Unmanned Aerial Systems and Wyoming's Road Networks:

Accelerating Deployment and Realizing Advantages

Prepared by:

Austin Woody

Transportation Specialist

&

Khaled Ksaibati, Ph.D., P.E.

Department of Civil & Architectural Engineering
Wyoming Technology Transfer Center
University of Wyoming
1000 E. University Avenue, Dept. 3395
Laramie, Wyoming 82071

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FOREWORD

The term Unmanned Aerial Systems (UAS) describes the airborne segment of the drone world. First developed for military applications, UAS have recently exploded across numerous civilian industries and have rapidly become commonplace on jobsites and in households around the world. Construction and transportation industries have been early to adopt UAS technology and are rapidly integrating aerial drones into a variety of everyday work tasks with incredible results. The benefits are numerous; increased safety, time and money saved, all while enhancing the quality and accuracy of work results. UAS have become an indispensable tool for transportation professionals everywhere, and it is safe to say that they will soon be a part of many people's jobs in the transportation world.

The intention of this manual is to assist transportation professionals in Wyoming at all levels of government and industry to get up-to speed with this rapidly developing technology. The process of incorporating UAS into a work place and everyday tasks is complex and will take some time. Increasing understanding of what this process involves and realizing where and how UAS technology can benefit your organization are great pieces of knowledge to build future efforts upon. It is our hope that the following pages will assist in building this foundational knowledge of UAS and help your organization to take the initial steps to integrating this technology into your work place.

ACKNOWLEDGMENTS

This project was made possible through a generous STIC grant from the Federal Highway Administration. The FHWA selected drone technology for inclusion as a part of their Every Day Counts (EDC) innovation program. The EDC initiative "is a State-based model that identifies and rapidly deploys proven, yet underutilized innovations to shorten the project delivery process" (FHWA, 2019). As the following pages will demonstrate, aerial drone technology fits under this definition perfectly.

This project was further assisted through a partnership with WYDOT and Sheri Taylor of WYDOT Aeronautics Division specifically. Participating on WYDOT's UAS Taskforce and the opportunity to complete demonstrative UAS flight missions on WYDOT property and assets provided valuable opportunities to further our knowledge of UAS operations and considerations surrounding deploying this technology at an organizational level.

We would also like to extend our gratitude to Destry Dearden of Lincoln County. Mr. Dearden provided us with an excellent example of what successful and effective UAS deployment looks like at a local government level in Wyoming. His willingness to share knowledge and digital media from Lincoln County UAS projects was instrumental in this project.

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Acronyms Used

As is common in governmental regulatory language, the aviation world is full of acronyms. Here are a few acronyms that you will see in this publication and UAS related literature.

AGL-Above Ground Level

ATC-Air Traffic Control

FAA-Federal Aviation Administration

GCP-Ground Control Point

HD-High Definition

LAANC- Low Altitude Authorization and Notification Capability

Lidar-Light detection and Ranging

POV- Point of View

RPIC-Remote Pilot in Command

RTK-Real Time Kinematics

SOP-Standard Operating Procedures

UA-Unmanned Aircraft

UAS-Unmanned Aerial Systems, includes aircraft and all attached sensors.

UAV-Unmanned Aerial Vehicle

VO- Visual Observer

WYDOT-Wyoming Department of Transportation

Applications

One of the preliminary steps toward successfully integrating Unmanned Aerial Systems (UAS) into your workplace is to build knowledge of the ever-expanding variety of applications where this technology is being utilized. One of the most remarkable aspects of modern UAS is their versatility. Even an entry-level UAS equipped with a basic camera can be used to achieve a wide variety of tasks and enhance numerous work outputs.

Aerial Imagery

For most tasks in the transportation world, aerial drones equipped with high definition digital cameras are the most common, affordable and versatile type of UAS. Digital photography and video captured from an aerial perspective allows for a remarkable level of detail and context of the scene. Transportation professionals have used this capability to document and survey the extent of road damage sustained during natural disasters such as flooding and landslides (see Figure 1). Especially during dangerous events such as these, aerial imagery allows road managers to quickly inspect areas which may be hazardous to access by a live person. For additional reading on how UAS can benefit emergency response please see the tech brief titled, "Use of Small UAS for Emergency Management of Flooding" by the Federal Highway Administration (FHWA) in Appendix A found at the end of this manual.

Construction Inspection

Construction job sites are finding novel uses of camera-equipped UAS as well. Construction progress can be quickly and easily documented by launching a drone and photographing or capturing video of the job site from above. These digital image files are recorded with data describing the time captured and are easily uploaded to computers where they can be shared or published electronically creating a lasting and detailed record of progress on projects. These overhead images have proven their value for tasks on construction sites such as identifying and monitoring erosion, quality assurance/quality control functions among others. For those interested in learning more about how UAS can enhance construction management follow the link for the FHWA tech brief titled, "Use of Small UAS for Construction Inspection" in Appendix A.

Figure 1: *Photo Courtesy of Destry Dearden/Lincoln County*

Imagery of Porcupine Land Slide in Western Wyoming captured by UAV in 2019. This photo illustrates the depth of context provided by an aerial perspective and how this can be particularly useful in emergency response applications.

Asset Inspection

Aerial imagery also allows for the inspection of difficult to reach assets such as bridges and towers. UAV's have become especially common in bridge inspections and have greatly simplified a once dangerous and time consuming task that required equipment such as snooper trucks, fall protection equipment and lane closures. Bridge inspectors can now fly a UAS underneath a bridge deck capturing high definition photographs and videos of bridge joints, bolts and other structural componentry at close range. This capability is further enhanced by augmenting the UAS with a virtual reality headset, which allows for a secondary inspector to manipulate the camera's field of vision, photographic exposure settings and zoom level. This allows the UAS operator to concentrate on safely operating the drone and to position it in such a way as to optimize the camera operator's vantage point. Some more advanced UAV's can be equipped with infrared thermal cameras, which allow inspectors to rapidly scan large areas of bridge decks for subsurface delamination. For additional information about bridge inspection by UAS, see the FHWA tech brief titled, "Use of Small UAS for Bridge Inspection" linked in Appendix A.

Figure 2 *Inspection photo captured by a Parrot Anafi UAV showing general level of detail provided by prosumer level equipment. Assets such as this overhead traffic signal mast can safely and quickly be inspected by utilizing UAS*

Photogrammetry

Any conversation about aerial drone usage in construction or transportation applications industries isn't complete without a discussion of photogrammetry software. Photogrammetry describes a process in which a computer program transforms a series of photographs into a 3-dimensional model of an object or land surface. This is achieved by identifying common locations, or "points", between overlapping photographs taken from different vantage points. The computer is able to triangulate between the different camera locations and the common location to place that point in 3 dimensional space. After repeating this process thousands, or millions, of times, the photogrammetry software is able to form what is referred to as a point cloud. The point cloud is a true-to-scale, 3-dimensional rendering of the object or landscape being surveyed. Photogrammetry and the ability to create point cloud models is where UAS technology really takes off in terms of capturing and deriving quantifiable data. See Figure 4 for an example of a photogrammetric model captured on a survey project.

Volumetric Pile Measurement

One exceptionally useful function of a 3-dimensional point cloud model is the ability to draw highly accurate measurements from the digital rendering. Linear measurements, surface areas and volumetric measurements can all be drawn from these digital models. These capabilities are especially helpful in transportation functions. Volumetric measurement can be used to measure aggregate stock piles, as well as fill volume of excavations sites. This allows road professionals to make quick, accurate measurements of materials on-hand, or needed for a project. Multiple measurements can be drawn from a single point cloud, which allows workers to measure the volume of multiple piles and/or fill volumes of open excavation pits.

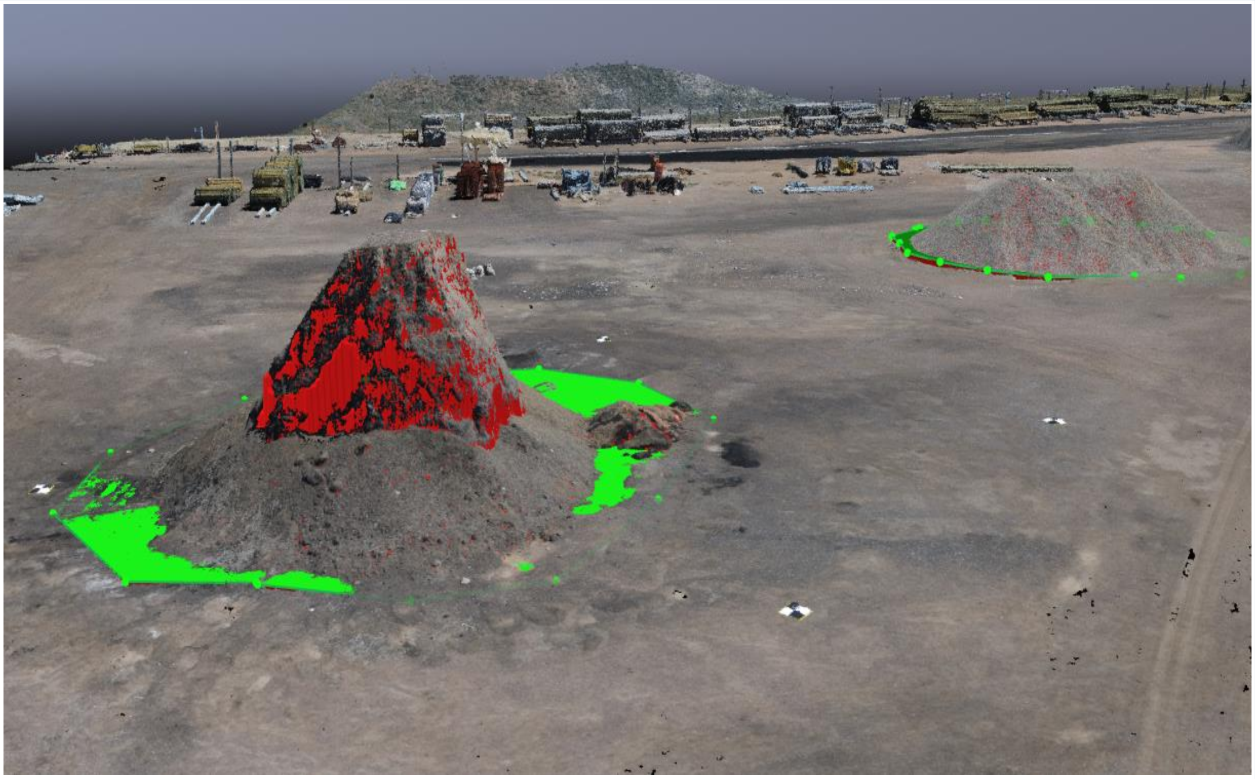

Figure 3: *Photogrammetry derived model showing volumetric measurement of aggregate stockpiles. Note how data collected from one UAS flight can be used to measure multiple stockpiles independently.*

Surveying

Land form surveying and modeling is another area where UAS and photogrammetry capabilities are expanding capabilities while decreasing expense. The same photogrammetry process described above is being used to model land forms, deriving similar results to those captured by much more expensive Lidar scanners. The ability to create accurate digital models of landforms is incredibly useful to transportation officials. Unstable slopes, such as rock slides or cut banks (See Figure 4), can be scanned at regular intervals. Changes between point clouds can be observed and tracked to detect instability and allow road managers to mitigate potential impacts to roadways before they occur. In some instances, road managers have been able to use point cloud data to calculate the volume of material threatening a roadway and plan their mitigating strategies in advance, including the severity of impact to the roadway and the specific equipment and time required to remove the materials. The FHWA produced an excellent tech brief describing in greater detail how UAS can be used for land survey applications, a link to this publication is found in Appendix A under the title "Use of Small UAS for Land Surveying."

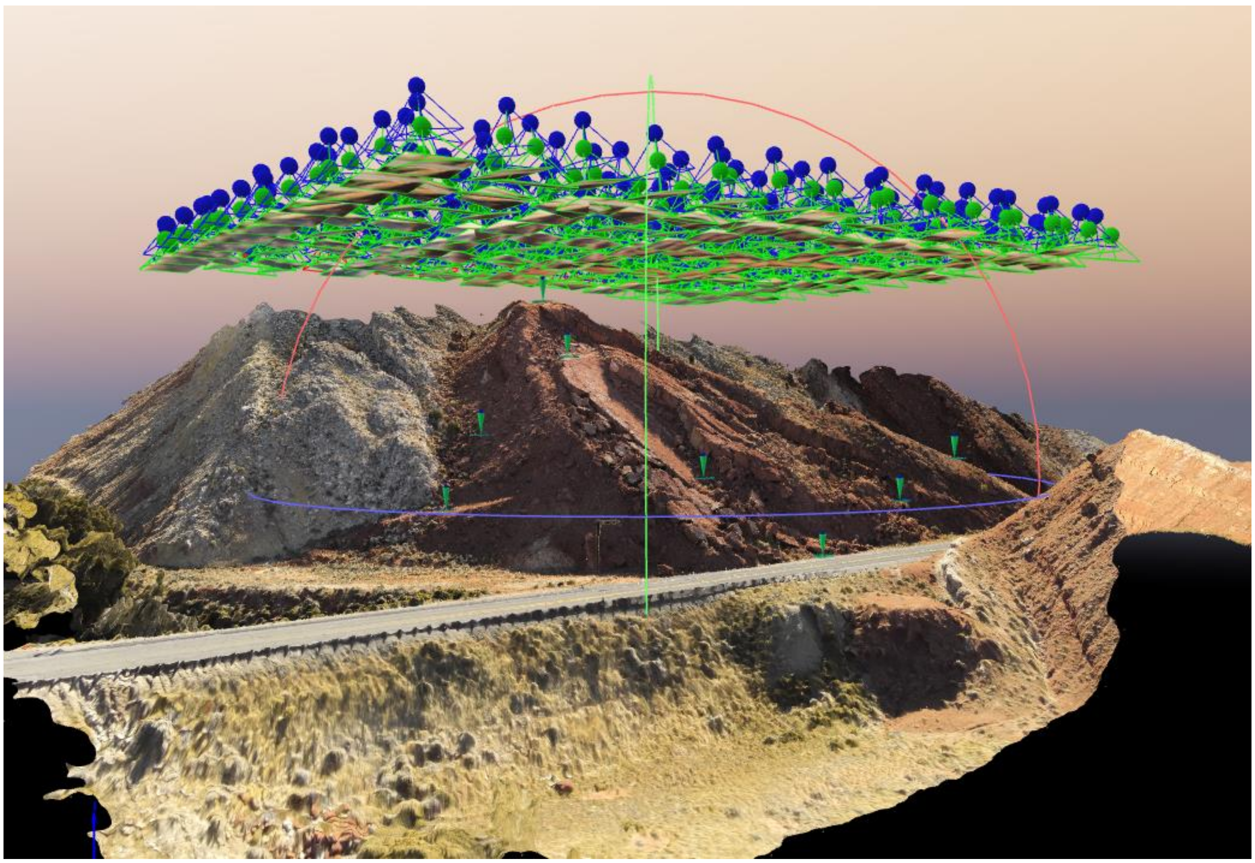

Figure 4: *Example of photogrammetry model derived from aerial imagery and point cloud data. Note the camera locations and individual photographs shown in green and blue over the survey area. This model utilized 224 individual photographs and identified 26 million "points" to create the model.*

Regulation

As UAS have proliferated across the United States, the Federal Aviation Administration has risen to the occasion by setting in place a rigorous regulatory framework to ensure public safety. While operating a small aerial drone poses minimal risk to the operator, it is essential for all UAS pilots to understand and recognize the risks they present to conventional manned aircraft as well as people and property on the ground. To this end, the FAA requires all commercial UAS operators to certify their knowledge of how to safely operate a UAV weighing between 0.55 lbs. and 55 lbs. This certification is known as Part 107. This testing protocol requires Remote Pilots to pass a 60 question airman knowledge test with a score of 70% or better. The Part 107 test doesn't require any flight ability demonstration, it mostly covers topics related to where, when and how an aerial drone can be operated.

Part 107 Test

The Part 107 test presents the primary regulatory hurdle for those wishing to deploy UAS for use on the job. There are many study resources available to aspiring UAV pilots, including in-person training seminars, on-line subscription-based training courses, as well as various free-of-charge online training materials. Larger organizations hoping to train and certify multiple operators at the same time may find that hiring live instruction may be their most effective option, as WYDOT has launched their new UAS program and requirements they have been able to hold training courses with multiple staff members in attendance. Smaller organizations certifying only one or a few UAS Pilots may find online resources to be a better fit. Subscription-based online training resources offer a one-stop-shop, directed course of study. Based on our own experience, as well as anecdotes of other operators, acquiring the knowledge to pass the 107 Examination is entirely possible using a variety of free online materials, the T2 Center has compiled a variety of Part 107 study materials; including YouTube videos, practice tests, airspace sectional charts etc. These study materials can be found in Figure 5. Regardless of personal preference for material delivery, achieving a passing score on the test requires students to invest a significant amount of time studying. A good recommendation would be to consume a variety of study resources available. Part 107 testing centers in Wyoming are located in Casper and Cody. Additional Part 107 testing information can be found at: https://www.faa.gov/uas/

FAA Part 107 Test Study Resources

https://www.youtube.com/watch?v=6_ucCKFJUCU&t=3704s
Very well produced and informative YouTube video overview of Part 107 materials. Provides overview of Part 107 materials in under two hours.

https://3drobotics.com/quiz/faa-part-107/
Free online practice test questions. This test is representative of the overall difficulty and subject matter of the actual 107 test.

https://www.youtube.com/watch?v=-IEjiWiFf5E&list=PL97T9qXKhh0jnnuNNHj18oiAdZ0_yZD3I&index=5&t=5324s
This YouTube video is a test review of all the practice questions from the 3dr.com website listed above.

https://www.faa.gov/sites/faa.gov/files/regulations_policies/handbooks_manuals/aviation/remote_pilot_study_guide.pdf
This is the FAA's official study guide from which the test is written. It is lower on entertainment value than some of the above mentioned resources, but it does cover several topic that were overlooked in other resources and is worth a thorough reading.

https://www.skyvector.com
This a free interactive source for viewing global aerial sectional charts. Successful testing requires an ability to read and understand the information found on these charts.

Figure 5: *List of online Part 107 study resources available free-of-charge*

Where Can Drones NOT Go?

Understanding some of the basic restrictions that FAA places on where and how UAS can be operated under Part 107 is another important step toward planning future drone usage and potential applications. To this end, we have compiled a list of some of the basic "no go" flight scenarios for UAS. It is important to note that this is by no means a comprehensive list of the FAA's restrictions on UAV usage, this is simply meant to highlight a few key restrictions that are pertinent to use cases that transportation professionals may encounter. Most of these restrictions can be worked around through a process of submitting paperwork to the FAA and obtaining a specific waiver. These restricted flight areas are summarized in Figure 6.

Restricted Use Areas for UAS
Requiring special waiver from FAA

- **Above 400 feet above ground level (AGL).**
- **Beyond Visual Line of Sight (BVLOS)**
- **Directly over live traffic or over unsheltered people not participating in flight activities.**
- **At nighttime**
- **In controlled airspaces near airports (requires Air traffic Control approval)**

Figure 6: *Summary of restricted areas for UAS operation. This is not a comprehensive list, consult FAA guidelines for a complete understanding of areas and scenarios where UAS operation is limited.*

Flight Elevation

One of the most basic and commonly referenced parameters placed on UAV usage (this applies to both commercial and recreational operators) is a flight ceiling of 400 ft. above ground level (AGL). Most commercially available UAV's utilize on-board altimeter readings to automatically "fence," or limit the pilot's ability to operate the drone in excess of 400 feet above the take-off elevation.

Visual Line of Sight

FAA regulations also require UAS Remote Pilots to maintain visual line of sight (VLOS) with their aircraft at all times during flight activities. Modern UAV's boast of impressive flight ranges of up to two miles, and POV video feeds allowing the Remote Pilot to view the UAV's camera view in real time, even from great distances. However, without specific waiver form the FAA, remote pilots' flight distances are significantly curtailed by this restriction. Visual observers can assist remote pilots to maintain VLOS during flight operations, this practice helps to ensure VLOS is maintained while the remote pilot is able to monitor controls and capture imagery.

Flights over People and Traffic

Several of the FAAs' basic restrictions on UAS usage have undergone recent changes. This includes a prohibition of flights over people and traffic. This restriction still stands, but as of December, 2020 the FAA has defined specific requirements which allow remote pilots to work around these restrictions without the process of obtaining a waiver by meeting very stringent guidelines governing aircraft weight, remote identification capability and rotor protection. The new exemption to this restriction won't go into effect until later in the spring of 2021, and won't apply to many currently available UAV platforms, but this is big news to many using aerial drones on the job. As history has shown, many UAS manufacturers develop their aircraft models specifically to meet FAA restrictions, so it is safe to say that these capabilities will become more accessible and commonplace for professionals looking to expand their aerial drone use in these areas.

Flights at Nighttime

The FAA also places restrictions on UAS flights during nighttime. Night time flying makes it difficult or impossible to maintain VLOS, and prior to 2021 night-time UAS flights required operators to obtain a waiver from the FAA. However, similar to rules governing flights over people, this restriction has also undergone recent changes (Spring 2021) making it possible to make night-time flights without obtaining an FAA waiver by meeting specific aircraft requirements including remote identification capabilities and high-visibility anti-collisions lights visible for 3 miles.

Airspace

Knowledge of different classifications of airspace and where drone operations are permitted is one of the most critical pieces of knowledge for successful Part 107 testing and crucial to ensure safe and legal operation of your UAV. Airspace classifications vary based on elevation and proximity to airports, military installments and any other areas where UAV operations could pose a risk to conventional manned aircraft. The process of understanding airspace classifications begins with learning how to read aeronautical charts, or maps showing different airspace boundaries, hazards, communication channels and other pertinent information for all pilots sharing the skies. Skyvector.com is a free online source of aeronautical charts and a valuable tool for those studying for the Part 107 test.

LAANC Data Exchange

The LAANC (Low Altitude Authorization and Notification Capability) is a relatively new communications system set up by the FAA which allows aerial drone operators to ensure their compliance with airspace restrictions while simultaneously alerting airports and pilots in the area to current UAS operations. While LAANC approval isn't required in the most permissive of airspaces (Class E, general airspace), many UAS pilots find themselves needing to operate in closer proximity to airports or in more complex scenarios in which flight isn't permitted without alerting local aviation agencies to your intentions and presence. LAANC approval of UAS operation is gained through a variety of third party service providers, most of which are provided free-of-charge to RPICs. One of the most prevalent providers of this service is AIRMAP. This application provides an aeronautical chart with geolocation showing the UAS operator's location. For flights in airspace other than Class E RPIC's can request permission to fly, which is either approved or denied immediately based on other activities in the area. This new system has been a boon to UAS operators as it has allowed them to expand the areas in which they can operate with instantaneous approval, as well as removing guess-work as to where and when UAS operations are permitted.

UAS Deployment for Organizations

As described above, the FAA has a substantial regulatory framework designed to ensure that UAS operators are knowledgeable about their operating environment, equipment and relevant safety concerns. Many large organizations that are deploying UAS technology and certifying multiple remote pilots within their ranks are also implementing their own secondary regulatory structures. These redundant organization-level regulatory systems aren't in place to further restrict aerial drone usage, but exist for the purpose of ensuring all UAS operations strictly adhere to Part 107 guidelines and creates documentation of important safety protocols at all stages of the process.

Risk Assessment/Project Approval

Adherence to Part 107 guidelines is vital to ensure that UAS operation can be done safely and legally. For organizations overseeing UAS usage, it is important to document adherence to FAA guidelines and to create records showing due-diligence in ensuring the safety of proposed flight operations through project planning and the assessment of potential risks. For example, both WYDOT and the University of Wyoming have set in place protocols for RPIC's to complete risk assessment forms documenting known hazards, weather conditions and emergency procedures for project specific locations. As the primary function of a project approval process is to ensure and document adherence to Part 107 guidelines, it is important that project approval is granted by an individual who holds a Part 107 remote pilot certification and has a thorough understanding of the FAA's requirements in this area.

Pilot Training

As discussed earlier in this publication, the FAA's testing requirements under Part 107 involves where and how UAV's can be operated. Unlike the certification process to operate conventional, manned aircraft, Part 107 requires no demonstration of the remote pilot's ability to successfully operate the aircraft. For organizations seeking to protect their investment in expensive UAS equipment, instituting some form of basic remote pilot skill test may be warranted. This may come in the form of some sort of obstacle course, demonstration of basic maneuvers (ie. figure-8's, orbiting etc.). In-field testing requirements can also encompass the pilot's ability to adhere to pre-defined standard operating procedures such as assessing the flight area, checking battery levels, maintaining control over the take-off/recovery area etc. Remote pilots who have gained certification as well as demonstrated their abilities to operate their aircraft should also be encouraged, or even required, to operate UAV's on a regular basis to maintain comfort and sharpen their skills, much in the same way that conventional pilots are required to log regular hours in their airplanes.

Insurance

As organizations explore the possibility of taking to the skies with unmanned technology, questions regarding liability and insuring such activities often dominate the process. Dependent on the type of organization you work for (public, private, local government, state government, etc.) liability insurance providers vary widely, from public insurance pools to commercial providers. Based on conversations with several public insurance providers and public entities in the state who have already deployed UAS, many insurance pools and providers are covering aerial drone usage without requiring additional coverage. Providers of this coverage stipulate that all drone operations strictly adhere to relevant rules and regulations set forth by the FAA under Part 107. This requirement creates additional incentive for organizations to set in place standard procedures for documenting their adherence to these regulations as described earlier in this publication. As with many aspects of UAS deployment, insuring this emerging technology is a continually developing topic. There is little in the way of universal guidance for insuring UAS operations in the workplace other than a recommendation that interested parties contact their current insurance provider to inquire if these activities are covered.

Figure 7: *Wyoming Highway Patrolmen practice UAS operations as part of WYDOT's remote pilot training/skill certification. WYDOT has instituted skill certifications and standard operating procedures in addition to FAA Part 107 requirements to ensure their pilots are competent and to document adherence to federal guidelines.*

Data Management
Operating UAS for the purpose of collecting imagery and/or survey data produces large quantities of digital data. Photo, video and point cloud files are stored as digital files which can occupy many gigabytes of storage capacity on computer hard drives or other digital storage devices. Data collected from even a few projects can overwhelm many computers' storage capacity. Some form of cloud storage or external hard drives are useful in order to store and preserve these large data sets. Organizations that plan on utilizing and storing UAS data in their workplace may find it necessary to standardize procedures for storing and eventually deleting these data files at regular intervals.

Privacy Concerns
In addition to issues surrounding the storage of images and data collected by UAS, this information also poses unique concerns in terms of privacy. By FAA regulation, it is legal for aerial drone operators to fly over private property and to capture imagery of people and their belongings. However, at an organizational level, capturing imagery of private property or persons creates a host of concerns in terms of privacy and liability. This aspect of UAS operation is currently evolving and is bound to undergo changes through litigation in the future. For those operating UAS in an official capacity, a good rule of thumb to avoid such complications is well summarized in WYDOT's recently drafted *UAS Operations Manual* which states, "UAS operators must limit operations to the specific, approved project purpose and employ reasonable precautions to avoid capturing images of the public, except images incidental to the project."

Cyber Security
As electronic technology has become entwined in modern workplaces, so have concerns over hacking threats and cybersecurity. As discussed in this manual, UAS can collect and create massive amounts of data which is often digitally catalogued on physical hard drives or network based "cloud" storage systems. How potentially valuable or attractive this information is to bad-actors varies widely based on the nature and subject matter of the data, but this is also very difficult to predict. Especially within the transportation industry, most of the data collected by UAS relates to critical public infrastructure, which has been targeted by hackers and foreign adversaries in the past. While there is no "one size fits all" solution to these concerns, it is important for transportation organizations to take this into consideration and to develop guidelines for the secure storage of data collected by UAS.

Selecting Equipment

As UAS become more common place in workplaces and households across the globe, the associated technology continues to advance at lightning speed. Selecting the right equipment and software for your needs creates a significant hurdle for consumers attempting to make an informed purchase. The pace of advancement in the UAS industry can further complicate this process. The following section is intended to provide some insight to assist transportation professionals as they navigate the purchasing process.

Aircraft

Selecting an appropriate remote aircraft for your organization's specific needs can be a daunting process. Numerous manufacturers, and an even wider variety of models can be overwhelming to take in and make an informed decision. UAV pricing generally ranges from several hundred dollars, to hundreds of thousands of dollars. As a general rule, as the price of a UA increases the size of the aircraft follows suit, as well as it's payload capacity for carrying multiple or more specialized sensors onboard. UAVs can be divided into two basic groups, rotor wing and fixed wing. Rotor wing aircraft are much more common, affordable and versatile given their ability to hover, take off and land easily. Fixed wing UAVs excel in their ability to fly at higher speeds and cover larger areas of ground, however this often involves flight beyond VLOS and the requirement for FAA waiver to operate. These longer fixed wing UAS flights have shown their value in collecting data from long, linear flight paths such as highway right-of-ways. The majority of material in this manual covers rotor-wing aircraft, but it is important to understand where fixed wing UA's excel as they are bound to become more common in the future.

Prosumer Technology

The term "prosumer" has been adopted by the drone world to refer to UAs which are designed with recreational users in mind, while still providing impressive capabilities which can deliver professional level results in many applications. Prosumer level drones range in price from approximately $500-$2,000. Within this price range almost all product offerings will be rotor-wing quad-copters. This segment of the aerial drone industry has benefitted from the most drastic advancements and reductions in cost in recent years. These aircraft are equipped with integrated gimbal stabilized high-definition cameras, crash detection sensors, GPS fencing to prevent violation of FAA airspace restrictions and easy to use flight control applications which utilize smart phones as monitors. A reasonable comparison to this level of technology would be a flying I-phone, where mass market appeal and mass production has made state-of-the art technology surprisingly affordable. Prosumer level UAS provide an excellent entry point to organizations beginning the process of integrating UAS into their workplace.

UAS Manufacturers/Country of Origin Concerns

Manufacturer and country of origin can play a larger role In the process of selecting a specific UAS platform than one might expect. Any discussion of aerial drone manufacturers is incomplete without mentioning DJI. Hailing from China, Da-Jiang Innovations or DJI as it is commonly referred to, is the world's largest UAS maker owning 70-80% of the world's aerial drone market. DJI has led the UAV industry in many areas in recent years, advancing prosumer UAS to incredible heights and improving more advanced systems through full integration of camera and gimbal systems. In many ways DJI can be considered as the benchmark of the UAS industry. Whether purchasing DJI products or not, using their product line as a source of comparison can help to simplify the purchasing process.

Security concerns from adversarial nations as well as a desire to support American companies, have recently led to a ban on the purchase of Chinese sourced UAS equipment by federal agencies. These concerns have led some state and local agencies to place their own similar bans on Chinese sourced drones, including the Wyoming Department of Transportation. While these bans do not apply to recreational UAS users, private transportation professionals or local agencies; some grants have stipulations against funds being used to purchase of Chinese products. For public agencies exploring their options for purchasing UAS, it is important to consult specific procurement restrictions and sources of grant funds to inquire about any concerns in this area. Other Chinese UAS manufacturers subject to similar restrictions include Autel and Yuneec. See Figure 8 for a list of UAS models ranked by price group, capabilities and country of origin.

Aerial Drone Offerings Sorted

By Category and Features (not comprehensive)

UAS Category	Features/Sensors	Make/Model (* Indicates Chinese device, see Section IV)
Prosumer $500-$2,000	4 rotor quad-copter 3-axis gimbal stabilized HD camera	• *DJI Mavic Series (Mavic 2, Mavic Air & Mavic Mini) • *DJI Phantom 4 • Parrot Anafi • Teal One • Skydio 2 • *Autel Robotics Evo II Pro
Built-in Multi-Sensor $3,000-$10,000	3-axis gimbal stabilized HD camera Built-in FLIR infrared sensor	• *DJI Mavic 2 Enterprise Dual • Parrot Anafi USA • *Autel Robotics EVO II 640T • Intel Falcon
Compact RTK Survey $10,000+	3-axis gimbal stabilized HD camera Real Time Kinematic Antennae & Base Station	• *DJI Phantom 4 RTK • *Autel Robotics EVO II RTK • *Yuneec H520E RTK
Interchangeable Sensor Commercial $20,000+ (without sensors)	Robust propulsion systems capable of carrying multi-sensor payloads Supports professional level sensors of all types (cameras, gimbals, Lidar, FLIR, RTK, multispectral etc) Customizable aircraft built to specific needs and purposes.	• *DJI Matrice Series (200,300 & 600) • AceCore Zoe • MicroDrones mdMAPPER series

Figure 8: *This list shows a sampling of current (as of 2021) product offerings from various UAS manufacturers. This is not a comprehensive list and is subject to change as new models are released.*

Sensors
Disparities in pricing of UAs stems primarily from the types or varieties of sensors on board. Some UAs have the ability to carry different types and/or combinations of sensors, which allows for a wide variety of data to be collected by the aircraft. The term sensors refers to electronic devices carried by the drone which are capable to gathering and recording data. The most common type of sensor found on most all UAS is a digital camera, similar to the one found on your cell phone. This basic device makes aerial imagery, photogrammetry modeling and the majority of applications mentioned above possible.

Infrared
The second most common type of sensor found on UAs is an infrared camera which displays color coded temperature gradients. Infrared sensors have proven useful in transportation inspection applications where delaminated paving material on bridge decks are highlighted and large areas can be surveyed quickly from overhead. Law enforcement has found infrared sensor particularly useful in search and rescue and manhunt scenarios. Several UAS makers have released multi-sensor versions of their popular prosumer models with integrated infrared sensors in addition to conventional cameras.

Lidar
Lidar is an acronym for light detection and ranging. This technology is used to collect detailed topographic information by shooting laser beams to the ground and measuring the elapsed time until the laser beam is bounced back to the sensor. This technology creates remarkably accurate 3 dimensional renderings of land forms or objects and has the ability to scan very large areas. Lidar scanners can be operated from the ground surface, from conventional manned aircraft and from aerial drones. Similar to photogrammetry technology, Lidar returns results in the form of a 3-dimensional point cloud. One area where Lidar technology has an advantage over photogrammetry modelling is its ability to collect ground surface data through small openings in vegetation covering. A significant downside to Lidar is the cost of equipment, with price tags on professional level Lidar sensors costing many thousands of dollars.

Photogrammetry Software and Processing Options
As discussed earlier, the ability to process digital photographs into 3-dimensional photogrammetry models is one of the most versatile and powerful capabilities of UAS technology in the transportation sphere. Deriving point cloud data and photogrammetry models from photographs requires specific computer software and a computer systems capable of processing very large amounts of data. This processing capability can be achieved by purchasing a subscription to one of several photogrammetry software providers. Photogrammetry processing is also available through cloud processing in which geo-referenced

photos are captured in the field and then uploaded to a remote server where they are processed into point cloud data and a photogrammetry model by a service provider. Cloud processing is a popular option, especially for organizations new to the technology or who will be using the capabilities on an intermittent basis. Cloud processing offers significant cost savings and eliminates the necessity of learning how to use the software. The T2 center has a perpetual licensing subscription to PIX4D Mapper software and we are available to assist Wyoming transportation professionals with photogrammetry processing on a demonstrative first-come, first-served basis.

Figure 9: *Many prosumer UAS rely on a smartphone or tablet device to act as a view monitor and to provide computing capacity to operate third-party applications to control the UAV, collect/record data and to plan flight activities by checking airspace and weather conditions.*

Flight Control and Airspace Applications

Smart phones or similarly capable tablet computers play a vital role in the operation of UAVs. These devices not only act as a view monitor on many systems, but also provide the computing capabilities which can store and run various applications necessary to many of the functions discussed in this manual. Especially within the prosumer category of drones, most UAVs are operated by proprietary flight control applications specific to the UAV manufacturer. These applications can be downloaded free-of-charge. Once downloaded and wirelessly connected to your drone, these flight application provide access to the variety of settings and features available on the UAV. From this wireless interface maximum flight elevation and distances can be set, different flight settings controlling the aircraft's maneuvering speed can be selected. Additionally, these applications automatically record a history of flights including flight duration, location and date; assisting in maintaining flight logs. In addition to providing an operating controls interface for UAS, software applications operated on smart phones or tablet devices are also useful during UAS operations for checking weather conditions, airspace restrictions and securing LAANC flight approvals.

Ground Control

Photogrammetry and survey projects where global position accuracy is of upmost importance often utilize some form of ground control markers to enhance accuracy. Ground Control Points (GCP's) are locations within the survey area with known and verified GPS coordinates. The location of GCP's is verified by utilizing a redundant GPS device (in addition to the on-board GPS capability of the UAS). GCP's must be marked in a highly visible manner, often times using ground marking paint or large object which is easily seen on aerial imagery, and then used to "pin down" the photogrammetry model to these known, verified points.

Traditional ground control points are generally marked with ground paint and then the location verified with a high-grade GPS unit. Especially as UAS driven aerial surveying has become more commonplace, automated GCP devices are proving to be highly effective and save substantial amounts of time. Propeller AeroPoints® are one such device. AeroPoints are electronic 24"x24" flat panels with on-board GPS units. Sold in sets of ten, Aeropoint users need to only turn the panels on and distribute them around the survey site. The solar-powered devices record their own GPS location which is later uploaded and located within the 3D model during processing of the photogrammetry model. In addition to the convenience of this ground control method, Aeropoints also provide the flexibility to work in conjunction with any UAV, including lower-cost prosumer level devices.

Figure 10: *WYDOT survey crew works to verify location of ground control points during photogrammetry project utilizing UAS based data collection.*

An additional method of achieving ground control precision in aerial drone based surveying is through real time kinematic (RTK) equipped UAVs. This technology utilizes a mobile ground station, which communicates with satellites as well as the UAV during the flight operation to make corrections and enhance the position data of the project results. This technique saves time and enhances safety as it doesn't require workers to physically place, mark or locate multiple GCP's in sometimes hazardous locations within a jobsite. Downsides to RTK corrections in UAS mapping include more expensive and specialized equipment. RTK ground stations are expensive pieces of equipment and they require a UAV equipped with a specialized antennae in order to maintain a link between the devices.

In Conclusion

As emerging technologies tend to do, aerial drone systems have advanced at a fever-pitch in recent years. This advancement has led to increased capabilities, but it has also made UAS incredibly user friendly and affordable. These developments are making UAS commonplace tools in many industries. As this manual describes, this is particularly true within the transportation industry. With numerous advantages and continuously decreasing prices it would be a safe bet to assume that UAS capabilities will be a part of many Wyoming road shops and construction projects in the near future.

Despite these advancements in the accessibility of UAS, integrating drone technology into your day-to-day work flow still requires a process of gathering information as to where and how UAS technology can benefit your organization and then determining how to best incorporate these capabilities into your desired work outputs. Even for transportation agencies who are not ready to acquire the equipment and certifications necessary to operate UAS on an "in-house" basis, it is important to build this foundational knowledge in order to make more informed decisions when contracting through a UAS service provider. Regardless of where your workplace sits in this process, we hope that this manual will provide some of the information necessary for your organization to explore the next step toward utilizing this impressive new technology.

As mentioned throughout this publication, UAS technology and regulations are continually evolving subjects. As this evolutions continues, the Wyoming Technology Transfer Center will work to stay abreast of current trends and considerations. We will continue to be a resource for transportation professionals in Wyoming exploring UAS options for their workplace. We offer free-of-charge assistance through technical support, data processing capabilities and on-site demonstration on projects.

Appendix A

Federal Highway Administration tech briefs detailing specific UAS applications

- Use of Small Unmanned Aerial Systems for Land Surveying Tech Brief

  https://www.fhwa.dot.gov/uas/resources/hif20034.pdf

- Use of Small Unmanned Aerial Systems for Construction Inspection Tech Brief

  https://www.fhwa.dot.gov/uas/resources/hif19096.pdf

- Use of Small Unmanned Aerial Systems for Bridge Inspection Tech Brief

  https://www.fhwa.dot.gov/uas/resources/hif19056.pdf

- Use of Small Unmanned Aerial Systems for Emergency Management of Flooding Tech Brief

  https://www.fhwa.dot.gov/uas/resources/hif19019.pdf