BEYOND VISUAL LINE OF SIGHT COMMERCIAL UNMANNED AIRCRAFT OPERATIONS:

SITE SUITABILITY FOR LANDING ZONE LOCATIONS

by

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To the internal and external voices that try to tell us what we can’t do.

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Abbreviations

AHP	Analytical Hierarchy Process
BVLOS	Beyond Visual Line of Sight
C2	Command and Control
CFR	Code of Federal Regulations
DOT	Department of Transportation
FAA	Federal Aviation Administration
GCS	Ground Control Station
GIS	Geographic Information System
GMTOW	Gross Maximum Takeoff Weight
GNSS	Global Navigation Satellite System
IMU	Inertial Measurement Unit
JARUS	Joint Authority on Rulemaking of Unmanned Systems
KML	Keyhole Markup Language
LiDAR	Light Detection and Ranging
LZ	Landing Zone
NESC	National Electric Safety Code
NOTAM	Notice to Airmen
QA/QC	Quality Assurance/Quality Control
RPIC	Remote Pilot in Command (or control)
SMS	Safety Management System
SOP	Standard Operating Procedure
SORA	Specific Operations Risk Assessment

TLS	Target Level of Safety
UAS	Unmanned Aerial (or aircraft) System
USGS	United States Geological Service
VLOS	Visual Line of Sight
VO	Visual Observer
WLC	Weighted Linear Combination

Abstract

Commercial UAS operations are one of the fastest growing industries in the world, exceeding 127 billion dollars per year as of 2016. The exponential growth combined with the relative lack of regulation over the last few years has highlighted the struggles of government to keep up with regulating a dynamic industry. With companies looking to perform beyond visual line of sight (BVLOS) operations over large areas, the remote pilot(s) in command (RPIC) may have to choose places to launch or recover their aircraft without being able to visually perform an initial site survey. There is no formal training apart from actual real-world experience that can prepare a RPIC for landing zone (LZ) site selection for BVLOS operations even though it is one of the most critical factors to the success of an unmanned flight operation. GIS-based approaches for planning, especially with BVLOS flight operations, is crucial to the future of the industry. This approach utilizes three use cases. Two of the use cases (transmission lines and railroads) are linear in nature while the third (wind farms) is non-linear in nature. Current approaches that are utilized are using manned aircraft, choosing landing areas in situ without prior planning, or ignoring regulations altogether. The last approach is rarely used negligently, but instead results from a lack of knowledge regarding regulations. Results show this approach to LZ planning is superior to existing practices in ensuring compliance and project efficiency. BVLOS operations are increasing exponentially, and advancements such as these demonstrate benefits for a variety of commercial applications.

Chapter 1 - Introduction

Commercial Beyond Visual Line of Sight (BVLOS) operations are one of the most effective ways to increase project efficiency and reduce cost per mile. The only barrier that exists between operators flying BVLOS en masse is the FAA. In the United States, operators are not permitted to fly any unmanned aerial system (UAS) farther away from them than they can see unaided (CFR 2016). This distance is not set to any fixed measurement, but merely whatever distance the RPIC or their visual observer (VO) can see the aircraft with unaided vision, other than corrective lenses for sight. Companies must apply for and be granted a waiver to fly BVLOS, specifically to part 107.31, visual line of sight of the aircraft (CFR 2016), mentioned above. In order to be granted a BVLOS waiver, each operator must fully prove to the FAA that they have identified and mitigated flight risks. There are two primary categories for flight risk with respect to BVLOS operations: midair collisions with another aircraft or obstacle, or a collision with persons or obstacles on the ground (Washington, Clothier, & Silva 2017). It can be argued that the greatest risk category is to people on the ground (Washington, Clothier, & Silva 2017; Clothier et al. 2015).

Most BVLOS flights are conducted autonomously because manually flying aircraft BVLOS generally increases risk to an unacceptable point. Autonomous flight is relatively straightforward, with the autopilot handling all flight tasks while the RPIC monitors telemetry to ensure there are no in-flight failures with the Global Navigation Satellite System (GNSS) or the Inertial Measurement Unit (IMU). Takeoff and landing are the two most critical phases of flight during BVLOS operations, because autonomous flight is stopped and the RPIC assumes direct control of the aircraft (Finn & Scheding 2010). Ensuring that the RPIC can safely and effectively conduct BVLOS operations without undue stress due to obstacles or other structures near the LZ is critical.

As critical as the takeoff and landing phases of flight are, ensuring that BVLOS flights are not conducted in areas where they are not permitted is equally as critical a task. Flights over people, moving vehicles, in controlled airspace or near airports are not permitted by Part 107 unless the operator has a waiver covering those operations as well. The industry is not at the point yet where the FAA is comfortable enough granting waivers to several regulations, primarily due to the lack of a safety framework. Because of this policy, the FAA is perceived to have been overly strict regarding regulatory waivers (Clothier et al. 2015, 1168; Congress 2015; Congress 2016). This is not entirely the fault of the FAA, however, because the regulatory framework is in place to protect people's lives in an industry that is still trying to understand where the middle ground exists between protecting people and allowing operations latitude.

The process for obtaining a waiver to fly BVLOS is an arduous, time intensive process. Over 99% of companies that have applied for a BVLOS waiver have been denied (Ferguson 2019). Each company must submit to the FAA its operational plan, which must include documentation for how the company plans to mitigate risks to other airspace users as well as to people and property on the ground. Most of these requests are denied because operators have failed to make a compelling case for the safety of the operation (Ferguson 2019). Operators can face harsh fines and punishment if they violate the terms of any waivers they are approved for, which only makes the critical task of choosing appropriate LZs that much more important. Appendix A contains a sample BVLOS waiver awarded to Xcel Energy in 2019 to perform BVLOS operations over a span of 2,500 miles (L3Harris 2019).

Analysis of available GIS data presents one of the most effective ways to identify ground risks from a spatial standpoint. It allows flight planners to analyze the 2D risk aspect such as road crossings and population density, as well as the 3D risk aspect in analyzing airspace conflicts and obstacle avoidance. This analysis combined with a comprehensive risk mitigation strategy ensures that a company that is well equipped to perform the analysis could be successful in both choosing safe and efficient LZs and making their case for a safe operation to the FAA, or any regulatory body where the onus is on the operator to prove they can operate safely.

The primary objective of this research is to demonstrate an effective and efficient process for selecting LZs when the ability to physically inspect the areas prior to operating is not possible. This objective will be accomplished by utilizing a criteria-based approach to select landing zones. The bottom line is that companies that want to perform BVLOS flights and achieve an FAA approval to do so will need to take safety very highly into consideration. This research is one portion of that safety case that is a pathway to FAA approval to fly BVLOS.

Three use cases will be presented. Two of these cases are linear in nature, transmission line inspections and railway inspections. The third, wind turbine farm inspections, is inherently non-linear. It is important to show differences in not only LZ selection, but risk identification and mitigation from a safety standpoint. The workflow that will be used to demonstrate landing zone selection allows the user to essentially backwards plan, because it is crucial to assess the areas that contain greater concentrations of risks first and then move to the easier areas next to ensure proper coverage of the flight lines.

1.1 Study Area and Use Cases

One must understand the motivations and goals of the project when considering the three use cases. Each has their own scope, risks, benefits and stakeholders. The following sections will detail each of the use cases in terms of a hypothetical company that owns the utility and has approached our company as a client. Each of these companies that would hypothetically be funding the projects in the use cases need imagery that clearly shows that the structure is still in satisfactory condition and that there is no damage that reduces the integrity of the structure.

The quality of imagery needed by the client is directly related to the payload the aircraft uses to capture the imagery. An aircraft that uses a higher resolution camera can fly at a higher altitude without sacrificing image quality. The tradeoff is that higher resolution cameras generally add weight, which forces the aircraft to use more power to maintain altitude, thus reducing range and total flight time. Range is critical regarding LZ selection as longer range allows for fewer takeoffs and landings, reducing the number of times the aircraft must enter a critical phase of flight. Let us assume for a moment that ten flights had to be conducted to complete a segment but could have been done in five if weight had been reduced. The overall flight risk is reduced because the amount of time spent in a critical phase of flight is lower. If an aircraft must fly at a certain altitude to avoid obstacles but in doing so the image quality is reduced to an unacceptable level, the data will not meet the specification and that flight will have to be re-flown, increasing risk, cost, and time on project.

There are many factors that go into performing these types of inspections. Weather patterns must be considered, as many large-scale projects span several months. Flights should be planned in areas that are expected to have consistently good weather. Prevailing winds are part of the weather consideration as well, in order to determine best direction of flight.

1.1.1. Transmission Line Inspections

Transmission line inspections are required by the Department of Energy. There is no regulated time interval for inspections, but only that structures be inspected often enough to ensure safety, according to the National Electric Safety Code (NESC) (Young 2003). Inspections are done for several reasons. Inspecting line sag, pole condition, insulator condition, vegetation along the right of way, among other potential issues. There are over 5.5 million miles of distribution and 200,000 transmission lines within the United States (Weeks 2010). For this project, a 100-mile segment will be selected from the dataset shown in Figure 1 below that presents challenges in selecting LZ placement.

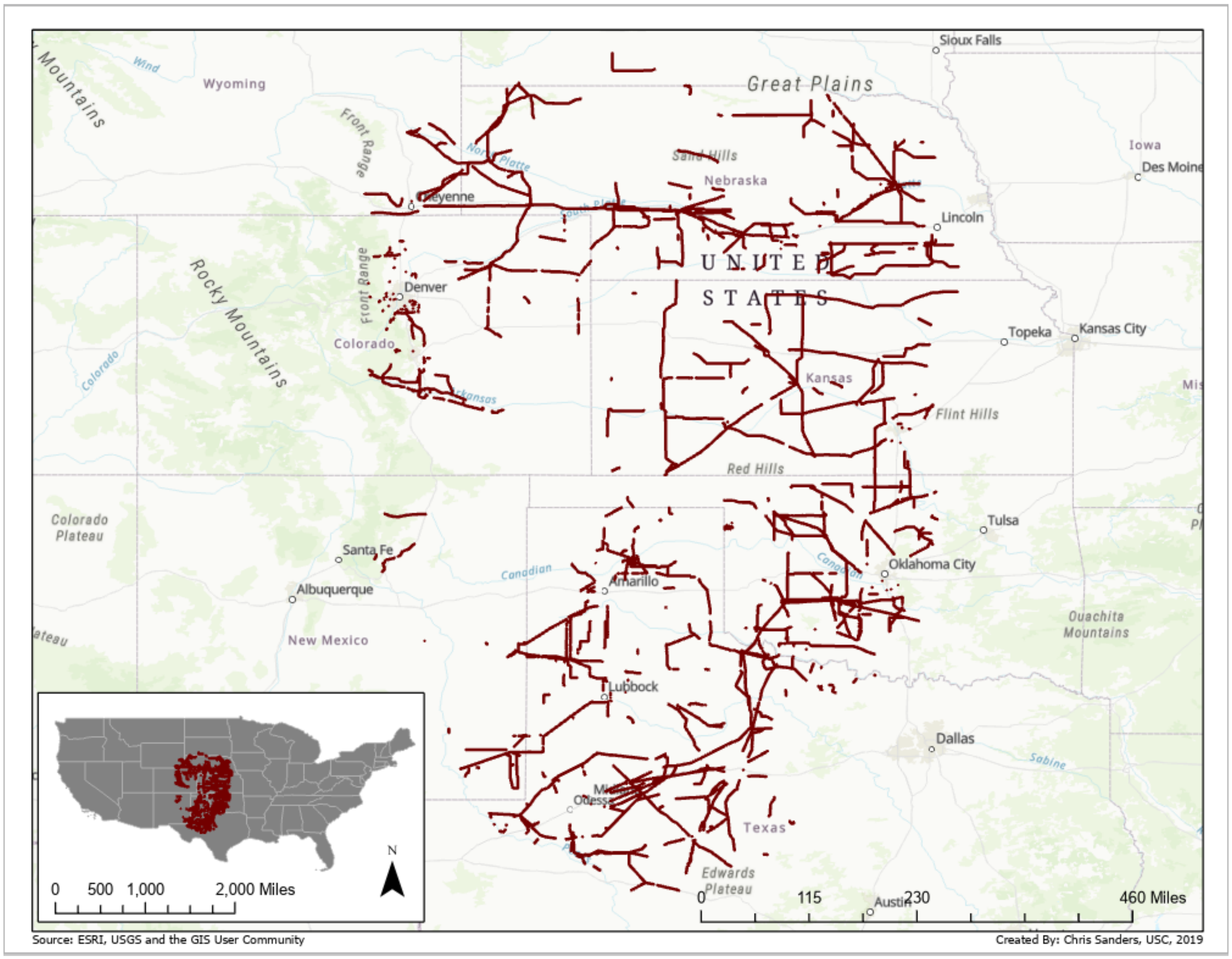


Figure 1 – Transmission Line Dataset (USGS 2010)

1.1.2. Railroad Line Inspections

There are over 140,000 miles of railways in the United States (ASCE 2017). Inspections of railways are mandated by the federal government to ensure that the railways are maintained in a safe and acceptable manner. Inspections look for defects in rails, crossties, fallen signs, debris preventing rail changes from taking place, among other issues. Table 1 below is an excerpt from the Code of Federal Regulations that outlines the frequency of railway inspections.

Table 1 – Railway Inspection Frequency (CFR 2019)

Class of Track	Type of Track	Required Frequency
Excepted track and Class 1, 2, and 3 track	Main track and sidings	Weekly with at least 3 calendar days interval between inspections, or before use, if the track is used less than once a week, or twice weekly with at least 1 calendar day interval between inspections, if the track carries passenger trains or more than 10 million gross tons of traffic during
Excepted track and Class 1, 2, and 3 track	Other than main track and sidings	Monthly with at least 20 calendar days interval between inspections.
Class 4 and 5 track		Twice weekly with at least 1 calendar day interval between inspections.

Inspections are traditionally conducted via foot patrol or by railcar or vehicle. BVLOS operations along rails are performed using several different methods. BNSF utilizes fixed-wing aircraft located inside code-locked buildings along rail routes, so LZs are already configured, as they are co-located with the buildings where the Ground Control Station (GCS) and the RPICs are located (Brajkovic 2019). This use case will not consider these LZs, as they are confidential in nature. A 100-mile segment will be selected from the dataset shown in Figure 2 below that presents challenges in selecting LZs by having a more concentrated amount of risk considerations to take into account versus an area in a very remote location with fewer safety considerations.

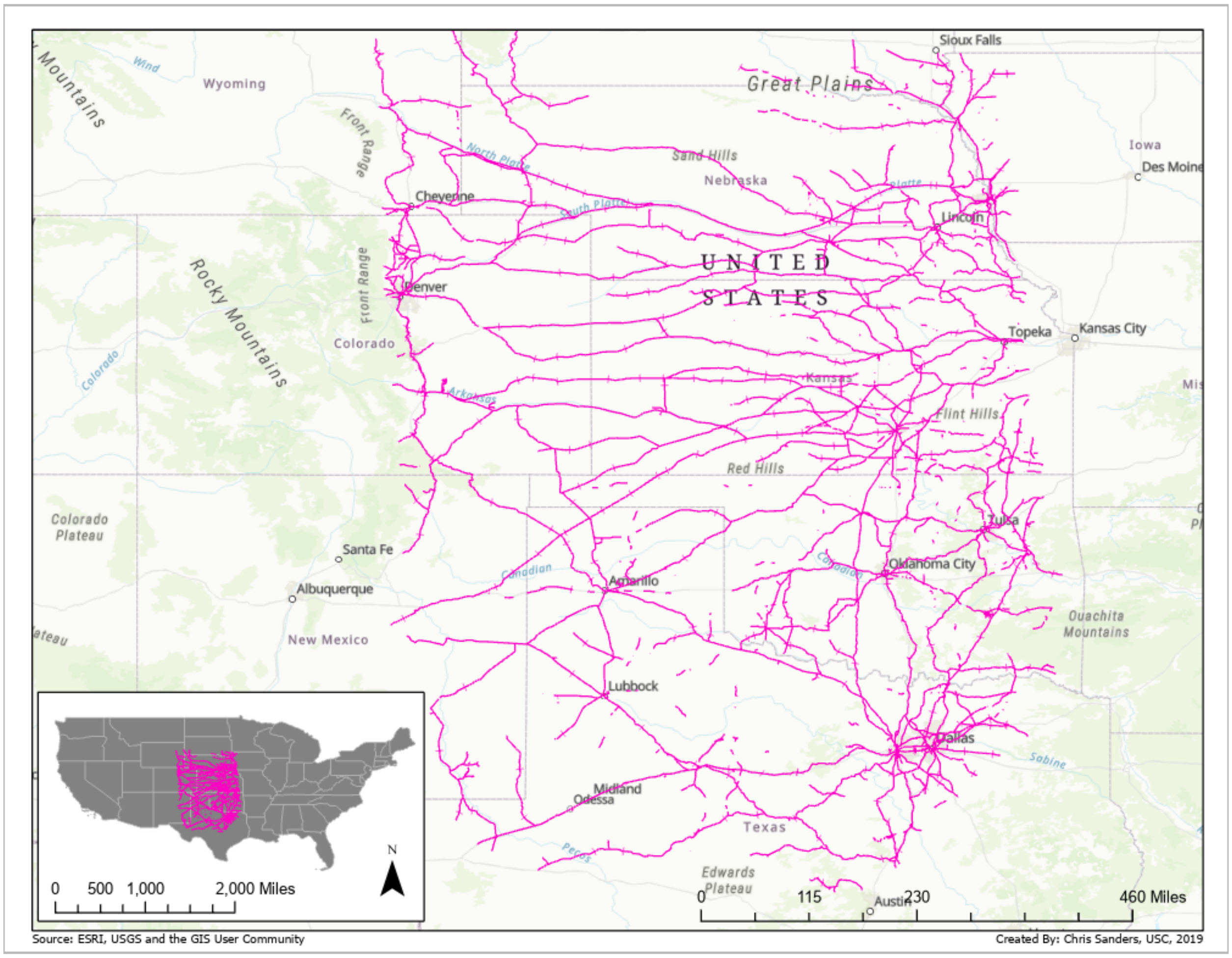


Figure 2 – Railway Dataset (U.S. Census Bureau 2015)

1.1.3. Wind Farm Inspections

There are over 54,000 wind turbines in the United States (Vaughan 2018). The renewable industry, wind specifically, accounts for 6% of the energy generated in the United States (Feller 2018). The blades on the turbines are susceptible to damage from birds and other debris that can puncture the blade. Damage to blades accounts for 23% of costs annually, which is causing operators to turn to UAS to attempt to find issues early before damage to a blade gets worse and causes a blade failure or complete separation (Feller 2018). Quadcopters are traditionally used, flown within visual line of sight (VLOS) to ensure that obstacle avoidance is maintained, but this requires a team to position to each turbine. It currently takes about an hour to perform an inspection using a quadcopter (Smith 2019). Currently inspections can be completed at a rate of 6-8 turbines per day if flown via automated flight plans, and approximately 11 per day if flown manually (Smith 2019). Companies are also charging an estimated $300 to $500 per turbine (Smith 2019). Performing BVLOS inspection with a heavier, higher resolution payload will allow for faster inspections. Using Light Detection and Ranging (LiDAR) payloads will allow for even the smallest defects to be detected, though the turbines would need to be stopped in order to perform a complete and thorough LiDAR scan. A 100-mile segment will be selected from the dataset shown in Figure 3 below that presents challenges in selecting LZs.

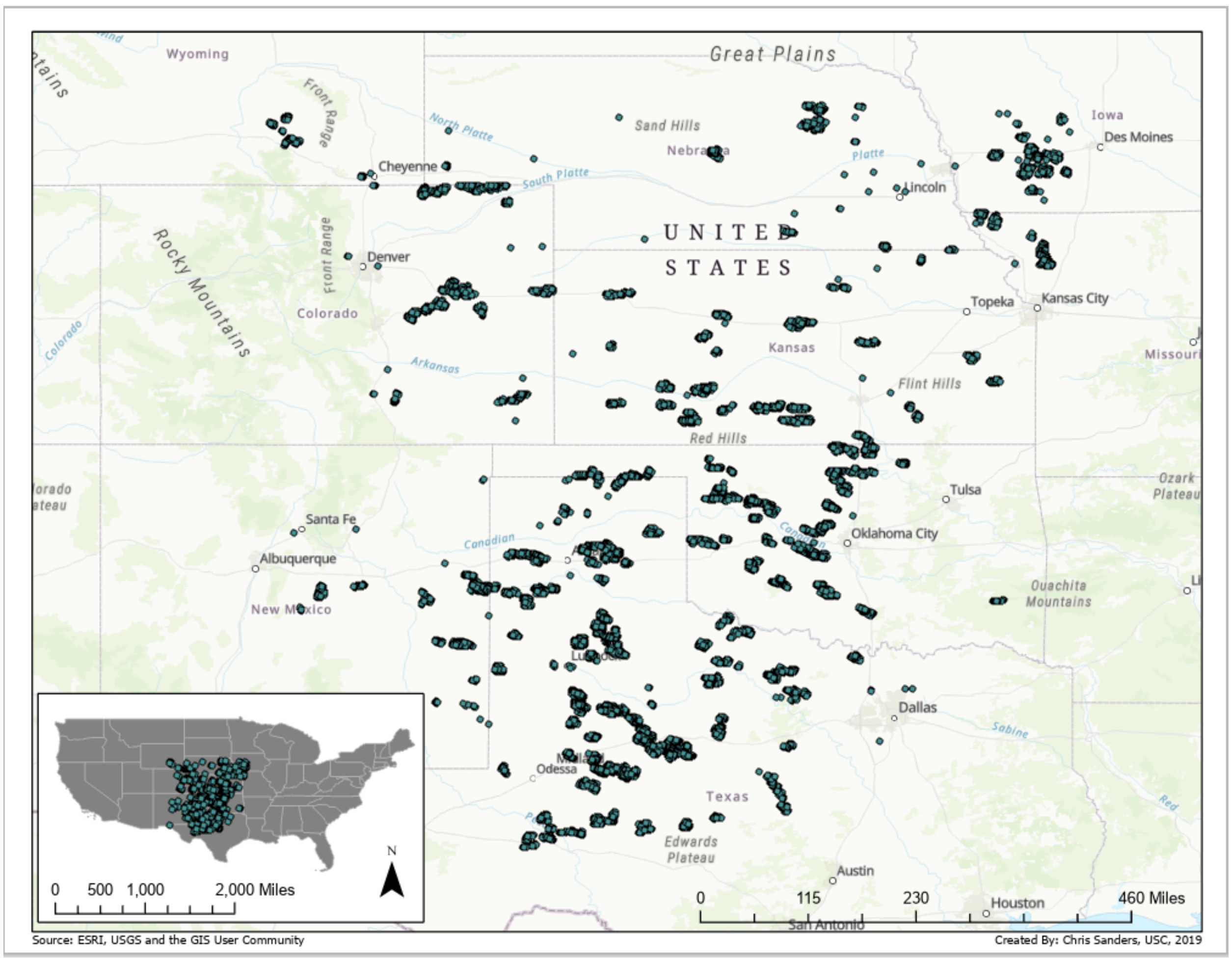


Figure 3 – Wind Farm Dataset (USGS 2016)

1.1.4. Landing Zone Specifications

There is no specific requirement, guidance or regulation regarding LZ selection for UAS operators. An area that has enough obstacle clearance for takeoff or landing is considered the minimum for adequacy. For the purpose of this research, LZs will be selected that have an area at least ten times the radius of the blades. The blade radius on an Aerovironment Vapor 55 is approximately 3.5 feet, therefore the clearance area for this research will be a minimum of 350 feet. This is in addition to the other mitigations that are applied. This distance ensures more than just the safety of the RPIC and any other crewmembers or bystanders that are present, it also ensures that there is adequate vertical clearance during launch and ascent. This distance also adds to the confidence that whatever vehicle the crew needs to drive into the area has enough room to park and not be considered an obstruction to other vehicles if near a road.

Additionally, the area should be free of people, structures, vehicles and other obstacles. This distance should also give adequate consideration to potential winds or other mechanical forces and allows for room to abort landing and make any necessary adjustments if needed.

1.2 Motivation

Until the commercial UAS industry and regulatory bodies start to push forward a framework for safety and comprehensive risk mitigation, the industry will be subjected to inefficiencies and harsh operational restrictions (Washington, Clothier & Silva 2017, 24). The Government Accountability Office found in October 2019 that the FAA has no true knowledge of how extensive unsafe operations are, where they are happening or who is or is not truly attempting to mitigate risk (GAO 2018). This is true even though in 2016 the FAA put forth a framework together with a small business coalition that proposed regulatory guidance moving forward (Congress 2016) which implies that in three years there has been no real progress in developing a framework for safety.

This lack of a true regulatory framework has secondary and tertiary effects. If there is no framework for safety in place, operators are not forced to standardize operations at all. Using LZ site selection as an example, it is in the interest of the operator to choose suitable LZs before the operation begins. If the operator does not select suitable LZs, they will lose valuable flight time upon arrival when they discover their intended site is unusable. While I am not suggesting that companies be forced to perform LZ site selection processes the same way, there must be an environment of safety that exists that allows operators to perform site selection flexibly that best suits their operation but still ensures that the site meets all safety criteria.

The motivation for this project is ensuring the safety of crews and personnel. Choosing a suitable LZ is not something that an algorithm can do correctly every time, and still must be programmed by someone who understands what is needed. It is not something that you can google. It is only something that comes with experience. Understanding the risk mitigations such as not overflying interstates or heavily populated areas is something that could be lost in translation if an individual must plan over 600 LZs. For the industry to truly move forward, consistent workflows need to be developed around a risk mitigation framework.

1.3 Thesis Organization

The remainder of this thesis contains five chapters. Chapter two covers previous studies performed in the areas of risk management and mitigation, site suitability, GIS project management, and personal BVLOS experience gained through field operations. Chapter three covers the methodology for gathering and processing the data, as well as mission parameters and use case selection areas. Chapter four contains the results of the analyses resulting from LZ site selection and a cost-benefit analysis for planned BVLOS flights and LZs versus other approaches being conducted throughout the industry. Finally, a discussion regarding the state of the industry, the importance of BVLOS site selection, the results of the research conducted, recommendations as well as future work can be found in chapter 5.

Chapter 2 – Related Work

The body of knowledge that exists within commercial UAS BVLOS operations is not especially developed for two reasons. First, the FAA's traditional regulatory framework has been that of a 'tombstone policy', where regulations follow accidents that have resulted in death (Clothier et al. 2015). The second reason revolves around profitability and market share. The processes that companies use for flight planning, LZ site selection and other internal operations are kept private to prevent competition from gaining a foothold or increasing their market share by easily replicating successful operations. While this is completely understandable from a business standpoint, in the interest of creating a safer overall environment some basic information must be shared to increase the base level of knowledge required to perform an operation safely and successfully. The articles discussed within this section address multiple functions required to accomplish the critical task of LZ site selection for commercial BVLOS UAS operations. General site suitability approaches and risk mitigation will be discussed, though almost none exist specifically for UAS LZ selection. This is generally because how companies select landing zones and the associated methodologies are simply not publicly available. Also discussed are GIS program management aspects, as well as aspects related to overall flight planning.

2.1 Risk Mitigation for UAS Operations

Dr. Reece Clothier is one of the leading figures where UAS risk mitigation is concerned. He has written several papers and articles covering UAS risk mitigation strategies for both ground and air operations. Clothier (2007) asserts correctly that there are several aspects to consider when developing a risk management framework. Specifically, there are seven aspects he refers to: technological, performance, operations, human, sociological, market drivers, and integration. He also asserts correctly that the major risks to consider are regarding people and property on the ground because UAS mishap rates are on the order of two magnitudes greater than manned aircraft. The greater consideration given to people and property on the ground reverberate throughout the research, but particularly with Washington, Clothier and Silva (2017) who performed a comprehensive analysis of the models used to assess ground risk and determined that there were approximately 33 different models with which to assess ground risk. This is particularly important because the study compared these models and determined that there were 7 sub-models that each of the 33 models could be grouped into. The first four models, associated with the UAS and its operation, are identified as failure, impact location, recovery, and stress. The remaining three models, associated with people and property on the ground are identified as exposure, incident stress, and harm. Another assertion made by Washington is that there is uncertainty when considering any risk model for UAS, primarily due to a lack of reliability data from manufacturers and non-certified components.

Melnyk et al. (2013) developed a framework that considers risk mitigation from a target level of safety (TLS) approach. A "target level of safety" means an acceptable level of probability in which an accident could happen, such as the chances being one in 250,000 or one accident over 250 flight hours. TLS approaches look at risk to individuals on the ground based on UAS failure rates and the operating environment. This differs from other approaches in that for the approach to be successful the failure rate data must be accurate and complete. This is rarely the case in the commercial UAS market. Companies that manufacture UAS commercially typically do not have failure rate data or other data because there is no requirement for it. The aircraft are not type-certified, do not have to conform to many FAA regulations or quality assurance/quality control (QA/QC) standards. They also ask a very good question regarding

UAS integration into the National Airspace System (NAS); "How safe is safe enough?" This ties back into other research performed by Washington, Clothier and Silva (2017) that asserts that the industry will be subject to increasingly harsh restrictions until risk mitigation standards and policies become more standardized across the spectrum. The primary obstacle to this is that each operator's operational approach can be vastly different, therefore making standardization quite difficult. Regardless of the concept or approach, comprehensive risk mitigation should take LZ site selection into consideration.

2.2 Site Suitability

Determining site suitability for a LZ can only begin once the applicable risk mitigation efforts (hereafter referred to as either mitigations or mitigation strategies) and range of the aircraft are known. Additionally, the suitability of a landing zone is intrinsically linked to the characteristics of the aircraft that will be utilizing the landing zone (Scherer, Chamberlain & Singh 2012). Scherer, Chamberlain and Singh (2012) performed research into developing a method for autonomous landing at unprepared sites by aircraft that are full-size in nature. They outline the ground conditions that should be considered for a suitable landing site as size of the site, appropriate area for the skids or landing gear to contact the ground, load bearing capability of the ground, site vegetation, and rotor clearance with respect to obstacles in the area. They also listed approach considerations as clearance of the path regarding terrain, wind direction and abort paths. It is important to note that the same considerations they give to full-size aircraft are the same considerations that need to be given to unmanned aircraft in order to ensure safe landings. The authors also correctly assert that a primary problem with landing site selection is that many factors need to be simultaneously considered in order to determine "goodness" of a site. Though their approach was to develop criteria for autonomous landings, these same criteria are applicable to choosing a landing zone through GIS.

Perhaps one of the best analogies to this research is attempting to select landing sites on Mars. This is obviously an area that cannot be visually inspected prior to the beginning of the operation, and therefore must be carefully planned to ensure that the vehicle does not encounter any obstacles or other features that could damage it. The work performed by Arvidson et al. (2008) perfectly highlights the challenges of selecting landing zones. This project was a multi-year effort to find suitable areas for the Phoenix Lander program to safely land and conduct operations. They had seven criteria that had to be met for an area to be considered “good”. The authors utilized several different maps and GIS products to comparatively evaluate locations. While they did not specifically refer to their criteria by weight, or what criteria were important, it did appear that they used a loose version of the analytical hierarchy process (AHP).

Another arena in which it is almost impossible to visually inspect every landing site prior to operations is aerial delivery. Though it will almost certainly require automated landing site selection, the algorithms used will be developed by criteria set by people as to what constitutes a “good” landing area. Kushleyev, MacAllister and Likhachev (2015) utilized probabilistic planning with clear preferences to develop their algorithm. One shortfall here is that the actual criteria for what would constitute the UAS determining whether a site was good or bad is not discussed, only that the criteria is programmed into the UAS for deterministic reasoning.

Work performed by Garg, Abhishek and Sujit (2015) looked at terrain-based site selection for fixed-wing UAS to determine how best to autonomously determine a suitable landing site for a UAS during an emergency. While this is different from the research being conducted here, it is interesting to note that future iterations and safety cases may have to make use of automated methods of landing site selection for emergencies to ensure that risk to people is fully mitigated.

Tweddale et al. (2011) developed an automated tool to analyze terrain to rapidly identify sites based on operational criteria. This tool, while not expressly defined as such, appears to be a type of AHP methodology because criteria are weighed against each other and ranked according to priority, with points being added to a site's merit if it met criteria without needing additional analysis. Figures 4 and 5 show the workflows that Tweddale et al. developed specifically with respect to UAS site selection.

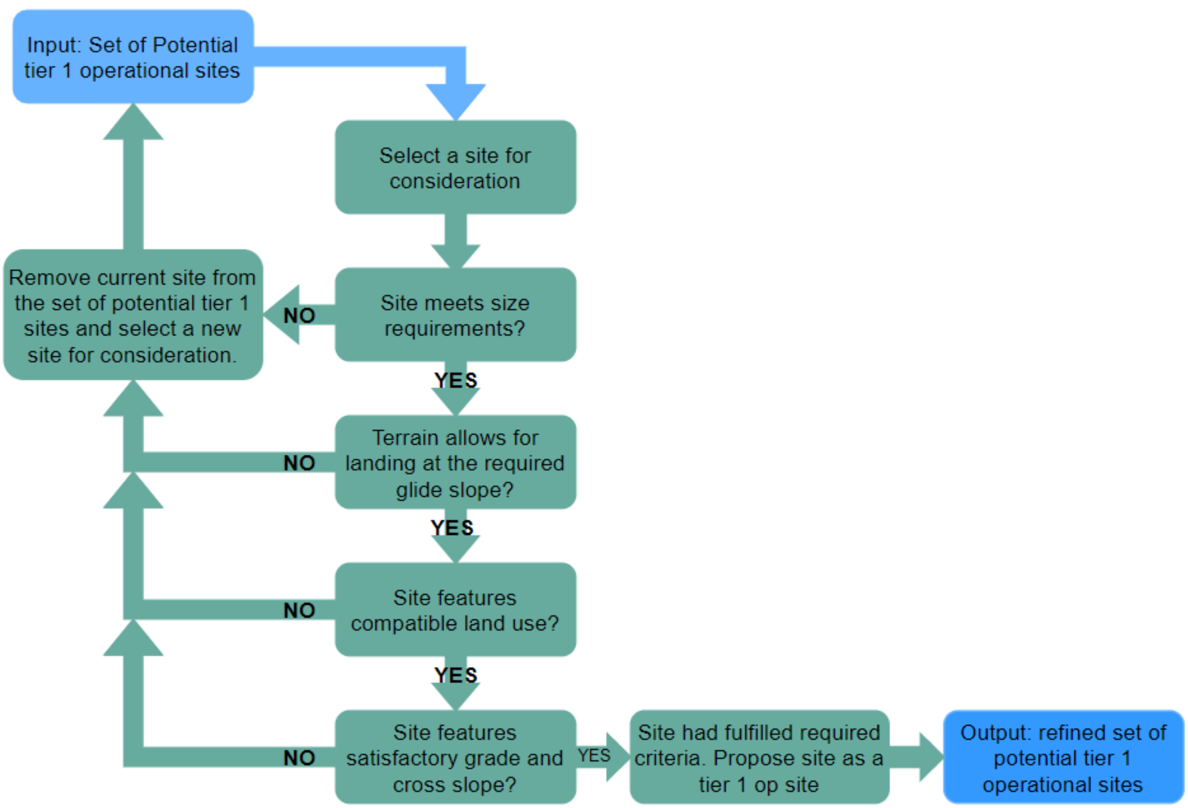


Figure 4 – Required Criteria for Site Selection Workflow (Tweddale et al. 2011)

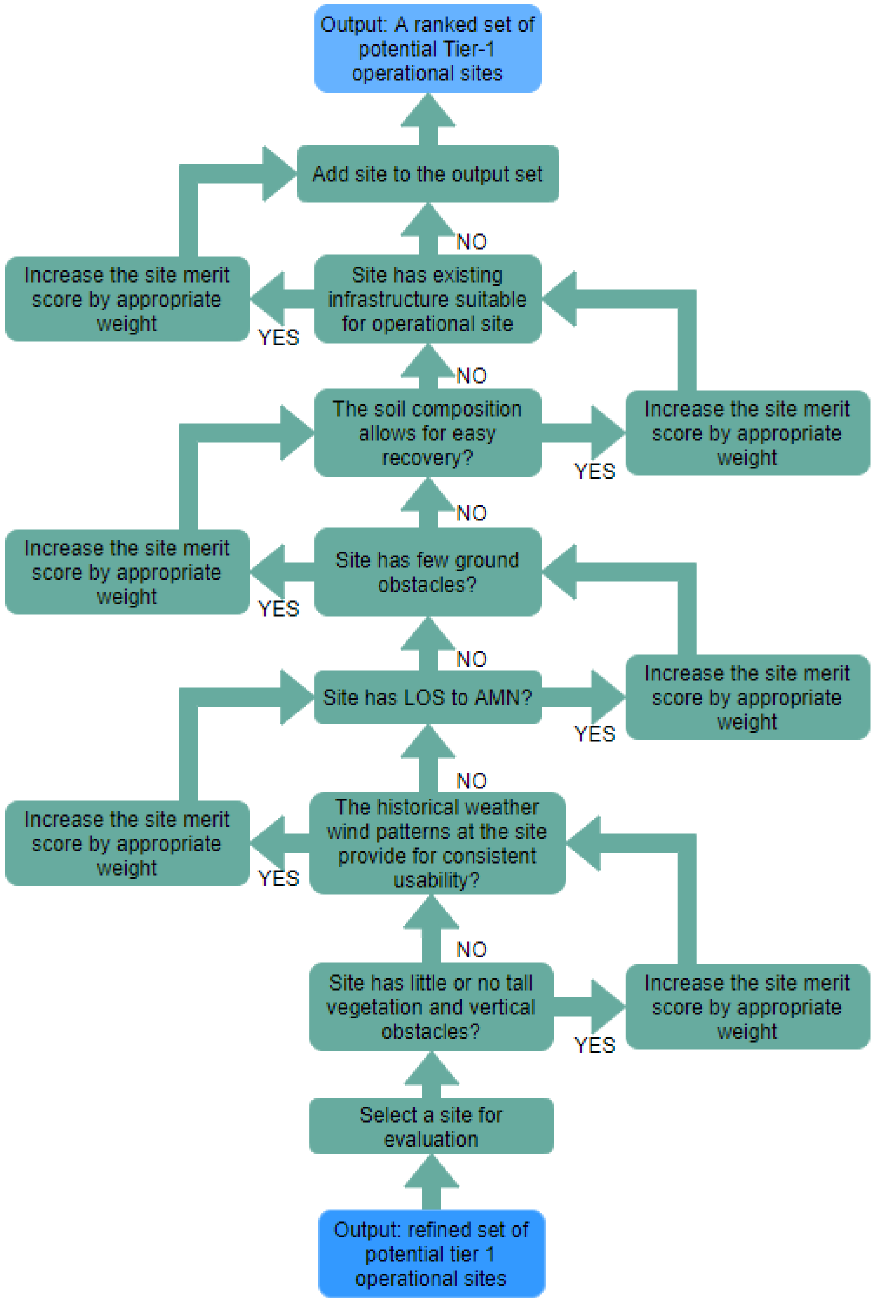


Figure 5 – Negotiable Site Selection Criteria Workflow (Tweddale et al. 2011)

Tweddale et al. performed this analysis for the Army Corps of Engineers with the intention of identifying sites for large fixed wing UAS. While the criteria are different, this approach is similar to the approach Phoenix Air Unmanned used for LZ site selection. The similarities in approach should be noted, as Phoenix Air Unmanned had not had any familiarization with the work Tweddale et al. performed. Tweddale et al. has established a methodology workflow that any company could use to approach LZ site suitability based on competing criteria. Different operations would have different criteria that would rank differently depending on the type of operation. Kessler and Cutler (2018) developed standard operating procedures (SOP) in Texas for the North Central Texas Council of Governments. The authors only recommend an area that ensures the RPIC can maintain a minimum safe distance of 25 feet for VTOL aircraft but does not speak to what minimum safe distance should be adhered to for aircraft that are not VTOL. This SOP, while clearly designed for smaller quadcopters, should be taken in context for how the industry generally approaches site selection, including with larger aircraft in some situations. There is no regulation or regulatory framework that requires any formal approach to site selection for landing zones, so it is up to each company to approach site selection and suitability for themselves.

2.2.1. Analytical Hierarchy Process

Thomas L. Saaty (2012) first developed the AHP in the 1970's to quantify criteria and give them appropriate weights for consideration. It is highly regarded as the most accurate method for estimating magnitude relatively and comparing criteria to each other. While not developed solely for site suitability, it has become one of the go-to methods used for site suitability. The key to the AHP is developing the hierarchy correctly. After that, it can be processed and compared. Extensive research and development have been done to further develop AHP, including developing software programs to assist in facilitating AHP processing.

Banai-Kashani (1989) developed an approach to Saaty's AHP at Memphis State University in 1989 out of recognition that there was a gap in methods that allowed for error detection and correction. Many other models were too rigid and could allow for unsuitable sites to be selected due to the rigidity in the model. Banai-Kashani understood that there were tradeoffs among criteria that required flexibility in site selection that other methods did not allow for. This applies to UAS operations in LZ site selection for several reasons, because over large projects the factors that make a LZ "suitable" change. Terrain, C2 link line of sight, prevailing winds, proximity to structures or buildings, availability of placing the aircraft a safe distance from the RPIC for takeoff are all part of the overall criteria that must be considered. Banai-Kashani correctly recognized that individuals that are faced with several different potential sites must have a way to measure the viability of each site to determine the best option. The AHP method, shown below in Figure 6 outlines the methodology for choosing an optimal site.

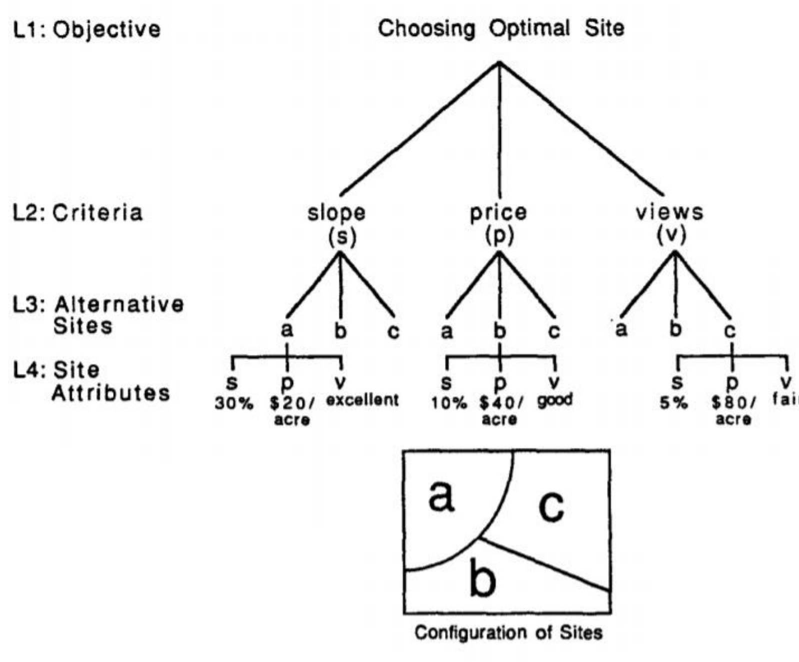


Figure 6 – The Analytical Hierarchy Process (Banai-Kashani 1989)

The AHP method has proven very valuable in site selection over a large variety of use cases. Vasiljevic et al. (2012) used the AHP to determine suitable sites for regional landfills in Serbia, which is often a difficult and complex process with many competing criteria. They established seventeen different factors that were competing for site selection. One issue with their final restriction map is that it was not at a spatial extent that accurately portrayed smaller areas that were restricted, which could lead to potential issues with decision making if a map with higher resolution is not provided. Kar and Hodgson (2008) used Weighted Linear Combination (WLC) with Pass/Fail screening to determine site suitability for emergency shelters in Florida. Shahabi et al. (2013) performed an evaluation of Boolean, AHP and WLC methods to determine the best site to place a landfill. They found that AHP gives decision makers more enhanced ability to make good decisions, but the WLC method had better site segregation powers.

2.3 Industry Operational Experience

For the majority of the UAS industry, there is not a great deal of information that exists regarding internal company operations. Developing a successful UAS program is extremely difficult for several reasons. Keltgen (2017) accurately depicts the minefield companies must navigate in today's UAS industry, because there is no guide to build a program yet simultaneously there are dozens of ways to build one. He continues describing the dichotomy between advancing technology and regulators, and how technology is essentially outpacing the FAA's ability to keep up. He continues by explaining that it takes a large amount of two specific things that many startup companies do not have: time and money. This is exemplified by the fact that Xcel Energy has been working since 2015 to get a true BVLOS waiver (Gomez et al. 2018). There are very few companies that can afford to work for four years without getting a true waiver, because the time in between is spent in meetings and doing research, not necessarily flying.

Xcel Energy was awarded a waiver to perform BVLOS flight operations over a span of 2,500 miles within the United States in a partnership with L3Harris, Phoenix Air Unmanned, the Northern Plains UAS Test Site and Aerovironment Inc. (L3Harris 2019). I functioned as both Safety Program Manager and RPIC for Phoenix Air Unmanned and was part of the team that performed the initial GIS analysis over the entire 2,500-mile project. Part of my overall task was to select LZs based on the chosen risk mitigations developed during the creation of our comprehensive safety risk mitigation document. The mitigations developed in this internal document became instrumental during the initial planning phase, which resulted in over 600 LZs being placed over eight states. Being awarded a waiver to fly BVLOS came only after our entire team presented our safety case to the FAA. Tully (2016) argues that part 107 is too restrictive on businesses, and rightly so.

Until there is some sort of standardization regarding safety and operations the FAA will not give businesses carte blanche to operate however they see fit. It is understandable that the government is leery of relaxing their firm grasp on who performs what operations, because there is still a large environment of fear regarding UAS. Myers III (2019) states that approximately 26% of people experience feelings of nervousness when they see UAS flying, while approximately 10% get either angry or scared. This essentially means one in four people get nervous, while one in five either get angry or scared. This easily explains the hesitation of the federal government to simply release companies to fly BVLOS.

Considering the operating environment is a small but critical part of the task of selecting landing zones. Terwilliger et al. (2017) highlight a few of the considerations that should be given to the operating environment. While it does not specifically refer to LZ site selection, it does have applicability as part of the overall operating environment. Some of those considerations are things such as persistent weather, obstacles, density altitude, and environmental impact. Special consideration is given to populated areas, as federal policy limits operations that could place people into a situation where they are exposed to undue risk.

Prior to the commencement of operations, a physical site survey of all LZs selected were visually inspected. At the completion of the site surveys, approximately 12% of LZs required complete replanning due to factors that GIS cannot anticipate, such as buildings built after the satellite imagery was last taken, and other factors that are largely temporal in nature. Land access issues accounted for 60% of the LZs that required replanning, such as areas where a landowner did not give permission to us to access the land, or a locked gate that we were unable to access or acquire a key for. Other issues were related to obstacles that were not visible in any of the GIS tools used, preventing the RPIC from safely taking off or recovering the aircraft such as distribution lines or other overhead obstacles.

Commercial operators generally do not release information on their internal operations for intellectual property purposes (Wheeler 2019). It is critical to note here that the methods I will outline are only specific enough to show application of criteria for general site selection, and do not encompass the entirety of LZ site selection for BVLOS operations. One of the most unique challenges to BVLOS operations is the balance that must be found between the operators and the regulators. Operators must ensure terrain and obstacles are avoided at all times, but often do not have or are not given all of the data to support obstacle avoidance over 100% of their intended flying area, such as cell phone tower locations, accurate building heights, and other obstacle information. The operator, to ensure obstacle avoidance, would naturally want to raise their operating altitude to such that all potential obstacles are avoided. This then places the aircraft into controlled airspace, which the operator is not permitted to fly in without a waiver from the FAA. There is a fine line that operators must walk between avoiding obstacles and avoiding manned traffic, especially if they intend to fly BVLOS.

It cannot be stressed enough that any operator planning to perform BVLOS operations should conduct visual inspections of intended operating areas. It should also be noted that the sites where obstacles existed that were not visible in the GIS tools were still adequate for the RPIC to find a new site without having to reposition any vehicles or equipment farther than 1,000 feet.

Chapter 3 – Methodology

Before data can be analyzed, there must be a set of parameters established regarding several factors. The aircraft used for this research will be established and described. The risk mitigations that will be utilized that affect where LZs can be placed or BVLOS operations can be performed will be established and described. The term "mitigations" is used to describe those areas in which BVLOS operations cannot be conducted, and instead must be conducted within VLOS It can be considered the "strategy" used to accomplish project completion. Finally, the data limitations regarding the datasets used in this research, and how they differ from specific operational datasets will be discussed.

3.1 Mission Parameters

3.1.1. Aircraft

For this research, the aircraft being used will be the Aerovironment Inc. Vapor 55, shown below in Figure 7.

Figure 7 – Aerovironment Inc. Vapor 55 (Aerovironment Inc.)

In order to remain compliant with Part 107 and any applicable waivers, the aircraft will not be modified to exceed any of the operating parameters listed in Figure 8, shown below.

SPECIFICATIONS	
GROSS WEIGHT	55 lbs (24.9 kg)
USEABLE PAYLOAD	10 lbs (4.5 kg)
GROUND SPEED LIMIT	33 mph (15 m/s)
MAX ENDURANCE	Cruise: 60 mins, Hover: 45 mins
RANGE	35 miles (56 km)
DIMENSIONS	Aircraft: 6.4 ft (1,941 mm) x 2.2 ft (672 mm) x 1.9 ft (583 mm) Rotor Diameter: 7.5 ft (2,291 mm)
OPERATING ALTITUDE	0-12,000 MSL
MAX WIND PEAK	20 kts (23 MPH); Gusts 40 kts (45 MPH)
DATA LINKS	900 MHz, 2.4 GHz, 5.8 GHz, Satellite
PAYLOAD OPTIONS	EO/IR Sensor, Lidar, Hyperspectral, PPK Mapping, Drop Mechanism, Multi-Payload

Figure 8 – Aerovironment Vapor 55 Operating Specifications (Aerovironment Inc.)

The assumption is that flight plans will not exceed 45 minutes of flight time while flying at approximately 15 m/s. While this roughly equates to 25 miles of linear flight, it will also be assumed that the datalink cannot be sustained over ten miles away, thus limiting max range to ten-mile flights. For the purposes of this research, the aircraft will have a datalink that can perform an operational handover during flight, thus allowing takeoff from one landing area and landing in another area by another team visually.

3.1.2. Risk Mitigation

A set of mitigation strategies must be established for each use case and applied individually when choosing suitable sites for takeoff and landing. These mitigation strategies are hypothetical but do reflect experience gained during commercial field operations. The risk mitigation strategies are not outlined in any regulation but are instead chosen by the operator and then evaluated by the FAA. The FAA then determines whether the operator has demonstrated their safety case adequately enough to be warranted a BVLOS waiver.

3.1.2.1. Line of Sight Considerations

When flying VLOS, there is no hard distance that has been established by the FAA. It is generally accepted that unaided ability to see an aircraft is diminished past one mile. For this research it will be assumed that the range for visual line of sight will be approximately 1.25 miles before the RPIC loses visual of the aircraft.

3.1.2.2. Transmission Line Risks and Mitigation

For this use case, table 2 below outlines risks regarding where BVLOS operations cannot be conducted and their mitigation strategies:

Table 2 – Risks and Mitigation of the Transmission Line Use Case

Risk	**Mitigation**
Flight over heavily populated areas	Flights will be conducted within VLOS in areas where population density exceeds 100 people per square mile.
Flights over congested roads	Flights will be conducted within VLOS over any portion of line where the aircraft must cross a road.
Flights in Controlled airspace or within five miles of an airport	Flights will be conducted within VLOS any time the aircraft must fly in controlled airspace or within five miles of any airport.

3.1.2.3. Railway Risks and Mitigation

For this use case, table 3 below outlines risks regarding where BVLOS operations cannot be conducted and their mitigation strategies:

Table 3 – Risks and Mitigation of the Railway Use Case

Risk	**Mitigation**
Flight over heavily populated areas	Flights will be conducted within VLOS in areas where population density exceeds 100 people per square mile.
Flights over congested roads	Flights will be conducted within VLOS over any portion of line where the aircraft must cross a road.
Flights in Controlled airspace or within five miles of an airport	Flights will be conducted within VLOS any time the aircraft must fly in controlled airspace or within five miles of any airport.
Striking a tunnel entrance or bridge	Flights will be flown within VLOS of any bridge, and no flights will be conducted in the vicinity of any tunnel entrance.

3.1.2.4. Wind Farm Risks and Mitigation

For this use case, table 4 below outlines risks regarding where BVLOS operations cannot be conducted and their mitigation strategies:

Table 4 – Wind Farm Mitigations

Risk	Mitigation
Flight over heavily populated areas	Flights will be conducted within VLOS in areas where population density exceeds 100 people per square mile.
Flights over congested roads	Flights will be conducted within VLOS over any portion of line where the aircraft must cross a road.
Flights in Controlled airspace or within five miles of an airport	Flights will be conducted within VLOS any time the aircraft must fly in controlled airspace or within five miles of any airport.
Aircraft striking a turbine blade	The aircraft will not be permitted to fly within 500 feet of any turbine blade to ensure proper clearance.

3.2 Data Sources

This thesis intends to demonstrate approaches of landing site selection for Beyond Visual Line of Sight (BVLOS) flight planning; specifically, how best to identify suitable areas to fly from or land to are. This is a skill that must be developed especially for projects with large spatial extents that span thousands of miles and cannot or may not be completely scouted visually. Table 5 below outlines the datasets utilized in this project.

Table 5: Data Sources

Data	Date	Content/Format	Usage	Availability
Transmission Line	2010	.shp	Data covering hundreds of miles of transmission lines.	https://www.sciencebase.gov/catalog/item/5148ab0fe4b022dd171afff3
Railroad Lines	2015	.shp	Data layer covering hundreds of miles of railroad lines.	https://catalog.data.gov/dataset/tiger-line-shapefile-2015-nation-u-s-rails-national-shapefile
Wind Turbine Database	2016	.shp Latitude Longitude	Data layer representing locations of wind turbines.	https://eerscmap.usgs.gov/uswtdb/
LandScan Population Distribution Data (Oak Ridge National Laboratory)	2018	Raster Population Density Data	Population density layer covering the entire United States.	https://landscan.ornl.gov/landscan-datasets
FAA Airspace Map	2019	.KMZ Controlled Airspace (Class B, C, E) Airport Locations	Used to show areas where BVLOS operations are not permitted (within controlled airspace, within 5 miles of airports)	https://www.faa.gov/nextgen/equipadsb/research/airspace/
Road Dataset	2019	.shp Major Interstates Major Highways	BVLOS operations are not permitted to fly over roads where traffic counts are high	https://catalog.data.gov/dataset/tiger-line-shapefile-2016-nation-u-s-primary-roads-national-shapefile

3.2.1. Data Limitations

The three use cases outlined above are publicly available datasets. The datasets utilized by an operator should have much more detail than these would. The actual datasets would have, for example, structure locations and heights for transmission lines, tower heights and blade lengths for wind turbines, or locations of tunnels, bridge overcrossings or other overhead obstacles for railways. This data, while not vital for landing zone site selection, is critical for overall flight planning to avoid planning flights into structures, wind turbine blades, or tunnel entrances. The datasets that contain the extra information are almost always sensitive information protected by non-disclosure agreements to protect the company's business interests.

3.3 Research Design

The research design follows two workflows. After the individual 100-mile segments are selected for each use case, An ArcGIS workflow will then be implemented to ensure that all risk mitigations are properly planned for and flights can be deemed acceptable for BVLOS or not. After this workflow is complete, the resulting LZs will be converted to Keyhole Markup Language (KML) and comparatively analyzed in Google Earth to ascertain whether the actual site is acceptable or not. After these workflows have been utilized and the resulting LZ areas are mapped, they will be compared to two other potential methods of LZ planning that currently exists within the commercial UAS community: in situ planning and planning without applying risk mitigation strategies. The average miles per flight, number of landing zone areas, estimated costs for project completion and time required to complete will all be factors for quantification and comparison.

3.3.1. ArcGIS Planning

The key to selecting suitable landing zones hinges on being able to identify areas where BVLOS operations may not take place. After a 100-mile section of line is selected, ten-mile increments will be designated for initial LZs. The additional layers will then be overlaid to determine if the initial LZs are still acceptable. Areas where BVLOS operations are not acceptable will have additional landing zones placed to meet the criteria set forth in the mitigation strategies and follow on the flow chart represented in Figure 9.

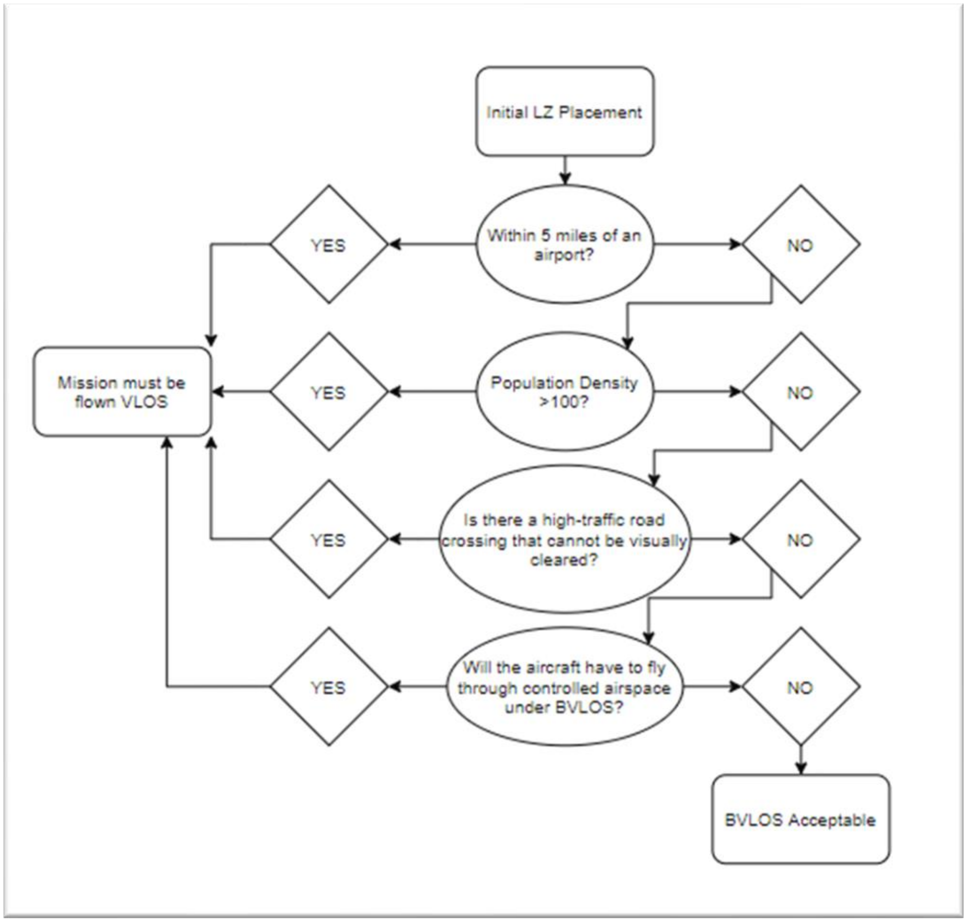


Figure 9 – ArcGIS site suitability Workflow

The workflow above does not include use-case specific mitigation, merely the mitigation strategies that are common across all use cases. Companies want to fly as far as possible to maximize value and save money. The more flights that must be conducted at less than the maximum distance the aircraft can safely fly, the lower the average miles per flight becomes. This in turn increases the amount of time needed to complete the project. Flight safety is also a large consideration for LZ placement. Once the landing zones are selected, further analysis will be conducted in Google Earth Pro. Google Earth Pro is a crosscheck to identify any obstacles as the satellite imagery in Google Earth Pro tends to be more recently updated when compared to other software suites. It is highly recommended that a software suite with different basemap imagery from the primary suite be used for comparative analysis.

3.3.2. Google Earth Validation and Crosscheck

After the LZs are selected in ArcGIS, the output is converted to a KML and placed in Google Earth for further analysis. Here terrain is considered to ensure that line of sight can be maintained between the teams at each landing zone and the aircraft, to reduce chance of a lost link scenario. A lost link scenario is one where the RPIC has lost radio telemetry and active control of the aircraft. In these situations, the aircraft generally follows a “lost link plan” that is preloaded into the autopilot, but it is incumbent on the operator to reduce the chance of this happening to the greatest extent possible. Site accessibility and any flight hazards that ArcGIS may have missed will also be considered during this phase, shown in Figure 10 below.

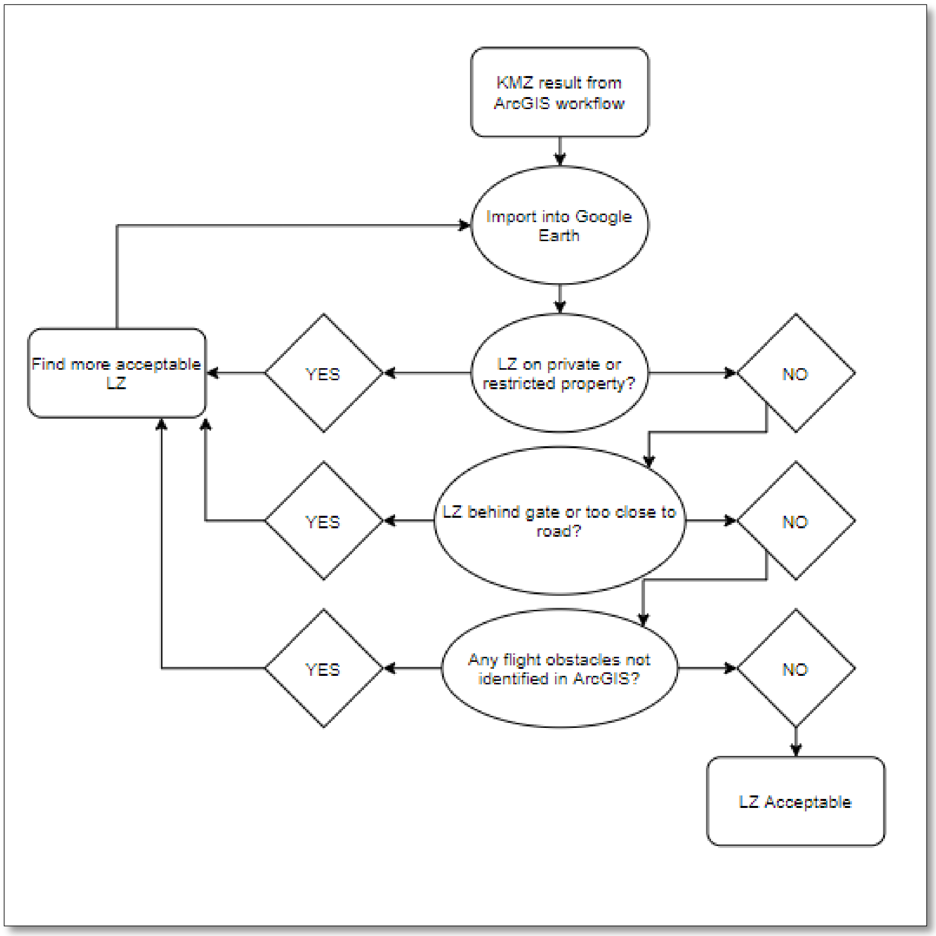


Figure 10 – Google Earth Site Suitability Workflow

If the answers to the questions posed in the workflow about flight obstacle identification are all negative (NOs), then the landing zone can be utilized for flight operations. There are drawbacks to using Google Earth for site suitability. It does not have the same analysis power that ArcGIS has, so all the accuracy of feature identification in Google Earth Pro relies on the user himself/herself. The more skill a user has at spatially recognizing areal features from 2D images stretched onto a 3D surface such as identifying a cell phone tower or recognizing a gate, the chance of that site needing to be replanned is greatly reduced. Though Google Earth's strength lies in quickly being able to manipulate a map in 3D, this strength is only as useful as the user is at being able to recognize the difference between a paved road and a dirt road, or a field and a forest. Recognizing areas where obstructions may be, such as overhead wires or towers is also a crucial skill that needs to be developed.

3.4 Use Case Area Selection

The 100-mile areas selected for each individual use case are areas where more instances of required application of risk mitigation strategies are found. These areas will be utilized in conjunction with the LZ risk mitigation strategies mentioned in section 3.3.

3.4.1. Transmission Line Use Case Area

The area selected for the transmission line use case is located in central Oklahoma. The selected area is approximately 106.36 miles long and covers five different line segments. It was chosen because it contains several airspace conflicts, as well as population density and road crossing conflicts.

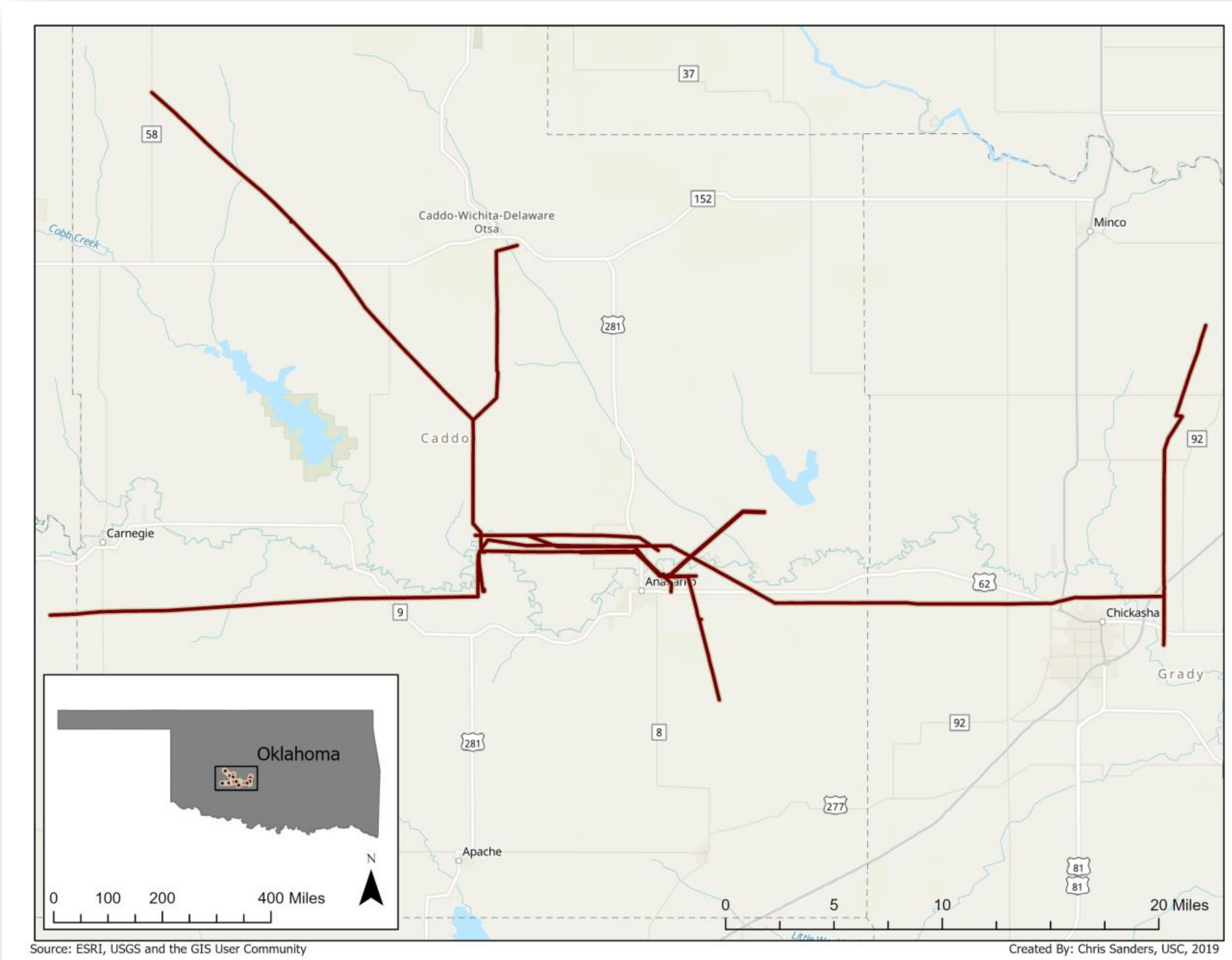


Figure 11 – Transmission Line Use Case Area Selection

3.4.1.1. Applied Risk Mitigation

Figure 12 shows the risk mitigation areas as they apply to the transmission line use case. There are approximately eight airspace areas that are to be considered, as well as two areas with higher population densities.

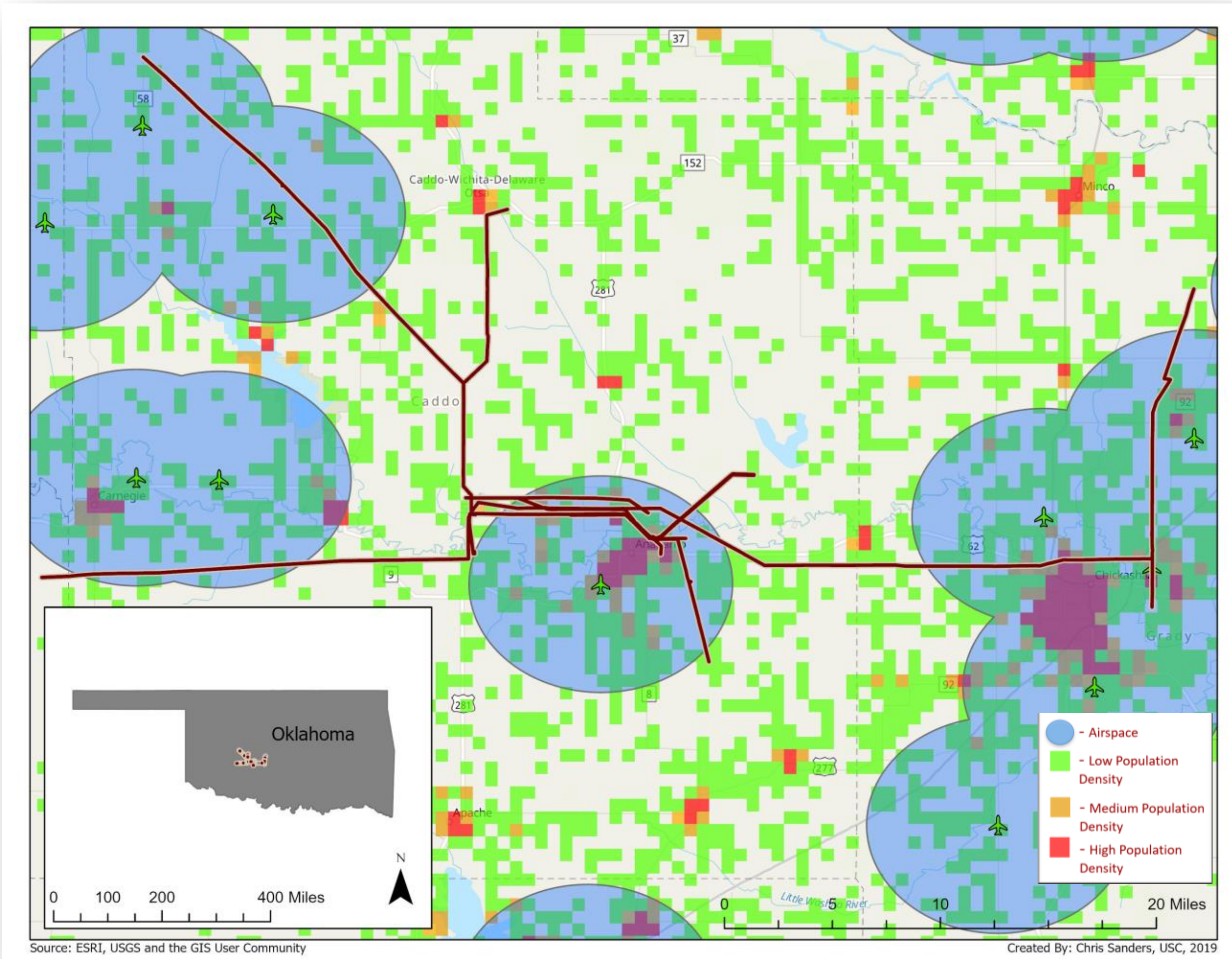


Figure 12 – Risk Mitigation for the Transmission Line Use Case

3.4.2. Railroad Use Case Area

The area selected for the railroad use case is located in northeast Texas, near the Oklahoma border. The selected area is approximately 105.91 miles long. For this dataset there are no tunnels to contend with, but there are areas containing overpasses and bridges.

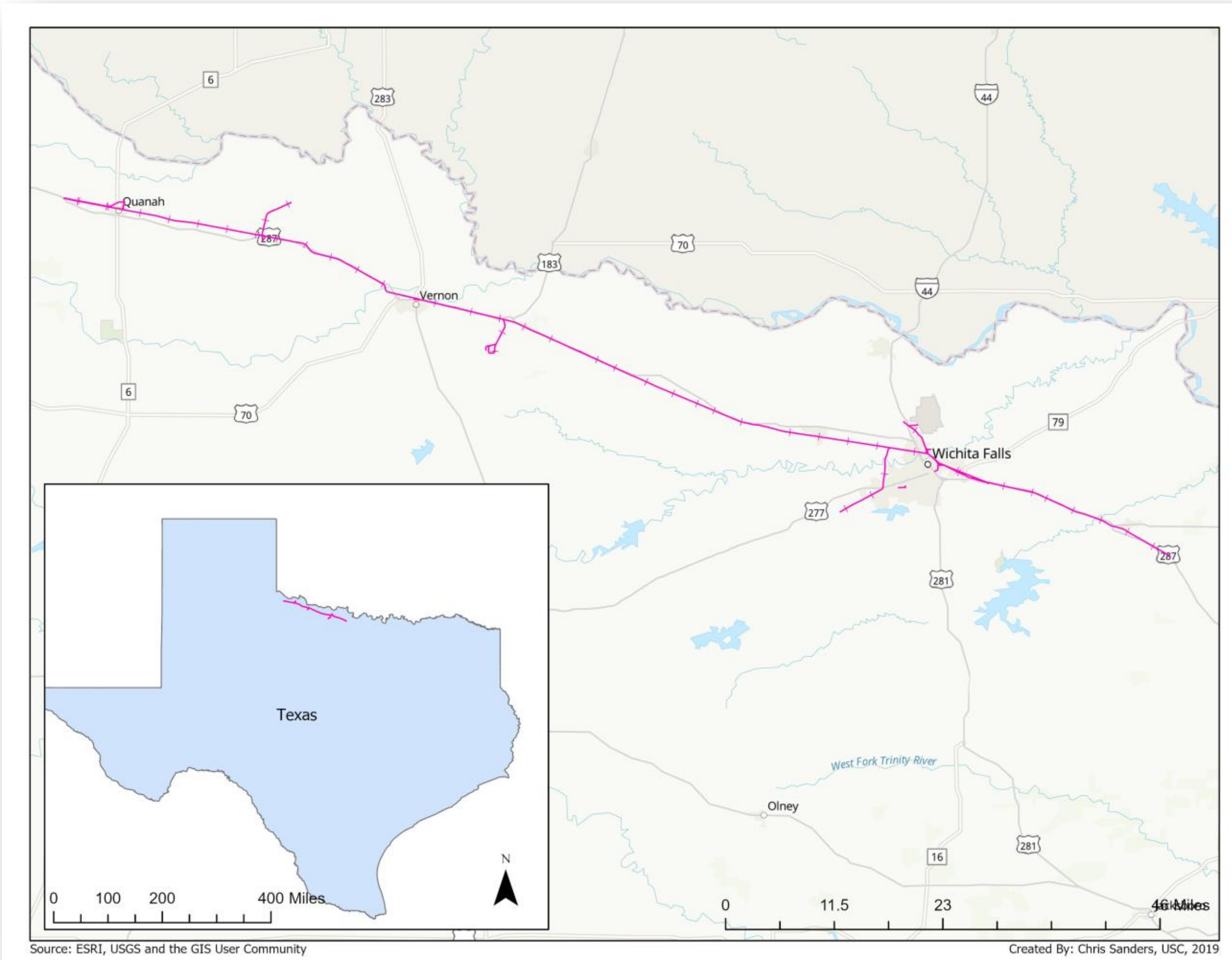


Figure 13 – Railroad Use Case Area Selection

3.4.2.1. Applied Risk Mitigations

Figure 14 below shows the risk mitigation areas as they apply to the railroad use case. There are approximately ten airspace areas to consider, as well as six areas of higher population density. There are also road crossing areas to consider that may not be considered a primary road but still exceed the traffic density set forth in the mitigations listed in chapter 3.

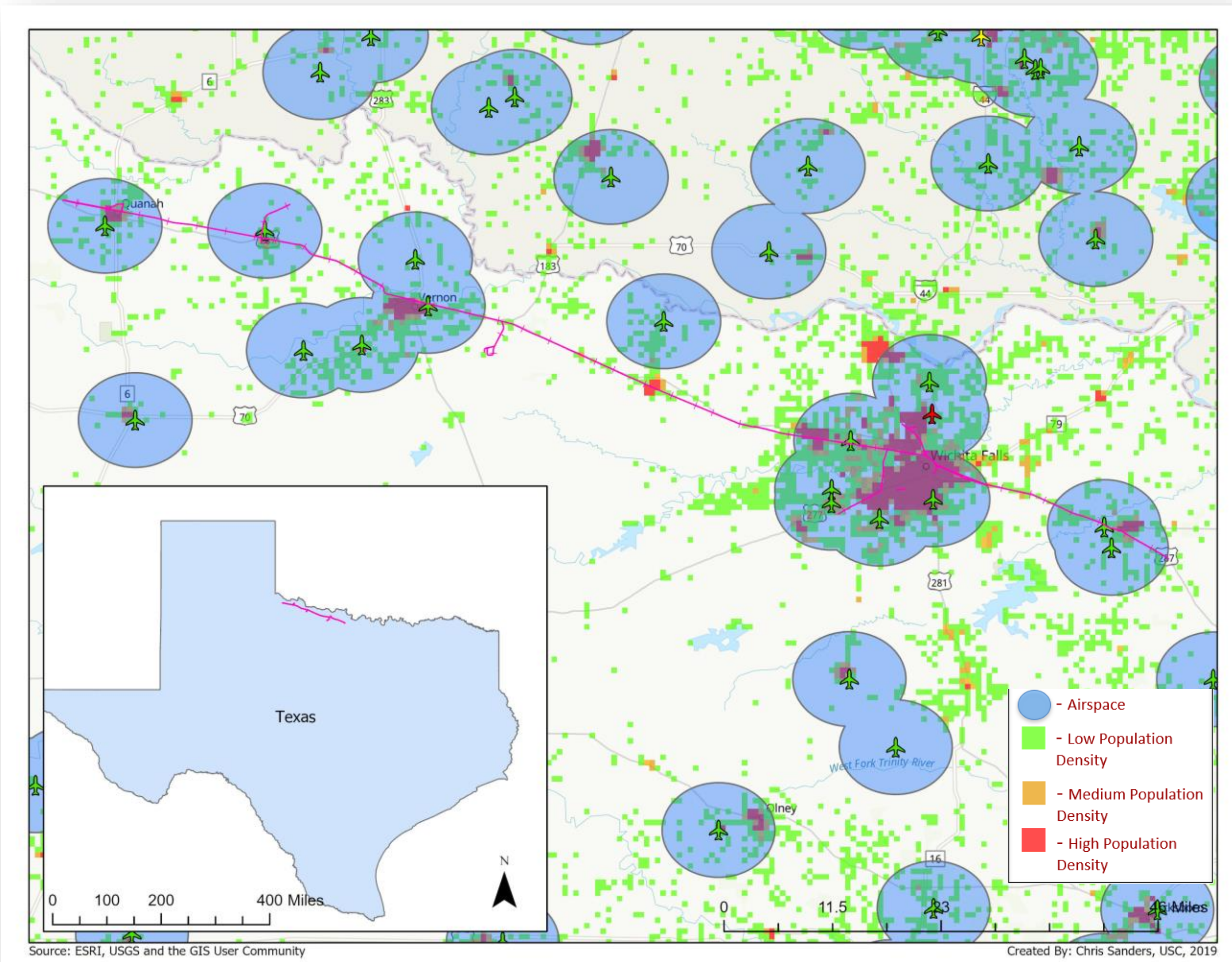


Figure 14 – Risk Mitigation for the Railroad Use Case Area

3.4.3. Wind Farm Use Case Area

The area below in Figure 15 shows the area selected for the wind farm use case. There are approximately 336 wind turbines to be inspected in this use case. It was chosen because there are several clusters of wind turbines in nonlinear arrangements, which increases difficulty in approach. There are airspace and road crossing risk considerations to consider. Population density is not as much of a factor due to few people wanting to live amidst a wind farm.

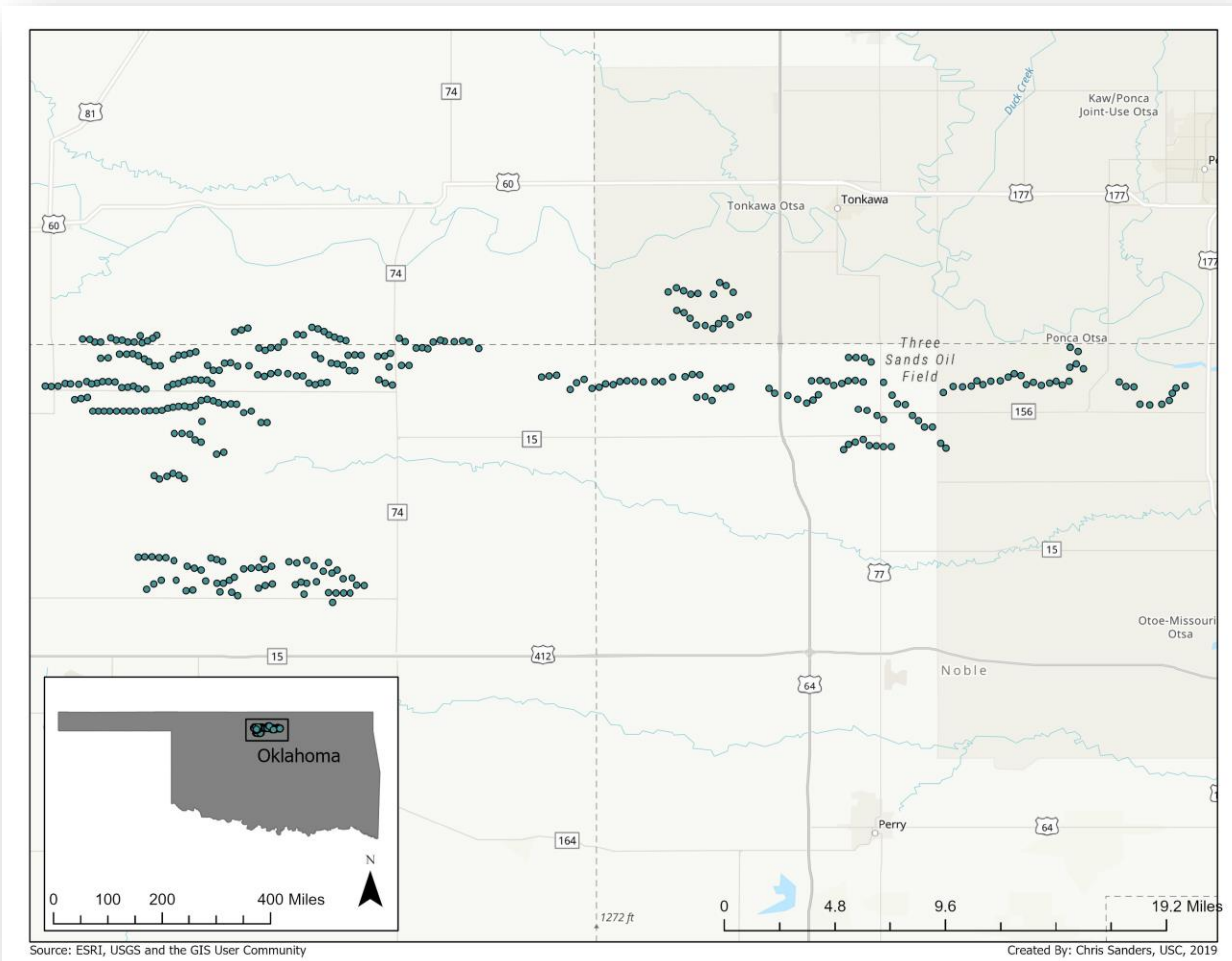


Figure 15 – Wind Farm Use Case Selection Area

3.4.3.1. Applied Risk Mitigations

Figure 16 below shows the risk mitigation areas as they apply to the wind farm use case. There is only one airspace area to contend with, but it will likely require several flights within this area. This was selected to hopefully better show the effectiveness of BVLOS operations in nonlinear use cases.

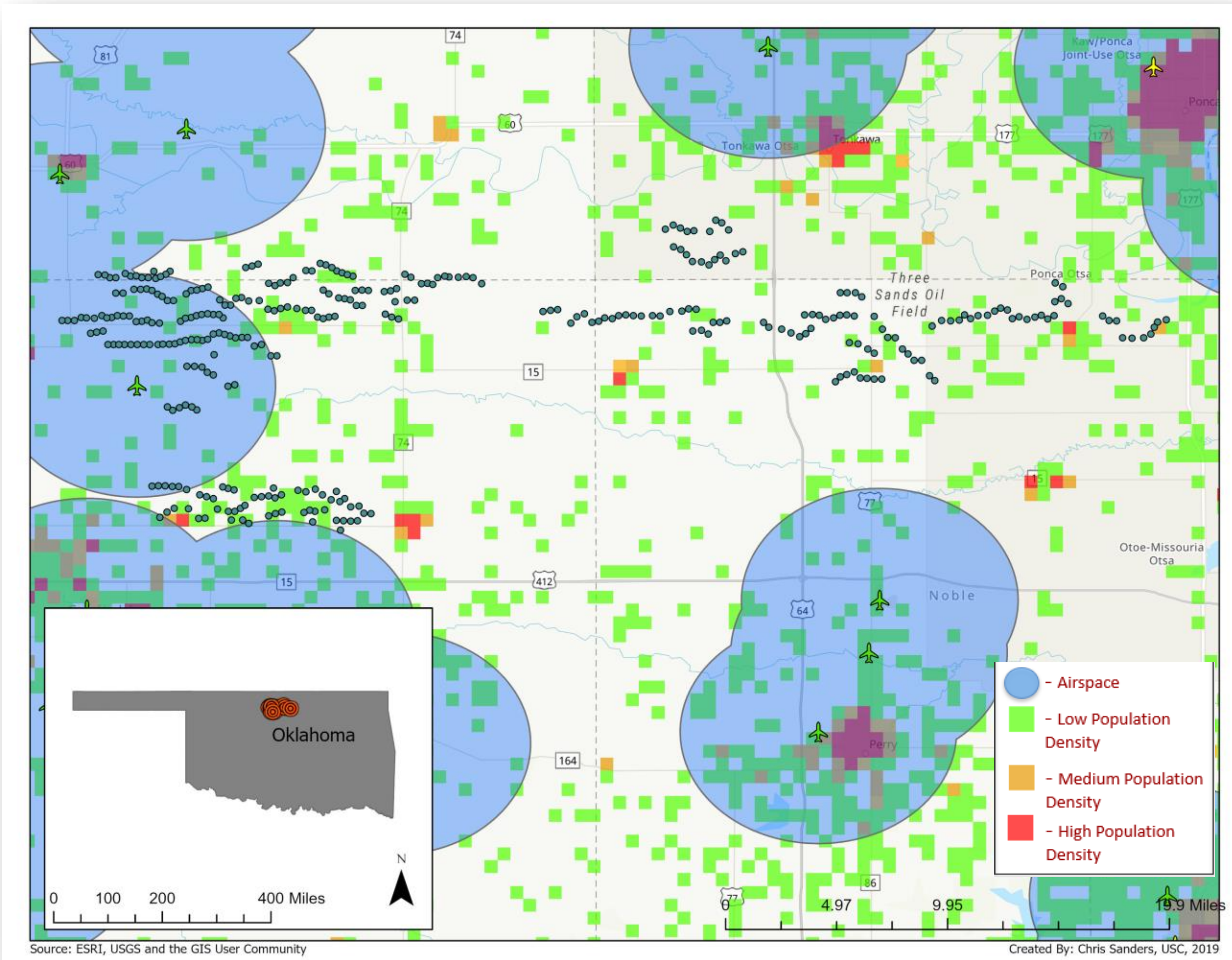


Figure 16 – Risk Mitigation for the Wind Farm Use Case Area

3.4.3.2. Wind Farm Use Case Landing Zone Selection Approach

As wind farms cannot be flown in a directly linear manner, zones will be selected based on whether BVLOS flights may be conducted in the area or not. If they can, an area consisting of a circle with a 10-mile radius will be utilized with a landing zone in the center and landing zones dispersed throughout the area for the aircraft receiving team to maximize the amount of structures that can be inspected while maintaining a flight profile that does not exceed 45 minutes. Again, it should be noted that this approach is merely a hypothetical approach to a use case that does not currently exist within industry.

Chapter 4 – Results

Upon completion of the work in ArcGIS, the areas were placed in Google Earth as mentioned in chapter 3 to ensure that there were no obstacles that could be identified from the satellite imagery. It cannot be overstated that it is vitally important to both project success and cost management that the landing areas be visually inspected before commencing operations if possible. Throughout all use cases, the most important risk mitigation factor that presented itself was airspace considerations. Having to maintain VLOS within 5 miles of airport airspace significantly impacts average miles per flight leg. Once the industry and the FAA are better poised to integrate UAS into the NAS, perhaps these requirements will be less strict, which will ultimately increase miles per flight leg while decreasing cost per mile and decreasing time on project.

Throughout each use case, the LZs chosen with risk mitigations in mind will be compared to plans where risk mitigations are not considered, and how many potential waiver violations would result due to lack of planning.

4.1 Transmission Line Use Case Results

The transmission line use case covered five different circuits across 106 miles. 38 landing zones were chosen with an average flight distance of 3.03 miles. It is estimated that 35 flights would be needed to complete this project, four of which are true BVLOS 10-mile flights. The use case with no mitigations required 13 landing zones.

4.1.1. Transmission Line Landing Zones with Risk Mitigations

Figure 17 below shows the resulting LZs based on the risk mitigation strategy as applied. The LZs are colored differently to reduce confusion and highlight areas where lines are to be flown that are not the same line. Additionally, the segments where BVLOS flights take place are highlighted in yellow.

Airspace is the largest factor for consideration of BVLOS versus VLOS flights. While population density did play a role in LZ placement on the right side, there was not any area considered too dense to require replanning of any landing area. Maintaining VLOS in areas where airspace was a consideration means the RPIC must have visual up to 1.5 miles. This means that flight legs in those areas can only be up to 3 miles, because as the aircraft leaves one RPICs line of sight, it is entering the other RPICs area who would be receiving the aircraft. Placing the LZ in such a manner that the aircraft is within visual line of sight over roads also ensures that road crossings do not become a factor.

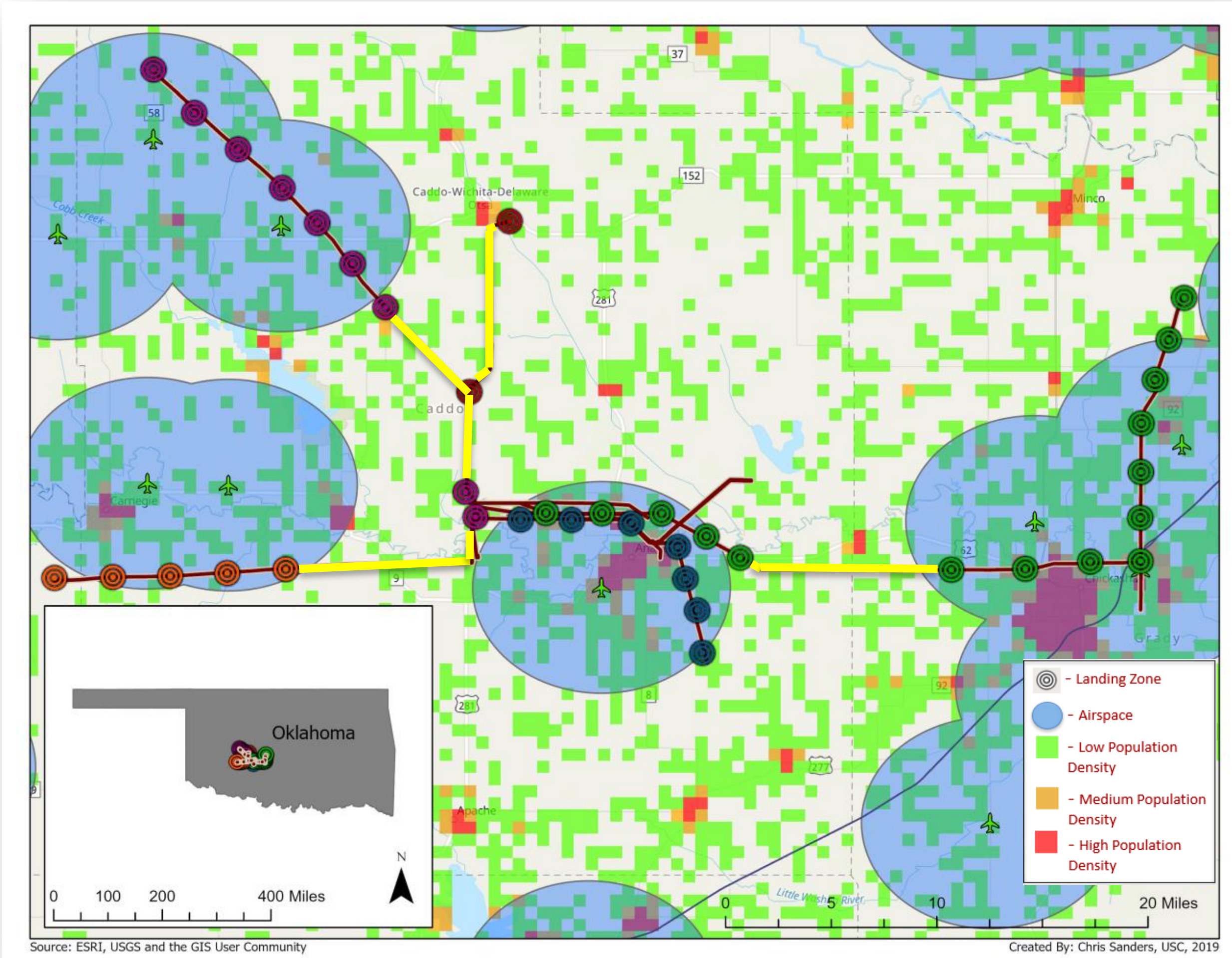


Figure 17 – Transmission Line LZ Results Using Risk Mitigation Strategies

4.1.2. Google Earth Verification

The images in Figure 18 below represent the comparative analysis performed in Google Earth Pro after the workflow in ArcGIS Pro had been completed. The Google Earth imagery allows for better oblique viewing of the areas intended to be flown. Verifying distances and highlighting roads allows the mission planner to ensure that there are no potential waiver violations that go unnoticed.

Figure 18 – Transmission Line Google Earth Comparative Analysis

4.1.3. Transmission Line Landing Zones Without Risk Mitigations

Figure 19 below shows the resulting LZs when no risk mitigation strategy is applied. If risk mitigations are not taken into consideration, only 13 landing zones are needed and this then only requires 12 flights that can be completed in two days, bringing the cost per mile down to $47. It must be noted that if the BVLOS waiver is not adhered to, there would be approximately 12 waiver violations committed. These would consist of eight airspace violations, two busy road crossing violations and two population density violations.

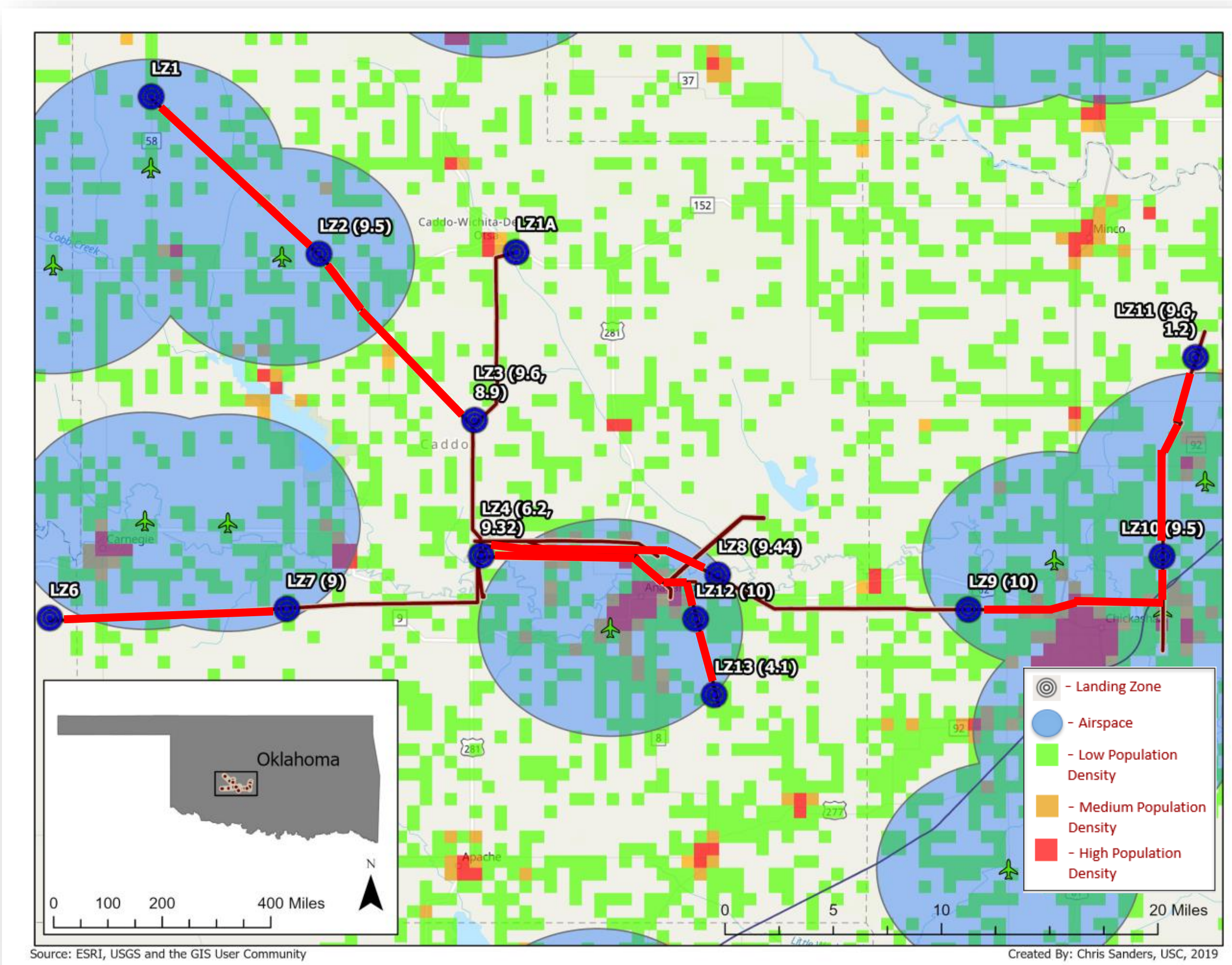


Figure 19 – Transmission Line Use Case (No Safety Mitigation Strategies Used)

4.1.4. Project Summary

Having a project that spans 106 miles and requires 35 flights would require approximately four flying days with at least two extra days built into the plan to cover inclement weather or other factors that could reduce how long flight operations could be sustained for a day. Assuming the teams were able to complete ten flights daily, with a daily rate of $2,500 per day, it would cost approximately $10,000 to complete the project. This means that cost per mile for this project is approximately $94.02. When no mitigations are considered, the number of landing zones decreases to 12, project time decreases to two days and average miles per flight increases from 3.03 to 8.1.

Table 6 – Transmission Use Case Project Summary

Mitigations Used?	# of LZs	Total # of Flights	Average Miles Per Flight	Cost Per Mile	# of Flights Conducted VLOS	# of Flights Conducted BVLOS	# of Waiver Violations
Yes	38	35	3.03	$94.02	31	4	0
No	13	12	8.10	$47.01	0	12	12

4.2 Railroad Use Case Results

The railroad use case spanned approximately 105.91 miles. The project required approximately 28 landing zones to be selected when risk mitigations were applied, and approximately 12 landing zones when no mitigations were considered.

4.2.1. Railroad Landing Zones with Risk Mitigations

Figure 20 below shows the resulting LZs based on the risk mitigation strategy as applied. Again, the largest risk consideration here is airspace. The distances between flight legs clearly increases outside of airspace areas, and population density is also more of a factor in areas where airspace is more congested. Areas where BVLOS flights take place are highlighted in yellow.

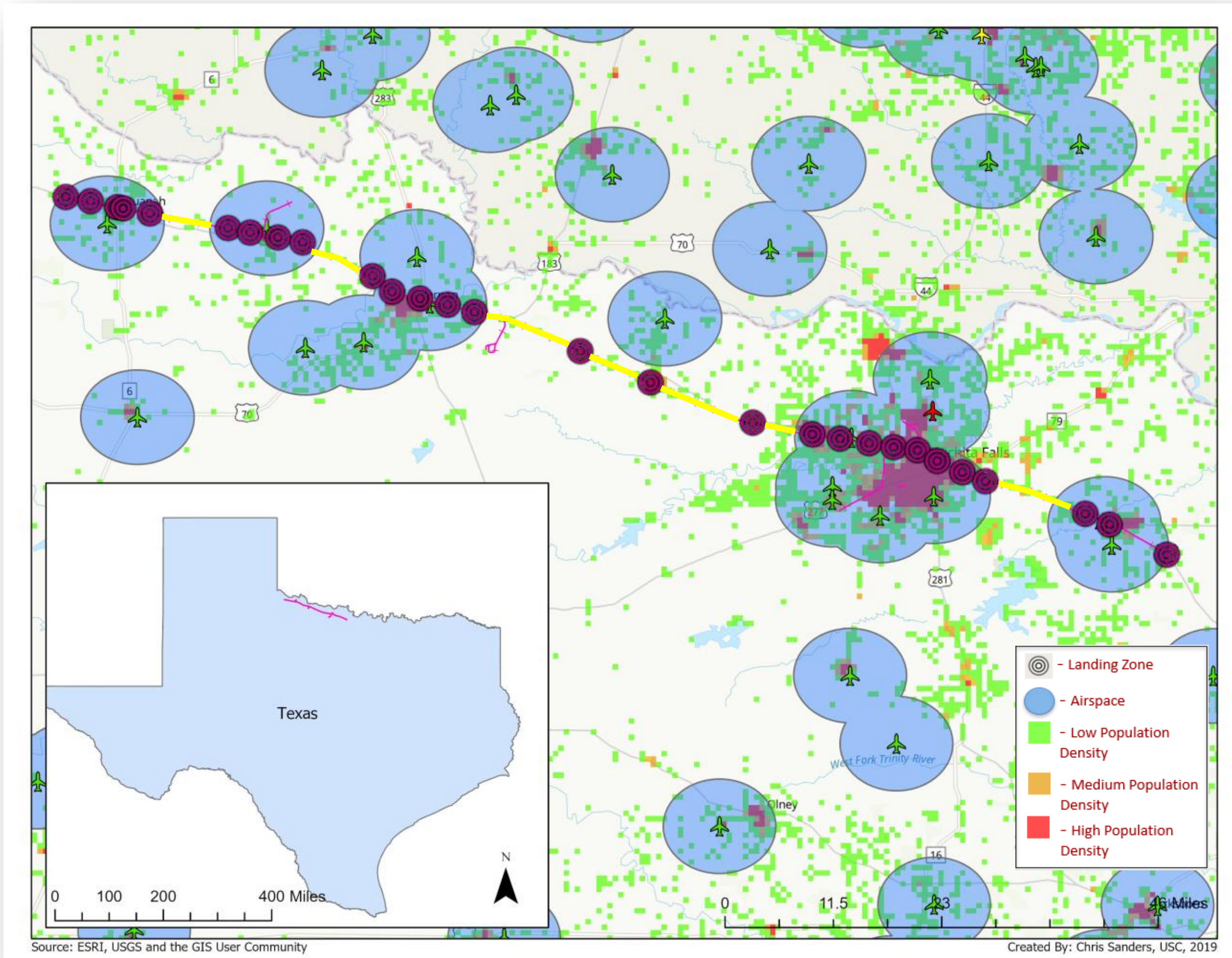
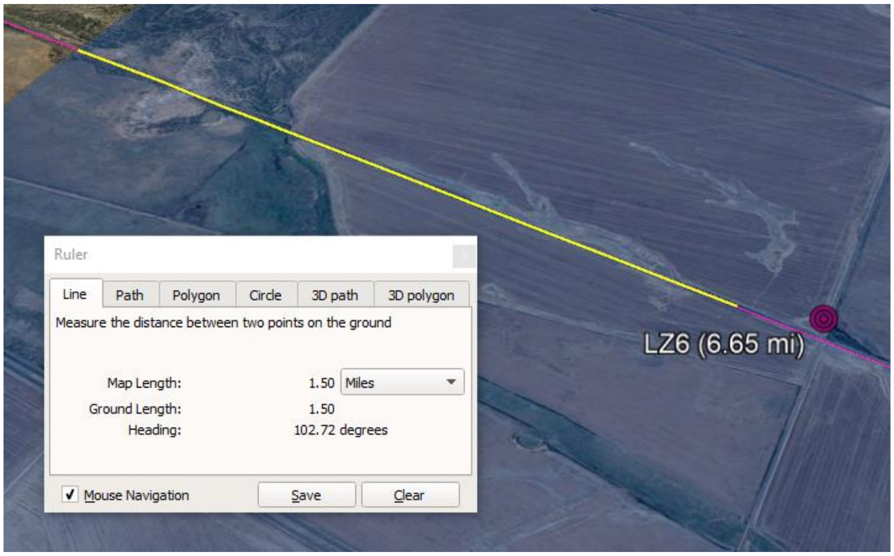


Figure 20 – Railroad LZ Results Using Risk Mitigation Strategies

Again, the largest risk consideration here is airspace. The distances between flight legs clearly increases outside of airspace areas, and population density is also more of a factor in areas where airspace is more congested.

4.2.2. Google Earth Verification

The images in Figure 21 below represent the comparative analysis performed in Google Earth Pro after the workflow in ArcGIS Pro had been completed. The verification in Google Earth is crucial to ensure that all potential flight risks are identified. Having imagery such as shown above greatly fully increases the mission planner's ability to recognize hazards and mitigate them. The red line in the image above represents a major highway where traffic exceeds acceptable BVLOS thresholds.



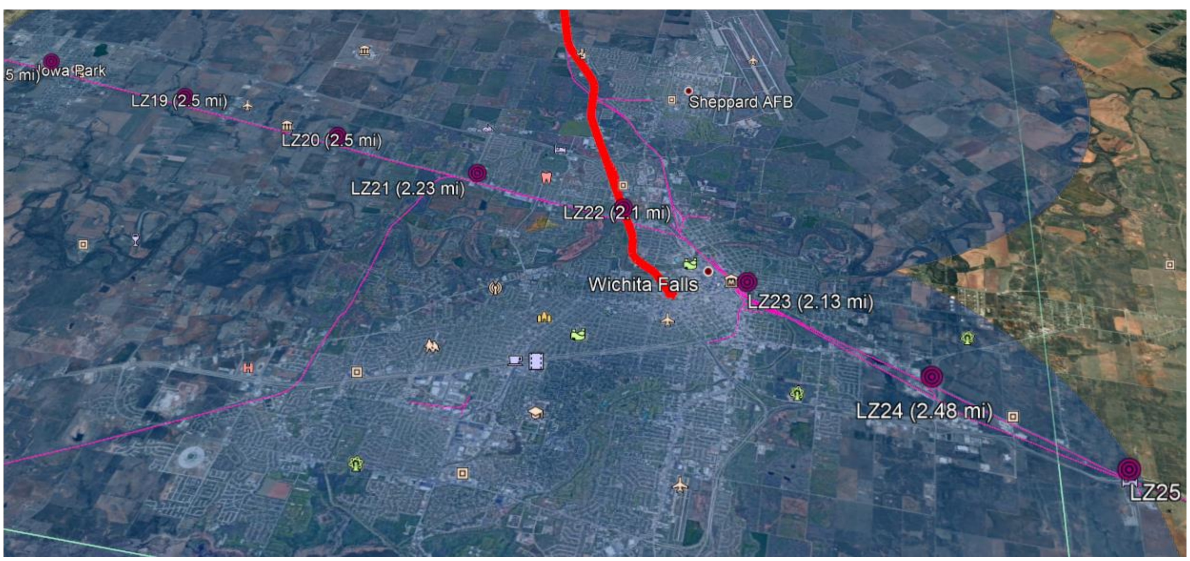


Figure 21 – Railroad Google Earth Comparative Analysis

4.2.3. Railroad Landing Zones Without Risk Mitigations

Figure 22 below shows the resulting LZs when no risk mitigation strategy is applied. Using no risk mitigations for the railroad use case and flying the maximum range the aircraft can handle would result in 12 LZs being utilized over the selected area. This would require approximately 11 flights to complete and could be completed in two days if the team could complete ten flights per day with two days extra for inclement weather or other flight limiting factors. At the same cost of 2,500 per day this would cost 5,000 dollars to complete, or $47.16 per mile. The areas highlighted in bright red show flights where violations occur.

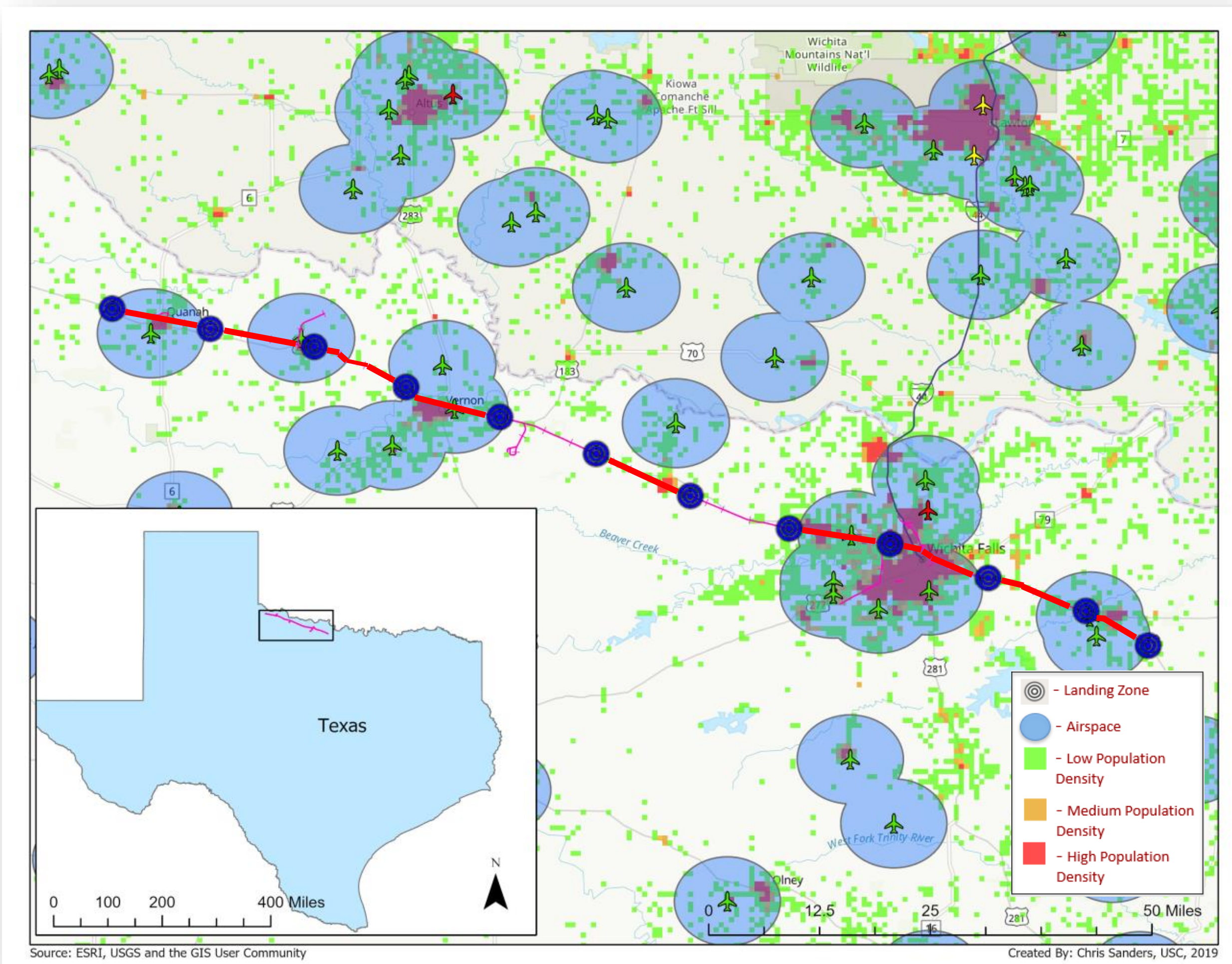


Figure 22 – Railroad Use Case (No Safety Mitigation Strategies Used)

It must be noted that over the course of this project, there would be approximately 28 total waiver violations. There would have been eleven bridge overcrossings, nine airspace violations, three busy highway crossings and five dense population overflight violations. Had an aircraft crashed in any of the dense population areas where these violations were taking place it is highly likely that someone could have been seriously injured. It would also have been nearly impossible to respond to such an emergency in a timely manner, thus potentially also being considered criminal negligence. Below is an example of one of the overcrossings that would have constituted a violation:

Figure 23 – Google Earth Railroad Use Case Bridge Violation

4.2.4. Project Summary

This project spanned 105.91 miles and would require 27 flights to complete. The timeline for project completion would require approximately three days. Two extra days in case of inclement weather or some other flight-limiting occurrence should be factored into the plan. If the teams were able to complete ten flights daily, with a daily rate of $2,500 per day, it would cost approximately $7,500 to complete the project. This means that cost per mile for this project is approximately $70.81 per mile.

Table 7 – Railroad Project Summary

Mitigations Used?	# of LZs	Total # of Flights	Average Miles Per Flight	Cost Per Mile	# of Flights Conducted VLOS	# of Flights Conducted BVLOS	# of Waiver Violations
Yes	28	27	3.93	$70.81	20	7	0
No	12	11	8.10	$47.16	0	11	28

4.3 Wind Farm Use Case Results

This approach for planning LZs for wind farms is currently not being utilized in industry. The method being utilized most often involves turbines being inspected one at a time via two methods. These methods are collecting imagery via manual flight or an automated flight plan that takes imagery of the turbine. In either case, the team is always nearby. Using a LiDAR payload could scan several turbines through the course of one flight and land at the receiving team who would be positioned near the turbines. In cases where risk mitigations are applied, the team will be positioned such that the aircraft launches, performs the scan within VLOS of the team, and lands back at the launch team area.

4.3.1. Wind Farm Landing Zones with Risk Mitigations

Figure 24 below shows the resulting LZs based on the risk mitigation strategy as applied. This use case illustrates the impact airspace restrictions imposed by the FAA has on operating areas. Areas within airspace are much smaller to ensure that VLOS is always maintained, thus reducing efficiency. In the areas where BVLOS flights could be conducted, multiple LZs are utilized to ensure that flight times of the aircraft are not exceeded. This both decreases chance for a battery becoming depleted during flight and allows for the receiving team to have a visual of the aircraft in the general operating area. This use case would require nine LZs and approximately 18 flights. The estimated average number of turbines inspected per flight is approximately 24.

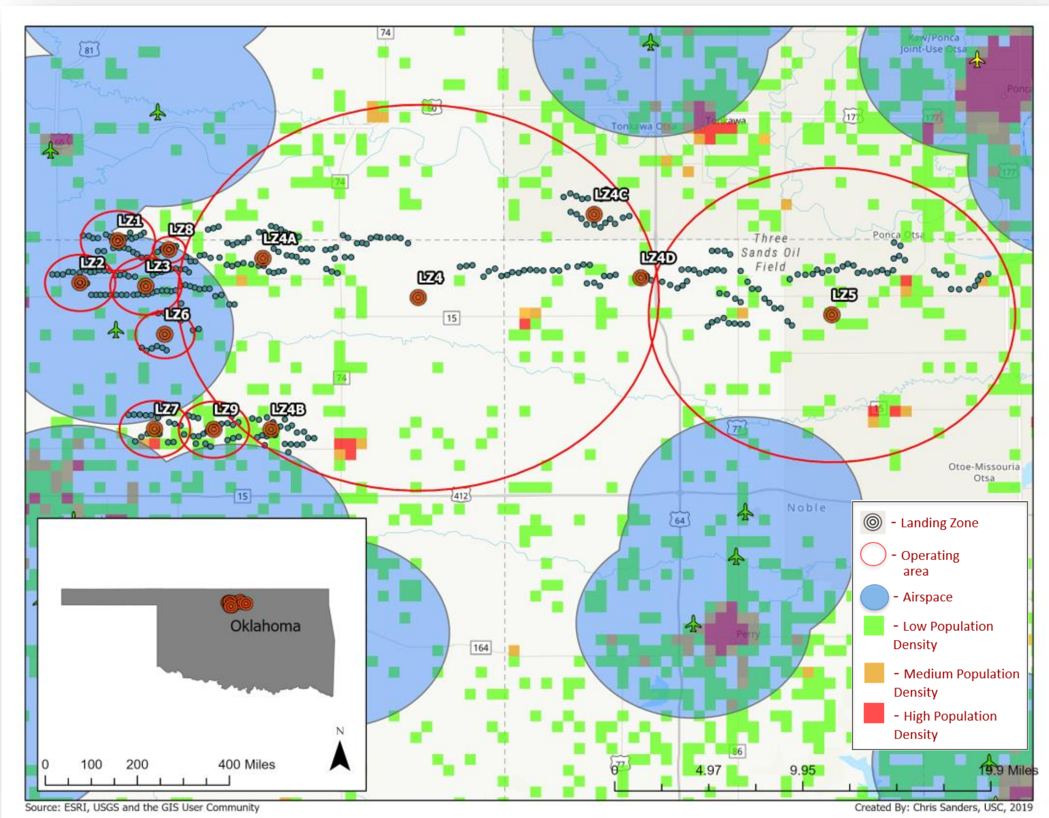


Figure 24 – Wind Farm Use Case Results with Risk Mitigation Strategies Used

4.3.2. Google Earth Verification

The images in Figure 25 below represent the comparative analysis performed in Google Earth Pro after the workflow in ArcGIS Pro had been completed. Conducting BVLOS scanning of wind turbines would also require that several turbines be shut down during operations. It would be crucial that coordination with the energy company take place prior to conducting operations to ensure safety.

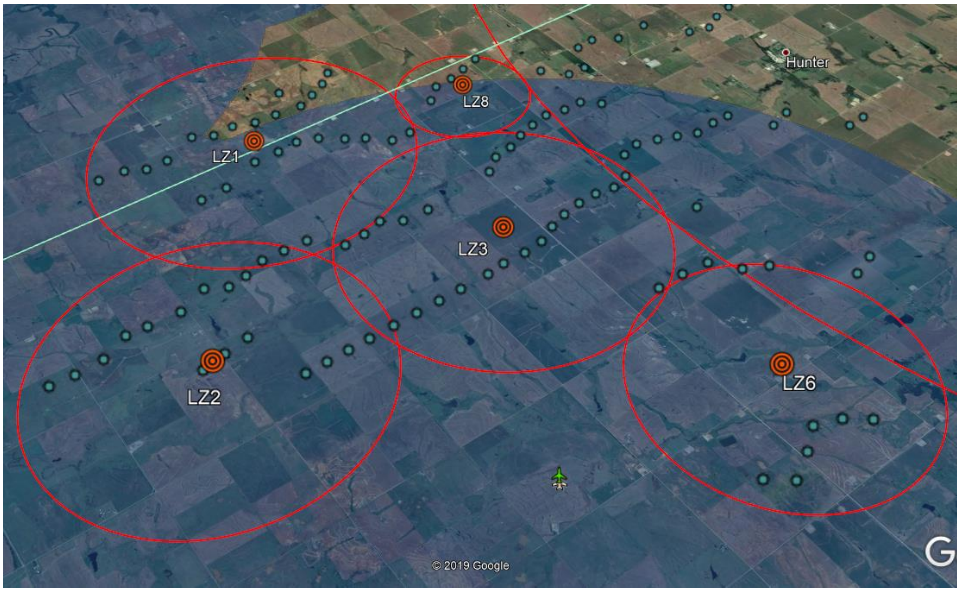


Figure 25 – Wind Farm Google Earth Comparative Analysis

4.3.3. Wind Farm Landing Zones Without Risk Mitigations

If risk mitigations are not considered in this area, the number of LZs stays the same, but the average number of turbines inspected increases from 24 to 43. In Figure 26, This gain in efficiency can be seen in the area within airspace to the left, where the airspace violations would occur. Additionally, a major highway running north to south bisects the area on the right and is not accounted for.

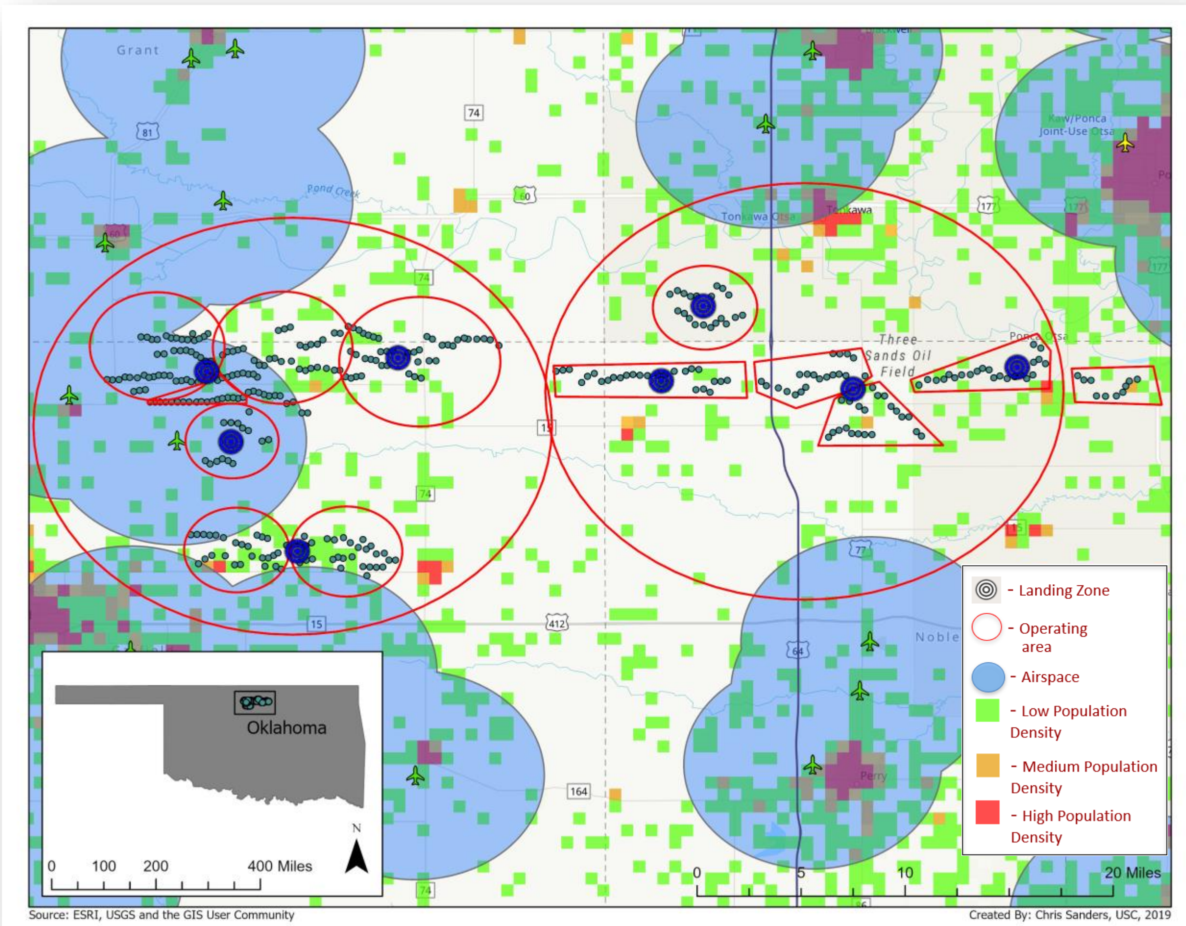


Figure 26 – Wind Farm Use Case Results (No Safety Mitigation Strategies Used)

4.3.4. Project Summary

This use case, not being a linear in nature, would likely be more accurately measured by how many turbines could be scanned per flight, or how many turbines would be scanned per project. I estimate this project would require 18 flights to complete. LiDAR flights generally take more preparation before and during the flight, therefore I would assume the teams would complete approximately six flights per day. This project would therefore require approximately three days to complete, with two extra days in case of inclement weather or some other flight-limiting occurrence. With a daily rate of $2,500 per day, it would cost approximately $7,500 to complete the project. With a total of 336 turbines to be scanned in the project, this means that the estimated cost per turbine for this project is approximately $22. Not considering the risk mitigations would see the same number of landing zones, just placed in different locations. The cost per structure decreases because the average number of structures scanned per flight jumps from 24 to 43.

Table 8 – Wind Farm Project Summary

Mitigations Used?	**# of LZs**	**Total # of Flights**	**Average Turbines Inspected Per Flight**	**Cost Per Structure**	**# of Flights Conducted VLOS**	**# of Flights Conducted BVLOS**	**# of Waiver Violations**
Yes	9	18	24	$22.00	13	5	0
No	9	12	43	$14.80	0	12	10

4.4 Overall Use Case Summary

Table 9 represents an overall summary of the three use cases. Outlined are the total costs of each, as well as the cost per mile and waiver violations.

Table 9: Overall Use Case Summary

Railroad						
Method	# of flights conducted VLOS	# of flights conducted BVLOS	Average Miles per flight	Cost Per Mile	Total Cost	# of waiver violations
Proposed	20	7	3.93	$70.81	$7,500	0
In-Situ	11	8	6.80	$118.02	$12,500	18
No Mitgation Strategy	0	12	8.80	$47.16	$5,000	28
Windfarm						
Method	# of flights conducted VLOS	# of flights conducted BVLOS	Average Structures per flight	Cost Per Structure	Total Cost	# of waiver violations
Proposed	13	5	24	$22.00	$7,500	0
In-Situ	6	9	33	$29.76	$10,000	8
No Mitgation Strategy	0	12	43	$14.80	$5,000	10
Transmission Line						
Method	# of flights conducted VLOS	# of flights conducted BVLOS	Average Miles per flight	Cost Per Mile	Total Cost	# of waiver violations
Proposed	31	4	3.03	$94.02	$10,000	0
In-Situ	11	8	6.80	$141.03	$15,000	7
No Mitgation Strategy	0	12	8.10	$47.01	$5,000	12

4.5 In Situ Landing Zone Selection

Some companies do not perform much preflight planning before conducting operations. Though this should be relatively unlikely in cases where projects span thousands of miles, it cannot be ruled out. They may have a loose plan that entails choosing where to launch and recover from when they arrive on site. The largest problem with this approach is that if the launch team must reposition farther away from the landing team, and they are already at their flight max, it then requires the other team to move to accommodate. This exponentially increases cost per mile and time on project because now teams are playing tag and time spent not flying is time spent not making revenue.

It is crucial that as more companies start to move into BVLOS operations that they take LZ consideration into account and understand that choosing a good launch and recovery area will ultimately decrease their time on project, their cost per mile, and increase revenue. Though choosing a launch site in situ may work for VLOS operations where what has to be imaged is nearby, it is not effective on linear line operations such as transmission and railroads where moving one landing area could affect all of the potential subsequent landing areas and cause what is effectively an “accordion effect”.

In situ site selection has its place in operations where small teams are used to perform flights on smaller scale projects such as cell phone towers or individual wind farm inspections. With projects smaller in scope such as these, there should almost certainly be time built into the plan to allow for a proper site survey prior to conducting operations. There are no associated maps or figures to represent in situ landing site selection because of its very nature of not being planned in the first place. The costs associated with this approach are highlighted in the next section.

Chapter 5 – Conclusions

The workflows demonstrated in this study exemplifies how landing zones for BVLOS operations can be selected when the areas cannot be visually inspected beforehand. It considers any applicable safety and risk mitigations and allows for the user to adjust launch and recovery areas based on those mitigations. This method of landing zone selection is certainly more efficient than in situ site selection, and will not result in levies, fines or waiver cancellation as compared to not considering the risk mitigations. Not having to consider airspace or population density does greatly increase flight efficiency. This approach will be more likely once the industry develops to the point where flying through airspace or over densely populated areas is less of a concern due to increased safety systems on the aircraft or type-certificated aircraft that are more reliable overall.

5.1 Use Case Discussion

The different use cases here could be considered subsets of projects that span hundreds or thousands of miles. The work that will have to go into planning must be considered from the outset. Having over 20 landing sites in a 100-mile area only speaks to the base expectations of the rest of the project if it is to span thousands of miles. This is also an important consideration for how many personnel will be needed to complete the project, as well as how many aircraft, vehicles, etc. The two linear use cases will continue to be inspected as time goes on, as the companies that own and manage these critical infrastructure assets meet their federally required mandate to inspect these areas at regular intervals. The wind farm use case is theoretical in nature but could be used as described here. One obstacle that would have to be overcome would be ensuring that all turbines to be inspected were turned off so that the blades could be properly imaged. This may not be a difficult problem, but should be worth considering, especially as to how turning off so many turbines at once could affect the power grid that is fed by those turbines.

Using risk mitigations is more expensive in general, but it also ensures that there will be no waiver violations, which in the long run could be considered a cost worth paying. Using risk mitigations and proper mission planning is not as expensive as simply showing up and trying to fly, which introduces a myriad of problems and inefficiencies to the project. Planning a project to ignore risk mitigations is the least expensive when violations or the cost if there is an aircraft accident are not considered. If it is found that an operator was violating the waiver they were operating under, they could be liable for criminal negligence or worse depending on the severity of the accident. Operators want the FAA to loosen the grip that on BVLOS waivers, but that will only happen once the FAA sees either operators performing at highly professional and safe levels, or when aircraft become much more reliable and manufacturers are required to type certify aircraft.

5.2 Future Work

The industry will certainly evolve to the eventual point of selecting launch and recovery zones automatically on projects whose scope is extremely large. Having to select hundreds of landing areas by hand requires an incredible amount of focus and skill to do correctly. Future work in this area or other BVLOS areas should certainly focus on algorithms that consider obstacles that could be in the vicinity and rank sites based on risk levels. This will give the RPIC preplanned areas to setup in the event something prevents the first site from being usable.

The UAS industry is evolving so rapidly that there are dozens of different directions that research could go. I believe automation and algorithm development is, or will be, one of the largest future sectors of UAS and commercial BVLOS operations. GIS is crucial to the success of BVLOS operations and will continue to be moving forward. A major roadblock for automation is the limitations of satellite imagery in finding obstacles, as well as the need for any algorithm that is developed to be trained by an individual who understands what to look for at any given landing area. Another roadblock will continue to be the fact that satellite imagery is not updated at such an interval that potential construction obstacles can always be avoided. This is a large part of the reason why site surveys of intended landing areas are crucial. As computer vision gets better so shall obstacle detection. I would also like to note that I believe it will be very important for those who develop these algorithms also have experience with unmanned flight operations. Understanding how the teams that use the aircraft operate is key, especially with energy planning, altitude planning and other factors. It is also very important to have aviation knowledge or experience. Understanding how airspace works, as well as where you can and cannot fly is one of the most important factors of BVLOS operations. Understanding how to read aviation sectional charts or other products plays a crucial role in flight safety. These factors will likely not change, especially in an industry that must be safety conscious.

Additional future work in this vein of research should also look at comparing how battery endurance is increasing. The longer a battery can sustain flight, the farther that aircraft will be able to go per flight. Being able to perform flights at 30 or 40 miles per leg versus ten miles will be a huge advancement in BVLOS operations. The increased flight leg capability will only be truly useful if the aircraft does not have to abide by the mitigations as they exist in this research. There are very few places within the United States that a team could fly an aircraft without running into one of the mitigations described in this research. There will have to eventually be some reduction to those mitigations to allow aircraft to fly longer distances BVLOS. Research into reliability of aircraft parts and how they affect different aircraft would also be particularly useful.

Perhaps the most important thing the industry can do is to stop focusing on pushing technology forward as the only way to improve safety. Individuals and teams set the foundation for a safe culture, safety technology only helps the users that are willing to and understand how to use them. There's no point to having aircraft that can see and avoid obstacles or satellites that can detect overhead wires if the pilots aren't going to implement safety in all they do. It will have to be a complete circle, starting with planning and ending with the post-flight checks.

The UAS manufacturing industry should also understand that if they want to truly break into the commercial BVLOS market they will have to make reliability not just a focus, but a science. It will not be long before having reliability data is not just a recommendation, but a requirement. They will have to have data on hand that demonstrates that their aircraft is reliable and give actual failure rates that operators can then use to plan when to conduct maintenance and perform parts changes. This will ultimately increase efficiency for the operators if they can more reliably understand what will fail on an aircraft and when. There is a bright future for the UAS commercial industry, but only if we forge the path ahead together to help make the industry better.

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Appendix A: Example BVLOS Waiver

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

CERTIFICATE OF WAIVER

ISSUED TO;
Xcel Energy
Responsible Person: Eileen Lockhart
Waiver Number: 107W-2019-00055A

ADDRESS:
10001 W. Hampden Ave
Lakewood, CO 80127

This certificate is issued for the operations specifically described hereinafter. No person shall conduct any operation pursuant to the authority of this certificate except in accordance with the standard and special provisions contained in this certificate, and such other requirements of the Federal Aviation Regulations not specifically waived by this certificate.

OPERATIONS AUTHORIZED

Small unmanned aircraft system (sUAS) operations beyond the visual line of sight of the remote pilot in command (PIC) and Visual Observer (VO), in lieu of visual line of sight (VLOS) for the purpose of electrical power transmission line inspection.

LIST OF WAIVED REGULATIONS BY SECTION AND TITLE

14 CFR § 107.31 — Visual line of sight aircraft operation, and
14 CFR § 107.33(b) and (c)(2) — Visual observer.

STANDARD PROVISIONS

1. A copy of the application made for this certificate shall be attached to and become a part hereof.
2. This certificate shall be presented for inspection upon the request of any authorized representative of the Administrator of the Federal Aviation Administration, or of any State or municipal official charged with the duty of enforcing local laws or regulations.
3. The holder of this certificate shall be responsible for the strict observance of the terms and provisions contained herein.
4. This certificate is nontransferable.

NOTE—This certificate constitutes a waiver of those Federal rules or regulations specifically referred to above. It does not constitute a waiver of any State law or local ordinance.

SPECIAL PROVISIONS

Special Provisions Nos. 1 to 39, inclusive, are set forth on the attached pages.

This Certificate of Waiver is effective from August 8, 2019 to October 31, 2021 and is subject to cancellation at any time upon notice by the Administrator or an authorized representative.

Executive Director
Aviation Safety Flight Standards Service

SPECIAL PROVISIONS ISSUED TO

Xcel Energy

General.

This waiver is an amendment and supersedes and replaces waiver 107W-2019-00055. Waiver 107W-2019-00055 is no longer valid.

The FAA's Flight Standards Service has reviewed your application to ensure compliance with the requirements of 14 CFR § 107.200. The Administrator finds that the proposed sUAS operation can be conducted safely under the provisions of this Certificate of Waiver (Waiver) as listed below because you have established adequate mitigations for risks involved with operating your sUAS in the manner you described. Adherence to the provisions of this Waiver establishes the required level of safety within the national airspace system.

This Waiver may be canceled at any time by the Administrator, the person authorized to grant the Waiver, or a representative designated to monitor a specific operation. As a general rule, this Waiver may be canceled when it is no longer required, there is an abuse of its provisions, or when unforeseen safety factors develop. Failure to comply with any provision listed below is a violation of the terms of this Waiver and may serve as justification for cancellation.

List of Regulations Waived by Section and Title. The following regulations are waived:

14 CFR § 107.31, Visual line of sight aircraft operation, is waived to allow operation of the small unmanned aircraft (sUA) beyond the direct visual line of sight of the remote pilot in command (PIC) and any visual observer (VO) who is participating in the operation.

14 CFR § 107.33(b) and (c) (2), is waived to the extent necessary to allow operation of the small unmanned aircraft (sUA) when any VO who is participating in the operation may not be able see the unmanned aircraft in the manner specified in §107.31.

No part of this waiver will function as an airspace authorization under 14 CFR § 107.41. The FAA's Air Traffic Organization responds directly to requests for such authorizations.

Common Special Provisions. The Responsible Person is directly responsible for safety of operations conducted under this Waiver and will ensure the remote PIC, manipulator of the controls, and VO[1] comply with all provisions of this Waiver.

1. The Responsible Person listed on the Waiver is responsible to the FAA for the safe conduct of the operations. Prior to conducting operations that are the subject of this Waiver, the responsible person:
   a. Must ensure the remote PIC, manipulators of the controls, and VOs are informed of the terms and provisions of this Waiver and strictly observe the terms and provisions herein;
   b. Must ensure the remote PIC, manipulators of the controls, and VOs are informed and familiar with part 107 regulations; and
   c. Evidence of the above (a and b) must be documented and must be presented for inspection upon request from the Administrator or an authorized representative;

2. This Waiver may not be combined with any other waiver(s), authorizations(s), or exemption(s) without specific authorization from the FAA;

3. The FAA has the authority to cancel or delay any or all flight operations if the safety of persons or property on the ground or in the air are in jeopardy or there is a violation of the terms of this Waiver;

4. A copy of this Waiver must be accessible and available to the Remote Pilot in Command (remote PIC) at the ground control station during sUAS operations that are the subject of this Waiver;

5. The Responsible Person listed on this Waiver must maintain a current list of pilots by name and remote pilot certificate number used in operations under this Waiver. This list must be presented for inspection upon request from the Administrator or an authorized representative;

6. The Responsible Person listed on this Waiver must maintain a current list of small unmanned aircraft (sUA) by registration number(s) used in the Waiver holder's operations. This list must be presented for inspection upon request from the Administrator or an authorized representative;

7. For the purposes of this Waiver, Direct Participants are the remote pilots in command (PICs), persons manipulating the controls, visual observers (VOs), and any persons whose involvement is necessary for safety of the sUAS operation;

[1] Title 14 CFR § 107.3 defines the term "visual observer." Any VO participating in operations conducted under this Waiver must meet the requirements listed in § 107.33 throughout the duration of flight operations.

Waiver Specific Special Provisions. sUAS operations beyond the visual line of sight (BVLOS) of the remote PIC and VO(s) may be conducted under this waiver when the operation complies with the following provisions:

OPERATIONAL PROVISIONS

8. The remote PIC must ensure sufficient VO(s) are used to identify any non-participating aircraft in sufficient time for the sUAS to maneuver and remain well clear of other aircraft. For the purpose of this Waiver sufficient VO(s) is defined as at least one VO using the electronic means described in the waiver application to monitor the airspace, or the minimum number of VO(s) required to continuously observe, using human vision unaided by any device other than corrective lenses, at least a 2.5 statute mile radius of airspace surrounding the sUA in flight;

9. Individuals directly participating in the operation of the sUAS must be easily identifiable visually (e.g., apparel, safety vests);

10. The Responsible Person must ensure all operations conducted under this Waiver follow the procedures outlined in the submitted operations manual. If a discrepancy exists between the provisions in this Waiver and the procedures outlined in the operations manual, the provisions of this Waiver take precedence and must be followed;

11. The Responsible Person may update or revise its operations manual. The Responsible Person must track such revisions and present revised documents to the Administrator or an authorized representative upon request. The Responsible Person must also present revised documents when applying for extension of or amendment to this Waiver. If any revision to the manual would be contrary to the information provided in the waiver application or obviate a condition or limitation of this waiver, then the Responsible Person must apply for an amendment to this Waiver;

12. The Responsible Person must ensure a copy of the current operations manual is available to the remote PIC and all other direct participants prior to and during sUAS operations that are the subject of this Waiver;

13. Prior to conducting operations under this Waiver, the remote pilot must be proficient in visual line of sight (VLOS) operations and trained in accordance with waiver application's specific training program. This proficiency and training must be documented and must be presented for inspection upon request from the Administrator or an authorized representative;

14. The Responsible Person must establish and maintain a Safety Management System (SMS) appropriate for the size, scope, and complexity of operations that occur under this Waiver. Guidance on establishing and maintaining an SMS is available in FAA Advisory Circular 120-92B (or current revision). This program must be made available upon request by the Administrator;

15. Prior to operations under this Waiver, all direct participants must attend a safety briefing that addresses at minimum, the following items:
    a. Designated positions, physical locations, responsibilities, and Crew Resource Management,
    b. Planned flight operating area,
    c. Designated launch and recovery areas,
    d. Lost link contingency plan,
    e. GPS availability for the planned duration of the sUAS flight operation,
    f. Normal procedures,
    g. Abnormal procedures, and
    h. Emergency procedures;

16. Communication between the remote PIC and any VO(s) must occur to facilitate, when necessary, the remote PIC taking action to maneuver the sUA with sufficient time to:
    a. Give way to all other aircraft accordance with § 107.37,
    b. React to any unforeseen operational or mechanical failure without creating a hazard to other people, other aircraft, or property in the event of a loss of control of the sUA, and
    c. Maintain compliance with this Waiver and the requirements of part 107;

17. Operations subject to this waiver must cease if, at any time:
    a. Safety of human beings or property on the ground or in the air is in jeopardy,
    b. Any failure to comply with the provisions of this Waiver exists,
    c. Communications cannot be maintained between the remote PIC and any VO participating in the operation,
    d. GPS signal is lost, or
    e. sUA GPS location information is degraded;

18. Launch or recovery areas must be pre-designated and monitored to keep any human being who is not directly participating in the operation out of the areas prior to, during, and immediately following flight operations;

19. All planned launches and recoveries of the sUA must be within VLOS of the remote PIC;

20. As described in the application, outreach must be conducted and coordinated with other potentially affected aircraft operators prior to any sUAS operations subject to this Waiver and not less than 24 hours prior to conducting operations that are the subject of this Waiver, a Notice to Airmen (NOTAM) must be filed. The NOTAM must include location, altitude, and/or operating area, time and nature of the activity;

21. The Responsible Person shall keep at its principal business office or at other places approved by the Administrator, and email the Administrator at 9-afs-820-Part107Reports@faa.gov monthly, the information listed below. The Responsible Person must retain all such records for a period of 90 days after the expiration date of the Waiver.
    a. For each sUAS flight operation conducted under the terms of this waiver:
        i. Date and location of operation
        ii. Registration number of the sUA,
        iii. Make and model of the sUA,
        iv. Name and certificate number of the remote PIC's,
        v. Name and location of the VO for the sUAS operation,
        vi. The name and location of any additional persons who acted as VO(s),
        vii. The distance flown and time duration of the sUA operation,
        viii. Number of non-participant aircraft detected within 500 feet vertical or 6000 feet horizontal of the power line, and
        ix. Number of avoidance maneuvers or sUA flight path changes made by the RPIC to remain well clear of other aircraft or avoid a mid-air collision;

    b. For each sUAS flight conducted under this Waiver that includes any equipment degradation, malfunction, or failure, the Responsible Person must make a record of the degradation, malfunction, or failure by recording the date, time, and a description of the degradation, malfunction or failure. sUAS equipment degradations, malfunctions, or failures include, but are not limited to, the following:
        i. Onboard flight control system,
        ii. Any portion of the navigation system to include GPS functionality,
        iii. Power plant malfunction or failure,
        iv. Battery malfunction or failure,
        v. Electrical power system malfunction,
        vi. Control station malfunction or failure, and
        vii. Loss of control link within the sUAS;

TECHNICAL PROVISIONS

22. Operations conducted under this Waiver may only occur with the make and model sUAS described in the waiver application Proposed operations of any other manufacturer, make or model of sUAS will require a new waiver application or a request to amend this Waiver;

23. All sUAS operations conducted in accordance with this Waiver must comply with all manufacturer recommendations and limitations for the sUAS;

24. The Responsible Person must maintain each sUAS and its components in accordance with manufacturer's instructions and recommendations. sUAS maintenance includes scheduled and unscheduled overhaul, repair, inspection, modification, replacement, and system software upgrades of the sUAS and its components necessary for flight. A log of all maintenance performed must be kept for each aircraft operated under this waiver. This log must be available to the remote PIC for review prior to conducting operations that are the subject of this waiver. Each sUAS maintenance log must be presented to the Administrator when requested. The log must contain the following information for each maintenance activity:
    a. A description (or reference data acceptable to the Administrator) of work performed,
    b. The date of completion of the work performed,
    c. The name of the person who performed the work, and
    d. The signature of the person who performed the work;

25. Any sUAS that has undergone maintenance must undergo a functional test flight prior to conducting operations under this Waiver. A log entry must be made for each functional test flight. The log entry must contain at minimum the:
    a. Calendar date,
    b. sUA registration number,
    c. Remote PIC who performed the functional test flight,
    d. Duration of the flight, and
    e. The result of the functional flight test;

26. A functional test flight may only be conducted under the standard requirements of part 107 (without waiver);

27. The sUA must be equipped with high visibility markings and lighting to increase the conspicuity of the sUA to be visible for at least 1 statute mile;

28. All sUA operated under this Waiver must be capable of automatic operations. A preplanned flight path for the sUA to follow must be verified by the remote PIC and at least one other direct participant in the sUAS operation prior to sUA flight;

29. As described in the waiver application, sUAS ground control station must display in real time the following information: sUA altitude, sUA position, sUA direction of flight, and sUAS flight mode. This information must be available at all times to the remote PIC;

30. The sUAS must audibly or visually alert the remote PIC of degraded system performance, sUAS malfunction, or loss of Command and Control (C2) link between the ground control station and the sUA;

31. Prior to conducting operations under this Waiver, the remote PIC must determine all control links the used in the sUAS are sufficient to maintain control link within the sUAS at the maximum planned distance for the proposed operation. At all times during operations that are the subject of this Waiver, the remote PIC must maintain a command and control link with the sUA and the ability to direct the sUA to ensure compliance with the applicable provisions of this chapter;

32. If the remote PIC loses command or control link with the sUA, the sUA must follow a predetermined route to either reestablish link or immediately recover/land;

33. If communication between the VO and the remote PIC will occur by electronic device:
    a. The device must be continuous full-duplex,
    b. The remote PIC must be able to use the device hands-free, and
    c. There must be a reliable back-up communication method;

34. ADS-B out (1090/978 MHz) may not be transmitted from the sUAS when operating pursuant to this Waiver;

35. All emitters used in sUAS must be in compliance with all applicable FCC regulations and all provisions of the FCC authorization granted for the emitter. A FCC experimental authorization may not be used for sUAS operations under this Waiver;

ENVIRONMENTAL PROVISIONS

36. Operations under this Waiver may only be conducted in Class G airspace;

37. Operations under this Waiver may not be conducted within 5 miles of a public or military use airport.

38. sUA operations are limited to within 100 feet vertically and 20 feet horizonally from the centerline of electrical power transmission line structures owned or controlled by Xcel Energy; and

39. Operations conducted under this Waiver are limited to the sections of power line infrastructure Xcel Energy owns or controls that meet the criteria described in the waiver application.

Source: FAA (2019)