited timeframe for project completion. The team undertook this challenge as a one semester project beginning in mid-January and finishing in mid-April. With hindsight now available, we as a team agree we would have preferred to take this competition on as a longer term project perhaps starting in August or September. However, we were able to effectively manage the limited time we had available in order to accomplish our goals. An additional challenge we ran into was discussed in some detail in the feasibility section of the paper. During the testing of the team methodology at Kit Carson County Airport, we were unable to conduct automatic flights, and ended up having to fly our data acquisition mission manually. This was a very challenging experience as it made the acquisition of high quality and complete imagery a more difficult prospect. However, solving this problem by operating manually, was a very valuable experience, especially for the UAS members of the operations team.

3. Describe the process you or your team used for developing your hypothesis.

This team was initially formed with the understanding that we would pursue a project that focused on an airport issue which UAS may have the potential to mitigate. From the early stages of the project, we were partnered with Coffman Associates Airport Consultants who provided suggestions on areas where they believed UAS had the potential to impact airport operations based on their experiences. Considering their input and our own research, we arrived at the hypothesis that a UAS based methodology has the potential to address high cost and efficiency issues often associated with current imagery and geospatial data acquisition methodologies at airports.

4. Was participation by industry in the project appropriate, meaningful and useful? Why or why not?

The participation of industry was a critical component throughout the completion of this project. Industry interaction provided the team with input on the designed methodology, a location for testing, sample data/cost estimates, and insight into current practices within geospatial data collection and planning industries at airports. The team also produced a more viable project by keeping contact with industry and listening to their business-minded comments as the proof-of-concept was finalized.

5. **What did you learn? Did this project help you with skills and knowledge you need to be successful for entry in the workforce or to pursue further study? Why or why not?**

Throughout the course of this project, we have learned a lot about how imagery and geospatial data collection plays into the planning and operation of airports. Our interactions with Coffman Associates taught us a lot we didn't know about airport master planning, and airport layout plans, especially in the case of the UAS student. The research involved in the project, as well as the real-world testing of the team's solution at KITR gave the airport management students a much better understanding of the what, where, why, and how of UAS, and the UAS student in the group the rather unique experience of conducting operations on an active airport. We believe what we learned during this project will be helpful as we go into the workforce. The airport management students among the group will have a deeper understanding of UAS which will help during the increasing interactions that will be seen between airports and unmanned aircraft as the UAS industry grows. In the case of the UAS student in the group, the knowledge gained about how airports operate, as well as the real-world experience with some of the issues and restrictions currently causing a less than ideal relationship between airports and UAS. Will be helpful moving forward as those in the UAS industry try to improve the relationship between manned and unmanned aviation so that we may more safely and effectively share the airspace.

Faculty:

1. **Describe the value of the educational experience for your student(s) participating in this competition submission.**

   The project was undertaken to educate UAS and Airport Management majors about each other's worlds and enable them to speak each other's "language" with hopes to find solutions for the ever-growing challenges of airport/UAS interdependence. As the two student groups came to together and began to share knowledge about each arena of expertise it has been quite magical to watch the students grow, not only within their own area of major, but to have their knowledge base expanded into the other. The value placed upon this endeavor has been the training of future leaders for the aviation industry, far more prepared to understand the challenges our airport/UAS arena faces and hopefully find solutions for those challenges.

2. **Was the learning experience appropriate to the course level or context in which the competition was undertaken?**

   Yes very much so. They are all seniors about to graduate and with that, they must be able to take their place within industry with cutting edge knowledge industry will demand they have and be able to share.

3. **What challenges did the students face and overcome?**

   Learning each other's "language", Federal Regulations, nuances, habits, passion for their major and cross pollinating into a world they had little knowledge of before the project began. They took it on with tenacity and humor and though challenged beyond what even they assumed they would be, have risen to the occasion with high marks. Add to the fact the group has a member from Taiwan whose first language is not English, has only proven their abilities above and beyond anyone’s wildest hopes.

4. **Would you use this competition as an educational vehicle in the future? Why or why not?**

Yes both programs, Airport Management and UAS are in talks about using this project for future senior project course requirements that will continue to cross pollinate the two majors knowledge bases.

5. **Are there changes to the competition that you would suggest for future years?**

Requiring one specific style of writing (APA, MLA, Chicago, Etc.) Students are used to having research papers required in a particular style of writing. With ACRP giving them free option for writing in no particular style it was a bit of a twist that, while not throwing them off, did prove a bit distracting.

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