ALTERNATIVE APPROACHES TO INSPECTIONS FOR FEDERAL LAND MANAGEMENT AGENCY ROADS

Using Uncrewed Aircraft Systems to Support the Road Inventory Program

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13. ABSTRACT
The Federal Highway Administration's Federal Lands Highway Innovation and Research Council Research Program funded this research to identify opportunities and challenges related to using uncrewed aircraft systems (UAS) to support condition inspections for Federal Land Management Agency Roads. The report synthesizes the current state of the practice, identifies ways that UAS-acquired data can be integrated with existing road condition rating approaches, and describes the outcomes of a demonstration to fly UAS equipped with various sensors at a National Wildlife Refuge to collect information necessary to automate road distress detection. Results from the demonstration are compared to results from an inspection of the same roads using customary approaches.

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Contents

Abbreviations and Acronyms

2D	Two-dimensional
3D	Three-dimensional
AASHTO	American Association of State Highway and Transportation Officials
AI	Artificial Intelligence
AGL	Above ground level
BLM	U.S. Bureau of Land Management
DEM	Digital Elevation Model
DOI	U.S. Department of the Interior
DOT	Department of Transportation
EAC	Executive Aviation Committee
EO	Executive Order
FAA	Federal Aviation Administration
FAA Small UAS Rule	14 CFR, Part 107
FHWA	Federal Highway Administration
FLH	Federal Lands Highway Division
FLMA	Federal Land Management Agency
FS	U.S. Forest Service
FWS	U.S. Fish and Wildlife Service
FY	Fiscal Year
GCP	Ground control point
GIS	Geographic Information System
GPS	Global Positioning System
GSD	Ground Sampling Distance
IRI	International Roughness Index
Lidar	Light Detection and Ranging
MOA	Memorandum of Agreement
MP	Megapixel
NPS	National Park Service
OAS	Office of Aviation Services
PASER	Pavement Surface Evaluation and Rating
PASP	Project Aviation Safety Plan
PCI	Pavement Condition Index
PPE	Personal protective equipment
RAM	Random Access Memory
Reclamation	U.S. Bureau of Reclamation
RIP	Road Inventory Program
RPIC	Remote Pilot in Command
SD	Secure Digital
SfM	Structure from Motion

SO	Secretary Order
sUAS	Small Unmanned Aircraft System
UAS	Uncrewed Aircraft System
UAV	Uncrewed Aircraft Vehicle
UMass	University of Massachusetts
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture

Executive Summary

The U.S. Fish and Wildlife Service (FWS) and other Federal Land Management Agencies (FLMAs) are vitally interested in maintaining a public road system that provides access for the use, management, and enjoyment of Federal lands. Unpaved roads play an important role in that road system. A requirement under the Federal Lands Transportation Program is for FLMAs, in cooperation with the Federal Highway Administration (FHWA), to maintain a comprehensive national inventory of public transportation facilities, including unpaved roads, with the goal of quantifying transportation infrastructure needs and conditions within each agency for performance and asset management. The FWS, for example, works with FHWA to comprehensively assess and validate conditions for each FWS station's Real Property Inventory of roads and parking lots. Their inspections often consist of manual inspections and windshield surveys involving observations made from a moving vehicle. Afterwards, a practitioner processes the collected data to compute road condition scores, enabling the FWS to determine where infrastructure interventions are necessary and to prioritize investments based on relative needs across its transportation network, thus optimizing a limited budget.

This research, funded through FHWA's Federal Lands Highway Innovation and Research Council Research Program, investigated how uncrewed aircraft system (UAS) technologies might supplement or enhance existing road condition inspection practices on Federal lands, particularly those that the FWS manages. The report summarizes the current state of the practice, identifies ways that UAS-acquired data can be integrated with the existing road condition rating approach used for FWS roads, and describes the outcomes of a demonstration UAS mission at Alamosa National Wildlife Refuge (NWR) to collect information necessary to automate some aspects of unpaved road distress detection. It also compares results from the UAS demonstration and proposed post-processing workflow to results from an inspection of the same roads using customary approaches, showing promising outcomes that could enhance future inspection efforts for unpaved roads. Evidence suggests that despite a clear need to further refine UAS-related approaches adding UAS equipment to a RIP team's "toolbox" where practicable could help save time and cost while improving the level of detail possible in RIP inspections.

INTRODUCTION

FHWA's Federal Lands Highway (FLH) Innovation and Research Council Research Program funded the research project documented in this report to identify opportunities, challenges, and needs related to using UAS[1] to support condition inspections of FLMA roads. The project team collected insights from a literature review and interviews with subject matter experts. This desk work was followed by a demonstration at the Alamosa NWR, which served as a testbed for applying and assessing the relevant UAS concepts, data-analysis approaches, and observations described in this report.

Section 1, Background, provides an overview of current road inspection approaches at FLMAs and the policy landscape for using UAS to support related processes. Current, FLMA-specific guidance on UAS procedures and requirements are included where available.

Section 2, Demonstration, describes the approach used in a proof-of-concept UAS mission conducted in

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[1] The term "UAS" is sometimes used synonymously with other terms including unmanned aerial system, unoccupied aircraft system, unmanned aerial vehicle, or drone. A small unmanned aircraft system (sUAS) is an unmanned aircraft weighing less than 55 pounds on takeoff, including everything that is on board or otherwise attached to the aircraft, and its associated elements (including communication links and the components that control the small unmanned aircraft) that are required for the safe and efficient operation of the small unmanned aircraft in the national airspace system (14 CFR 107.3).

a National Wildlife Refuge setting during August 2023 to test the application of concepts explored in relevant literature. Automated post-processing methods are also proposed.

Section 3, Conclusions deliberates on the use of UAS to support inspections on FLMA roads, particularly those under responsibility of the FWS. Opportunities and challenges related to using UAS for FLMA road inspections are offered.

Other resources that were developed as part of the research are included as three appendices, namely:

- **Appendix A. Literature Review and Annotated Bibliography** draws upon information from research studies, practice papers, and Federal agency policies and guidance. It discusses the experiences of researchers who have tested various approaches to using UAS for road inspections and highlights their suggested methods where the research teams made such recommendations.

- **Appendix B. Section 4, Mission Planning** provides guidelines for conceiving and conducting UAS missions for FLMA road condition inspections. It organizes mission steps into four categories: pre-flight planning, on-site preparations, on-site UAS mission, and post-mission.

- **Appendix C. Hardware and Software Requirements** documents equipment and computing needs related to using UAS for road inspections. Minimum equipment, data, and post-processing demands, as well as pros, cons, relative costs, and effective practices related to those demands are provided where possible. The appendix also describes data analysis and storage standards, offering suggestions on data formats, sizes, complexity, and data-sharing practices to help ensure the efficient management of input imagery and output products so that the UAS-acquired data are as straightforward to access and use as possible.

1. BACKGROUND

The Federal government owns roughly 640 million acres, about 28 percent of land in the United States. The four major FLMAs—the Bureau of Land Management (BLM), FWS, and National Park Service (NPS), all within the Department of the Interior (DOI), and the U.S. Forest Service (FS)—manage 95 percent of that land, most of which is concentrated in the western U.S., including Alaska.[2] In addition to protecting and managing the lands and resources under their jurisdictions, FLMAs are vitally interested in the maintenance of a public road system that provides access for the use, management, and enjoyment of Federal Lands. FLMAs work to ensure that their road construction, maintenance, and operations activities are carried out in ways that minimize impacts on operations while complying with adopted standards and the federal law regarding highways (23 United States Code). A requirement under the Federal Lands Transportation Program is for FLMAs, in cooperation with the FHWA, to maintain a comprehensive national inventory of public transportation facilities, with the goal of quantifying transportation infrastructure needs and conditions within each agency for performance and asset management. Additional requirements for the Federal Lands Transportation Program are found in 23

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[2] Other FLMAs include the Bureau of Reclamation and U.S. Army Corps of Engineers. The Department of Defense administers approximately one percent of all Federal land with a number of government agencies managing the remaining acreage. Congressional Research Service. April 21, 2021. *Federal Lands and Related Resources: Overview and Selected Issues*. https://crsreports.congress.gov/product/pdf/R/R43429

U.S.C. § 201 and 23 U.S.C. § 203.

Over time, however, deferred maintenance and asset repair, sometimes referred to as the "maintenance backlog," has become a growing problem for FLMAs. For FS, deferred maintenance for roads represented the largest contributor (58% of a total $7.66 billion) to that backlog in terms of dollars in Fiscal Year (FY) 2022. For NPS and BLM, the roads, bridges, and trails asset classes comprised the largest proportion of their deferred maintenance estimates (33% of a total $21.1 billion for NPS and 82% of a total $4.77 billion for BLM). Unlike these FLMAs, roads, bridges, and trails made up the smallest portion of FWS's deferred maintenance among asset classes, totaling $0.29 billion in FY20.[3]

Understanding that roads deteriorate over time due to traffic loading and environmental factors, and preventive maintenance can be significantly less expensive than rehabilitation or reconstruction, FLMAs periodically inspect their roadway networks to help minimize the maintenance backlog. These inspections, which help to guide maintenance and construction investment decisions so that roads can be kept safely in service, can range from assessments of general conditions along given road segments to very detailed assessments of specific distresses, such as cracking, potholing, rutting, washboarding, and raveling, among others.[4] They can also include evaluations of roadway characteristics that are indicators of condition rather than specific distresses.

1.1 Road Inventory Program

The Transportation Equity Act for the 21st Century (Public Law 105-178) outlined the FWS's Refuge Roads Program. Within that program, the FHWA Road Inventory Program (RIP) works with the FWS under a special agreement to comprehensively assess and validate conditions for each FWS station's Real Property Inventory of roads and parking lots. Through the RIP, FWS determines where infrastructure interventions are necessary and then prioritizes investments based on relative needs across its transportation network, thus optimizing a limited budget.

RIP Field Data Collection

The RIP process generally begins with coordination between the FWS and FHWA's FLH to set a schedule for conducting road inspections across the country. With a schedule in place, Regional Transportation Coordinators meet with FWS refuge and hatchery field staff at a given station to verify the administrative and geographical data accuracy of existing transportation asset records contained in the

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[3] For FY22, FS reported on 11 classes of assets, including roads, while DOI agencies currently report annual deferred maintenance estimates for four broad categories of assets: (1) roads, bridges, and trails, (2) irrigation, dams, and other water structures, (3) buildings, and (4) other structures, which includes a variety of assets such as recreation sites and hatcheries. Congressional Research Service. August 8, 2023. *Deferred Maintenance of Federal Land Management Agencies: FY2013—FY2022, Estimates and Issues*. https://crsreports.congress.gov/product/pdf/R/R43997

[4] FHWA illustrates distresses found in three basic pavement types in its *Distress Identification Manual for the Long-Term Pavement Performance Program*. www.fhwa.dot.gov/publications/research/infrastructure/pavements/ltpp/13092/13092.pdf In its *Unsurfaced Road Maintenance Management* guide, the Department of Defense defines seven types of distresses for unpaved roads as improper cross section, inadequate roadside drainage, rutting, dust, potholes, ruts, and loose aggregate. https://armypubs.army.mil/epubs/DR_pubs/DR_a/pdf/web/tm5_626.pdf

FWS's asset management system; FWS station and regional office staff will conduct a virtual "Route ID meeting" to examine data, update and assign route IDs, and determine what changes are needed to assets in the geographic information system (GIS) and other databases. After this meeting, FWS staff will make any necessary edits to records in its Service Asset Maintenance Management System, or "SAMMS," including to add new assets or delete or dispose of decommissioned assets. FLH and FWS then meet virtually to share and compare data. Further data reconciliation and editing is done as necessary to ensure that that teams doing data collections in the field are working with the best available information.

With a field visit scheduled and data inconsistencies reconciled, FLH staff and/or its contractors travel to the station to observe the station's transportation assets. This typically involves having two people representing FLH present; a Federal employee may be paired with a contractor to maximize skillsets. A field collection begins with a meeting with station staff, often the station manager or maintenance lead, to confirm local conditions, any additional changes necessary since the Route ID meeting, and the inspection plan for the visit. After the meeting, the FLH staff and select station staff drive all of the station's routes designated for inspections. The team usually uses one vehicle, either FLH's rented vehicle or a station vehicle depending on the suitability of each vehicle given road conditions and group size. The expectation is that all of the roads that are to be inspected should be able to be driven in a passenger car; however, some teams have found that a vehicle with 4WD can be preferable. Regardless, a camera is mounted on the vehicle's hood, and it is programmed to collect images at a regular interval that the FLH field team determines, usually based on the length of roads being inspected. Longer intervals (e.g., between 10 to 30 seconds) are used for longer roads and vice versa.[5]

The field team drives at approximately 10 to 15 mph while using two iPads and a data collection app to input information on five unpaved road distresses (Table 1) as they are observed from the vehicle.

Table 1. Unpaved Road Distresses Collected during RIP Field Collection and Associated Ratings

Distress	Minor (Score: 1)	Moderate (Score: 2)	Severe (Score: 3)
Crown	Center 3–6" above sides.	Center < 3" above sides.	Surface is flat or bowled.
Drainage	Road edge 2" above ground level (AGL).	Road edge level with ground level.	Road edge below ground level. Inadequate or missing ditches and side drains. Ponding.
Potholes/ Loose Aggregate	Potholes Few <2". Loose Aggregate No exposure of subgrade or stone protrusion.	Potholes 2–4" Loose Aggregate < 20% (width of road) exposure of subgrade.	Potholes > 4" Loose Aggregate > 20% (width of road) exposure of subgrade.
Rutting/ Washboarding	Rutting < 1" Washboarding < 1"	Rutting 1–3" Washboarding 1–3"	Rutting > 3" Washboarding > 3"
Dust*	Dust slight or not visible.	Dust < 2 feet	Dust > 2 feet
**Information on dust is collected but is not used in the final road rating given how condition-specific (e.g., recent rain or not) the metric is.*			

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[5] For shorter roads, a photo interval of approximately five seconds may be used with the goal being to capture at least six photos (a minimum per-road rule of thumb that field teams try to ensure).

Inspectors collect the extent (begin and endpoints) of distresses encountered, and the severity of each distress. Field teams stop at locations where they observe significant damage or where there are roadside appurtenances that require special inspection. Teams take photos of all deficiencies they see. Additionally, road width measurements are taken at the beginning and end of routes, and at places where road width is observed to change significantly. GPS receiver antennae that are connected via Bluetooth to an iPad are also used to help confirm or update GPS road traces, locations, or geometries during the drive.

The field collections typically take one day, but stations with more road mileage may take two or more days. FLH field teams may link visits to several FWS stations (or visits to other FLMA units) close to one another across a one- or two-week travel trip.

RIP Field Data Post-processing

After driving a station's roads and parking areas, the FLH field team uploads data into a data collection application cloud server and debriefs station staff on initial observations. The FLH field team then prepares a summary Closeout Report of key observations, which is usually sent to station staff and the Regional Transportation Program Coordinator (RTC) within 10 days of the visit. The Closeout Report may include questions to FWS staff regarding changes to the route inventory or route specific attributes that were observed to be different than the initial pre-field trip inventory. These questions are addressed and reconciled before the final RIP report for the Station is completed for the cycle.

At the office, FLH uses a Secure Large File Transfer Solution to send and manage most large files, including uploading field-collected data from the iPad server to the FLH cloud. File sizes for photos have not been problematic. To date videos have not been collected, as video files can become too big for most FLH computers currently available to process. . For photos, a mostly automated process is in place; the hood-mounted camera's georeferenced images are opened in a GIS, renamed with route number and milepost information, and mapped to the station's road network.

FLH staff then compute a distress score for each 1/10–mile road segment based on the length of road where the distress was observed (in feet) and weight it according to severity observed. The scores are combined into an overall distress score for every 1–mile of a route, and for the entire route length. FLH staff spot check the data against field photos as a quality assurance and control mechanism. A treatment decision tree is used to determine the recommended treatment for each segment. The RIP inspection process concludes when FLH sends a final RIP report and accompanying GIS files to FWS.

1.2 UAS for Road Inspections

The use of UASs to enhance existing inspection practices is an emerging practice among agencies that manage transportation networks in the United States. A 2019 American Association of State Highway and Transportation Officials (AASHTO) survey found that 36 out of 50 state Departments of Transportation (DOTs) were funding centers or programs to operate UASs, up from 0 in 2016 and 20 in

2018.[6] The breadth of activities for which DOTs are using UAS has similarly grown, with the top five state DOT mission types at the time of the AASHTO survey being photography/videography, surveying, infrastructure inspections, emergency response purposes, and public education and outreach. Across state DOTs, the use of UASs for bridge inspections in particular has proliferated (Plotnikov and Collura 2021). In West Virginia, for example, the Division of Highways has used UAS spanning activities such as mapping, reconnaissance, and construction inspection in a fraction of the time it would take field survey crews.[7] Likewise, the Utah DOT has used fixed-wing UASs equipped with normal and infrared cameras to help continuously document highway conditions before and after construction projects—information it could immediately add to its internal GIS database. In North Carolina, the DOT has institutionalized its UAS approach for these and other missions in a standard operating procedures guide that covers pre-, during-, and post-flight instructions.

This demonstrated, emerging utility has generated increased legislative attention. In September 2022, House Resolution 5315, *Drone Infrastructure Inspection Grant Act*,[8] passed the House of Representatives and is gathering support from several national organizations, including AASHTO. The bill, which would earmark up to $200 million in spending to broaden the use of UAS for infrastructure inspection purposes, recognizes how the advent and widespread availability of affordable, easy-to-use UAS technologies offers road managers new opportunities in their asset condition assessment efforts.

For FLMAs, this is especially the case given that they have already invested significantly in UAS fleets to help meet their multiple statutory obligations, including emergency management, fighting wildland fires, conducting search and rescue, surveying Federal land, collecting research data, and assisting law enforcement.[9] FLMA UAS flights grew from 260 in FY10 to more than 11,000 in FY19. UAS flights on Federal lands then declined to around 5,000 per year due to the now lifted Secretary's Order (SO) 3379, which had grounded some types of UAS flights.[10] Together, these UAS flights have helped the Department of the Interior (DOI) investigate hard-to-reach locations and broadly speed up tasks; across nearly 30,000 UAS flights flown through FY20, DOI observed that a UAS can complete a given task in 1/7th of the time and at 1/10th of the cost of traditional means of accomplishing the same task.[11] Despite "maintenance and inspection" activities currently accounting for a relatively small proportion of FLMA UAS flights (23 of 4,668 in FY21[12]), their relatively low cost and low risk compared to traditional aircraft make UAS a potentially inviting tool for FLMA road condition inspections.

The DOI has noted that measurable, relevant UAS outcomes can be grouped into the "Four S's" of

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[6] AASHTO. 2019. Mission Control: UAS/Drone Survey of All State DOTs. https://uas-aam.transportation.org/aashto-research/

[7] FHWA. April 9, 2020. Innovation of the Month: UAS. www.fhwa.dot.gov/innovation/everydaycounts/edcnews/20200409.cfm

[8] www.congress.gov/bill/117th-congress/house-bill/5315

[9] DOI has published a list of its demonstrated UAS mission applications at www.doi.gov/sites/doi.gov/files/uploads/doi_uas_mission_applications_v4.0.pdf. Example FS UAS case studies are available at www.fs.usda.gov/fs-tags/drones.

[10] DOI. January 29, 2020. Temporary Cessation of Non-Emergency UAS Fleet Operations, available at www.doi.gov/sites/doi.gov/files/elips/documents/signed-so-3379-uas-1.29.2020-508.pdf

[11] DOI. UAS Program 2020 Use Report, available at www.doi.gov/sites/doi.gov/files/fy20-doi-uas-flight-use-report-final.pdf

[12] DOI/Forest Service FY21 UAS Interactive Program Report

success metrics: *Science, Safety, Savings,* and *Service*. In terms of "science," DOI has noted that sensors carried on DOI UAS's have provided image resolution improvements of 1,200 percent over NASA's Landsat 8 satellite and 400 percent better than manned aircraft acquired data. In terms of "safety," from 1937 to 2000, two-thirds of all field biologist fatalities in DOI were aviation-related, and thus UAS use is viewed as a way to improve safety. For "savings," the DOI and FS have jointly indicated that most effective time periods since their UAS programs began have occurred when UAS aircraft was affordable and capable of informing their remote pilots' diverse needs.[13] In 2018 and 2019, the DOI's UAS use resulted in annual operational savings of $14.8M and $15.7M, respectively, as compared to traditional methods of carrying out the same missions. Finally, related to "service," UASs have allowed DOI staff in the field to be more responsive, agile, and flexible than otherwise possible.

The relevant literature makes similar conclusions, especially given UASs' abilities to carry and use multiple types of sensors (see Appendix A for the comprehensive literature on using UAS for road inspections summarized here). Three sensor types have primarily been used in combination with UASs for road inspections: cameras, lidar (Light Detection and Ranging), and multi- and hyperspectral imaging sensors (Ceylan 2017)—the best sensor for a given job being based on project-specific considerations and not an assumption that one sensor is more accurate than the other (Millian 2019). With that said, the literature to date has largely been oriented toward what is possible with UASs from a technical perspective in the road inspection context versus what may be practical given different agency and/or road manager capacities and policies. A University of Massachusetts team observed that the field of using UAS for road condition inspection was still in its infancy and that "no UAS platform can provide pavement condition analysis as currently obtained by traditional automated and manual methods" (UMass 2019). Other research in subsequent years (e.g., Outay 2020) has made similar conclusions that these concepts are still in a developmental phase and not yet in practice.

1.3 FLMA UAS Policy Landscape

U.S. Department of the Interior

In 2015, the DOI authorized its bureaus to operate UAS upon satisfactory completion of in-house training and through cooperation of the agency with the Federal Aviation Administration (FAA). Additionally, in August 2016, the FAA legalized the use of commercial UAS through its 14 CFR, Part 107 rule (FAA Small UAS Rule). Shortly afterward, DOI's Office of Aviation Services (OAS), the department-level lead on UAS, updated Operational Procedures Memoranda-11 (OPM-11)[14] to reflect the newer, less complicated rules.

The FAA and the DOI have a Memorandum of Agreement (MOA) that allows DOI ready access to operate its UAS fleet over DOI lands and the outer continental shelf.[15] When the DOI does activate its fleet, all of

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[13] DOI and FS. 2021. FY21 Unmanned Aircraft System Interactive Program Report, available at www.doi.gov/sites/doi.gov/files/fy21-interagency-uas-program-report-final-2022-02-22.pdf

[14] OPM-11 is available at www.doi.gov/sites/doi.gov/files/opm-11.pdf.

[15] MOA between DOI and the FAA Regarding Operation of sUAS in Class G Airspace. www.doi.gov/sites/doi.gov/files/uploads/DOI_FAA_MOA_Class_G_09112015.pdf

its bureaus do so under 14 CFR, Part 107, OPM-11, and national aviation plans. Additionally, the DOI's Privacy Impact Assessment[16] identifies and addresses privacy implications for the use of UAS, particularly surveillance, image, and video capabilities. It covers the general use of UAS in accordance with Federal and DOI policies.

On January 29, 2020, the DOI issued SO 3379, "Temporary Cessation of Non-Emergency Unmanned Aircraft Systems Fleet Operations," to "better ensure the cybersecurity and supply of American technology of [UAS]." To meet this purpose, SO 3379, pending the completion of an ongoing review, grounded the Department's fleet of UAS (with the exception of emergency operations for missions such as wildland fire or search and rescue) and prohibited additional procurement of "designated" UAS. Per SO 3379's direction, the DOI released implementing guidance related to SO 3379 over the course of the year, including the definition of "designated UAS" and a waiver process for non-emergency flights.

The following year on January 18, 2021, the White House issued Executive Order (EO) 13981, "Protecting the United States from Certain Unmanned Aircraft Systems," to similarly ensure "the security of [UAS]" and to prevent the use of taxpayer dollars to procure UAS that present "unacceptable risks." EO 13981 specifically directed agencies to review whether they could cease procuring "covered UAS." Under EO 13981's controlling definition, a majority of the DOI's current UAS fleet were considered covered UAS. Given this classification and SO 3379's grounding order, the DOI reviewed its UAS program to ascertain potential security risks and identify any measures that might sufficiently mitigate those risks.

On May 30, 2021, the DOI's Executive Aviation Committee and related subcommittee completed a comprehensive review of the DOI UAS Program. The committee concluded that the Department's thorough and rigorous defense-in-depth security strategy, which includes overlapping technical, policy, training, and oversight components, sufficiently mitigates potential risks that the fleet of covered UAS pose. It further found that the DOI's generally "benign" operating environment, largely accessible to the public and typically removed from populated areas or areas of national security interest, created a primarily low security risk mission environment for the operation of covered UAS. These factors, taken together, mitigate the security risk of the fleet as currently understood to an acceptable level.

On October 21, 2022, consistent with SO 3379, the findings of the committee's review, and EO 13981's direction to prevent unacceptable risks, DOI issued an updated UAS operations and procurement policy that resumed operation of all DOI-mission appropriate UAS flights using the existing fleet. The policy also authorized the procurement of appropriate non-covered UAS to diversify DOI's fleet and further mitigate potential risk. This research project was well underway as these latest developments panned out; all demonstration considerations were planned in a way as to ensure alignment with the current DOI policy. Specific management structures for FLMAs are summarized below.

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[16] DOI. Privacy Impact Assessment: UAS Program. www.doi.gov/sites/doi.gov/files/uploads/di-4001-unmanned-aircraft-system-program-pia-01.12.2016.pdf

Table 2. Overview of UAS Management Structures at Four FLMAs[17]

Agency	UAS Management Structure or Key Policy
BLM	The BLM National Aviation Office is responsible for aircraft operation support for wildfire and resource management missions within the bureau. BLM's Aviation program is the largest within the DOI's eight bureaus. BLM Fire and Aviation is the lead group within the agency for UAS operations.[18] The BLM's National Operations Center conducts project-level work, including science and technology aspects as well as managing collected data. Safety is the BLM's foremost concern when flying UAS missions. Every mission is conducted within Federal, departmental, and interagency policy.
FWS	The FWS Branch of Aviation administers the agency's UAS program. The Branch develops and establishes interagency and departmental aviation policy in partnership with several internal and interagency committees. It manages more than 150 UAS, representing 65 percent of the DOI's UAS fleet, and supports more than 60 UAS remote pilots across the country.
NPS	The NPS Branch of Aviation provides leadership at the national, regional, and park levels to ensure safe and efficient use of aviation resources. Concern for UAS's impact on park resources and compatibility with the NPS mission led to a review and the creation of formalized policies regarding the use of UASs as described in Policy Memorandum 14-05.19 Launching, landing, or operating UAS in NPS units is generally prohibited, with limited exceptions subject to NPS approval. One of those exceptions is the administrative use when NPS approves in writing. Administrative use includes when UAS are to be flown by (i) NPS personnel as operators or crew; (ii) cooperators such as government agencies and universities that conduct UAS operations for the NPS pursuant to a written agreement; and (iii) other entities, including commercial entities, conducting UAS operations for the NPS, provided such entities are in compliance with all applicable FAA and DOI requirements. Guidance on using UAS for administrative and research operations is further outlined in NPS Reference Manual 60.[20]
Forest Service (FS)	The FS operates under the FAA Small UAS Rule; FS Manual 5700,[21] FS Handbook 5709.16,[22] national and regional aviation plans, and the FS Standards for UAS Operations.[23] The latter is intended to promote safe, efficient, and lawful operation of UAS in support of the FS mission; as such, it describes the agency's UAS procedures and requirements. In support of its UAS policies, the FS has established an interdisciplinary UAS Executive Steering Committee and a UAS Advisory Group to oversee and coordinate UAS issues for the agency. The National UAS Program Manager provides overall leadership, direction, and vision for the FS's UAS activities while coordinating across the agency to establish UAS specifications, protocols, and standards.

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[17] Other agencies sometimes considered FLMAs but not listed in this table are the Bureau of Reclamation (Reclamation) and the U.S. Army Corps of Engineers (USACE). Reclamation began using UAS in 2012, an effort that Pacific Northwest Region's GIS group in Boise, Idaho spearheaded. The applications for UAS were largely limited to river mapping and aerial media testing, though other applications were proposed. The directives in Reclamation's National Aviation Management Plan (August 2020) guide the agency's UAS operations (www.usbr.gov/recman/sle/NAMP.pdf). At USACE, Engineering Circular 1100-1-109 (August 2018) provides guidance for USACE's acquisition and operation of UAS within the National Airspace System. It describes how the public or commercial organizations and government agencies can use UAS at water resource development projects that the USACE administers.

[18] BLM. BLM Unmanned Aircraft systems Communications Plan. May 30, 2020 www.nifc.gov/drones/blm/UASCommPlan.pdf

[19] NPS. Policy Memorandum 14-05. June 19, 2014. www.nps.gov/policy/PolMemos/PM_14-05.htm

[20] NPS. Reference Manual 60, Aviation Management, 2019 (links updated in 2022). www.nps.gov/subjects/aviation/upload/reference-manual-60.pdf.

[21] FS Manual 5700, September 9, 2020. https://gacc.nifc.gov/swcc/dc/azpdc/operations/documents/aircraft/policy/USFS_5700_Policy.pdf

[22] FS Handbook 5709.16, September 15, 2017. www.fs.usda.gov/cgi-bin/Directives/get_dirs/fsh?5709.16

[23] FS Standards for UAS Operations. July 2022. www.fs.usda.gov/sites/default/files/2020-07/Forest%20Service%20Standards%20for%20UAS%20Operations%2007012020.pdf

2. DEMONSTRATION

On August 8–9, 2023, the FWS, USDOT, and USGS partnered to conduct a UAS demonstration at Alamosa NWR in Colorado. The objective of the demonstration was two-fold:

- To determine whether a UAS mission for road inspection purposes was possible given administrative considerations; and,
- To implement a mission plan testing whether UAS can help improve the efficiency of the RIP road inspection process for unpaved roads as measured by time, cost, and level of detail.

2.1 Pre-Demonstration Planning

To plan and conduct the UAS mission, the project team partnered with the U.S. Geological Survey through its National Uncrewed Systems Office an FHWA's FLH, both of which volunteered staff time, expertise, and equipment to the effort. After a series of approximately four virtual meetings with USGS and FLH, it was settled that USGS would lead the interagency team in the field (i.e., in conducting safety briefings, placing ground control points and planning, and coordinating multiple UAS flights, etc.). USGS would fly its UAS to collect lidar data and perform basic post-processing afterwards, and FLH would fly its UAS to collect imagery to be used later in a photogrammetric analysis.[24]

The project team screened candidate locations for the demonstration based on variables such as the extent of unpaved roads at the station, the availability of a recent inspection report, the variability of conditions previously observed, and various physical characteristics (e.g., canopy cover, wetland presence, and average slope). The proximity to USGS and FLH offices were also important considerations. The “ideal” site as envisioned was one that had unpaved roads presenting each of the distresses typically measured, that had variable topography and canopy, and that was within reasonable driving distance from the National Uncrewed Systems Office. Ultimately, Alamosa NWR in Alamosa, Colorado—pending its willingness to host the demonstration—was selected having met most of the preferred characteristics.

In preparation for the mission, the project team completed a special use permit application at the Refuge’s request. The process involved one team member filling out FWS Form 3-1383-R (Rev. 03/2020),[25] which the Refuge provided. The form took approximately 30 minutes to fill out. Approval was received from the Refuge the following week. USGS and FLH both separately submitted airspace authorizations to the Low Altitude Authorization and Notification Capability waiver system. That process involved one team member completing an online form, which was approved in near real-time. USGS wrote a Project Aviation Safety Plan (Appendix D) in accordance with OPM-6.[26] In parallel, the project team prioritized approximately three miles of roads at Alamosa on which the demonstration would focus (Figure 1). This represented the road length that the collective demonstration partners believed to be feasible given the time available, the planned dual UAS missions, and the desired field staging (e.g., canopy, GCPs, team vehicles).

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[24] USGS flew its DJI Matrice 600 Pro, operating on U.S. Government-approved firmware, with a YellowScan VX20-100 lidar payload. FLH flew its Freefly Alta X with a Sony ILCE-7RM4 camera payload.

[25] www.fws.gov/sites/default/files/documents/Form-3-1383-Research-Special-Use.pdf

[26] www.doi.gov/sites/doi.gov/files/opm-06.pdf

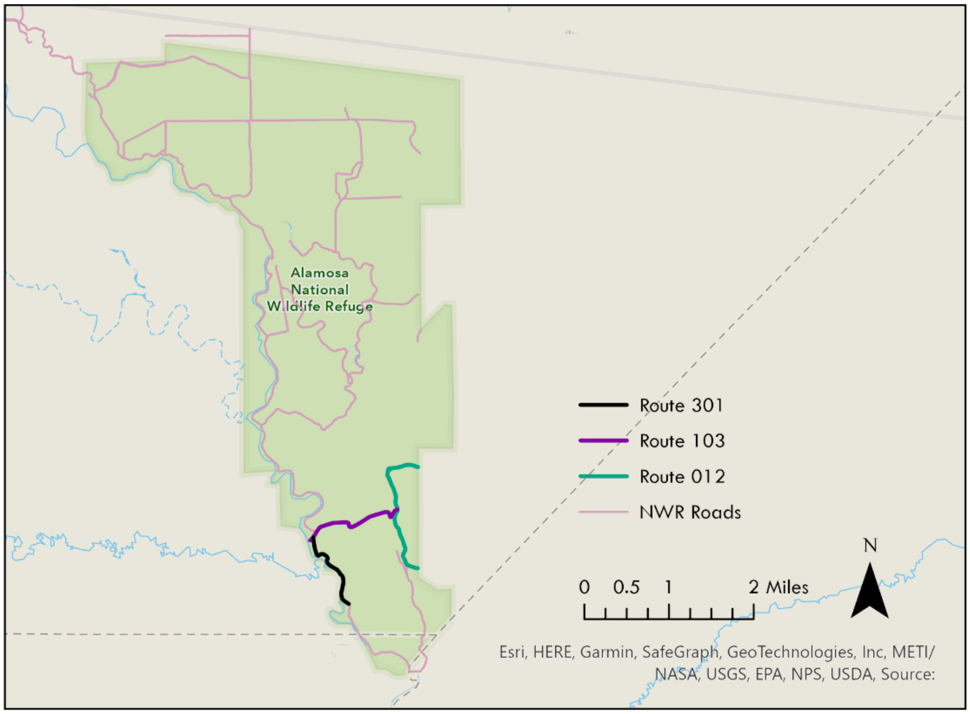

Figure 1. Priority UAS Demonstration Roads at Alamosa NWR

2.2 Demonstration Implementation

Once on site, the RPIC set up a GPS base station while the team placed 10 to 12 GCPs (Propeller AeroPoints, v1.2 and 2.0) in general alignment with a pre-mission flight plan. The GCPs were placed in pairs at regular but imprecise intervals, one GCP on each side of the roads flown, approximately every 150 m (Figure 2). Placement adjustments were made in the field as necessary. All GCPs were allowed to operate for at least three hours in order to minimize location error.

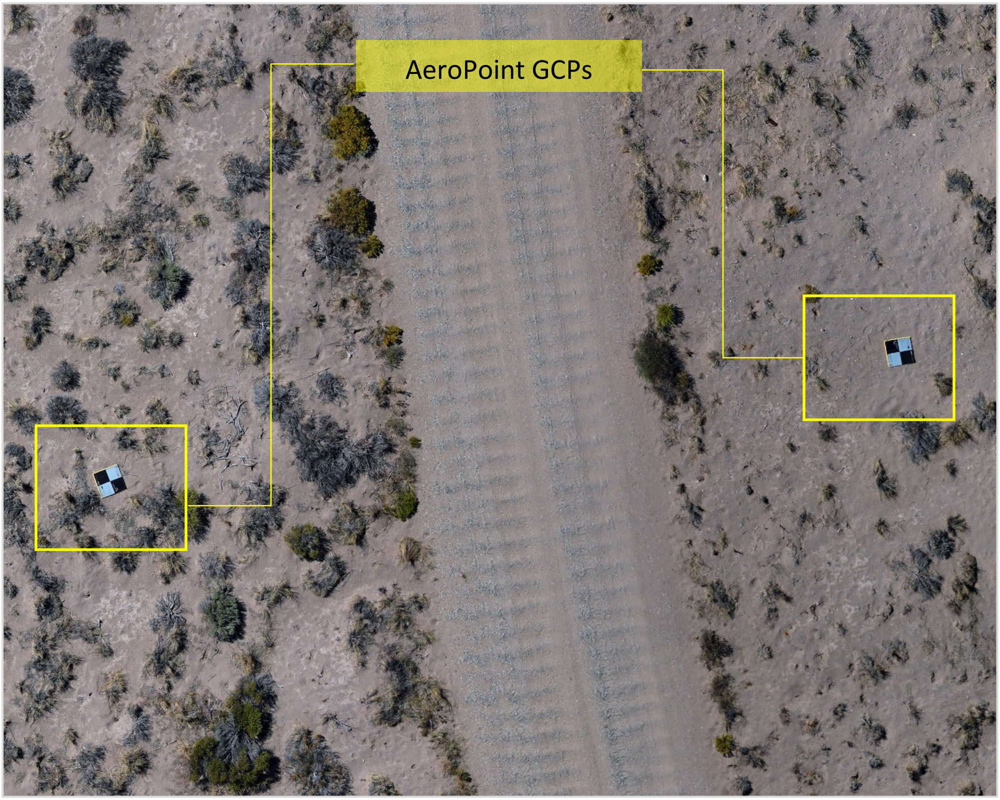

Figure 2. Example Placement of GCPs Relative to Flown Road

After a safety briefing, USGS and FLH conducted a series of UAS flights in accordance with the Project Aviation Safety Plan. The mission entailed a total of eight UAS flights—four to acquire lidar data and four to acquire imagery using a Firefly Alta X. Each flight was between 8 to 10 minutes long following two parallel transect passes along either side of the road of interest for a total of approximately 60 to 80 minutes of flight time. Total flight distance was approximately 6.5 miles (cumulative out and back distance for all roads of interest). Launch points for the lidar flights and imagery flights were slightly different from one another due to staging considerations and, for the last imagery flight of the demonstration, remaining battery life. All but one flight was flown at 200 feet (61m) AGL; one lidar flight was flown at a lower altitude for the sake of comparison.[27] Only lidar-acquisition flights were flown on the first day of the demonstration. Strong winds in the afternoon prevented any additional UAS flights, including any for imagery acquisition.[28] With nondisruptive weather on the demonstration's second day, the team coordinated lidar and imagery flights to alternate in time and space in order to streamline safe operations while sharing the GPS base station and GCPs; there was no occasion where more than one UAS was operating coincidentally.

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[27] The project team also collected near-ground-level imagery for approximately 15 miles of roads (within and outside the NWR) using a smartphone mounted in a handheld gimbal.

[28] Smartphone weather apps indicated sustained winds of 10 m/s (~22 mph) with higher gusts.

Figure 3. DJI Matrice 600 Pro with YellowScan VX20-100 lidar

Visual observers monitored the UAS flights, documenting any notable events. The roads flown were each over mostly flat terrain except for one short road segment that traversed a bluff of approximately 20 meters. No tree cover, powerlines, or other potential flight obstructions were present. Various bird species were present nearby and grazing cattle were seen in the vicinity of the flights. There was one apparent privately-owned building adjacent to the flight area, but no activity or human presence during the demonstration was observed. Tables 3-5 detail route-specific observations the project team made during the UAS flights.

Table 3. Observations During Route 012 UAS Flights

<table>
<tr><td>**ROUTE:** 012</td><td colspan="2">**NAME:** Bluff Overlook Drive</td><td>**From:** Baca Lane N</td><td>**To:** Baca Lane S</td></tr>
<tr><td>**Class:** 1</td><td>**Surface:** Gravel</td><td>**Paved (mi):** 0</td><td>**Unpaved (mi):** 1.69</td><td>**Width(s):** ~ 11–14 ft</td></tr>
<tr><td colspan="5">• Presence of people/vehicles: prior to the UAS flights, two separate groups of visitors/tourists arrived at the area where the UAS flights were being staged (scenic overlook parking). No interaction between the project team and the visitors was deemed necessary.
• General set-up prior to the first flights took approximately 2.5 hours. This period included a safety briefing, instruction about how to deploy the GCP equipment, setting up a shade tent and safety cones, and setting up the UAS itself.
• Radios were used for communications beyond hearing distance.
• Lidar mission flown at 5 m/second and 200 ft AGL on both sides of northern half of Rt012, capturing field approximately 120 meters in total width. 50% overlap between out and back passes. Flight duration approximately 9 minutes to cover 1 mile out and back. Major limiter was battery life (roughly 10-minute flights possible with available equipment before battery change necessary).
• Imagery mission flown at 5 m/second and 200 ft AGL on both sides of northern half of Rt012, capturing field approximately 100 meters in total width. Camera sensor at nadir. Flight time approximately 6 minutes to cover 1 mile out and back.
• During two of four flights above Rt012 various birds may have taken interest in the flying UAS. In one case what appeared to be a raptor briefly followed the UAS at a distance and then appeared to grow disinterested. It may have also been indifferent to the UAS, flying on thermals rising off the bluff. In another case, what appeared to be approximately four ravens began flying from the ground after the UAS passed above. They flew back to the ground shortly afterwards.
• During one flight an aircraft (estimated 500 ft+ AGL) passed uneventfully in vicinity of UAS flight
• Using laptops, team was able to retrieve and visualize both lidar and imagery data from the on-board SD cards moments after the UAS flights.
• The team made general observations about most of the northern section of Rt012’s conditions visually. The observations were also recorded via smartphone camera mounted on a handheld gimbal. These general observations were for reference only.</td></tr>
<tr><td colspan="5">**Notable Events**: During one of the imagery flights, radio contact with the aircraft was momentarily lost. This flight was also momentarily paused to avoid a passing aircraft, and when the mission resumed, the UAS flew at twice the speed programmed (10 m/s versus 5 m/s).</td></tr>
</table>

Table 4. Observations During Route 103 UAS Flights

ROUTE: 103	**NAME:** Hunter Crossing Road		**From:** Bluff Overlook Rd	**To:** Parking Area 3
Class: 2	**Surface:** Gravel	**Paved (mi):** 0	**Unpaved (mi):** 1.3	**Width(s):** ~ 9-11 ft

- Presence of people, vehicles: N/A
- General set-up prior to the first flights took approximately 1 hour, including site reconnaissance, GCP placement, and flight preparation.
- Radios were used for communications beyond hearing distance.
- Lidar and imagery flights were both flown with similar flight parameters to demonstration day 1.
- UAS and imagery flights never flew simultaneously. Flights were coordinated to alternate in time and space in order to streamline operations while sharing the GPS base station and established GCPs.
- No noticeable wildlife interactions or behavior changes.
- The team made general observations about the entire length of Rt103's conditions visually. The observations were also recorded via smartphone camera mounted on a handheld gimbal. These general observations were for reference only.

Notable Events: At one point, a low-flying (estimated 400-500 ft AGL) aircraft was observed flying directly toward an on-going UAS imagery flight. Visual observers used radio communications to alter the UAS pilot of the approaching aircraft, at which point the pilot lowered the UAS. The approaching aircraft passed uneventfully.

Table 5. Observations During Route 301 UAS Flights

ROUTE: 301	**NAME:** River Service Road		**From:** Hunter Crossing	**To:** Apprx. 1 km
Class: 2	**Surface:** Native	**Paved (mi):** 0	**Unpaved (mi):** 1.3	**Width(s):** ~ 7-8 ft

- Presence of people, vehicles: N/A
- General set-up prior to the first flights took approximately 30 minutes, including GCP placement and flight preparation.
- Radios were used for communications beyond hearing distance.
- Lidar and imagery flights were both flown; the imagery flight was truncated relative to the lidar flight due to battery considerations.
- UAS and imagery flights never flew simultaneously. Flights were coordinated to alternate in time and space in order to streamline operations while sharing the GPS base station and established GCPs.
- No noticeable wildlife interactions or behavior changes.
- The team made general observations about a portion of Rt301's conditions visually. The observations were also recorded via smartphone camera mounted on a handheld gimbal. These general observations were for reference only. The extent to which Rt301 could be further observed from the ground was limited by the condition of the road. It became increasingly overgrown and impassable the further from the base of UAS operations for the Rt301 flights.

Mishaps/Notable Events: At the conclusion of the demonstration's final flight, the team picked up the GCPs and packed up equipment. Once back at the gate connecting Rt103/Rt301 to Rt012, the team noticed that two GCPs had not been recovered from Rt301. Team members drove approximately 2 miles back to the site of the final flights to retrieve the GCPs. Additionally, one hand-held radio for communications was lost.

2.3 Data Post-Processing and Analysis

After the field work, USGS sent the project team three .zip files via a Secure Large File Transfer Site, one each containing GCP location data, FLH's UAS imagery, and a lidar point cloud that USGS processed and colorized using Agisoft Metashape, Yellowscan Cloudstation v2304.0, Applanix PosPac UAV 8.8, and Global Mapper. Using ArcGIS Pro (Advanced 3.1.3) and several related extensions, including Drone2Map, Spatial Analyst, Image Analyst, 3D Analyst, and Esri Deep Learning Python libraries for ArcGIS Pro 3.1, the project team completed the workflow described below. Specifications for the hardware used to complete these workflows are in Table 6.

Table 6. Hardware Used for Analysis

GPU	NVIDIA RTX A5500 Laptop GPU
Storage	938 GB
Installed RAM	64.0 GB
Processor	12th Gen Intel(R) Core(TM) i9-12950HX, 2.30 GHz

Photogrammetry Workflow

The project team created a photogrammetrically corrected orthomosaic image using ArcGIS Pro's Ortho Mapping Product generation tools (Figure 4). Imagery data were loaded into the workspace to create an image collection. During this step, seven images that had not rendered a geolocation (Lat (X), Long (Y), and elevation (Z) values) were removed from the collection. ArcGIS Pro automatically detected the spatial reference (WGS_1984_UTM_Zone_13N), camera model, and additional camera parameters. Default settings were used for all other parameters. Once the images were combined to make an image collection, the project team geometrically and color corrected it using the "Block Adjustment" and "Tie Point Matching" geoprocessing tools with default settings. All settings were left at their default to create an orthomosaic image, except the output format, which was changed from a CRF file format to a TIF.

Figure 4. Orthomosaic of Unpaved Road at Alamosa NWR

LiDAR Workflow

USGS sent the project team a LAS point cloud that had been post-processed (as further described in USGS-provided metadata) (Figure 5). A vertical accuracy assessment using 22 validation check points in non-vegetated and low-vegetated areas had already been performed. Building off this, the project team conducted further visual accuracy assessments of the Amercian Society of Photogrammetry and Remote Sensing bare-earth ground classification and refined the point classifications accordingly. The data was surveyed and processed using orthometric heights using model geoid18. The project team used ArcGIS Pro's "LAS Dataset to Raster" geoprocessing tool with a Sampling Value of 0.25 and default values for the remaining settings to convert the LAS point cloud to a raster. The resulting digital elevation model had a horizontal resolution of 0.5m x 0.5m.

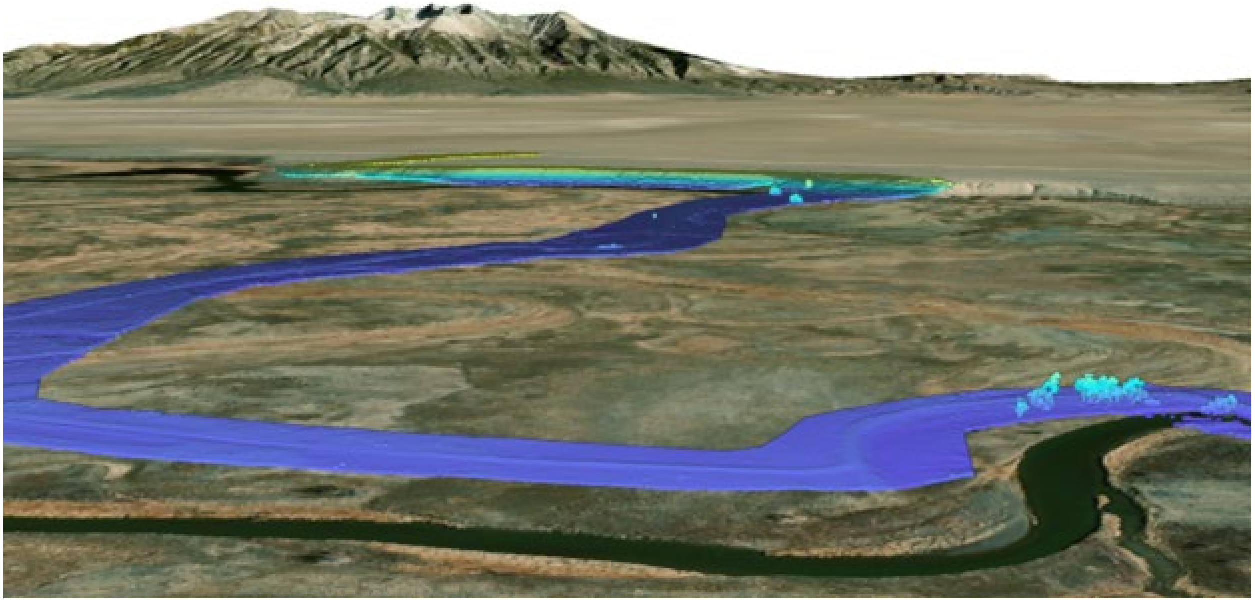

Figure 5. Colorized Lidar Point Cloud for Three Unpaved Roads at Alamosa NWR

Prepare Roads for Analysis

The research team first digitized the roads in the study site. Using the orthomosaic, the team created a line feature class representing the outline of the roads' surface areas. A polygon feature class and a centerline feature class were generated from the outline feature class, using the geoprocessing tools "Collapse Dual Lines to Centerlines" and "Feature to Polygon," respectively.

Crown and Drainage Analyses

The project team analyzed crown and drainage distresses by finding the elevation profile of a series of road transects. For road crown, the team generated transect lines perpendicular to the road every 1 foot along the road centerlines. The transect lines were clipped with the manually digitized road polygon feature class so that they did not extend beyond the expected road edge. Sample points were generated at 1-meter intervals on each transect line. The profile of each transect line was obtained by overlaying the sample points on the orthomosaic-derived DEM and the lidar-derived DEM and finding the elevations; both DEMs were used for comparison purposes.[29] For each transect, the elevations of each road edge were found by averaging the elevation of the two sample points closest to each edge to account for error and outliers. The elevation of the road crown was found by averaging the three highest, consecutive elevation values in the remaining points. Per the modified Pavement Surface Evaluation and Rating (PASER) scale that FWS uses, transects where the crown was calculated to be 3 to 6 inches higher than both edges were assigned a score of "MINOR" or 1. Transects where the crown was higher than both edges by less than 3 inches were assigned a score of "MODERATE" or 2. Finally, transects where the crown was the same elevation or lower than one or both edges were assigned a score of "SEVERE" or 3. For each transect, the crown score was assigned to the segment of road for which the transect is the midpoint.

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[29] The orthomosaic-derived DEM was observed to be more practical to use for all distresses given alignment issues between the orthomosaic and the lidar-derived DEM.

The project team used a similar process to analyze drainage. Transects were created at 1-foot intervals extending 1 foot from each road edge away from the road. Elevations along each transect were obtained at 0.5-ft intervals. The elevation of the road edge was calculated as the average of the two sample points closest to the edge. Ground level was calculated by averaging the two lowest, consecutive values from the remaining points. Per the modified PASER scale that FWS uses, transects where the road edge was at least 2 inches above ground level were rated “MINOR,” or 1. Transects where the road edge was level[30] with the ground were scored “MODERATE” or 2. Transects where the road was found to be below ground level were scored “SEVERE” or 3. For each pair of transects (e.g., the transects on the left and right sides of the road), a drainage score was assigned to the segment of road for which the transect is the midpoint. Where the left and right drainage scores differed, the score representing the more severe condition was used.

To mirror the current RIP process of reporting distress scores in 0.1-mile (528-ft) segments, FWS’s methodology for arriving at a modified PASER score for each distress type was followed. For example, to calculate the distress score for crown for a given 0.1-mile segment, the length of the segment on which each distress level (mild, moderate, severe) is determined. Then, the length of each distress level is multiplied by a weight: 1 for minor, 2 for moderate, 3 for severe:

$$Segment\ Distress\ Score = Max(\ (Length_{MILD} \times 1), (Length_{MODERATE} \times 2), (Length_{SEVERE} \times 3)\ )$$

The scores for the crown and drainage distresses for the entire segment are identified as the highest of the three distress levels within that segment.

Potholes, Loose Aggregate, Rutting, and Washboarding Analyses

The project team analyzed the UAS-acquired data in an effort to discern pothole, loose aggregate, rutting, and washboarding distresses. For the manual inspection, the project team used the orthomosaic to visually identify and demarcate these distresses. To calculate distress scores for each individual distress in 0.1-mile (528-ft) segments, the project team used the GIS to measure the length of roadway where each severity level of a given distress was observed. Severities were ascertained using the ArcGIS Pro’s Interactive Elevation Profile tool referencing the orthomosaic-derived DEM.

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[30] For the purposes of this study, “level” is considered with 0.5 inches to account for the vertical precision of the lidar.

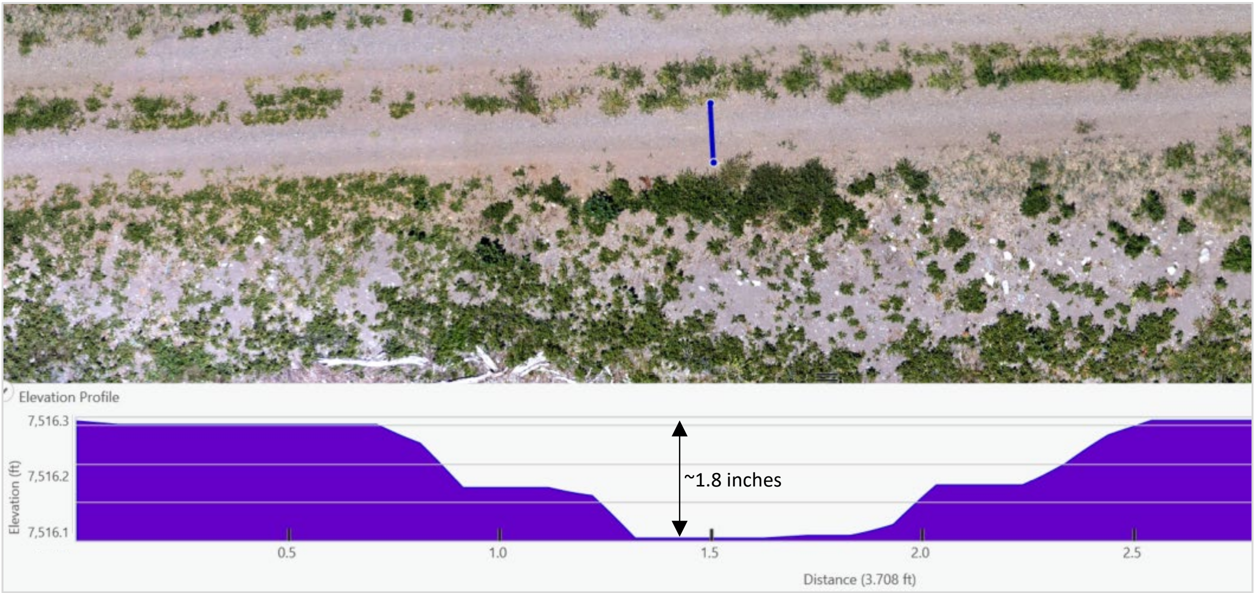

Figure 6. Example measurement of rutting depth

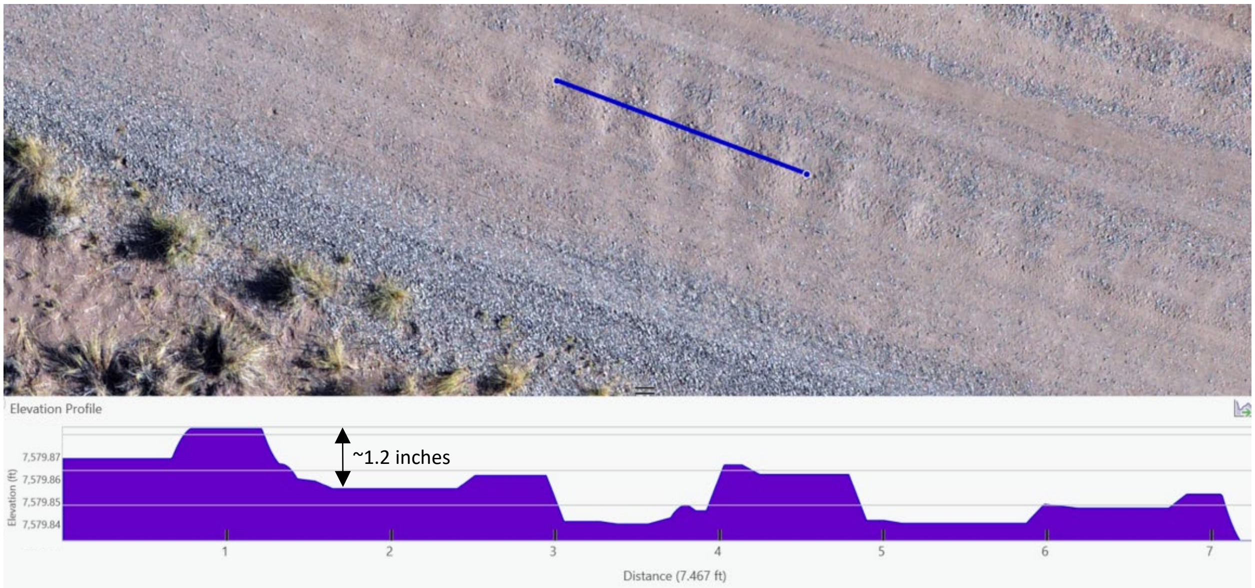

Figure 7. Example measurement of washboarding depth

Finally, distress scores were calculated based on the weighted length calculation described in the Crown and Drainage Analyses section above.

Automated Workflows

Manually digitizing the road features proved feasible for the relatively small study area; however, an automated workflow using available tools could facilitate future analyses. Using ArcGIS Pro's Image Analyst extension, the project team attempted to automate the digitization of the study area roads using the UAS-acquired imagery. The first step in the workflow involved using Esri's pretrained North American Roads Deep Learning Model, which utilizes a "Classify Pixels Using Deep Learning" geoprocessing tool.[31] This tool classifies pixels as road or non-road in the orthomosaic, which can then be used to generate polygons and centerlines following Esri's Extract Roads script or similar deep learning methods.[32]

The Image Analyst toolbox can also be used to automate the detection and classification of road distresses. To do this, a practitioner would prepare training data by labeling the distresses in a subsection of the study area imagery. These data would then train and validate a deep learning model,[33] which in turn would be used to identify similar distresses in the remaining imagery. With enough training data, a deep learning model could be used to detect distresses at all stations in a given region or even nationwide, eliminating the need to train a separate model for each station inspected.

The project team attempted to automate the detection of washboarding using this workflow.[34] The team created a training dataset shapefile with polygons outlining washboarding on approximately 3 miles of roadway. The training samples were then converted to Region-based Convolutional Neural Networks.[35] The model was trained on a MaskRCNN model type with a batch size of 3 and a backbone model of RESNET50. The resulting deep learning package became the model definition for the "Detect Objects Using Deep Learning" geoprocessing tool, which should output a classified raster of all areas within an image that have washboarding. Ultimately, the project team encountered computing challenges that were insurmountable given research timeline constraints, including known bugs in the interaction between deep learning tools and GPU processing environments. However, other researchers have used similar workflows to identify distresses in paved and unpaved roads (see Appendix A). The project team believes that similar successful deep learning model for FLMA roads is attainable through additional research and troubleshooting.

2.4 Road Condition Rating

Scores for each of the unpaved road distresses and the corresponding unpaved road rating as derived from the project team's analysis of the UAS-acquired data are listed in Table 7.

Table 7. Unpaved Road Ratings as Determined by Analysis of UAS-Acquired Data

			Distress Scores					
Route #	**Surface**	**Ave. Road Width (ft)**	**Crown**	**Drainage**	**Potholes/ Loose Aggregate**	**Rutting/ Washboarding**	**Dust***	**Unpaved Rating**
012N	Gravel	13.4	3	3	1	2	1	1
012S**	Gravel	13.7	3	3	1	2	1	1

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[31] https://pro.arcgis.com/en/pro-app/latest/tool-reference/image-analyst/classify-pixels-using-deep-learning.htm

[32] https://developers.arcgis.com/python/samples/automatic-road-extraction-using-deep-learning/

[33] https://developers.arcgis.com/python/samples/feature-categorization-using-satellite-imagery-and-deep-learning/#visualize-classification-results-in-validation-set

[34] The sample Alamosa imagery did not include enough examples of potholing, loose aggregate, or rutting to attempt to train and verify a deep learning model on these distresses.

[35] https://developers.arcgis.com/python/guide/how-maskrcnn-works/

103	Gravel	9.5	3	3	1	1	1	2
301**	Native	8	3	3	1	2	1	1

**Measurement in the GIS not possible. Score reported here is based on field observations during the demonstration. **The UAS demonstration flights for Route 012S covered approximately 0.2 miles of the road segment's total 0.837-mile length. The rating here is only based on the 0.2 miles flown. Similarly, the UAS demonstration flights for Route 301 covered only a portion of that road (0.4 miles). The rating here is based on those miles flown.*

Gravel Surface Treatments	Native Surface Treatments
Limited Local Maintenance (5)	Limited Local Maintenance (4)
Routine Maintenance (4)	Routine Maintenance (3)
Light Rehabilitation (3)	Light Rehabilitation (2)
Heavy Rehabilitation (2)	Heavy Rehabilitation (1)
Reconstruction (1)	

A FLH RIP team traveled to Alamosa NWR the week after the UAS demonstration to collect road data using customary methods. Table 8 lists FLH distress scores that the RIP team calculated based on their observations on the roads over which UAS flights also occurred. Recommended treatments ranged from routine maintenance on Route 103 to heavy rehabilitation on Routes 012N and 301.

Table 8. Unpaved Road Ratings for UAS-flown Roads as Determined by Current RIP Approach

			Distress Scores					
Route #	**Surface**	**Road Width (ft)**	**Crown**	**Drainage**	**Potholes/ Loose Aggregate**	**Rutting/ Washboarding**	**Dust**	**Unpaved Rating**
012N	Gravel	12	2	3	1	3	1	2
012S	Gravel	12.5	2	2	1	2	1	3
103	Gravel	12	2	1	2	2	1	4
301	Native	11	1	2	2	2	1	2

Gravel Surface Treatments	Native Surface Treatments
Limited Local Maintenance (5)	Limited Local Maintenance (4)
Routine Maintenance (4)	Routine Maintenance (3)
Light Rehabilitation (3)	Light Rehabilitation (2)
Heavy Rehabilitation (2)	Heavy Rehabilitation (1)
Reconstruction (1)	

Side-by-side results disaggregated at the 1/10-mile level are shown in Table 9 below for additional reference.

Table 9. Comparison of 1/10-mile Unpaved Distress Scores

			CURRENT RIP APPROACH SCORES AND RATING					UAS APPROACH SCORES AND RATING				
Route	**Begin**	**End**	CROWN	DRAINAGE	POTHOLES/ LOOSE AGGREGATE	RUTTING/ WASHBOARDING	UNPAVED RATING	CROWN	DRAINAGE	POTHOLES/ LOOSE AGGREGATE	RUTTING/ WASHBOARDING	UNPAVED RATING
012N (Gravel)	0	0.1	2	3	1	2	*2*	2	3	1	1	*3*
	0.1	0.2	2	3	1	2	*2*	2	3	1	1	*3*
	0.2	0.3	2	3	1	2	*2*	2	3	1	2	*2*
	0.3	0.4	2	2	1	2	*3*	2	3	1	2	*2*
	0.4	0.5	2	2	1	2	*3*	2	3	1	1	*3*
	0.5	0.6	2	2	1	3	*2*	3	3	1	1	*2*
	0.6	0.7	2	3	1	3	*2*	3	3	1	2	*1*
	0.7	0.8	2	3	1	3	*2*	3	3	1	2	*1*
	0.8	0.856	2	3	1	3	*2*	3	3	1	1	*2*
012S (Gravel)	0	0.1	2	2	1	3	*2*	3	3	1	2	*2*
	0.1	0.2	2	2	1	2	*3*	3	3	1	1	*1*
103 (Gravel)	0	0.1	3	3	2	2	*1*	3	3	1	1	*1*
	0.1	0.2	2	2	3	2	*2*	3	3	1	1	*1*
	0.2	0.3	2	1	2	2	*4*	3	3	1	1	*1*
	0.3	0.4	2	1	2	2	*4*	3	3	1	1	*1*
	0.4	0.5	2	1	2	2	*4*	3	3	1	1	*1*
	0.5	0.6	2	1	2	2	*4*	3	2	1	1	*3*
	0.6	0.7	2	1	2	2	*4*	3	3	1	1	*2*
	0.7	0.8	2	1	2	2	*4*	3	3	1	2	*1*
	0.8	0.9	2	1	2	2	*4*	3	2	1	1	*3*
	0.9	1	2	1	2	2	*4*	3	3	1	2	*1*
	1	1.1	2	1	2	2	*4*	3	2	1	2	*2*
	1.1	1.2	2	1	1	2	*4*	3	2	1	1	*3*
	1.2	1.23	2	1	1	2	*4*	2	2	1	1	*3*
301 (Native)	0	0.1	1	1	1	2	*3*	3	3	1	2	*1*
	0.1	0.2	1	2	2	2	*2*	3	2	1	2	*2*
	0.2	0.3	1	2	2	2	*2*	3	2	1	2	*2*
	0.3	0.4	1	2	3	2	*1*	3	2	1	2	*2*

3. CONCLUSIONS

Public lands offer opportunities for the use of UAS as unique monitoring tools, including conducting road condition inspections on FLMA roads. Research in this area has focused on gauging whether using different UAS sensors and, in some cases, computer processing techniques to identify specific road distresses offers a viable alternative or improvement to existing practice. The literature to date has largely been oriented toward what is possible with UASs from a technical perspective in the road inspection context versus what may be practical given different agency and/or road manager capacities and policies. Generally, research teams have found evidence indicating that UASs are a promising technology in the road condition inspection field, whether they are equipped with camera sensors used to simply collect images for viewing or are paired with photogrammetry or machine learning methods after image acquisition. The experience with lidar-equipped UAS for road inspections has been more mixed.

The demonstration confirmed that using UAS for road inspection purposes is possible given current administrative considerations of flying UAS on some public lands. The project team was able to successfully work with a NWR to plan, approve, and conduct the UAS mission. The demonstration also afforded important insights regarding time, cost, and level of detail possible. For FLMA purposes, road managers might consider UAS missions for road inspections in situations where using UASs were expected to improve safety, save time or money, and/or enhance the level of detail and accuracy relative to customary methods. Achievement of some of these goals may be more realistic than others in the context of the existing and foreseeable RIP data collection process.

3.1 Time Savings

Pre-UAS Mission

The typical RIP field collection trip is one to two weeks in duration, covering multiple FWS stations. Individual collections range from approximately one hour to a couple days depending on the extent of a station's road network. The reported driving speed for a collection is approximately 10 to 15 miles per hour. The RIP driving inspection at Alamosa NWR during the week after the demonstration is estimated to have taken approximately one hour for the unpaved roads that the UAS missions also covered. The UAS demonstration took longer due to a lengthy pre-flight staging process that was necessary. On demonstration day 1, the UAS unpacking, assembly, and deployment process, including a safety briefing and the placement of GCPs, took approximately 2.5 hours. The UAS equipment does not need to be calibrated. The set-up process was progressively faster for each demonstration flight. By the last UAS flight on demonstration day 2, the pre-flight process had been reduced to approximately 30 minutes. Assuming the vehicle used has room in it to carry the assembled UAS, the only aspect of the process described here that would need to be repeated in places where road assets are located far from each other would be placing the GCPs. With that said, the project team believes it is likely possible to obtain the necessary level of precision without using ground control, especially if using UAS with real-time kinematic (RTK) GPS processing capabilities.

During UAS Mission

There were minimal to no potential obstructions to UAS takeoff (e.g., tree canopy, power lines) in the areas flown at Alamosa NWR. Once airborne, UAS flights were flown at a speed of 5 m/second (approximately 11 mph) and thus flights times were similar to or faster than drive times. Flights were programmed to follow an out and back path along each side of the road and did not add time to the mission; the UAS would have had to return to the takeoff site to land itself regardless.

RIP teams currently carry multiple batteries for the vehicle-mounted cameras. Those batteries are reported to last approximately 90–120 minutes. The longest enduring battery in the current DOI UAS fleet lasts 50–60 minutes. The batteries utilized in the demonstration lasted approximately 10 minutes, constraining flight times; the UASs had to be landed several times to replace batteries. This was not necessarily a problem in and of itself, but it could aggravate quick deployment in future settings if repeated battery changes became unavoidable. In other words, the time to collect an entire network of roads at a Station could be higher for the UAS than the RIP approach given the need to potentially revise flight plans, place GCPs in multiple disparate locations, and replace batteries.

It should be noted that the demonstration involved a total of 10 people *and* the testing of two UASs carrying different payload sensors, making a direct comparison of the total time needed to drive the routes with the total time needed to set-up and fly the routes potentially misleading. Demonstration experience suggested that further streamlining of the UAS process to make it on par with driving times would be possible with additional experience and a smaller team. At times, the demonstration involved more than 10 people and included time for showing refuge staff equipment and raw data outputs. The UAS approach being tested could be accomplished with two people (and regularly is in other settings as per input from USGS staff). The use of smaller or different UAS equipment and/or conducting imagery-only flights could also make the process more efficient.[36] For example, time could be saved by using UAS that obviate the need for placing GCPs, such as the WingtraOne which is in the DOI UAS fleet. Furthermore, no aspect of the existing RIP process would seem to limit the ability of a UAS to be more easily deployed during RIP data collections. With the exception of potentially needing to have a larger airplane carry-on for team members, the UAS itself and related items would not appear to add a significant time due to equipment burden to a field team. There could be a time due to weather penalty for trying to use UAS for road inspections under some weather conditions. Although UASs are becoming increasingly weather-resistant, winds higher than approximately 25 mph could hinder UAS operations. This was observed during the demonstration where high winds caused the project team to shut down UAS flights during the afternoon of demonstration day 1. Roads with a dense tree canopy or overgrown vegetation could also limit a UAS's utility in collecting data about a road. A beyond line-of-sight mission or tracking features onboard a UAS could mitigate this constraint but may also be impractical.

Finally, it is expected that there could be a travel time savings in the future if an alternative inspection approach were adopted. For example, an authorized UAS pilot at a station could fly the station's roads according to a standard process to acquire road data on their own schedules. Afterwards, they could send raw imagery and/or Lidar data to FLH project managers who could remotely rate the roads either manually or by an automated process like that described in Section 2 above. Alternatively, a refuge manager could drive the roads to be inspected with the support of a car-mounted LiDAR sensor and/or cameras. In this scenario, refuge managers who bring local knowledge and only have to travel locally can facilitate data collection, while the RIP team could devote more of their time and expertise to road condition analysis. Authorized UAS pilots are currently not commonplace at stations. However, training additional pilots could minimize the need for travel and allow for decentralized UAS-based data collection nationwide.

UAS flights on refuges near airports may require additional planning to ensure compliance in controlled airspace. Pilots should consult FAA's UAS Facility Maps to identify controlled airspace. Pilots flying under Part 107 regulations can use the Low Altitude Authorization and Notification Capability (LAANC) to receive near-real time airspace authorization to fly at or below the pre-approved altitudes noted on the UAS Facility Maps. [37]Flying above the pre-approved altitudes, but below 400 ft above ground level, requires coordination with the Air Traffic Manager who manages the airspace; these requests must be submitted at least 72 hours prior to the start of the operation. For such requests, and for certain airports that are not LAANC-enabled, pilots may us the FAA Drone Zone to obtain authorization in advance of the operation. In limited instances, controlled airspace may be completely off-limits to UAS operations – for

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[36]

[37] www.ecfr.gov/current/title-14/chapter-I/subchapter-F/part-107

example, near military installations or major sporting venues. These areas are published through FAA's Notice to Airmen (NOTAM) system.

Post-UAS Mission

After flying a UAS mission, the data acquired need to be downloaded and processed into information that is useful. The UAS flights to acquire imagery resulted in more than 1,000 photos (~28 GB) taken. Of these images, 568 (12.7 GB) were used for post-processing. The UAS flights to acquire lidar data resulted in a .LAS file approximately 1 GB in size. For comparison, over the three routes flown during the UAS demonstration the RIP data collection conducted by vehicle the following week resulted in 173 forward-oriented images (459 MB) and 173 images that were 360-degrees in scope (603 MB). Although the UAS acquired nearly twice as many images at an order of approximately 30 times the magnitude of larger file size, the project team did not encounter any issues retrieving the data from USGS's Secure Large File Transfer Site nor during importing the demonstration images into the GIS. If this approach were scaled up to cover all FWS roads, file sizes may become more of a limiting factor that analysts would need address; however, no observations during the demonstration suggest that it would be advantageous to use UAS in all road data collection scenarios.

The project team did encounter several issues at the analytical stage that added time. At the data analysis stage, the project team opted to use ESRI's ArcGIS Pro because it is widely available to government agencies, including USDOT and FWS, and it was thought that doing so could minimize the need for software or data management practices that might require special expertise not currently available to RIP program managers. It became apparent in developing the analytical workflow that several software extensions that are not currently part of USDOT's default GIS configuration would be necessary to identify and measure the desired road distresses. This effectuated a relatively long process of securing necessary IT approvals, followed by troubleshooting various installation issues encountered. Presumably, these challenges could be eliminated over time. However, the automated workflow itself also proved time-consuming. Despite using computer hardware that was expected to be powerful enough to process the UAS-acquired data, the project team found that many hours were elapsing with minimal progress being made toward completing the deep learning image classification workflow; the process was not failing due to any error, but neither was it advancing beyond approximately 10 percent complete. Importantly, a separate deep-learning model would not be required for every public land—in this case an FWS station. Assuming this computing resource challenge could be overcome, an FLMA, such as FWS, could scale up this workflow by training and refining a model using imagery collected at a diverse set of public lands, which could then serve as a national model specification capable of detecting unpaved road distresses nationwide.[38]

3.2 Cost Savings

Pre-UAS Mission

The UAS demonstration involved UAS and sensor equipment that USGS and FLH offered to share. The

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[38] www.esri.in/en-in/newsroom/blog/pothole-detection-system-using-arcgis/

costs of this equipment were considered sunk costs and not included here beyond noting that their equipment was likely more advanced (i.e., expensive) than would be necessary for future RIP team UAS applications, particularly regarding images collected for photogrammetry. In terms of preparing for the visit, only minimal administrative work was necessary to secure necessary approvals and would not likely be considered an additional cost relative to preparations normally done for a current RIP data collection.

During UAS Mission
There is the potential for travel costs savings in the future if an authorized UAS pilot who worked at a given station could fly that station's roads according to a standard process. That pilot would then need to forward data collected to FLH project managers for post-processing and analysis. At an assumed labor rate of $100/hour, an approximate 40-hour work week during a collection week, and $2,000 for travel expenses, a RIP data collection as currently conducted is expected to cost approximately $6,000 per person per week. To reduce or avoid these costs, UAS and sensor equipment would need to be available at or shipped to the station. The cost of such shipment would depend on factors such as the size and weight of the UAS, the distance of the shipment, and insurance required. One UAS retailer estimates that shipping smaller UAS costs up to $18 one-way, while larger UAS may cost up to $40 one-way. More likely at present, however, is a scenario where a RIP team carries a UAS with them for selective use. In this case, costs of using UAS would likely be similar to or the same as the cost of current RIP data collections.

Post-UAS Mission
The demonstration involved some post-processing challenges attributable to software issues beyond the project team's control. These challenges could be interpreted as additional costs; however, they would likely be avoidable in the future by either using a different software configuration and/or using one type of UAS-acquired data (e.g., imagery or lidar) for the road rating analysis.

3.3 Level of Detail

Before the UAS demonstration it was hypothesized that alternative inspection approaches could offer project managers an opportunity to improve inspection standardization and/or minimize the risk of human error. UASs were viewed as a potential important job aid to help improve decision-making, especially since UAS missions can allow for data to be reproducibly captured at angles and views not otherwise possible, ultimately providing precise, high-quality data. Strictly speaking, the level of detail possible from using UAS to acquire data about unpaved roads does appear to be higher than that possible from the current RIP method at its customary speed. For example, the average vertical accuracy of the lidar data acquired, which was calculated using 22 validation checkpoints in non- and low-vegetated areas, was 6.29 cm, or 2.47 inches for any location along the roads of interest.

However, considering the level of detail metric on a distress-by-distress basis offers additional nuance. Namely, the crown and drainage scores derived from the GIS analysis are currently believed to have a higher degree of reliability than the scores for the other distresses given the scale currently used in the rating criteria. Crown and drainage measurements were able to quickly be taken every one foot (Figure 8), revealing that the roads of interest were relatively flat or bowled. It is notable that this consequently made the final road ratings appear more severe than the ratings from the current RIP approach, failing to consider the local context (e.g., the arid environment; some roads being on a high bluff; etc.).

Figure 8. Drainage Ratings at One-Foot Intervals

The limited presence of potholes in the study area made it difficult to impossible to assess that distress here other than to observe that there were very few to none. Similarly, the project team was unable to identify areas where there was loose aggregate other than to manually inspect the orthomosaic, using professional judgement. Even then, the assessment was likely biased from having been on-site during the UAS demonstration. In other words, it is unclear whether the loose aggregate would have been noticeable in the orthomosaic by someone not present during the demonstration. For washboarding, areas where the distress occurred were easily detectible, but the severities were less clear. It was observed that that the vertical accuracy of the DEMs may introduce error in detecting the difference between minor and moderate washboarding since the 1” (2.5 cm) or better precision would be necessary to detect this as currently defined in the rating criteria. Spot-check washboarding measurements in the GIS were almost always below or right at the 1” level. As with loose aggregate, the level of detail currently possible for the rutting/washboarding distresses using the UAS-acquired data remains based on visual inspection and professional judgement (of the orthomosaic and field observations in this case).

Finally, the demonstration focused on attempting to collect data on the condition of the road surface and did not focus on the collection of roadside features, such as guard rails, signs, or culverts. The level of detail in collecting data on such appurtenances was untested and remains an area for potential further investigation.

In Summary

Notwithstanding some shortcomings, the use of UAS in the unpaved road inspection context appeared to be largely compatible with the current RIP collection process and presumed future needs. Adding UAS to the RIP team's "toolbox" where practicable could be helpful in RIP inspections and analysis despite the clear need for further refinement of the UAS approach. On balance, the UAS approach attempted to apply RIP distress rating criteria as rigorously as possible, and in doing so was not always able to achieve that standard. To some extent, it also lost a human interpretation of the distress metrics element part and parcel of the current RIP approach. However, when demonstration-specific considerations are corrected for, the UAS approach is not expected to add significant time or cost to the RIP data collection process. When conditions are advantageous for using UAS, the tool should offer a powerful data collection resource that can yield a specificity for certain road characteristics likely not possible from windshield inspection for certain .

Table 10. Summary of Key Metrics for UAS-Aided Approach as Compared to the Current RIP Approach

Metric		**UAS Demonstration**	**Current RIP Approach**
TIME	Staging	30 minutes – 2.5 hours per road • Minimal GCP staging expected to be necessary with small, RTK-capable UAS • Max range depends on UAS/battery used and the topography and orientation of road	N/A
	Collection	11.1 mph ~1 hour total flight time (3 roads, out and back)	10–15 mph ~ 45 minute drive time for study roads (3 roads, out and back)
	Post-processing	• Imagery: 568 photos (~ 28 GB) • Lidar: 1 .LAS file (~ 1 GB) • Orthomosaic generation: 1 hour • Condition rating workflow analysis: Challenging to time-prohibitive using currently available equipment and software	• 173 forward-oriented images (459 MB) • 173 images that were 360-degrees in scope (603 MB)* • Condition rating workflow analysis: Manageable as demonstrated by history of RIP inspections
COST		Estimated to be ~ $6,000 per person per week unless UAS could be flown by station staff (which is expected to lower costs as would any technology that allows station staff to collect data on their own). Total costs are expected to vary from site to site.	Estimated to be ~ $6,000 per person per week.
LEVEL OF DETAIL		High level of detail; unable to detect all distresses at level called for under current rating criteria	Moderate level of detail; professional observation

**To date these data have remained unused due to software limitations.*

Recommendations for future RIP data collections contemplating the use of UASs include:

- **Aircraft**–Select a vertical take-off and landing copter aircraft that can fly a pre-programmed waypoint flight path. This type of UAS will likely allow for maximum flexibility and maneuverability. The ability to fly in wet conditions could be a beneficial attribute, although it should be noted that some literature has suggested that road rain, snow, or high heat or humidity conditions are not ideal for road distress detection by UAS, nor was this able to be tested during the demonstration. Wind conditions did limit flight time on demonstration day 1.

- **Battery**—Use batteries with longer lives or the ability to recharge quickly. This is especially the case given that collections for several FWS stations may be stacked together across one or two weeks.

- **Sensor**—Evidence suggested camera imagery is likely sufficient for RIP purposes. This would include the gimbal-mounted digital single lens reflex camera available on most mid- to high-range UASs. The resolution possible using stock cameras on UASs now available—and in the DOI UAS fleet—is better than that which research in previous years was finding to be adequate.[39]

- **Location**—Optimal RIP inspection locations for UAS use are those where barriers or obstructions would otherwise prohibit vehicular access. The use of UAS for unpaved road data collection is less viable or not viable at all in settings where dense tree canopy limits the ability to acquire imagery. Lidar can avoid this challenge, but this was untested in the demonstration due to absence of trees at Alamosa NWR.

Other observations:

- **Wildlife**: During the demonstration the UAS flights did not appear to disturb wildlife. Strategies that can be used to mitigate potential harmful effects of UAS operations on wildlife are described in the literature review (Appendix A).

- **Improved Safety and Increased Accessibility**— Uniquely dangerous conditions are not expected for most RIP collections as they are occurring on roads that are in locations typically reachable by vehicle. Sometimes those locations can involve roads that require a 4WD vehicle. It is not uncommon for a RIP team to encounter a road section that is impassable due to standing water, a closed gate, or some other barrier or obstruction (Figure 9).[40] The use of UASs present an opportunity to improve safety and increase accessibility in these cases. FLMAs and others have demonstrated this for years in their various deployments of UAS before, during, and after

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[39] For example, *Requirements for Remote Sensing Assessments of Unpaved Road Conditions* (Brooks et al 2011) provides a summary of requirements of successful system. Among the minimum recommendations were a 4 MP camera sensor and an ability to acquire at least 2.25 frames per second, each far lower than modern UAS equipment. Other elements of a successful system as per Brooks et al (2011) are included in Appendix A, section (e).

[40] The project team reviewed final RIP Road Condition Inventory Reports for geographically diverse FWS stations to better understand to what extent obstructions might hamper collections. Reasons for unpaved road mileage *not* being collected included the presence of concrete blocks, severe erosion, overgrown or fallen vegetation, closed gates, inundated and soft roadbeds, construction, and access restrictions due the presence of a military base.

disasters, for example. The ability to fly at very low altitudes, over complex terrain, and without humans on board offers UASs an inherent security that other current technologies or approaches do not. They also can help minimize danger to teams because the pilot and team can choose the location(s) of UAS operations thus reducing their exposure to potentially unsafe conditions. This benefit was observed during the demonstration on Route 301 where the road eventually became impassable to vehicles. The UAS could have safely continued the data collection beyond the point at which the road could be driven.

Figure 9. Example Obstructions Limiting Road Data Collection. Images clockwise from top left: concrete blocks marking closed road, overgrown vegetation, closed gate blocking travel, and soft roadbeds. Source: FWS

- **Emissions:** If the use of UAS could reduce the mileage that UAS RIP field teams drive, greenhouse gas emissions could be reduced. This could be achieved, for example, through reduced travel to the station (i.e., shipping UAS to on-site pilots) or at small refuges with roads that could be be all flown from a central location (e.g., the Tour Loop at Alamosa).

- **Leading and Learning by Example**: The field of using UAS to support road inspections is relatively new, and research to date has tended to focus on the utility of UAS operations to identify one of many road distresses. Apart from a recent research project to explore using a bicycle-mounted camera and accelerometer system to enhance the National Park Service’s approach to rating multi-use trail conditions, no other project was found to have researched UAS operations within the constraints of an existing road inspection process and program, such as the RIP.

APPENDICES

Appendix A. Literature Review and Annotated Bibliography

UASs are versatile tools due in part to their ability to carry and use multiple types of sensors. Ceylan (2017) summarized the general types of UASs available and information on their payloads. Although UAS specifications vary among models, three sensor types have primarily been used in combination with UASs for road inspections: cameras, lidar (Light Detection and Ranging), and multi- and hyperspectral imaging sensors. Millian (2019) discussed each of these, described in more detail below, in the context of the requirements necessary to incorporate UAS into the regular pavement maintenance practice. Factors such as sensor quality, flight speed and elevation, weather, and the presence of obstacles were identified as affecting data resolution across the sensor technologies. Millian also asserted that UAS sensor selection would depend on project-specific considerations made early during a project and not an assumption that one sensor technology was more accurate than the other.

A University of Massachusetts (UMass) team working under a research project that the Massachusetts DOT and FHWA sponsored made a similar observation. After reviewing the literature on UAS technologies available, and particularly sensors that could be integrated with advanced algorithms and image processing methods for analyzing pavement distress data, UMass (2019) believed that the field of using UAS for pavement condition inspection was still in its infancy. It noted that there was little experience or information available in the literature and that “no UAS platform can provide pavement condition analysis as currently obtained by traditional automated and manual methods.” Outay (2020) agreed, stating that the use of UASs to help assess road distress, unevenness, rutting, and cracks widths was still in a developmental phase and not yet in practice.

a) Research on UAS-Mounted Camera Sensors for Road Inspections

Cameras are the most common payloads in UASs, and consequently are one of the most widely explored topics in the literature (Millian 2019).[41] Brooks et al (2011) found evidence that digital photos alone, taken from low-altitude UAS, provide data with appropriate resolutions for identifying distress such as potholes, ruts, corrugations, and changes in road surface elevation. Coenen and Golroo’s literature review (2017) found similar evidence, noting that digital imagery, and likely videos, have satisfactory detail for identifying most pavement distresses. This finding may also be applicable to unpaved roads, especially as part of a road management system similar to that which Walker (1991) presented. That research described a simplified gravel road rating system that involves visual inspection of roads and a categorization of all of them that need routine minor regrading and ditch maintenance, a separate listing of those that need additional gravel and major ditch cleaning, and a listing of those needing

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[41] Five broad analysis techniques are presented in this section. Two of them, photogrammetry and lidar, rely on having an aerial perspective. The other techniques, using cameras, computer vision equipment, or multi- or hyperspectral imaging sensors could rely on other non-UAS data collection platforms.

complete reconstruction. Walker commented that such a review was helpful in selecting projects given that priority project listings are usually oriented toward worse conditions and thus routine maintenance projects may not surface until the road segment is completely deteriorated.

Petkova (2016) developed an autonomous pavement inspection system using streamed video. The system involved dispatching a UAS to survey an area along a flight path created in Google Maps, attempting to identify pavement distresses in real-time and recording video and locations requiring needed repair. The video was streamed at a frame rate of 24 frames per second (sampled to analyze only one frame per second) at 1080-pixel resolution in a narrow field of view. The UAS was flown at an altitude of 3-4 meters above the ground and at a speed of 1 meter per second. After system tests, it was concluded that the process was most useful for identifying potholes, but not other pavement distresses given the high rate of false positives. Results also suggested that the onboard computer mounted to the UAS was not able to process the pothole classification algorithm fast enough for the tool to be reliably deployed in real-time.

Beyond two-dimensional (2D) digital images or videos, much of the literature centers on using either photogrammetry or deep learning techniques to automate the detection of cracks from pavement surface imagery. The former is the science of obtaining reliable topographical information about physical objects and the environment by capturing, measuring, and interpreting photographic images. Machine learning, on the other hand, is an application of artificial intelligence (AI) where computer systems are trained to learn and improve on a process of interest, such as identifying a road feature in an image.[42] UMass (2019) noted that photogrammetry for crack detection appeared to be the most promising road condition assessment technique for potential integration with UAS. According to the team, it is also the oldest, most common, and least expensive type of data collection system that practitioners have used with UAS.

Research on Photogrammetry Applications Using UAS-Acquired Imagery for Road Inspections

In 2008, a South Dakota State University study (Zhang 2008) that the U.S. DOT sponsored demonstrated a UAS-based photogrammetric mapping system architecture for assessing unpaved road conditions. The research combined 2D and three-dimensional (3D) image features through pattern recognition and image classification.[43] The results suggested that many of the parameters needed for monitoring the condition of unpaved roads could be sufficiently extracted from UAS-acquired images, including identifying defects such as rutting, washboarding, and potholes. In 2009 and 2012, Zhang furthered this

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[42] The "National Artificial Intelligence Initiative Act of 2020," which became law on January 1, 2021, defines AI as: a machine-based system that can, for a given set of human-defined objectives, make predictions, recommendations or decisions influencing real or virtual environments. Artificial intelligence systems use machine and human-based inputs to—(A) perceive real and virtual environments; (B) abstract such perceptions into models through analysis in an automated manner; and (C) use model inference to formulate options for information or action.

[43] Recognition and classification refer to a procedure for taking in raw data and using a set of properties and features to assign them specific categories and take action on the data.

research, combining photogrammetry and computer visioning[44] techniques, to develop a digital image-based system to collect data for creating 3D surface distress models for rural roads. After comparing the extracted 3D information with onsite measurements of road distresses, evidence suggested the 3D reconstruction was accurate up to 0.5 cm and that the method could be faster, more reliable, and generally less expensive than manual inspection methods. Regarding the latter point, Ceylan (2017) estimated the cost of using a UAS with high-resolution camera and good-quality lens for unpaved road inspections to be $0.74 per mile. Knyaz and Chibunichev (2016) observed similar results as Zhang when they tested two photogrammetric techniques for analyzing road deformation using UAS-acquired images. The researchers used image processing software along with various reference and control points to successfully extract road surface characteristics from 24 images taken from a height of 30 meters.

Inzerillo et al (2018) compared the effectiveness of using UAS aerial images versus camera images that a researcher took directly at head-level with Structure from Motion (SfM)[45] techniques to create 3D reconstruction models. The accuracy of the resulting models was then compared with a terrestrial laser-scanned model. Results suggested that the reconstruction using head-level camera images was more accurate than that created from the UAS images. However, the researchers noted that the UAS approach allowed for the quick identification of the presence of pavement distresses and road conditions on a large-scale, and for that reason believed the UAS approach could be particularly helpful identifying critical road surface sections where it is necessary to carry out more detailed analyses.

Saad and Tahar (2019) analyzed potholes and ruts for flexible pavement sections using images from a multirotor UAS. The team processed the UAS-acquired images using a photogrammetric software based on SfM. The team acquired images at different altitudes to determine the effect of image resolution on rut and pothole extraction, ultimately concluding that lower flight altitudes (10 meters) give better results. The team also concluded that its proposed approach did provide an accurate and efficient way to identify ruts and potholes. Tan and Li (2019) acquired road images from UAS, which it processed to reconstruct 3D models derived from Pix4Dmapper photogrammetry. Algorithms were then applied to extract the pavement surface from irrelevant surroundings in the derived 3D models and to detect road distress regions and extract features such as length, width, and height/depth of the distress regions. Results showed that the method could accurately identify road distress regions within 1 centimeter accuracy. Similarly, Lee (2019) used a UAS equipped with a 4-K high-resolution camera to obtain images (25-meter altitude, 45-degree angle, 80 percent and 81–90 percent overlaps) that were processed to detect potholes. Lee processed the images using commercial (e.g., Pix4Dmapper and ESRI's ArcGIS 10.6.1) and open source (e.g., CloudCompare and Point Cloud) software for comparison purposes. Results suggested that images with greater than 80 percent overlap did not improve point cloud quality but increased processing time. Pothole geometries were obtained within +/−1.0 inch accuracy.

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[44] Computer vision is the practice of using a computer to process visual information and produce data based on that visual information input.

[45] SfM is a photogrammetric technique that allows users to create 3D models from a photo data set; its current application is mostly used for architectural and archeological studies.

Toribio and Gutierrez (2019) proposed a UAS-based methodology for obtaining Pavement Condition Index and International Roughness Index (IRI).[46] In a fieldwork stage, pre-programmed UAS flights at an altitude of 20 meters AGL surveyed pavement surfaces. Images were taken with 80 percent overlap. In a subsequent office stage, the researchers used Pix4D Mapper Pro software to generate orthophotos and then sampled points every 25 cm, which they analyzed using FHWA's Profile Viewer and Analyzer (ProVAL) software[47] to calculate IRI. Results suggested that the use of georeferenced images to estimate IRI is an effective and efficient approach relative to a manual assessment of IRI along the same test road section.

Prosser-Contreras et al (2020) similarly evaluated the feasibility of obtaining the IRI for a road segment using UAS-acquired digital imagery. The team established a mission-planning workflow and described and defined important flight conditions and parameters, including camera focus considerations, storage capacity, and energy expenditure. Using UAS-acquired imagery, the research team created 3D models to obtain longitudinal road profiles, which were used to calculate IRI. Results were within 0.1 m/km of certified IRI results, suggesting the method might provide an alternative to traditional methods of determining IRI. The team noted that the proposed approach should be applied with caution given that it may slightly underestimate actual road roughness.

Research on Machine Learning Applications Using UAS-Acquired Imagery for Road Inspections

Zakeri et al (2016) used a quadcopter-based digital imaging system to collect pavement surface data over a distressed area, which it then processed in software known as a support vector machine[48] to automatically detect and interpret crack distresses. Similarly, Ersoz et al (2017) used UAS-acquired images and machine learning to identify cracks in rigid pavement sections autonomously. The team first used computers to separate crack and non-crack road sections from the background image. The team then used the geometric properties of the extracted sections to train a support vector machine to classify the crack and non-crack pavement regions. Although the approach worked, the team noted that a potential drawback was that shadowy or low-resolution images could reduce the performance of the model. The conclusion argues that "the main advantage of the system is that it offers a cost-effective solution compared to currently used systems such as a truck-mounted road monitoring system, as the UAS are getting cheaper and easily transportable," but that "the digital image processing algorithms still need significant improvement."

UMass (2019) demonstrated the feasibility of collecting pavement images of an airport runway using cameras mounted on rotary wing UASs and extracting useful crack information using deep learning methods. The team observed that increasing a UAS's flight altitude decreases the pavement image

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[46] IRI is a standard used to quantify road surface roughness. A continuous profile along the road is measured and analyzed to summarize qualities of pavement surface deviations that impact vehicle suspension movement.

[47] ProVAL, available at www.fhwa.dot.gov/pavement/proval/, is a software developed to provide a means to view and analyze pavement profiles efficiently and robustly as part of FHWA's smoothness initiative. ProVAL imports, displays, and analyzes the characteristics of pavement profiles from many different sources.

[48] A support vector machine is a type of deep learning algorithm that learns from labeled training data consisting of a set of training examples.

quality but reduces costs. A qualitative comparison of images captured at different altitudes suggested that the best balance between efficiency and accuracy was achieved by flying the UAS at 50 feet AGL. For the camera used in the study, the 50-foot altitude resulted in a 0.16 inches per pixel ground sample distance. Additional investigation using thermal cameras returned evidence suggesting that thermal images did not add value compared to images taken with the regular camera. The team proposed that future research consider how the use of fixed-wing UAS could further expand the coverage and speed of UAS-based pavement condition data collection.

Recognizing that most of the research into using UAS-acquired imagery and deep learning techniques for road condition assessment has focused on paved roads, Khilji et al (2020) introduced a framework to use deep neural networks and UAS to detect major distresses on unpaved road surfaces. Using a Mavic Mini UAS flying at an altitude of 5.5 to 6.5 meters AGL, the team used the UAS's stock 12-megapixel (MP) camera to capture 100 photos (camera pitch set to –20 degrees and resolution of 1,920 x 1,080). Eighty-six additional photos taken at 2 meters AGL were used to train different deep neural network architectures. The researchers then used three metrics to assess the performance of the trained models: (1) Intersection Over Union, or the Jaccard index, measuring the amount of overlap between predicted classes with manually labeled pixels (i.e., ground truth), (2) recall, which calculates the percentage of correctly recognized pixels, and (3) the Boundary F1 score, which assesses how aligned the contours of the predicted and ground-truth areas are. While the researchers were not able to provide the depths of identified distresses and indicated that the method could not be used for quantitative road condition assessment, namely roughness (IRI), they indicated that detection of distress types and 2D dimensions were valuable data for qualitative road condition rating methods.

Chawla (2021) provided a literature review on the possible image classification and deep learning approaches using UAS-acquired images before proposing a new, potentially more straightforward approach. Given that the reviewed studies often relied on multiple different pieces of equipment and image pre-processing to extract relevant information for a model, Chawla investigated whether aerial images that are not pre-processed and, rather, used in their raw form to create an image classification model using a Convolutional Neural Network[49] could reduce image processing time while also identifying alligator and longitudinal cracks on flexible pavements. Test images yielded a prediction accuracy of 90 percent, providing a theoretical basis for future improvements in automated pavement condition assessment methods.

b) Research on UAS-Mounted Lidar Sensors for Road Inspections

When mounted on a moving platform, road surfaces can be mapped through lidar. Lidar pulses a laser and records the time it takes for the pulse to return in order to measure distance. The point clouds it creates can be used to make 3D models of any surface within a line of sight of the lidar. Unlike

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[49] A Convolutional Neural Network is a computing system commonly applied to analyze visual imagery. Image data are loaded into the model and then passed through the layers of the network. The model learns features from the images and creates feature maps. In this context, Chawla used a single platform, MATLAB, for development of the Convolutional Neural Network model to classify pavement distresses.

photogrammetry, lidar is insensitive to lighting or contrast conditions.

Relative to the literature available on camera-equipped UASs for road condition inspection, research available on lidar -equipped UASs is more limited. Guan et al (2016) summarized the literature available at the time on using mobile Lidar for road inventorying purposes, including the detection and extraction of road surfaces, small structures on the road surfaces, and pole-like objects. The team concluded that a point cloud taken from a UAS could successfully be used for road pavement analysis, among other road inventory applications. Coenen and Golroo (2017) noted that lidar creates a point cloud image for an entire scene and thus is a relatively expensive tool, especially if only the road is being analyzed (versus a more complete infrastructure management program that includes, for example, analyses of noise barriers, traffic signs, and crash barriers). UMass (2019) describes pros and cons of a use case at the Hartsfield-Jackson Atlanta International Airport, which "has been a large supporter in the use of UAS for runway inspections."[50] Based on that experience, a benefit that pavement condition assessment could gain from UAS lidar payloads is that its "data can filter to the ground through the vegetation as long as light can be seen from under the tree canopy." UMass notes that this quality of lidar data presents the opportunity to perform data fusion and cross-comparison to compensate for reduced accuracy in photogrammetry due to sub-optimal lighting. A downside to using lidar onboard equipment for pavement inspection are that the technology tends to be expensive and can be heavy, potentially presenting challenges for UAS operations.

Montana Tech University (2020) used UASs and lidar data to develop an early warning model to monitor roadway conditions and imperfections before they become larger concerns. A UAS with an airborne, near-infrared laser scanner was used to collect data within 15 mm accuracy. After the demonstration, the research team worked with the Montana DOT to develop a list of recommendations for interventions needed on a specific section of Montana road and for more proactively using UAS and lidar to inspect roadways.

The USACE (Schwind et al 2019) compared SfM photogrammetry and lidar using sUAS for mapping and inspecting structures to identify pros and cons of each approach. In the study, a network of eight ground control points was placed to ensure location precision during computer post-processing. Three different types of sUAS were then deployed to collect both SfM and lidar data. After visual and statistical comparison, the researchers found evidence suggesting that using a SfM photogrammetric process to derive a quality point cloud of a structure is more time-intensive but less expensive than using lidar to do the same. They noted that the SfM approach did not lead to quality data when the subject of interest lacked unique features for the processing algorithms to match on, and thus large areas of concrete could prove problematic for the approach.

c) Research on UAS-Mounted Multispectral Imaging Sensors for Road

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[50] The primary source referenced in UMass 2019 (Prooyen, C.V., K. Eleam, J. Shivar, and J. Gobbel. Evaluating the Use of Unmanned Aerial Vehicles & Lidar for FAR Part 139 Inspections, Obstruction Analysis, and Airfield Maintenance. Hartsfield-Jackson Atlanta Airport. Michael Baker International. Pond & Company Architecture.) was not available for independent review. The information presented here is taken from UMass 2019 with minor edits for clarity.

Inspections

Multispectral and hyperspectral imaging sensors are camera-like sensors that capture imagery outside of the visible spectrum. As with lidar, applications of UAS equipped with multi- or hyperspectral imaging sensors have been “under-explored” (Millian 2019). This may be due to the fact that such technology presents two challenges when it comes to detecting pavement defects. First, the presence of foreign objects such as water can compromise an analysis since those objects have different reflectance values. Second, comparison between pavements or sections of the same pavement constructed at different times can be unproductive since different materials and/or different ages of the same materials can have different reflectance characteristics (Herold et al 2004).

With that said, pavements in different conditions exhibit different reflectivities, as do different pavement distress types (e.g., potholes have lower reflectivity than cracks). For this reason, UAS-acquired multispectral and hyperspectral images could present a viable tool for monitoring pavement conditions under certain circumstances. In one example, Pan et al (2018) was able to successfully use UAS-acquired multispectral images in concert with various machine learning algorithms to distinguish between normal asphalt pavement and potholed and cracked (greater than 13.54 mm in width) asphalt pavement. The team noted that future research should consider additional road surface types, such as cement and gravel, and pavement damages, such as rutting and road roughness.

Coenen (2017) also discusses a system that uses the infrared (IR) spectrum for recognizing cracks and other distresses in bridges and tunnels. These distresses cause the temperatures to differ locally in the pavement, which will be visible in the IR spectrum. MassDOT (2022) explored using IR combined with UAS to detect subsurface voids representative of failing culverts and drainage pipes, finding that they were able to determine the size of the voids with 97 percent accuracy. The research team also identified a number of lessons learned for other teams interested in using UAS and IR cameras for monitoring in-service roadways.

d) UAS Sensor Selection

Selection of the optimal combination of sensors and UAS can be an iterative process as mission planners consider other factors in addition to payload capacity, such as expected flight duration, area to cover, and relative costs (Millian 2019). In the American Society for Testing and Materials’ “Standard guide for Prioritization of Data Needs for Pavement Management” (ASTM 2015), priority guidelines are given for different data categories ranging from performance-related metrics to environment-related metrics:

> The level of importance of a data item does not necessarily indicate the required precision or preferred acquisition method for that data. Users should select a data acquisition method that is appropriate to their operational resources, to the reliability of their decision support model, and to their overall information management system. For example, although roughness may be of high importance for even low volume, major roads, this does not imply that a certain type of

equipment be used for data acquisition.

For minor highways in low-traffic areas (i.e., generally average annual daily traffic of less than 10,000), the guide's only high-priority performance-related data category is "surface distress." Likewise, "budget" is the only policy-related data category rated as high-priority.

e) Literature on UAS Effects on Wildlife

Many Federal lands provide core habitat for wildlife. FLMAs seek to conserve, protect, and enhance that habitat. Therefore, whether UAS operations may negatively impact wildlife is an important question for FLMAs to consider, and research agendas are being proposed along these lines (e.g., Thomsen et al 2021) to supplement the growing body of existing research in this area.[51] This section describes general observations from some of the research that has previously scanned and synthesized the literature on UAS effects on wildlife. (See below for an annotated bibliography of literature reviewed on UAS effects on wildlife in the United States).

In a comprehensive analysis on the subject, Mo and Bonatakis (2022a) examined trends in the scientific literature on using drones to approach wildlife between 2000 and 2020, reviewing 223 publications. The researchers concluded that since animal responses to drone flights vary among taxa, populations, and geographic locations, further research was necessary to inform policies and protocols for specific taxa and/or locations, particularly where knowledge gaps exist. Seier et al (2021) similarly reviewed a series of 89 journal articles, observing that that possible wildlife disturbances from UASs were discussed in approximately 17 percent of the papers. Of that subset, most of the papers concluded that negative wildlife effects were negligible or non-existent. Chabot and Bird (2015) noted that the general consensus has been that UAS cause low to no disturbance when used for wildlife surveying, in particular when compared to alternative methods, such as intrusive, direct surveys or low-altitude, conventional aircraft surveys. They added that close-up flights tend to elicit stronger reactions from subject animals than do higher altitude flights, but that those reactions were nothing more extreme than the reactions typically elicited when directly climbing to bird nests.

News articles have highlighted related findings, with some qualifications. For example, a 2015 National Geographic article cited multiple studies that test animals' abilities to live harmoniously with proximal UAS. One of the studies mentioned was from Minnesota where researchers flew 18 UAS flights at an average altitude of 21 meters, observing changes in bears' heart rates when near a UAS but not necessarily any behavioral changes (Ditmer et al 2015). The same team found evidence suggesting that because UASs have the ability to navigate off-road and underneath forest canopies, they may be less predictable for bears and therefore possibly perceived as more of a threat. Another study mentioned in the article found evidence that although birds may not experience behavioral changes when in close

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[51] A ScienceDirect search on the terms "drones" and "wildlife" yielded 1,058 results, many of which focused on the effectiveness of using UAS for wildlife surveys and monitoring. A search on the terms "drones," "wildlife," and "impacts" yielded 847 results.

proximity to UAS, the aircraft can still be a potential safety risk for birds if used improperly. The article asserted that these patterns could have negative long term affects for these animals, including contributing to acute stress in species, which could affect fertilization and health patterns.

Mo and Bonatakis (2022b) quantified the factors that should be considered in the development of UAS guidelines and policies. The most referenced controllable factors were approach distance, noise emissions, and airspeed. Other frequently referenced controllable factors included UAS type, take-off distance, flight pattern, pilot experience and competence, whether consecutive flights were conducted, and flight duration. The most referenced environmental factors were animal taxa, biological state of animals, and ambient noise, followed by the presence (or not) of conspecifics, weather variables, and habitat variables. Other factors cited included whether animals have received previous exposure to anthropogenic settings, animals' behavior prior to drone flights, and whether predators are present. The researchers asserted that managers seeking to develop policies and protocols to guide lowest-impact UAS flights are most likely to succeed if considerations are derived from knowledge of the above factors. A news article in The Conversation, a non-profit news organization featuring academic articles from subject matter experts, echoed these observations. It notes that planning UAS missions in ways that avoid breeding seasons, involve expert ethical committees in the decision-making process, allow for take-off at least 100 feet from animals, and involve high-as-possible flights can help avoid impacts (Mulero-Pazmany 2018).

f) Annotated Bibliography on UAS for Road Inspections

AASHTO. 2019. Mission Control: UAS/Drone Survey of All State DOTs.
https://uas-aam.transportation.org/aashto-research/
This survey found that in 2019, 49 0f 50 states were using UAS or drone technologies in some way. More than 70 percent had hired hundreds of staff, including highly skilled personnel to manage UAS operations. Thirty-six DOTs also reported having 279 FAA-certified drone pilots on staff, approximately 8 pilots per state.

ASTM. 2015. Standard Guide for Prioritization of Data Needs for Pavement Management.
www.kelid1.ir/FilesUp/ASTM_STANDARS_971222/E1777.PDF
This guide identifies data needs for pavement management systems. It also addresses the relative importance of various types of pavement data.

Barfuss, S. L., Jensen, A., and Clemens, S. 2012. Evaluation and development of unmanned aircraft (UAV) for UDOT needs.
https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1005&context=water_pubs
This paper discusses the Utah DOT's use of UAS during road construction projects, including documentation of conditions prior to, during, and after the project is complete. The study found that implementing a UAV accelerates the rate of aerial imagery updates in their internal GIS database which aids in signage and highway structures inventorying.

BLM. May 30, 2020. BLM Unmanned Aircraft Systems Communication Plan.
www.nifc.gov/drones/blm/UASCommPlan.pdf
This document provides BLM staff with talking points related to how BLM is currently using and may use UASs in its day-to-day activities. Central to the message conveyed is the idea that the BLM UAS program is growing, and the number of projects conducted every year involving wildfires, prescribed fires, mapping, archeological surveys, wildlife habitat surveys, and more is steadily increasing. The BLM also notes that it plans to collaborate with other agencies as they develop their own UAS programs.

Breen, Jory; Eichert, Patrick; Hunthausen, William; Logan, Bridger; Ludwick, Lakyn; Moodry, Christopher; Thatcher, Tucker; Winfield, Nickolas; Yocum, Harold; and Mohamed, Maged Dr. 2020. "Early Warning Model of Dangerous Road Pavement Condition Using UAV". TECHxpo. 8.
https://digitalcommons.mtech.edu/techxpo/8
This is Montana Technological University poster presented at the 8th Montana Tech Techxpo. The team used UAV imagery and lidar data to successfully develop an early warning model to monitor roadway conditions and imperfections before they become larger concerns. A UAV with an airborne, near-infrared laser scanner was used to collect data within 15 mm accuracy. After the demonstration, the research team worked with the Montana DOT to develop a list of recommendations both for interventions needed on a specific section of road and for using UAV and Lidar technologies to inspect roadways more proactively.

Brooks, Colin; Colling, Tim; and Roussi, Chris. October 2011. Characterization of Unpaved Road Conditions Through the Use of Remote Sensing. Deliverable 1-A: Requirements for Remote Sensing Assessments of Unpaved Road Conditions. Michigan Tech Research Institute.
This report documents critical indicators for unpaved road condition assessments. It describes sensing system requirements, including flight profile information by type of distress. The team found evidence that the sensor system should have at least the following properties:

- Flight altitude not above 400ft (~122 m)
- At an 11º field of view and an altitude of 400ft -> 75mm lens
- > 4MP sensor
- > 2.25 frames per second imaging rate

Brooks, Colin; Colling, Tim; Keuber, Melanie; Roussi, Chris; and Endsley, Arthur. November 2011. Characterization of Unpaved Road Conditions Through the Use of Remote Sensing. Deliverable 2-A: State of the Practice of Unpaved Road Condition Assessment. Michigan Tech Research Institute.
This paper describes the state of the practice available for assessing unpaved road conditions and managing their maintenance. The assessment methods can be classified into categories: visual, combination (visual and direct measurement), and indirect data acquisition with specialized equipment. The latter can entail using, for example, a laser profilometer, ground penetrating radar, accelerometers, digital video, and using a remote sensing system in a manned or UAS for data acquisition. The project team found the Department of the Army's Unsurfaced Road Condition Index method to be a good candidate method to focus on because it offers a clear set of measurement requirements, the realistic

possibility of collecting most of the condition indicator parameters, and the potential applicability to a wide variety of U.S. unpaved roads.

Summary of Remove Sensing Requirements of Successful Unpaved Road Condition Assessments. Adapted from Brooks et al, 2011

Type	Parameter	Requirement
Sensor	Data Collection Rate	The systems must collect data at a rate that is competitive with current practice
	Sensor Operation	"easy", little training required
	Field-of-View	11 degrees
	Resolution	0.5", (4M pixels)
	Image Capture Speed	2.25 frames per second
System	Data Output Rate	Processed outputs from the system will be available no later than 5 days after collection
	Reporting Segment	<100 ft x 70ft, with location precision of 10ft. Map position accuracy +/- 40ft
	Sample Locations	User-specified map waypoints
	Inventory	A classified inventory of road types is required prior to system operation, e.g., paved, gravel, unimproved earth
	Surface Width	This is part of the inventory, and may also be estimated by the system measured every 10ft, precision of +/- 4"
Platform	Platform Operation	Training needed TBD, based on platform choice
	Flight Altitude	~400'
Distress	Cross Section	Estimate every 10ft, able to detect 1" elevation change in 9', from center to edge
	Potholes	Detect hole width >6", precision +/-4", hole depth >4", precision +/-2". Report in 4 classes: 3'
	Ruts	Detect >5" wide x 10' long, precision +/-2"
	Corrugations	Detect spacing perpendicular to direction of travel >8" - 1". Report 3 classes: 3". Report total surface area of the reporting segment exhibiting these features
	Roadside Drainage	Detect depth >6" from pavement bottom, precision +/- 2", every 10ft. Sense presence of standing water, elevation precision +/-2", width precision +/-4"
	Loose Aggregate	Detect berms in less-traveled part of lane, elevation precision +/-2", width +/-4"
	Dust	Optional – measure opacity and settling time of plume generated by pilot vehicle

Bureau of Reclamation. September 2019. Unmanned Aerial System (UAS) Data Collection at Reclamation Sites. Research and Development Office.
www.usbr.gov/research/projects/download_product.cfm?id=2837
This report documents the outcomes of a Bureau of Reclamation research project to create a testing and evaluation platform that was wide ranging and would ultimately provide a robust synopsis of UAS technology. The three-year project marked the beginning of UAS operations at Reclamation's Technical Service Center (TSC). It allowed personnel to research training and equipment and conduct demonstrations to assess whether UAS could be a tool used within Reclamation's mission. The team attended and presented at UAS conferences within Reclamation, other Federal agencies and within industry, and due to the special close-range, high resolution UAS data collection techniques that TSC developed, it was recognized as a leader in the use of UAS for inspection, deterioration monitoring and conditions assessment. Example lessons that were learned after a crash during a demonstration was that during close-range data collection: 1) everything should be done to avoid the conditions of settling,

including descending straight down and 2) flight should be controlled autonomously. A general finding from the USBR research was that UAS can collect data faster, more cheaply, and more safely than traditional methods.

Ceylan, H. August 17, 2017. Presentation: Infrastructure Health Monitoring and Management Using Unmanned Aircraft Systems. Iowa State University.
https://intrans.iastate.edu/app/uploads/2018/07/4D-Ceylan-et-al.pdf
This is a presentation from the Director of Iowa State University's Program for Sustainable Pavement Engineering & Research (PROSPER), which aims to advance research, education and technology transfer in the area of sustainable highway and airport pavement infrastructure systems. The presentation gives examples of various applications of UAS technologies for monitoring the condition of infrastructure, including assessing paved and unpaved roads.

Chawla, V. May 2021. Automated Pavement Condition Assessment using UAVs and Convolutional Neural Network. East Carolina University. https://thescholarship.ecu.edu/handle/10342/9121
This master's thesis proposed an approach for rapid assessment of flexible pavement condition using high-resolution aerial images obtained from UAVs and an image classification model based on a deep learning approach. Results indicated a model accuracy of 96.7% in classifying alligator and longitudinal cracks. The research argues that the methodology behind the model could help to reduce the need for on-site presence, increase safety, enable transportation engineers in rapidly assessing the pavement damage, especially after natural disasters. The Thesis includes a literature review of existing pavement condition assessment and image classification practices and identifies gaps in those practices.

Coenen, T., and Golroo, A. 2017 A review on automated pavement distress detection methods, Cogent Engineering, 4:1, 1374822. https://doi.org/10.1080/23311916.2017.1374822
This paper presents a literature review on various pavement distresses and commercially available methods to automate their detection. The researchers also conducted a gap analysis that led them to conclude, among other things, that depth-related distresses are detectible fairly well but rely on expensive tools. Evidence suggested that raveling, polished aggregate, and bleeding are difficult to detect at high speeds and that bleeding and polished aggregated require a tremendously high resolution when making use of imaging techniques, even when using high-quality artificial illuminance.

Dye Management Group, for Michigan DOT. 2014. Monitoring Highway Assets with Remote Technology. https://rosap.ntl.bts.gov/view/dot/27844
This research evaluated the benefits and costs of various remote sensing technology options and compare them to the manual data collection alternative in use at the time. The team used several selected routes in Michigan DOT's Southwest Region to evaluate different remote technologies and to provide recommendations for how best to implement the most viable of these technologies as data collection tools and data centralization methods. Among the results were the following:

- Remote technologies are capable of gathering highway asset data on most MDOT assets. Notable exceptions include assets not readily visible from the roadway (e.g., culverts).
- Lidar, while useful in the appropriate application, produces a level of detail

beyond that necessary for the assets identified under this study and was not considered a cost-effective alternative.

- Mobile imaging technology offers an opportunity to effectively gather highway asset data while decreasing worker exposure to traffic, increasing data accuracy and quality, speeding data collection, and reducing overall costs relative to manual data collection methods.

Ersoz, A. B., Pekcan, O., & Teke, T. (2017). Crack identification for rigid pavements using unmanned aerial vehicles. IOP Conference Series: Materials Science and Engineering, 236(1), 012101. DOI:
https://doi.org/10.1088/1757-899X/236/1/012101
This research used UAV images and an image classification algorithm to identify cracks in rigid pavement sections. A quadcopter captured aerial images of cracked and non-cracked regions of rigid pavement. The images were processed and converted into grayscale images, and a threshold for segmentation was applied individually to each image. The images were then converted into binary images using median filtering and morphological operations for the training of a Support Vector Machine model. Results were successful, but the team found that images containing shadows or that were low resolution could compromise model performance.

FS. July 2020. Forest Service Standards for UAS Operations.
This document provides guidance for all FS operational control and non-operational control missions, operations and management utilizing UAS. www.fs.usda.gov/sites/default/files/2020-07/Forest%20Service%20Standards%20for%20UAS%20Operations%2007012020.pdf

Gopalakrishnan, K., H. Gholami, A. Vidyadharan, A. Choudhary, and A. Agrawal. Crack Damage Detection in Unmanned Aerial Vehicle Images of Civil Infrastructure Using Pre-Trained Deep Learning Model. International Journal for Traffic and Transport Engineering,. Vol. 8, pp. 1–14. (2018).
https://doi.org/10.7708/ijtte.2018.8(1).01
This paper proposes a method for using a pre-trained Deep Convolutional Neural Network model with transfer learning for automated crack detection in UAS images.

Grandsaert, P. 2015. Integrating Pavement Crack Detection and Analysis Using Autonomous Unmanned Aerial Vehicle Imagery. United States Airforce Institute of Technology.
https://apps.dtic.mil/sti/pdfs/ADA615401.pdf
This research evaluated the strengths of applying UAS to pavement assessments and identified where further work was needed. One outcome of the study was a chart showing the relationship between maximum flight velocity (while still attaining full coverage) and the number of MPs in a given camera. A computer software was used to interpret the intensity of light values that pictures of pavement gave off and then to characterize that intensity within certain thresholds. Results suggested that accurately detecting road defects using computer vision remains a challenging problem for future research. However, the study validated using autonomous UASs as a viable way to collect pavement data, and one that is theoretically faster than current methods at freeway speeds.

Guan, H., Li J., Cao, S., and Yu, Y. 2016. Use of mobile Lidar in road information inventory: a

review, International Journal of Image and Data Fusion, 7:3, 219-242, DOI: 10.1080/19479832.2016.1188860
A review of literature available at the time on mobile lidar technologies and their applications in road information inventory is provided. It describes the state of the practice in using mobile lidar to detect and extract road surfaces, small structures on the road surfaces, and pole-like objects. Challenges and future trends are also discussed.

Herold, M., Roberts, D., Smadi, O., & Noronha, V. (2004). Road condition mapping with hyperspectral remote sensing. www.geo-informatie.nl/Projects/Santa_Barbara_Urban_Spectral_Library/urbanspec/av04_roadmapping_heroldetal.pdf
This early study explored the effectiveness of using hyperspectral remote sensing to map road surface conditions relative to in-situ road surveys. The team concluded that mapping results were most accurate for roads in good conditions, but that hyperspectral remote sensing had some potential for assessing road conditions, adding that "[i]t is not likely that remote sensing will take the part of an expert field inspector, but it can offer insights into surface conditions and other aspects that the inspector cannot evaluate except with laborious and destructive testing and field surveys can be limited and optimized."

Inzerillo, L., Di Mino, G., and Roberts, R. 2018. Image-based 3D reconstruction using traditional and UAV datasets for analysis of road pavement distress. Automation in Construction, 96, 457-469. DOI: https://doi.org/10.1016/j.autcon.2018.10.010
This research combined UAV aerial images and images that operators took using a Nikon D5200 camera at head-level with SfM to create 3D reconstruction models. The accuracy of the resulting SfM models was compared with a terrestrial laser scanned model. The reconstruction using head-level camera images was found to be more accurate than that created from the UAV images. However, the researchers noted that the UAV approach allowed for the quick identification of the presence of pavement distresses and road conditions on a large-scale. For that reason, the researchers believed the UAV approach could be particularly helpful identifying critical areas of the road surface where it is necessary to carry out a more detailed analysis.

Khilji, T., Loures, L.L.A., and Azar, E.R. 2021. Distress Recognition in Unpaved Roads Using Unmanned Aerial Systems and Deep Learning Segmentation. J. Comput. Civ. Eng., 2021, 35(2): 04020061.
This paper introduces a framework to use deep neural networks and UAS to detect major distresses on unpaved road surfaces. The proposed method includes two parts: the first module segments the road surface pixels in UAS-captured frames, and the second module identifies distresses on the segmented road surface. The results were promising but not definitive.

Kim, Seungho and Kim, Sangyong. Opportunities for construction site monitoring by adopting first personal view (FPV) of a drone. Smart Structures Systems, Vol. 21, No. 2 139-149. (2018). DOI: https://doi.org/10.12989/sss.2018.21.2.139
This paper proposes the use of a first person view quadcopter UAS as a tool for monitoring on-site status of construction project and communicating between construction workers. An on-site management

system process is developed, verified, and applied to several construction work tasks after determining factors that affect efficient construction management.

Knyaz, V.A., and Chibunichev, A.G. 2016. Photogrammetric Techniques for Road Surface Analysis. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLI-B5, 2016 XXIII ISPRS Congress, 12–19 July 2016, Prague, Czech Republic.
https://pdfs.semanticscholar.org/4ce7/8e3a56b261cb6ea44728d514833f5d870a30.pdf
This paper explored using photogrammetric techniques for road surface analysis. Using Agisoft Photoscan software, a dense 3D model of the road surface was created from 24 images taken from a height of 30 meters. The results of processing of imagery indicated that the accuracy and resolution of the 3D road model were sufficient for determining macro road parameters, such longitudinal and transversal evenness, and road width, curvature, and slope.

Lee, J. K. 2019. UAV-based Pothole Identification: A Photogrammetric Approach. George Mason University. http://mars.gmu.edu/handle/1920/11499
This master's thesis investigated the use of sUAS for surveying and inspecting road surface conditions. The objective was to identify potholes from UAV-captured images and create GIS datasets containing key information such as dimensions, severity level, and location of potholes. To test the feasibility of methods proposed in the paper, pilot studies were conducted at two sites in Fairfax County, Virginia.

Loures, L. and Azar, E. November 2022. *Condition Assessment of Unpaved Roads Using Low-Cost Computer Vision-Based Solutions.* Journal of Transportation Engineering, Part B: Pavements, Vol. 149, Issue 1. https://ascelibrary.org/doi/10.1061/JPEODX.PVENG-1006
This paper proposes low-cost computer vision–based solutions for assessment of unpaved roads using two approaches: UAS and participatory-based imaging methods. Both methods use deep neural network to process captured images and locate major road distresses, including potholes, rutting, and corrugations. A method is also proposed to estimate the size of detected potholes in the UAS-captured video frames.

Mallela, J., et al. Effective Use of Geospatial Tools in Highway Construction. Washington, D.C. October 2019. www.fhwa.dot.gov/publications/research/infrastructure/pavements/19089/
This research documented the state of the practice for using UAS, lidar, photogrammetry, SfM, and global navigational satellite systems for highway applications. It describes effective practices for implementing geospatial technologies in a number of construction applications.

Markiewicz, A. and Nash. L. August 2016. White Paper—Small Unmanned Aircraft and the U.S. Forest Service: Benefits, Costs, and Recommendations for Using Small Unmanned Aircraft in Forest Service Operations. U.S. Department of Transportation Volpe Center for the US Forest Service.
https://rosap.ntl.bts.gov/view/dot/12349
This paper provides information to Forest Service leadership about how the agency could use unmanned aircraft across different programs, especially in program areas where aircraft use is currently limited. It draws from published uses of unmanned aircraft and conversations with representatives from peer

federal agencies that have established unmanned aircraft programs, including the DOI headquarters and two of its bureaus: the NPS and BLM.

MassDOT. 2022. Detecting Subsurface Voids in Roadways Using UAS with Infrared Thermal Imaging.
www.mass.gov/doc/detecting-subsurface-voids-in-roadways-using-uas-with-infrared-thermal-imaging-final-report/download
The research leveraged UASs to improve the efficiency and flexibility of IR thermography in detecting voids above damaged culverts and drainage pipes. The specific goals of the research included:

- Developing post-processing algorithms for image de-noising and correction to improve the detection accuracy of IRT;
- Determining the accuracy of IR systems as a function of depth and for field inspections to detect soil voids; and
- Defining operational problems associated with its field deployment and suggest operating procedures to optimize the use of IR imaging on UAS platforms.

Millian, J. 2019. Towards the application of UAS for road maintenance at the Norvik Port. Master's Thesis. Kth Royal Institute of Technology, Stockholm, Sweden.
http://kth.diva-portal.org/smash/record.jsf?pid=diva2%3A1329881&dswid=9231
This research evaluates the requirements of and possibilities for incorporating UAVs in the assessment of port infrastructure, with an emphasis on pavement infrastructure. It includes, as a first step, a comprehensive literature review of leading practices and trends in the use of UAS. Among the trends reviewed are pros and cons of different methods for assessing road condition using UAVs. Data collection suggestions regarding, for instance, resolution and flight altitude are provided. (E.g., "Pixel size quality is inversely proportional to flight altitude, but at the same time, image coverage increases with altitude. It is essential to balance those two parameters accordingly to the project needs"). Based on the literature review, the research proposes a framework for implementing UAS in the assessment of port infrastructure. The primary conclusion drawn from the research was that with the right UAS technology selected, UAS can offer viable solutions for assessing port infrastructure condition, including pavement defects.

Mo, M. and Bonatakis, K. January 2022a. An examination of trends in the growing scientific literature on approaching wildlife with drones. *Drone Systems and Applications*. 10(1): 111-139.
https://doi.org/10.1139/dsa-2021-0003
This study examines trends in the scientific literature on using drones to approach wildlife between 2000 and 2020, specifically in relation to the publication types, scientific journals that works are published in, purposes of drone flights reported, taxa studied, and locations of studies. From 223 publications, the researchers concluded that since animal responses to drone flights vary among taxa, populations, and geographic locations, further research was necessary to inform policies and protocols for specific taxa and (or) locations, particularly where knowledge gaps exist.

Mo, M. and Bonatakis, K. January 2022b. Approaching wildlife with drones: using scientific literature

to identify factors to consider for minimising disturbance. ***Australian Zoologist*****; 42 (1): 1–29.**
https://doi.org/10.7882/AZ.2021.015
Focusing on UAS flights conducted to approach wildlife, this literature review collated and quantified references to factors that should be considered in the development of guidelines and policies. The variability in animal responses across different taxa, different ways drone flights are performed, and the different circumstances under which they are deployed highlighted the need for taxa-specific protocols that also account for geographical and biological variations.

NCDOT Division of Aviation. UAS Standard Operating Procedures Flight Operations.
https://connect.ncdot.gov/resources/Aviation%20Resources%20Documents/NCDOT_UAS_SOP.pdf
This guide outlines the best practice procedure to follow during an NCDOT UAS mission.

Nermin, S., and Ahmed, K. Automating Highway Infrastructure Maintenance Using Unmanned Aerial Vehicles. Construction Research Congress 2018. (November 2, 2018).
https://doi.org/doi:10.1061/9780784481295.049
This research investigates the use of UAS in assessing highway maintenance needs while reducing labor-intensive inspection. The paper explored the capacity of UASs to collect data for roadway maintenance assessment; investigated the reliability of automating pavement distress recognition using object recognition software; and evaluated the viability of assessing highway maintenance needs using UASs as compared to traditional methods.

NPS. Best Practices for Avoiding Impacts to Natural, Cultural, and Historic Resources when Using UAS.
www.nps.gov/subjects/sound/upload/NRSS_UAS_BestPractices_FINAL_508_20171130-3.pdf
This is a list of pre-flight and during mission best practices intended to assist NPS personnel in developing and approving requests for UAS operations to avoid impacts to natural, cultural, and historic resources.

Outay, F., Mengash, H.A., and Adnan, M. 2020. Applications of unmanned aerial vehicle (UAV) in road safety, traffic and highway infrastructure management: Recent advances and challenges. Transportation Research Part A: Policy and Practice, Volume 141, Pages 116-129, ISSN 0965-8564,
https://doi.org/10.1016/j.tra.2020.09.018
This paper reviews developments in the application of UAVs for road safety purposes, traffic monitoring, and highway infrastructure management. Advances in computer vision algorithms to extract key features from UAV acquired videos and images are discussed, including for damage assessments for bridges and pavements. Barriers associated with the wide-scale deployment of UAVs technology are identified, and countermeasures to overcome these barriers are also presented along with their implications.

Pan, Y., Zhang, X., Cervone, G., and Yang, L. 2018. Detection of asphalt pavement potholes and cracks based on the UAV multispectral imagery. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 11(10), 3701-3712. DOI: 10.1109/JSTARS.2018.2865528
Researchers here used UAS-acquired multispectral pavement images to distinguish between normal

pavement and pavement damages (e.g., cracks and potholes) using machine learning algorithms. The team compared the performance among different data types and models, finding evidence to suggest that UAV remote sensing systems offer new tools for monitoring asphalt road pavement condition and potentially improving road maintenance practice.

Petkova, M. 2016. Deploying Drones for Autonomous Detection of Pavement Distress. Massachusetts Institution of Technology–School of Architecture and Planning.
https://dspace.mit.edu/handle/1721.1/106049
This master's thesis explores the capacity of UAS to perform autonomous pavement inspections. The tested system dispatched UAS to survey an area, diagnoses the presence of pavement distress in real time, and recorded imagery and coordinates of locations requiring repair. The results were visualized through a web platform.

Plotnikov, M. and Collura, J. September 2021. Integrating Unmanned Aircraft Systems into State Department of Transportation Highway Bridge Inspection Procedures: Challenges, Implications, and Lessons Learned. Transportation Research Board. https://doi.org/10.1177/03611981211044450
The paper examines standard bridge inspection procedures and protocols that state DOTs carry out; evaluates state DOTs' experiences with the integration of UAS technology into bridge inspections; and assesses the issues and challenges associated with the technology.

Prosser-Contreras, M.; Atencio, E.; La Riviera, F.; and Herrera, R. December 8, 2020. Use of Unmanned Aerial Vehicles (UAVs) and Photogrammetry to Obtain the International Roughness Index (IRI) on Roads. Appl. Sci. 2020, 10, 8788; https://doi.org/10.3390/app10248788
This research seeks to generate new knowledge regarding the use of UASs and "their direct applicability in road design, management, and maintenance." Using UASs, cameras, and global positioning system, the research team created 3D virtual models that were used to obtain longitudinal profiles associated with the road. Those profiles were then used to calculate the international roughness index (IRI). Results obtained via the UAV method were within 0.1 (m/km) of the official IRI results that the state road authority certified, suggesting the UAV method can be provide a viable alternative to traditional methods of calculating IRI. However, the team noted that the proposed approach should be applied with caution given that it slightly underestimated real road roughness.

Ram, P.V., Smith, K.L., Zimmerman, K.A., Ratfliff, T., and Amenta, J. 2016. Developing a Correlation Between the Five Pavement Condition Ratings Used by the Federal Lands Management Agencies. Transportation Research Record, 2589, 78086. DOI: https://doi.org/10.3141/2589-09
This paper reviews the various pavement conditions assessment methods that five FLMAs use. It characterizes the differences between the FLMAs' inspection practices and presents statistical models to crosswalk the paved road condition ratings.

Saad, A. M., and Tahar, K. N. 2019. Identification of rut and pothole by using multirotor UAV. Measurement, 137, 647-654. DOI: https://doi.org/10.1016/j.measurement.2019.01.093
This research analyzed two pavement distresses (potholes and ruts) for flexible pavement sections using

images from a multirotor UAV. The researchers processed the UAV-acquired images using a photogrammetric software based on SfM. The team acquired images at different altitudes to determine the effect of resolution on rut and pothole extraction, ultimately concluding that low altitudes give better results. The team also concluded that its proposed approach provided an accurate and efficient way to monitor road conditions.

Schnebele, E., Tanyu, B., Cervone, G., and Waters, N. 2015. Review of remote sensing methodologies for pavement management and assessment. European Transport Research Review, 7(2), 7.
https://doi.org/10.1007/s12544-015-0156-6
This research provided a review to the possible benefits of remote sensing techniques in the rapid assessment of pavements by covering larger area in less time reducing the need for site visits and manual inspection. Wanting to provide a bridge between traditional procedures for road evaluation and remote sensing methodologies, the team created a reference for geotechnical engineers and remote sensing experts alike. The comprehensive literature review and survey of techniques available at the time served to facilitate that bridge. Emphasis was given to the challenges associated with transportation assessment in the aftermath of major disasters.

Schwind, M., Sheid, R., and Boone, J. August 2019. A Comparative Analysis of Lidar and Structure from Motion Photogrammetry Utilizing a Small Unmanned Aerial System (sUAS) Approach for Structural Mapping and Inspection. USACE Army Engineer Research and Development Center.
http://dx.doi.org/10.21079/11681/29513
This research evaluates sensor types and sUAS platforms to gauge the feasibility of, as well as time and cost differences, the possible use of sUAS to map and inspect structures using lidar methods and SfM photogrammetry methods. The team believed that the results could provide engineers and scientists information directly applicable to all ongoing civil works projects in planning, engineering, and design. In the study, three different types of sUAS were employed to collect the lidar and SfM data. The Riegl RiCOPTER was used for lidar collection. The senseFly eBee RTK and albris were used to collect sequences of overlapping imagery for the SfM photogrammetric processing input. Prior to flying the sUAS, a network of eight ground control targets were placed, four on either side of the structure (U.S. Army Corps of Engineers, Vicksburg District 2016). Each ground control target was surveyed with a Trimble R10 real time kinematic GPS at 180 epoch observations per target. This resulted in highly accurate locations for the ground control target network. The targets later served as the means for georectifying the resultant point clouds to real world vertical and horizontal coordinates. All sUAS utilized the same ground control network in an attempt to decrease the spatial disagreements between the final data products. After post-processing and conducting visual and statistical comparisons, the researchers found evidence suggesting that using an SfM photogrammetric process to derive a quality point cloud of a structure is more time-intensive but less expensive than doing so by lidar. They noted, however, that SfM does not lead to quality data when the subject of interest lacks unique features for the processing algorithms to match on, and thus large areas of concrete could prove problematic for the SfM approach.

Tan, Y., and Li. Y. 2019. UAV Photogrammetry-Based 3D Road Distress Detection. International Journal of Geo-Information 8(9):409. DOI: 10.3390/ijgi8090409

Researchers used road images from UAV oblique photogrammetry to reconstruct 3D models, from which road pavement distress was automatically detected. The corresponding dimensions were extracted using an algorithm the team developed. Compared with a field survey, the detection result showed high precision with an error of around 1 cm in the height dimension for most cases.

Thomsen, J.M., Fowler, J.K., and Lang, T. 2021. A Proposed Research Agenda on Professional and Recreational Drone Use in National Forests and National Parks. Journal of park and recreation administration.
This paper proposes a research agenda to integrate the social, ecological, and managerial aspects of professional and recreational use of drones on USFS and NPS lands to stimulate discussion that can inform effective policies.

Toribio, J. and Gutierrez, L. 2019. Determination of the Pavement Condition Index (PCI) and International Roughness Index (IRI) in Urban Roads Using Images Obtained by Unmanned Air Vehicle (UAV). 26th World Road Congress. https://trid.trb.org/view/1743830
This research proposes a methodology to obtaining PCI and IRI using georeferenced images, obtained from UAVs, which are processed to generate a high-resolution orthophoto and a dense point cloud on the pavement surface. The method consists of a fieldwork stage, which involves surveying pavement surface information via pre-programmed UAV flights, and an office stage, whereby the images captured are processed to generate orthophotos and digital surface models that are then used to calculate the IRI. In the tested fieldwork stage, the researchers carried out their flights at an altitude of 20 meters to guarantee a resolution or ground sample distance of 5 mm per pixel, and also planned for 80 percent overlap of images taken. In the office stage, the researchers used Pix4D Mapper Pro software to generate orthophotos and then sampled points every 25 cm, which they analyzed using FHWA's ProVAL software to calculate IRI. Results suggested that the use of georeferenced images to estimate IRI is an effective and efficient approach as validated by a comparison with a manual assessment of IRI along the same test road section.

Transportation Builder. March–April 2014. Drone: Unsurfaced Road Conditions Assessment System. www.ugpti.org/smartse/research/citations/downloads/MichiganResearchInstitute-Unpaved_Road_Monitoring-2014.pdf
This article describes the benefits of the Michigan Tech Research Institute's Unsurfaced Road Conditions Assessment System. The system uses high-resolution photography and 3D modeling to perform assessment of unpaved roads. The technology provides local road managers with information needed for decision-making about maintenance and repairs at a cost of approximately $1 per mile (versus approximately $8 per mile for the least expensive alternative PASER method. As noted in the article, typically unpaved roads are gravel, which led the research team to want to analyze distresses related to the crown of the road. To do so, the team flew a hexacopter equipped with a very high-resolution camera at 80- to 100-feet above the ground to make a 3D image of the road surface. At the time of the article, the technology had been tested and verified in seven states.

Walker, D. 1991. Evaluation and Rating of Gravel Roads. Transportation Research Record 1291.

http://onlinepubs.trb.org/Onlinepubs/trr/1991/1291vol1/1291-053.pdf
This paper presents an evaluation and rating system for gravel roads that gives primary consideration to drainage, crown and the adequacy of the gravel thickness. It points out that agencies with many miles of low-volume roads may not believe that a sophisticated management system is justified and that a basic inventory and condition rating is adequate (and could evolve into a more sophisticated pavement management system as the benefits are demonstrated).

Zakeri, H., Nejad, F. M., and Fahimifar, A. 2016. Rahbin: A quadcopter UAV based on a systematic image processing approach toward an automated asphalt pavement inspection. Automation in Construction, 72, 211-235. DOI: https://doi.org/10.1016/j.autcon.2016.09.002
In this research a team used a quadcopter-based digital imaging system to collect pavement surface data over a distressed area for visual conditions interpretation. The team used the images gathered to develop an automated post-processing procedure to reliably detect and interpret crack distresses.

Zhang, C. 2008. An UAV-based photogrammetric mapping system for road condition assessment. Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci, 37, 627-632.
www.isprs.org/proceedings/XXXVII/congress/5_pdf/109.pdf
This paper, which was produced as part of a U.S. DOT-funded South Dakota State University research project, presents an early UAV-based photogrammetric mapping system. The paper describes the concept of using UASs and photogrammetry for assessing unpaved road condition, as well as the proposed system architecture. At the time of the research, the strategy presented was new to unpaved road condition monitoring.

Zhang, C. 2009. Monitoring the condition of unpaved roads with remote sensing and other technology. South Dakota State University for the U.S. Department of Transportation.
https://rosap.ntl.bts.gov/view/dot/36464
This research continued the research from 2008 to investigate remote sensing systems using UAVs that might support cost effective acquisition of unpaved road surface distress data for transportation agencies. The project entailed devising efficient methods to process UAV images and identify and quantify unpaved road surface condition parameters. The team processed UAS-captured images to reconstruct a 3D road surface model that was used to derive distresses and report them to a road management system. At the time of the study, the system was not commercially available but showed the potential to collect quantitative assessment measures in an automated fashion. The researchers found that the method may be faster, less expensive, and generally more reliable (and repeatable) than other methods.

Zhang, C., and Elaksher, A. 2012. An Unmanned Aerial Vehicle-Based Imaging System for 3D Measurement of Unpaved Road Surface Distresses. Computer-Aided Civil and Infrastructure Engineering, 27(2), 118-129. DOI: https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1467-8667.2011.00727.x
This research presented a system for using UAS-acquired imagery to create a low-cost, 3D surface model of distresses using image processing algorithms. The team compared the extracted 3D information with

onsite measurements to test the performance of the digital image-based system. The 3D reconstruction of the onsite distresses allowed near accurate measurements up to 0.5 cm for the characteristics of the distress on the computer application indicating promising results of the developed system.

g) Annotated Bibliography of Literature on UAS–Wildlife Interaction

Borrelle, S. B., and A. T. Fletcher. "Will Drones Reduce Investigator Disturbance to Surface-Nesting Seabirds?" Marine Ornithology 45 (April 15, 2017): 89–94.
The team found that attention to evaluating disturbance and risk assessments has been limited, but preliminary evidence suggests drones can reduce disturbance impacts on some species. On the other hand, in the face of widespread drone deployment, inexpensive and rapid data collection should not be put ahead of the potential risk and impact on species.

Brisson-Curadeau, Émile, David Bird, Chantelle Burke, David A. Fifield, Paul Pace, Richard B. Sherley, and Kyle H. Elliott. "Seabird Species Vary in Behavioural Response to Drone Census." ***Scientific Reports*** **7, no. 1 (December 20, 2017): 17884.** https://doi.org/10.1038/s41598-017-18202-3
The team surveyed four species of Arctic cliff-nesting seabirds (glaucous gull Larus hyperboreus, Iceland gull Larus glaucoides, common murre Uria aalge and thick-billed murre Uria lomvia) using a UAV and compared censusing techniques to ground photography. An average of 8.5 percent of murres flew off in response to the UAV, but greater than 99 percent of those birds were non-breeders. The team did not detect any impact of the UAV on breeding success of murres, except at a site where there were abundant aerial predators, and several birds lost their eggs to them following UAV flights. Furthermore, the team found little evidence for murres' habituation to the UAV. Most gulls flew off in response to the UAV but returned to the nest within five minutes. Counts of gull nests and adults were similar between UAV and ground photography, however the UAV detected up to 52.4 percent more chicks because chicks were camouflaged and invisible to ground observers. The team concluded that UAVs provide a less hazardous and potentially more accurate method for surveying wildlife.

Chabot, D., and Bird, D. "Wildlife Research and Management Methods in the 21st Century: Where Do Unmanned Aircraft Fit In?" Journal of Unmanned Vehicle Systems 3, no. 4 (December 2015): 137–55.
https://doi.org/10.1139/juvs-2015-0021
A key consideration is whether UAS disturb target or non-target animals, which a growing number of studies have quantitatively assessed. The general consensus has been that UAS cause low to no disturbance, in particular when compared to alternative methods, such as intrusive direct investigator surveying or the low-altitude surveying of larger and noisier conventional aircraft. Generally, any disturbance to animals that UAS may cause should be carefully weighed against the benefits of the information the technology can provide when deciding whether to proceed with UAS-based data collection.

Ditmer, M.A., Vincent, J.B., Werden, L.K., Tanner, J.C., Laske, T.G., Iaizzo, P.A., Garshelis, D. L., and Fieberg, J.R. "Bears Show a Physiological but Limited Behavioral Response to Unmanned Aerial

Vehicles." *Current Biology* 25, no. 17 (August 31, 2015): 2278–83.
https://doi.org/10.1016/j.cub.2015.07.024
This research assessed the effects of UAV flights on movements and heart rate responses of free-roaming American black bears. The team flew 18 flights, averaging 21 meters in absolute altitude. They observed consistently strong physiological responses but infrequent behavioral changes. All bears, including an individual denned for hibernation, responded to UAV flights with elevated heart rates, rising as much as 123 beats per minute above the pre-flight baseline.

"Drone Surveys Do Not Increase Colony-Wide Flight Behaviour at Waterbird Nesting Sites, But Sensitivity Varies Among Species | Scientific Reports." Accessed August 31, 2022.
www.nature.com/articles/s41598-020-60543-z
Wildlife disturbance was investigated by conducting aerial surveys with a consumer-grade quadcopter, while concurrently recording behavioral reactions on video. Surveys of mixed-species waterbird colonies (1-6 species per colony) were flown in horizontal transects at heights of 122, 91, 61, and 46 m. When compared to control periods, the team found no evidence that colony-wide escape (i.e., flight) behavior increased during drone flights, at any altitude flown. However, the disturbance score increased 53 percent for surveys at 46 m.

Egan, C.C., 2018. Evaluating the potential utility of drones to deter birds from areas of human-wildlife conflict, In Environmental and Conservation Sciences (Biological Sciences). p. 93. North Dakota State University. https://digitalcommons.unl.edu/icwdm_usdanwrc/2073/
This research using UAS platforms to haze blackbirds in sunflower fields found that an increased negative stimulus is needed to promote flock abandonment of sunflower fields.

Hodgson, Jarrod C., and Lian Pin Koh. "Best Practice for Minimising Unmanned Aerial Vehicle Disturbance to Wildlife in Biological Field Research." *Current Biology* 26, no. 10 (May 23, 2016): R404–5. https://doi.org/10.1016/j.cub.2016.04.001
This paper presents a preliminary code of best practice in the use of UAVs to mitigate or alleviate unforeseen impacts on wildlife. Considering the growing popularity of UAVs as a tool among field biologists, the researchers advocate for the precautionary principle to manage these risks.

Holland, J. S. August 25, 2015. National Geographic. *How Drones Are Affecting Wildlife in Surprising Ways*. www.nationalgeographic.com/animals/article/150825-drones-animals-wildlife-bears-science-technology
This article describes results from Ditmer, et al 2015. It includes remarks from the principal investigator that provide additional context for the academic study (described above at Ditmer et al).

Holldorf, E. May 2018. "Avifauna Ethological Response to Unmanned Aircraft Systems - CORE." Masters Thesis. University of San Francisco.
https://repository.usfca.edu/cgi/viewcontent.cgi?article=1815&context=capstone
This research involved a comprehensive review and metanalysis of the current body of literature reporting interactions between UAS and avifauna, as well as an original survey sent to 200 DOI remote

pilots (20 respondents) regarding their field observations of avifauna while flying UAS missions. Conclusions included: (1) birds can respond mildly to severely, evasively or antagonistically, to the operation of UAS, (2) 87 bird species had been documented interacting with UAS as of early 2018, (3) factors of each interaction component [bird, drone, and environment] are all important variables in determining the type of reactions seen, and (4) as a general rule the implementation of a 100-meter buffer between avifauna and UAS operations should sufficiently avoid or mitigate any behavioral impacts (e.g., disturbance) to those target species.

Howell, Ryan G., Kaylee Draughon, Haley Johnston, Melissa Myrick, Val J. Anderson, Dennis L. Eggett, and Steven L. Petersen. "Evaluating Changes in Horse Behavior as a Response to Small Unmanned Aerial Vehicles." Rangelands 44, no. 2 (April 1, 2022): 121–28.
https://doi.org/10.1016/j.rala.2021.12.004
This team developed an ethogram to classify and record horse behaviors and changes in response to disturbance using a DJI Phantom 4 Pro sUAS. The team monitored horse behavior at 5 second intervals from 3 m, 15 m, and 33 m AGL. Results suggested that vigilance was the most common behavior after initial approach at all AGLs. Horses took evasive measures after approximately 20 seconds at lower AGL (i.e., <3 m).

McEvoy, John F., Graham P. Hall, and Paul G. McDonald. "Evaluation of Unmanned Aerial Vehicle Shape, Flight Path and Camera Type for Waterfowl Surveys: Disturbance Effects and Species Recognition." PeerJ 4 (March 21, 2016): e1831. https://doi.org/10.7717/peerj.1831
This study assessed the level of disturbance that a range of UAV shapes and sizes had on free-living, non-breeding waterfowl surveyed in two sites in eastern Australia between March and May 2015, as well as the capability of airborne digital imaging systems to provide adequate resolution for unambiguous species identification of these taxa. The team found little or no obvious disturbance effects on wild, mixed-species flocks of waterfowl when UAVs were flown at least 60m above the water level (fixed wing models) or 40m above individuals (multirotor models).

Mulero-Pázmány, Margarita, Susanne Jenni-Eiermann, Nicolas Strebel, Thomas Sattler, Juan José Negro, and Zulima Tablado. "Unmanned Aircraft Systems as a New Source of Disturbance for Wildlife: A Systematic Review." PLOS ONE 12, no. 6 (June 21, 2017): e0178448.
https://doi.org/10.1371/journal.pone.0178448
The researchers found that wildlife reactions depended on both the UAS attributes (flight pattern, engine type and size of aircraft) and the characteristics of animals themselves (type of animal, life-history stage and level of aggregation). Target-oriented flight patterns, larger UAS sizes, and fuel-powered (noisier) engines evoked the strongest reactions in wildlife. Animals during the non-breeding period and in large groups were more likely to show behavioral reactions to UAS, and birds are more prone to react than other taxa.

Mulero-Pazmany, M. 2018. Viral bear video shows how drones threaten wildlife – and what to do about it. The Conversation. Liverpool John Moores University. https://theconversation.com/viral-bear-video-shows-how-drones-threaten-wildlife-and-what-to-do-about-it-106903

This article discusses patterns of responses in animals that interact with UASs and steps that can be taken to minimize effects when operating UAS near wildlife. Some research teams have found that UAS flights can increase heart rates in animals and cause stress that could affect wildlife reproductive. To prevent these impacts, the author suggested that UAS missions avoid breeding seasons, involve expert ethical committees in the decision-making process, and be planned in a way that allows for take-off at least 100 feet away from animals and flights as high as possible.

Reintsma, Kaitlyn M., Peter C. McGowan, Carl Callahan, Tom Collier, David Gray, Jeffery D. Sullivan, and Diann J. Prosser. "Preliminary Evaluation of Behavioral Response of Nesting Waterbirds to Small Unmanned Aircraft Flight." Waterbirds 41, no. 3 (September 2018): 326–31.
https://doi.org/10.1675/063.041.0314
During 2015–2016, this study tested the behavioral response of a mixed-species rookery (Cattle Egret (Bubulcus ibis), Snowy Egret (Egretta thula), Glossy Ibis (Plegadis falcinellus), and a ground nesting colony of Common Terns (Sterna hirundo)) in shrub habitat to sUAS flights at 12 m, 15 m, 30 m, and 50 m. Even at the lowest altitudes, the birds either showed no reaction or acclimated within 60 sec of the fly-over. Conversely, physically entering the colony to conduct ground surveys resulted in all Common Terns flushing from their nests beginning when the observer was 50 m away and required significantly more time in the colony overall: ~30–60 min vs. ~3–7 min with the sUAS.

Seier, G., Hödl, C., Abermann, J., Schöttl, S., Maringer, A., Hofstadler, D., Pröbstl-Haider, U., Lieb, G. 2021. Unmanned aircraft systems for protected areas: Gadgetry or necessity? *Journal for Nature Conservation*. Volume 64, 126078, ISSN 1617-1381, https://doi.org/10.1016/j.jnc.2021.126078
The researchers observed that a majority (73%) of selected articles (n=89) report the use of UAS in protected areas as relevant for the protected area management in terms of biodiversity. However, most of the studies did not consider impacts of UAS on wildlife or the environment. The possibility of disturbances was discussed in 15 (approximately 17%) of the reviewed works, of which most concluded that the effects were negligible or non-existent. Three articles (approximately 3%) demonstrated an impact.

Smith, Courtney E., Seth T. Sykora-Bodie, Brian Bloodworth, Shalynn M. Pack, Trevor R. Spradlin, and Nicole R. LeBoeuf. "Assessment of Known Impacts of Unmanned Aerial Systems (UAS) on Marine Mammals: Data Gaps and Recommendations for Researchers in the United States." Journal of Unmanned Vehicle Systems 4, no. 1 (March 2016): 31–44. https://doi.org/10.1139/juvs-2015-0017
Based on the existing information, it appears that flight altitude is an important factor. However, there was no conclusive information to distinguish between disturbance from noise versus disturbance from visual cues of the UAS or its shadow as a function of altitude. Many researchers reported that UAS elicited fewer disturbance and avoidance behaviors than would a traditional manned aerial survey, likely because noise levels were far less than those observed from manned aircraft and are often diminished by ambient noise levels from various environmental factors.

Wandrie, Lucas J., Page E. Klug, and Mark E. Clark. "Evaluation of Two Unmanned Aircraft Systems as Tools for Protecting Crops from Blackbird Damage." *Crop Protection* 117 (March 1, 2019): 15–19.

https://doi.org/10.1016/j.cropro.2018.11.008
This team evaluated the behavioral responses of captive and free-ranging red-winged blackbirds to a fixed-wing and a rotary-wing (multi-rotor, quadcopter) UAS. The researchers compared preflight behaviors to behaviors during UAS approach. Neither captive nor free-ranging flocks of red-winged blackbirds displayed behavioral responses to fixed-wing UAS approaches when flown at or above 52 m AGL. However, both captive and free-ranging flocks exhibited behavioral responses to the rotary-wing UAS when flown within 30 m AGL. Behavioral responses of blackbirds to the rotary-wing UAS were more pronounced with lower altitude approaches.

Weimerskirch, Henri, Aurélien Prudor, and Quentin Schull. "Flights of Drones over Sub-Antarctic Seabirds Show Species- and Status-Specific Behavioural and Physiological Responses." ***Polar Biology*** **41, no. 2 (February 1, 2018): 259–66.** https://doi.org/10.1007/s00300-017-2187-z
This team assessed and compared the behavioral response of 11 southern seabird species at the Crozet Islands, Southern Indian Ocean, to drone approaches at specific altitudes. Behavioural response differed between species depending on the altitude of the drone approach. At 50 m of altitude, only one of the studied species showed a detectable reaction, whereas at 10 m, most species showed strong behavioral postures of stress.

Appendix B. Mission Planning

This reference procedure focuses on the RIP road inspection process that FWS carries out in coordination with FHWA but is generalizable to other FLMAs. The guide organizes suggested steps into four categories but is presented with an awareness of and reiteration that all operations and management of UAS within the DOI and on DOI-managed lands and waters should be conducted in accordance with OPM-11. Aircraft and pilots must maintain compliance with OPM-11 and with applicable sections of Title 14 CFR to operate in the National Airspace System (see OPM-11 Section 5 Policy).[52] Teams should refer to other agency-specific requirements and guidelines, as appropriate.

Summary of UAS for Road Inspections Mission Planning Process

Mission Stage	Step
Pre-Flight Planning	1. Identify Remote Pilot in Command and Visual Observer 2. Define Mission Specifications a. Review Airspace b. Identify Station-specific Considerations and Constraints c. Plan Flight Trajectory 3. Select and Reserve UAS 4. Complete Project Aviation Safety Plan 5. Plan for Travel
On-Site Preparations	6. Brief Station Staff on UAS Mission 7. Obtain Weather Report 8. Set Ground Control Points, if applicable 9. Complete UAS for Road Inspection Flight-Day Checklist
On-Site UAS Mission	10. Conduct Flight(s) and Collect Data 11. Record Flight End Time
Post-Mission	12. Download Data and Conduct Analysis 13. Prepare Flight-Use Report

Pre-Flight Planning

1. Identify RIP Team Remote Pilot in Command (RPIC) and Visual Observer (VO)

UAS road inspection teams should identify a RPIC and VO for the road inspection(s) and record their names, job positions, and UAS qualifications. The RPIC is responsible for and is the final authority as to the operation of the aircraft; they can decline a flight mission that they consider excessively hazardous. DOI Remote Pilots conducting operations under 14 CFR Part 107 must maintain visual contact with the UAS, or utilize a VO. The use of VOs must comply with the provisions of Part 107.

DOI personnel who fly UAS on behalf of the DOI must be trained per OPM-11. Current training requirements are listed in the Interagency Aviation Training Guide (July 2022).[53] If Beyond Visual Line of

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[52] As per OPM-11, contractor-provided UAS flight services must follow the processes outlined in 353 Departmental Manual 1 and OPM-35.

[53] The Interagency Aviation Training Guide is available at www.iat.gov/docs/IAT_Guide.pdf.

Sight (BVLOS) flights are planned, those flights must be conducted with an FAA Part 91 waiver or under the terms of the DOI/FAA MOA for flights within a Temporary Flight Restriction.[54]

2. Define Mission Specifications

UAS road inspection teams should work to define flight parameters to the extent possible in advance of a Station visit with the understanding that adjustments may be necessary once on-site. This is likely a multi-step effort, including the following at a minimum:

2a. Review Airspace. UAS road inspection teams should work to ensure that the planned mission aligns and complies with any flight restrictions in the Station's airspace. They should check the airspace of the Station for any "No Drone Zones"[55] or other restrictions that would preclude or shape UAS operations. The RPIC may also check Notice to Airmen (NOTAMs) for any information that may affect the safety of their flight activities. An authoritative interactive map that the FAA provides offers one early planning resource: https://tfr.faa.gov/tfr_map_ims/html/index.html. The FAA maintains a list of UAS operations that require waivers at www.faa.gov/uas/commercial_operators/part_107_waivers; RIP UAS teams may consult this list, as appropriate as specific flight criteria are outlined.

2b. Identify Station-specific Considerations and Constraints. Prior to road inspection site visits that are planned to involve UAS flights, UAS road inspection teams should consult with Station staff to identify Station-specific considerations and constraints that may impact UAS operations in the mission area(s). Factors concerning the flight area that affect the complexity of a mission and that RIP UAS teams should consider becoming familiar with and discuss with Station staff include:

- Size/extent of flight area
- General topography
- Presence of structures
- Ecosystem/wildlife context (e.g., noise-sensitive species, breeding seasons)
- Vegetation/canopy coverage
- Presence of people, crowds, vehicles, etc.
- Adjacent property owners or neighbors
- Expected weather conditions (i.e., closer to the site visit teams should review the forecast weather, including, for example, temperature, wind speed and direction, precipitation, visibility, and cloud ceiling).

2c. Plan Flight Trajectory. It is assumed that UAS flights will occur in tandem with a vehicle that is driven along the Station's roads (versus completely replacing the need for vehicles).[56] Accordingly, UAS road inspection teams should plan a realistic mission scenario(s) for the Station where the road

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[54] The MOA is available at www.doi.gov/sites/doi.gov/files/uploads/FAA_DOI_UAS_TFR_MOA_8-13-15.pdf.

[55] FAA provides additional information on No Drone Zones at www.faa.gov/uas/resources/community_engagement/no_drone_zone.

[56] For some applications, such as inspecting parking areas, no vehicle may be necessary.

inspection(s) will occur. The flight scenarios should be flexible to allow for environmental uncertainties, external disturbances, and an incomplete situational awareness that may exist until being on site. First, the team should identify routes (or a decision tree for when UAS will be used) and decide what Station roads will be flown, taking into account constraints. Some possible route scenarios include:

- ***Do not fly any roads (or parking areas)***. Under this scenario, the road inspection would occur without any UAS flight(s).
- ***Fly all roads (and/or parking areas)***. Under this scenario, the road inspection would occur with a RPIC planning to fly all of a Station's roads that would normally be inspected as part of the site visit.
- ***Fly select or priority road(s) (and/or parking areas)***. Under this scenario, the road inspection would occur with a RPIC planning to fly a sub-set of a Station's roads based on some predefined characteristic(s). Examples of such characteristics include paved versus unpaved, or roads that are vulnerable, damage-prone, or repeat problem areas versus those that are not. A RIP UAS team might also opt to fly only over roads otherwise inaccessible by vehicle or foot.

In parallel with the mission scenario decision, UAS road inspection teams should consider the baseline configuration for flights from which adjustments may need to be made. Commercially available UAS flight planning apps/ground control systems may provide useful tools for optimizing this phase of defining mission specifications, including setting required imagery tolerances. Example flight parameters are listed below along with best practice suggestions for the road inspection setting:

<u>For imagery applications</u>

- ***Altitude***. Consider flying UAS missions at the minimum possible altitude that is high enough for the UAS sensor to capture the entire width of the road and adjacent appurtenances in one flight pass. If teams know the level of accuracy they aim to achieve, they can determine the GSD to identify the optimal flight altitude. A GSD of 3 cm or lower is recommended for road inspections that will involve photogrammetry or other automated computer post-processing approaches.
- ***Speed***. Consider flying UAS missions at the fastest speed possible that still allows for clear, unblurred (and properly overlapped, if applicable) imagery. It is expected that this speed is currently likely 15 mph (6.7 meters per second) or slower.
- ***Interval frequency for sensor data collection***. A distance-based photo interval (versus time-based) is recommended for RIP inspections where the UAS will be used to collect imagery for including in a GIS. If UAS are used to acquire imagery, it is recommended that a minimum 50 percent image overlap be used. Flight planning apps can assist.
- ***Sensor angle***. Consider positioning camera sensors between 0 (nadir) and 45 degrees.
- ***Locations for ground control points (GCPs), if applicable.*** Consider locating GCPs on flat ground and in areas with clear surroundings, ideally with high color contrast. For linear assets, such as roads, it may be helpful to offset GCPs from one another (e.g., zig-zag pattern).

- ***UAS position***. Consider maintaining a UAS flight position (and/or vehicle position) that keeps the team vehicle beyond the UAS sensor field of view to extent possible.

For Lidar applications

- ***Specify flight parameters in the software.*** Based on user-defined parameters such as corridor width and centerline, flight altitude and speed, and side overlap and field of view, software can plan the appropriate flight path.
- ***Locations for GCPs, if applicable***. Consider locating GCPs on flat ground and in areas with clear surroundings, ideally with high color contrast. For linear assets, such as roads, it may also be helpful to offset GCPs from one another (e.g., zig-zag pattern).

OPM-11 indicates that it is the responsibility of the RPIC to contact their National Aviation Manager/Office of Aviation Services to vet any procedure required for a mission that was not instructed during an approved agency training. Examples of operations or procedures not taught in an approved agency training include, but are not limited to, launch and recovery methods other than those taught or described during approved training or operations outside of manufacturer's recommendations, and/or any deviations not instructed during approved agency training.

3. Select and Reserve UAS and Related Equipment

Select the UAS equipment necessary to meet the mission and data tolerance requirements. Equipment to consider carrying includes:

- UAS aircraft
- UAS sensor, if external UAS payload required
- UAS batteries[57]
- Battery charging equipment/hub
- Storage, e.g., extra high-speed SD or Micro SD memory cards, depending on UAS compatibility
- Extra cables for battery charging, controller connection, laptop integration, etc.
- Sun hood or shade for UAS controller
- GCPs
- Rugged flight case

Road inspection teams should follow their agencies' equipment reservation process(es), allowing for adequate lead time in advance of a scheduled RIP inspection.

4. Complete Project Aviation Safety Plan

OPM-11 requires that a Project Aviation Safety Plan (PASP) be developed for all UAS missions. For UAS missions on a recurring or routine basis, the required PASP can be rolled into a Station/unit aviation plan that the National Aviation Manager reviews annually. A key component of the PASP is the risk and hazard assessment. This element identifies hazards associated with the operation and the mitigations and controls put in place to reduce or eliminate them. A UAS road inspection team can also use the

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[57] Recharging times can vary depending on charging source. RIP UAS teams should consider carrying enough batteries to minimize ground time for the UAS.

PASP as an opportunity to identify any protective equipment and clothing that may be necessary for the particular operation beyond the normal personal protective equipment (PPE).

5. Plan for Travel

If airplane flight(s) are involved for RIP team members to and from a road inspection site and the UAS is to be carried on the flight(s), a team member who will carry UAS batteries through airport security should be identified. This person will be responsible for checking the latest FAA, Transportation Security Administration (TSA), and airline specific UAS policies prior to traveling and discharging and packing the batteries for travel. UAS batteries should not be placed in checked baggage. PPE, as necessary, government Personal Identity Verification card for government employees, and a flight-day checklist should also be packed for travel to RIP inspections that will involve UAS flights.

On-Site Preparations

6. Brief Station Staff on UAS Mission

RIP teams ordinarily meet with Station staff in advance of driving Station roads for data collection purposes. Discussion of the planned UAS flight(s) should be included as part of this preliminary meeting's agenda. The team should identify, assess, and deconflict any potential impediments to the UAS flight(s). Safety, which depends on accurate risk assessment and informed decision-making, is the principal consideration in all aspects of UAS operation. A decision to conduct a mission requires weighing the risk against the benefit of the mission and deciding whether the risks are acceptable. Station staff can note any changes that may have occurred or new hazards that may have presented themselves since the pre-site visit consult and help confirm the flight plan is still reasonable and safe.[58]

With a goal of trying to remain beyond the UAS's field of view, the UAS road inspection team can also use the Station briefing to confirm the positioning of any follow vehicles or people on foot relative to the UAS's planned flight path. Expectations for the data acquired (e.g., images, video, or other) and the timeframe for delivery can also be discussed.

7. Obtain Weather Report

Although some UAS aircraft are all-weather systems, confirm in the hours before UAS missions that weather conditions are conducive for safe flight. If there is uncertainty regarding the relative safety of current conditions, the RPIC may conduct a brief test flight to verify the drone's navigation capabilities in the weather. In strong winds or precipitation, the RPIC may perform a hover test: if a drone is unable to hold a stationary position, it may not be able to navigate a flight course or return home.

8. Set GCPs, if applicable

If GCPs are to be used, evenly place them across the mission area.

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[58] See the National Wildfire Coordinating Group's website for more information on safety considerations: www.nwcg.gov/publications/pms515/safety-considerations.

9. Complete UAS for Road Inspection Flight-Day Checklist

An example checklist that road inspection teams using UAS can review and complete before UAS flights is provided below. Through a pre-flight check of both equipment and crew fitness, the checklist aims to help ensure the safety of UAS missions for road inspections. Generally, prior to take off, the RPIC should inspect the UAS in accordance with manufacturer's recommendations and agency best practice to ensure aircraft is in airworthy condition. This may include correctly positioning propellers, ensuring optimum battery charges in the aircraft and controller, and establishing connection between the controller and aircraft. If there is visible damage or a stable connection between the controller and aircraft cannot be created, the UAS flight should not occur until the issues are addressed. Assuming no issues are observed, the RPIC will confirm good GPS signal reception and establish a take-off zone, as well as return points in the event of signal loss. Any sensors to be used should also be ready to use and clear of obstructions.

On-Site UAS Mission

10. Conduct Flight(s) and Collect Data.

The RPIC should conduct the UAS flight(s) in accordance with the manufacturer's specifications and agency policies and training standards. This includes obtaining any necessary airspace authorization, exercising continuous operational risk management, being aware of battery and data storage capacities, and flying in accordance with the pre-defined mission specifications to the extent practicable. It may also include calibrating sensors (e.g., lidar) depending on the equipment used. Throughout the data collection, the VO should maintain a clear view of the area of operation and the UAS, always communicating with the RPIC, either within speaking distance or with a portable radio/cell phone equipped for immediate communication to advise the RPIC of any possible hazards.

Together, the crew should note any safety incidents or other irregularities or departures from the flight plan. The crew might also note any valuable resource information gathered from the mission, including wildlife sightings; identification or condition of natural, cultural, or historical resources; and any impacts to resources resulting from the UAS operation. If a mishap occurs, the crew should fill out and submit the Interagency Aviation Mishap Response Guide UAS Insert in accordance with their respective agency's policies.[59]

11. Record Flight End Time

The RPIC should record the time of the end of the flight(s) in the UAS for Road Inspection Flight-Day Checklist.

Post-Mission

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[59] See https://uas.nifc.gov/sites/default/files/sites/default/files/inline-files/UASP_Interagency_Aviation_Mishap_Response_Plan_Insert_FINAL.pdf

12. Download Data and Conduct Analysis

After the UAS mission, import the UAS-acquired data to a computer or cloud drive to confirm data capture.

13. Prepare Flight-Use Report

The DOI quantifies and reports on annual UAS program activity. This reporting relies on "OAS-2U" forms that DOI remote pilots are required to fill out after every UAS flight. The form captures information about the pilot, aircraft, payloads and mission objectives, and provide a snapshot of flights as they occur throughout the year. DOI summarizes the flight-use reports according to metrics of interest to inform DOI senior leadership, managers, and field personnel. As necessary, complete the OAS-2U form after UAS missions for road inspections.

Example UAS for Road Inspection Flight-Day Checklist

Location (Station/State):
Date:
Remote Pilot in Command:
Visual Observer:
Person Completing this Checklist:
UAS Aircraft Used:
UAS Aircraft Registration Number:
Payloads Used:

	Yes	**No**	**N/A**
1. Team members carrying their government IDs or other appropriate external indicator of identification (e.g., FWS uniform)?			
2. Team members wearing appropriate PPE?			
3. UAS firmware up to date?			
4. UAS free of visible defects?			
5. Batteries fully charged?			
6. Propellers properly installed?			
7. Sensor mounted properly?			
8. Sensor is clear of obstructions?			
9. Good GPS signal reception?			
10. Crew is within the work/rest policy for flight and duty limits?*			
11. Pre-programmed flight plan is properly loaded?			
12. GCPs in place?			
13. Weather conditions safe?			

Flight Start Time:
Flight End Time:
Total number of flights at this location for this date and aircraft:
Mishaps or Notable Events:

*Remote pilots are limited to 8 hours of flight time during any duty day. When conducting UAS operations, DOI UAS flight crewmembers are limited to a 16-hour duty day (Source: OPM-11).

Appendix C. Hardware and Software Requirements

Experimentation using UAS for road condition inspections to date has largely been divided into two primary steps: data collection and post-processing. The data collection step includes the selection of the UAS and geospatial tools and sensor for acquiring road condition data. The post-processing step involves using software to produce actionable information from the UAS-acquired data. Hardware and software requirements for each step are discussed below along with analysis and storage standards, including information on data formats, file size, and metadata guidelines.

a. Minimum Hardware Needs

The three broad types of hardware are required for using UAS to conduct a road condition:

1. The **UAS** to fly the mission,
2. A **sensor** integrated with or attached to the UAS to collect data during the mission, and
3. A **computer** to view and analyze the data collected.

UAS Hardware

A UAS consists of the uncrewed aircraft and other components that allow the operation of the aircraft. Basic components can include ground control stations, data link, navigation system, payload, launch and recovery/retrieval equipment, and a human operator. UAS aircraft themselves are built in many configurations but generally can be divided into two primary types: fixed-wing gliders and rotary wing, or rotorcraft. The former are fixed-wing propelled aircraft, while the latter use upward thrust that spinning rotors generate to fly (Figure 1). Small UAS, which the Federal Aviation Administration has defined as weighing less than 55 pounds and include both fixed and rotary wing aircraft, are most commonly used for civilian applications.

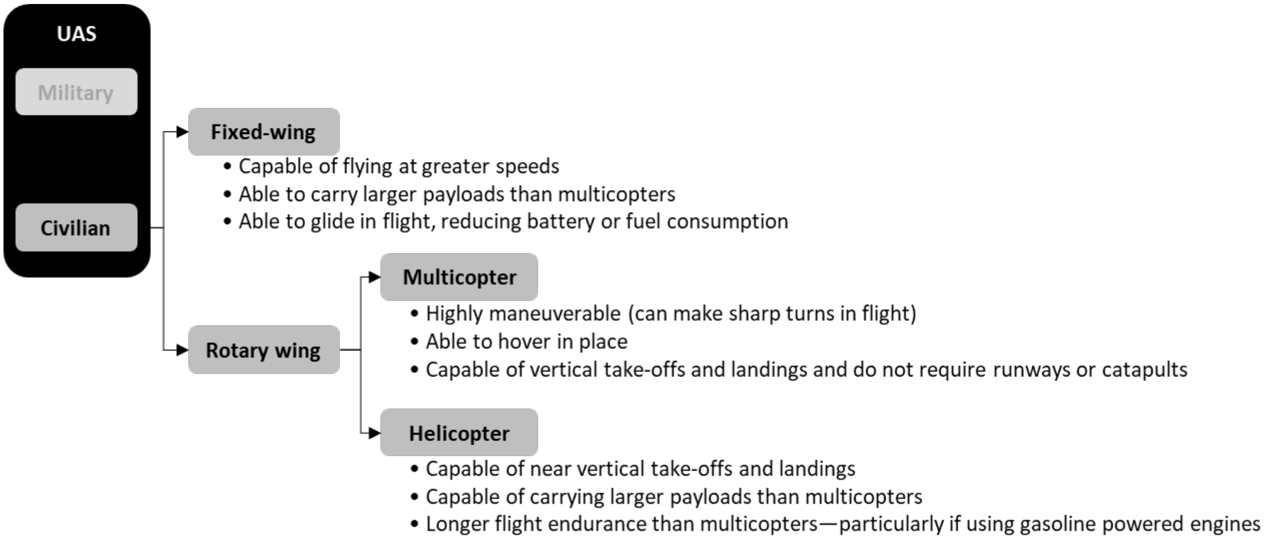

Figure 1. Advantages and examples of various types of small UAS. Source: Adapted from Mallela et al. 2017 and Kim, S. and Kim, S. 2018.

Beginning January 29, 2020, SO 3379 grounded most of the DOI's UAS fleet. On October 21, 2022, the DOI issued an updated UAS operations and procurement policy that resumed all DOI-mission appropriate UAS flights using the existing fleet. The policy also authorized the procurement of appropriate non-covered UAS to diversify its fleet and further mitigate potential risk. As of October 2022, there were four UAS models in the DOI UAS fleet with four others expected to be acquired during FY23 (Table 1 for reference only).

Table 1. UAS in DOI's Fleet (as of October 2022)

Status	**Aircraft**	**Type**	**Payload (lbs.)**	**Range**	**Endurance (minutes)**	**Weather**	**Approx. Cost ($)**
Operated in current fleet	Parrot Anafi USA GOV	quadcopter	–	4 km	25	Can be flown in rain	$14,000
	DJI Matrice 600	hexacopter	12	5 km	35–40	Not to be flown in rain, snow, or fog	No longer produced
	DJI Mavic Pro	quadcopter	–	6.5 km max travel distance	27	Not to be flown in rain, snow, or fog	No longer produced
	Birdseye Firefly	hybrid multirotor	0.7		59	Unavailable	Unavailable
Expected to acquire in FY23	Wingtra WingtraOne	fixed wing	–	10 km	59	Not to be flown in rain, snow, or fog	$20,000
	Freefly Alta X	quadcopter	35	limited by long range communications (RFD-900x)	50	All-weather UAS	$18,200
	FreeFly Astro	quadcopter	1.5 kg	2 km	25 (37 sans payload)	Weather shield sold separately	$12–18,000
	Skydio X2D (EO/IR)	quadcopter	–	6–10 km	35	Not to be flown in rain, snow, or fog	$13,000
	Teal Golden Eagle (EO/IR)	quadcopter	–	3 km	50	All-weather UAS	$14,800

Source: Payload, range, endurance, and other compiled from www.diu.mil/blue-uas-cleared-list, www.doi.gov/aviation/uas/fleet, and manufacturer specifications. Note: EO/IR = Electro-Optical/Infra-Red

Sensor Hardware

UAS can be equipped with a variety and/or combinations of passive or active sensor payloads. Passive sensors are those that gather information already present in the environment. For example, a camera on a UAS captures light freely available in the environment. They tend to be lower cost than active sensors, and at least in terms of cameras, more or less ubiquitous on new UAS. A downside is that that information irrelevant to the task at hand, which will need to be eliminated later on for analysis, may be captured. Active sensors expend energy to project some form of wave into the environment that is reflected back to the sensor for measurement. Lidar is one example as it projects lasers into an environment, which reflect light back to the sensor. These sensors can provide very high resolution at close ranges but can be expensive. For this study's purposes, the focus is on the camera (passive sensor) and lidar (active sensor) examples given that the relevant experience gleaned from the literature suggested that using other UAS-mounted sensor types for road inspections is at a lower technology maturity level.

It should be noted that UAS compatible sensors may be purchased through normal DOI procurement processes and do not require coordination with DOI's OAS. However, pursuant to OPM-11 only approved sensors may be mounted on DOI UAS platforms.[60] For the USDA FS, all UAS payload configurations must be in accordance with the interagency UAS approved payloads, sensors, and ground control station software/applications list. Requests for units requiring custom or non-approved payloads are processed through the Missoula Technology Development Center and the Interagency UAS. Some payloads may require additional training, which must be coordinated prior to acquisition to obtain the necessary training requirements.

Camera sensors

UAS cameras are typically lightweight, compact digital cameras. Some of the cameras are in a fixed position. Others are on a gimbal-based system with interchangeable sensors. Both 2D and 3D data can be acquired with UAS camera sensors.

Imagery resolution is the critical parameter that provides for the identification of defects in the pavement. It controls the degree of detail an image contains and is usually measured in pixel size.[61] Pixel size is a parameter that other camera characteristics, such as focal distance and lens aperture, affect. Some UAS cameras can have a sensor-width exceeding 40mm and a MP rating between 40MP and 100MP. The higher the MP camera, the lower the ground sampling distance (GSD) necessary.[62] Therefore, a higher resolution camera allows for photographs to taken at a greater distance from the target. The accuracy of camera sensors can be similar to lidar if the right equipment and support tools, such as ground control points, are used.

According to AASHTO, the resolution of imagery for road inspections should be enough to recognize road cracking approximately 3mm deep and 6mm wide.[63] It is also suggested that images capture the entire width of the lane along with its shoulders.[64] For photogrammetry applications, photos should likely have 80 percent longitudinal and transverse overlap, and the flight speed should be controlled to less than 5 m/s in fast photo shooting mode.[65]

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[60] The list of approved sensors is not static. The DOI frequently evaluates additional sensor and UAS systems. The most current list of approved sensors would be available upon request of the OAS.

[61] Millian, 2019.

[62] GSD refers to the amount of surface area that a single image in flight covers. GSD is calculated as (Flight Height in m * Sensor Width in cm) / (Focal Length in mm * Image Width in pixels).

[63] AASHTO's R 85-18: Standard Practice for Quantifying Cracks in Asphalt Pavement Surfaces from Collected Pavement Images Utilizing Automated Methods defines a crack as a discontinuity in the pavement surface with minimum dimensions of 1 mm (0.04 in) wide and 25 mm (1 in) long.

[64] Nermin and Ahmed, 2018

[65] Prosser-Contreras et al., 2020

The Parrot Anafi USA GOV is the one Blue UAS Cleared List device that the FWS currently has in its fleet. Its stock camera's focal length (35mm format equivalent) is 23–69mm for photos and 26–78mm for video. It has a resolution of 21 MP (5,344 x 4,016 pixels) with an 84° horizonal field of view and allows for JPEG and Adobe DNG photo formats. Live streaming at HD 720p resolution is possible.[66] This UAS with its stock camera could obtain a sufficient GSD at 10 m flight altitude.[67]

Lidar sensors

Lidar is an instrument that records the time it takes for a pulsed laser to return to the source in order to measure distances. Lidar sensors emit 50,000–200,000 pulses per second, enabling them to cover a wide area in much greater detail than cameras.[68] The point clouds it creates can be used to make 3D models of any surface within a line of sight of the lidar. Advantages of using lidar sensors are that they can provide higher accuracy data and involve less computational time when compared with the camera sensors. Lidar point clouds are dense enough that they can be used to produce elevation models with 1m-by-1m resolution when taken from planes; a UAS-mounted lidar system could easily produce a submeter elevation model. A downside is that they are more expensive than camera sensors and can weigh more than cameras and thus require additional battery power.

Computer Hardware for Post-Processing

For photogrammetry, software identifies related features in images that allow them to be stitched together. The software then removes distortions while creating a uniform scale, resulting in a photomosaic with accurate measurements and a detailed image of the asset photographed, while retaining the ability to zoom on distresses. For 3D modelling, software in the cloud or installed on standalone desktop computers uses the parallax, or the apparent displacement between two objects of different depths taken from different perspectives, to calculate the relative elevation and produce a digital surface model. Individual points in a lidar point cloud are classified to produce a smooth, rasterized surface model. Like other software, photogrammetry software that perform these functions each have minimum and recommended computer specifications. Some examples are provided below (Table 2).

Table 2. Select Suggested Computer System Requirements for UAS Imagery Analysis

Software	Requirements
ArcGIS Drone2Map	• Operating system: Windows 11 Home, Pro, and Enterprise (64 bit); Windows 10 Home, Pro, and Enterprise (64 bit); Windows 8.1 Pro and Enterprise (64 bit); Windows Server 2022 Standard and Datacenter (64 bit); Windows Server 2019 Standard and Datacenter (64 bit); Windows Server 2016 Standard and Datacenter (64 bit); Windows Server 2012 R2 Standard and Datacenter (64 bit); Windows Server 2012 Standard and Datacenter (64 bit)

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[66] Full specs are available at www.parrot.com/us/drones/anafi/technical-specifications.

[67] Other currently approved camera sensors available for the USGS's UAS fleet include the following: Cameras—Ricoh GRII, Ricoh GRIII, Sony RX1RII, Sony A7R, Sony A6000, Phaseone IXM-100, DJI XT2 RGB/Thermal camera, DJI Z30 RGB camera, FLIR Vue Pro IR; Multispectral—Micasense 10 band dual, Micasense RedEdge-P, Micasense Altum-PT; and Hyperspectral—Headwall Nano VisNIR; Resonon Pika-L VisNIR; HySpex Mjolinir VS-620 VisNIR/SWIR (in procurement, will need integration on HALE, NASA-S-2, and Alta X.

[68] www.usgs.gov/news/science-snippet/earthword-lidar

	• Central Processing Unit: minimum 4 cores, simultaneous multithreading. 6 cores recommended; 10 cores optimal. • Memory: minimum 16 GB; 32 GB recommended; 64+ GB optimal. • Dedicated (not shared) graphics memory: Recommended: 4 GB or more. • Temporary visualization cache: can consume up to 32 GB of space, if available, in the user-selected location.
https://doc.arcgis.com/en/drone2map/latest/get-started/arcgis-drone2map-system-requirements.htm	
Pix4D	• While small projects with fewer than 100 images at 14 MP require only 4 GB RAM and 10 GB HDD free space, storing and processing 100 and 500 images at 14 MP requires at least 8 GB RAM, 20 GB HDD free space. Large projects that involve between 500 and 1,000 images require at least 16 GB RAM, 40 GB free hard disk space, and very large projects that need up to 2,000 images to be processed and stored require at least 32 GB Random-access memory (RAM), 80 GB HDD free space. Regardless of the size of the project, Pix4D requires Windows 10 64-bit operating system computers, with Intel i5, i7, or Ryzen 7 CPUs, and any OpenGL 3.2 compatible GPU, such as Intel HD 4000 or above.
https://support.pix4d.com/hc/en-us/articles/202557289-System-requirements-Minimum-and-recommended-computer-specifications	
Agisoft Metadesk	• Central Processing Unit**:** 4–8 core Intel or AMD processor, 2.0+ GHz. • RAM**:** 16–32 GB • Graphics Processing Unit: NVIDIA or AMD GPU with 700+ CUDA cores / shader processor units.
www.agisoft.com/downloads/system-requirements/	

Research has shown that processor size and processing speed are the two most important parameters that determine how fast a computer can create a mosaic.[69] All other computing resources, e.g., the amount of RAM, display card size, and hard drive space, have less impact on the mosaic process. For this reason, it has been recommended that computers built or purchased for drone imagery mosaic and stitching operations emphasize attaining the largest and fastest processor available. Similarly, software used to process lidar data will have minimum recommended hardware requirements that may be above what is available in standard issue computers. General guidance is that computers used to process lidar point clouds be as powerful as possible, including having at least 8 CPU cores and 32 GB of RAM.[70]

b. Data Analysis and Storage

The analytical approach and data storage standards used for road inspections that UASs support depend on the mission purpose and type of data collected during the mission. Images collected for manual inspection, images for photogrammetry, hyperspectral images, and lidar point clouds differ in terms of data format, file size, and metadata guidelines.

Image Analysis and Storage

Data format

Images are initially stored on the camera as raw image files, which contain unprocessed data from the image sensor. Raw images are generally converted and compressed to a standard raster graphics format

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[69] Louisiana State University Ag Center (2019) at www.lsuagcenter.com/~/media/system/a/2/f/0/a2f0cd5d689615d2a7b38a1dc0c3c4f8/p3708_selectingtherightcomputerfordronemappingnew_ai1219rpricepdf.pdf

[70] The USGS describes lidar collection requirements and best practices to better control variability arising from different processing techniques, tools, and general approaches to data production in its Lidar Base Specification: Collection Requirements (2022) and Lidar Base Specification: Data Processing and Handling Requirements (2022), available respectively at www.usgs.gov/ngp-standards-and-specifications/lidar-base-specification-collection-requirements and www.usgs.gov/ngp-standards-and-specifications/lidar-base-specification-data-processing-and-handling-requirements.

such as JPEG or PNG by the camera itself and then stored internally on the camera or on an external media drive, such as a Secure Digital (SD) card. End users generally only access the converted raster images, although accessing raw image files is possible if reprocessing is necessary.[71]

Image and File Size

Pixel count and bit depth of the image determine image size. For the Parrot Anafi USA GOV, the resolution of 5,344 x 4,016 pixels and the 24-bit depth results in an average file size of 64.38 MB per image.[72]

Metadata

Metadata are encoded in image files using a metadata standard such as EXIF, XMP, and IPTC. Each standard defines hundreds of potential metadata attributes; different cameras store different combinations of the attributes. As an example, some of the more common and useful metadata attributes from the EXIF standard for UAS purposes include:[73]

- Date and time
- Capture information, such as
  - Exposure time
  - F number
  - ISO speed
  - Shutter speed
- Global Positioning System (GPS) information
  - Latitude and longitude
  - Altitude
  - Positioning error
- Color map (usually a red-green-blue colormap for visible spectrum images)

Storage

UAS-acquired images are generally stored on an on-aircraft microSD card until the user uploads to a computer or cloud storage for analysis. As an example, Table 6 describes the storage capacity of different standard-size SD card based on the average image size for the Parrot Anafi USA GOV.

Table 3. Approximate SD Card Storage Capacities

SD Cards	Storage Capacity
32 GB	492 images
64 GB	985 images
512 GB	7,877 images
1 TB	15,385 images

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[71] www.loc.gov/preservation/digital/formats/fdd/fdd000241.shtml and www.adobe.com/creativecloud/file-types/image/raw.html

[72] www.omnicalculator.com/other/image-file-size

[73] https://exiftool.org/TagNames/EXIF.html

Multispectral and Hyperspectral Image Analysis and Storage

Whereas conventional, visible-light images have 3 color bands (red, green, and blue), multispectral images have 4 or more bands, and hyperspectral images have 10 or more bands.[74] The additional bands represent electromagnetic radiation outside of the visible light spectrum, including infrared and ultraviolet light, depending on the sensor. Documenting the definition of each band in the metadata is an important consideration for multi- and hyperspectral images. Example band definitions for satellite and aerial imagery commonly used in remote sensing are provided in Table 4.

Table 4. Definition of bands by wavelength range (nm) for three satellite and aerial multispectral sensors

	Landsat 8 & 9[75]	**National Agriculture Imagery Program[76]**	**ESA Sentinel 2[77]**
	430–450		432–452
	450–510	420–492	460–525
Visible green	530–590	533–587	541–576
Visible red	640–670	604–664	649–680
Near infrared (NIR)	850–880	833–920	696–711
Near-Infrared (NIR) 2			733–746
NIR 3			770–789
NIR 4			854–875
Water vapor			933–953
Short Wave Infrared (SWIR) 1	1,570–1,650		1,563–1,657
SWIR 2	2,111–2,290		2,094–2,278
Panchromatic	500–680	465–676	
Cirrus	1,360–1,380		1,362–1,391
Thermal IR 1	10,600–11,190		
Thermal IR 2	11,500–12,510		

While multi- and hyperspectral images are typically collected and stored in the same manner as conventional images, at this stage their collection is not envisioned as part of road inspections for FLMA roads.

Analysis and Storage of Images for Photogrammetry

Images collected for photogrammetry have the same format, size, metadata, and storage considerations as images collected for other purposes. However, photogrammetry requires capturing many photographs for processing that presents some unique considerations. For example, a road corridor of 0.5 miles long and 100 ft wide, with a flight altitude of 200 ft and a resolution of 0.5 in/pixel, would require 122 images according to the DroneDeploy flight planning app, requiring 7.9 GB of storage at 65 MB/image.

Images from photogrammetry missions can be transferred from an on-board microSD card to a local

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[74] www.earthdatascience.org/courses/use-data-open-source-python/multispectral-remote-sensing/intro-multispectral-data/

[75] https://landsat.gsfc.nasa.gov/satellites/landsat-8/landsat-8-bands/

[76] https://gis.stackexchange.com/questions/89723/which-wavelengths-are-assigned-to-which-bands-in-naip-imagery

[77] https://sentinels.copernicus.eu/web/sentinel/user-guides/sentinel-2-msi/resolutions/radiometric

machine for processing, or automatically or manually uploaded to a cloud application. In either case, the photogrammetry software outputs a digital surface model or point cloud as a single file or file mosaic that can be viewed and measured directly in the photogrammetry software or exported to applications including GIS and computer-aided design software for further 3D analysis. Some applications that can accomplish these functions include Pix4Dmapper, Autodesk ReCap, and Agisoft Metashape, among others. Online services also exist for this process; they typically require a monthly subscription or per acre fee.

As an example, the Pix4Dmapper photogrammetry software can output:[78]

- Full-color point cloud (.las, .laz, .ply, .xyz)
- Orthomosaic (GeoTiff [.tif], .kml)
- Digital surface model (GeoTiff [.tif], .xyz, .las, .laz)
- 3D textured mesh (.ply, .fbx, .dxf, .obj, .pdf)

Similar to standard images, the output size of raster-based 3D surfaces depends on the number of pixels and the bit depth of each pixel. For the example above, a GeoTiff of a road segment 0.5 miles x 100 ft, at a resolution of 0.5 in/pixel, and a bit depth of 8 bits, would be 1.3 GB. Storing, sharing, displaying, and analyzing files of this size can currently be a challenge (improvements in computer processing may facilitate this in the future). Raster tiling is a technique that divides a raster into manageable pieces for faster loading and displaying locally and online. A lower-resolution version of the raster is displayed when zoomed out, and as the user zooms in progressively higher-resolution, finer-scale sections of the raster are loaded.[79]

It is possible to extract features from UAS-acquired imagery with additional software solutions or machine learning.[80] Software such as WiseCrax or CrackIT focus primarily on crack detection and classification of paved roads. Detection of other road distresses may require customized tools developed under packages like Python or MATLAB that can be used for newly developed machine learning techniques.

Video Analysis and Storage

Videos have largely the same metadata requirements as photos. Common video formats include MP4, MOV, WMV, and AVI.[81] Videos require more space than still images. As an example, a 20-min flight using the Parrot Anafi USA GOV stock camera, recording in MP4 format at full HD and 24 frames per second,[82] would require about 11.56 GB.[83]

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[78] www.pix4d.com/product/pix4dmapper/outputs

[79] https://help.arcgis.com/en/geodatabase/10.0/sdk/arcsde/concepts/rasters/entities/rastertiles.htm#:~:text=raster%20tiles&text=Tiles%20are%20used%20to%20divide,broken%2Dup%20into%20manageable%20pieces

[80] Gopalakrishnan (2018) compares some of the available techniques.

[81] www.adobe.com/creativecloud/video/discover/best-video-format.html

[82] www.parrot.com/assets/s3fs-public/2022-02/ANAFI-USA-update-productsheet-030222.pdf

[83] www.digitalrebellion.com/webapps/videocalc?format=h264_1080&frame_rate=f23.98&length=20&length_type=minutes

Lidar Data Analysis and Storage

Lidar sensors output 3D point cloud data stored as LAS files,[84] a binary format that is the published standard for the interchange of lidar data that the American Society for Photogrammetry and Remote Sensing maintains.[85] LAS files contain the metadata such as:[86]

- Data extent
- Flight date and time
- Number of point records
- Number of points by return
- Data offset
- Scale factor
- GPS location
- Timestamp
- Intensity
- Return number
- Number of returns
- Point classification
- Scan angle
- RGB values
- Scan direction
- Edge of flight line
- Point source ID
- Waveform information

The size of LAS files depends on the data extent and the point density.[87] As a reference point, a lidar dataset covering Dorchester County, SC, (576 square miles) is 10.5 GB when compressed.[88] The process of classifying points and producing surfaces from lidar data can be computationally taxing, so it is recommended to split LAS files into smaller files that are 200–500 MB each for parallel processing.[89] Some common lidar applications for classifying points include TerraScan, LAStools (+ArcGIS or ERDAS), ArcGIS, and ERDAS Imagine. PIX4D and Trimble Inpho can also manage lidar data, among others.

The final output of lidar is a raster surface, commonly a bare-earth Digital Terrain Model or a Digital Surface Model that includes tree canopy and/or built structures.[90] These files have similar storage, metadata, and sharing considerations as 3D surfaces produced using photogrammetry. If LAS files are divided for parallel processing, the resulting files can be mosaiced together in GIS for storage, viewing, and analysis.

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[84] See USGS FAQs on lidar point clouds at www.usgs.gov/faqs/what-difference-between-lidar-data-and-digital-elevation-model-dem.

[85] https://desktop.arcgis.com/en/arcmap/latest/manage-data/las-dataset/storing-lidar-data.htm

[86] Ibid

[87] Lidar data attributes can also vary depending upon how the data were collected and processed, but the initial point cloud is a collection of 3D elevation points of everything the lidar's laser beam encountered during the data survey. Lidar data can be classified in software to signify the type of object from which the laser return reflected (e.g., "road" for returns reflected off a road). Geospatial tools can then be used to extract other 3D features from the data.

[88] www.clemsongis.org/elevation-models-lidar

[89] Ibid and https://desktop.arcgis.com/en/arcmap/latest/manage-data/las-dataset/las-dataset-scalability.htm

[90] www.clemsongis.org/elevation-models-lidar

Appendix D. Project Aviation Safety Plan for the Alamosa NWR Demonstration

USGS Small Unmanned Aircraft Systems (sUAS) Project Aviation Safety Plan (PASP)

National Uncrewed Systems Office

This document covers the fourteen elements of a PASP as outlined in OPM-6. If an element does not apply to your sUAS operation, mark it as N/A (not applicable). Please add any additional information you feel is pertinent to your operations.

Project Name: Mapping Roads at the Alamosa Fish and Wildlife Refuge Alamosa, CO

Safety Provisions

1. Trainees/Students will be monitored by a qualified and current sUAS operator when flying.
2. sUAS pilots will maintain a safe operating distance from manned and unmanned aircraft.
3. sUAS Remote Pilots are responsible for determining the airworthiness of their aircraft in accordance with the appropriate standard.
4. sUAS operators must be credentialed to operate aircraft by the FAA and their agency.
5. sUAS operators who are not current on an aircraft must be supervised by an appropriately designated inspector.
6. One Pilot in Command (PIC) will be designated for each flight and will be responsible for the safety of the aircraft, persons, and property along the UAS flightpath.
7. First aid kit and fire extinguisher will be onsite.
8. Any injuries or property damage due to aircraft, lost aircraft, damage to aircraft, system anomalies, or sustained loss of link will be reported via the SAFECOM system.
9. All participants will take part in the preflight briefing and the briefing checklist must be completed at the start of each operational period.

1. **Mission Objective:**

Collect lidar and other UAS data as a proof of concept with the FWS and Federal Highways Department at Alamosa National Wildlife Refuge.

2. **Justification:**

This proof-of-concept project is set to test whether UAS lidar is a viable tool for large-scale (high detail, small area) road mapping.

3. **Dates of Operations:**

One-Year PASP: **Aug 7, 2023 – Aug 7, 2024**

Target Dates of fieldwork: **Aug 7, 2023 - Aug 11, 2023**

1. Location of sUAS Activities: *Enter a descriptive location, with latitude and longitude, and include a map (in the **Appendix A**) clearly showing the area(s) where the flights will occur. Include the class of airspace you will be operating in (e.g., Class G) and the airspace authorization you are operating under (e.g., Part 107, DOI Blanket COA # **2020-CSA-6708-COA**, LAANC authorization, etc.). Ensure you have landowner/ land manager authorization prior to flights and attach any documentation in the appendices.*

- **Location description:**
  Alamosa Fish and Wildlife Refuge, CO

- **Mission area coordinates:**
  37.377995°, -105.752487° Please see the map for the bounding box.

- **Airspace Class:**
  Class E Airspace. Requires a LAANC waiver for flight operations.

- **Airspace Authorization:**
  Airspace authorization will be submitted to the LAANC waiver system.

- **Landowner/Manager Authorization:**
  Permission from Fish and Wildlife Service will be received prior to flights.

2. Projected Cost of sUAS Operations

Cost Center Account #:
USGS National Uncrewed Systems Office and any participating units will fund their personnel at required levels with appropriate Account #s.

Cost Estimates:

Pilot Time:	$ Covered
Travel Costs:	$ Covered
Other Costs:	$ Covered
Estimated Total Operation Costs:	$ Covered

3. Aircraft

Make and Model:	FAA Registration #:	OAS Aircraft Data Card Expiration:	Approved Missions:
Mavic Pro	FA3AKCTER9	11/17/2023*	All Mavic Missions
Matrice 600 Pro	FA3AK7T4K9	11/17/2023*	All M600 Missions
Matrice 600 Pro	FA3AK7PAFH	11/17/2023*	All M600 Missions

*** Aircraft expiring during the 1-year period will be updated prior to the expiration date. Pen and Ink date changes are authorized by Regional Aviation Manager.**

4. Pilots

Pilot Name:	OAS Pilot Card Expiration:	Approved Aircraft:	Approved Missions:
Mark Bauer	3/31/2024	Solo, Mavic, M600, EVO, Anafi, FireFly, Skydio	All missions approved for aircraft

5. Mission Personnel

Personnel Name:	Aviation Qualifications:	Date of Last Aviation Training:	Project Responsibilities:

6. Communications Plan, Flight Following, and Emergency Operations

- **Communications:** *Identify communication to be used by sUAS flight crew (e.g., operating within talking distance, 2-way radios, etc.). Identify onsite communications, for check-in and in case of emergency (e.g., cell coverage, satellite communicator/phone, government radio, etc.). List any radio frequencies below (e.g., CTAF/UNICOM, Forest Service/BLM repeater, etc.).*

    - **Flight Crew Comms:**
      All pilots and flight crew will be operating within talking distance. Handheld radios will be available if communications are over greater than the talking distance required.

    - **Onsite Comms:**
      Cell coverage exists in the areas of fieldwork.

- **Radio Channels:**
  Aviation radio will be used to monitor aviation activity at San Luis Valley (ALS) the closest airport.

Channel Name/#	**Freq.**		**Phone #**
San Luis Valley (ALS) No Tower	122.8	Base Operator	719-589-5669
Alamosa (Pvt)	122.9	None	None
Blanca	122.9	None	None

- **Flight Following:** *Identify all applicable means of flight following (e.g., visual line-of-site, aircraft position via the GCS, etc.).*

  Visual line-of-site and aircraft position via tablet GCS app.
  RPIC and VOs will be positioned within talking distance.

- **Emergency Operations:** *All mishaps must be reported via the SAFECOM system. Mishaps involving missing aircraft, injuries to personnel, or damage to property other than the aircraft must be reported to 1-888-4MISHAP (1-888-464-7427).*

  - **Loss of control, communication, or visual contact with sUAS:**

    Contact the airspace controlling authority: The Air Route Traffic Control Center (ARTCC) for this area is: Denver ARTCC (ZDV) 303-651-4100.

    - **Information to include to ARTCC:**
      - Aircraft bearing
      - Altitude
      - If heading into controlled airspace
      - Battery time remaining
      - Any other appropriate or helpful information

  - **Medical emergencies**

    Emergency procedures and the nearest medical facilities, for each field site, can be found in **Appendix B**. The person on-site with the highest level of medical training will be identified prior to the start of flight operations. Any medical evacuation will be coordinated through the local emergency services (via 911). Field Covid protocols will be in place for the duration of the mission.

7. **Aerial Hazard Analysis:** *Aerial hazards need to be identified and known to all pilots prior to the start of the mission. List all known aerial hazards below. A ground survey or aerial reconnaissance flight may be needed prior to flying the mission. Utilize resources, such as SkyVector, to determine airspace in and around the project area. A sectional map of the flight area is included in Appendix*

C.

The on-site assessment is required before the first flights. Appropriate take-off and landing areas will be identified.

8. Personal Protective Equipment:

Appropriate attire, footwear, hats, and gloves will be worn based on weather conditions. Any required safety harness and additional PPE will be utilized if operating from a lift.

9. **Weight & Balance/Load Calculations:** *sUAS do not require a load calculation. Consult the manufacturer's specifications for the weight and balance of the aircraft prior to flying the project. List any concerns with the weight and balance of the aircraft (e.g., heavy payloads, hanging payloads, new sensor testing). All payloads must be approved by OAS prior to flights.*

Weight & Balance are not a factor. OAS-approved UAS aircraft and payloads will be used.

10. **Risk Assessment:** *A standard list of hazards and mitigations is listed in the tables below. Add any mission-specific hazards and mitigations. Utilizing the Risk Management Matrix, determine the likelihood, severity, and risk level for hazards and mitigations. The overall rating, for hazards and mitigations, is the highest Risk Level number listed in the corresponding tables.*

Risk Management and Safety

Reference the Aviation Risk Mgmt. Workbook, JHAs, etc., to assist completion of Risk Assessment Matrix

Risk Assessment Matrix				
	Severity			
Likelihood	IV Negligible	III Marginal	II Critical	I Catastrophic
Frequent A	2	3	4	4
Probable B	2	3	4	SERIOUS
Occasional C	1	2	HIGH	4
Remote D	1	MEDIUM	2	3
Improbable E	LOW	2	2	2

Severity Scale Definitions	
Catastrophic I	Mishaps may result in fatalities
Critical II	Severe injury/Irreparable UAS damage
Marginal III	Minor injury/Minor UAS damage
Negligible IV	No injury or UAS damage

Likelihood Scale Definitions		
Frequent	A	Occurs on a regular basis
Probable	B	High likelihood of occurring
Occasional	C	Occurs infrequently
Remote	D	Unlikely to occur, but possible
Improbable	E	Assumed will not occur

Assess the risks involved with the proposed operation. Use additional sheets if necessary.			
Describe the Hazard:	Pre-Mitigation hazards rate out as:		
	Likelihood A-E	Severity I-IV	Risk Level
1. Mid-air collision with another aircraft	D	I	3
2. Collision with fixed aerial hazard (radio tower, power lines, trees, etc.)	D	III	2
3. Collision with personnel or the general public	D	II	2
4. Collision with vehicles	D	III	2
5. Collision with birds	D	III	2
6. Operating Aircraft outside of the approved area	D	III	2
7. Operating aircraft outside of manual limitations	C	III	2
8. Fire	D	III	2
9. Cold/Heat Injury	C	II	3
10. Loss of Link with aircraft. (LOL)	C	II	3
11. Injury to fingers/hands due to spinning blades on aircraft	C	II	3
12. Hazardous wildlife (spiders, snakes, bees/wasps, etc.)	D	II	2
Pre-Mitigation Overall Rating:	3– High		

Mitigation Description and Rating:	Post Mitigation hazards rate out as:		
Describe mitigation strategies and final risk rating following migration implementation. Multiple mitigations may be listed for each risk.	Likelihood A-E	Severity I-IV	Risk Level
1. All sUAS flights will be conducted while monitoring communications channel San Luis Valley (ALS) 122.8. Observers will be placed to maintain a visual line-of-site with the sUAS and other aircraft at all times.	E	II	2
2. Prior to flights, all fixed aerial hazards will be identified, and flight route avoidance planned.	E	IV	1
3. Approach and departure patterns will be planned to avoid people. Non-participating personnel will remain clear of the ground control station so as not to be a distraction to the operators. Landing areas will be established to minimize risk to people. Overflight of personnel will be avoided.	D	II	2
4. Vehicles will be parked clear of approach and departure routes. Overflight of vehicles will be avoided.	D	IV	1
5. If a bird is seen attempting to contact the sUAS, the pilot will land as soon as practical in order to prevent injury to the animal or aircraft.	E	IV	1
6. All participants will be briefed on boundaries and maps will be uploaded into the operator control units if they have the capability. LOL will be set to return home and land. If communications with aircraft are lost and there is a fly-away, ARTCC will be contacted.	D	IV	1
7. Payloads and flight procedures are OAS approved. Acceptable weather conditions will be observed before flights commence.	D	IV	1
8. Fire extinguishers will be on-site at all operating locations and placement will be covered during the safety briefing. If fire restrictions are in place, appropriate fire suppression protocols will be in place.	E	III	2
9. Personnel will be briefed on the possible weather conditions and advised to bring proper clothing and equipment. Anyone showing signs of cold/heat stress will be moved out of the elements and, if necessary, EMS will be notified.	D	III	2
10. Prior to launching any aircraft, the LOL settings will be verified. LOL setting will be set to return to home and land. If the link cannot be re-established and there is a flyaway, ARTCC will be notified.	D	II	2
11. Checklist procedures will be followed to ensure that personnel ensures that their hands stay clear of rotating blades.	D	II	2
12. Personnel will be briefed on local hazardous wildlife and advised to always maintain situational awareness.	D	III	2
Post Mitigation Overall Rating:	2-Medium		

Appropriate Management Level for Risk Decisions		
Risk Level	Project	Incident
SERIOUS	OAS Associate Director	Incident Commander or Ops Chief
HIGH	Center Director or Regional Aviation Manager	Incident Commander or Ops Chief
MEDIUM	Immediate supervisor or higher	Air Operations
LOW	Immediate supervisor or higher	Air Operations

11. Signatures: *sUAS PASPs must be prepared by a certified DOI Remote Pilot. All sUAS PASPs will be sent to NUPO (uas@usgs.gov) for review. sUAS PASP approval is based on the Post Mitigation Overall Rating. Utilize the Appropriate Management Level for Risk Decisions chart to determine who should sign as Approver.*

Supervisors of sUAS pilots are required to be current in the following courses: A-200 Mishap Review and M-3 DOI Aviation Management for Supervisors. These courses make up the DOI Supervisor training plan and can be found on the Interagency Aviation Training website (www.iat.gov).

Review and Approval		
	Name and Title	Signature and Date
PASP Prepared by:	Mark Bauer (USGS) NUSO Remote Pilot / Geospatial Analyst	MARK BAUER Digitally signed by MARK BAUER Date: 2023.07.27 16:01:50 -06'00'
PASP Reviewed by:	Todd Burton (USGS) NUSO Regional Aviation Manager	TODD BURTON Digitally signed by TODD BURTON Date: 2023.07.27 14:11:32 -06'00'
PASP Approved by:	Lance Brady (USGS) NUSO Program Manager	

Mission Planning and Preflight Checklists

Review these checklists with all participants as part of the preflight briefing. This checklist will be completed for each operation/currency/training event.

General Safety			
1. Chain of command, individual roles, and responsibilities are identified to all participants?	☐ Yes	☐ No	☐ NA
2. Project Aviation Safety Plan is approved and signed at the appropriate levels?	☐ Yes	☐ No	☐ NA
3. Emergency evacuation plan has been reviewed.	☐ Yes	☐ No	☐ NA
4. Locate the nearest 1st Aid Kits and fire extinguishers	☐ Yes	☐ No	☐ NA
5. Discuss the communications plan and review cell coverage, and radio tests for the field site.	☐ Yes	☐ No	☐ NA
6. Have ground hazards and safety been identified to all participants?	☐ Yes	☐ No	☐ NA
7. Do all personnel have the required PPE?	☐ Yes	☐ No	☐ NA
8. Participants were briefed on landing announcements and only trained personnel recover sUAS.	☐ Yes	☐ No	☐ NA
9. Participants were briefed on sterile cockpit expectations.	☐ Yes	☐ No	☐ NA
UAS Operators and Personnel			
10. Are all agency personnel qualified for the mission?	☐ Yes	☐ No	☐ NA
11. Is the pilot carded and experienced for the mission to be conducted?	☐ Yes	☐ No	☐ NA
12. Are pilot flight and duty times compromised?	☐ Yes	☐ No	☐ NA
13. Is the aircraft properly carded?	☐ Yes	☐ No	☐ NA
14. Is the aircraft capable of performing the mission with a margin of safety?	☐ Yes	☐ No	☐ NA
15. Are there enough (qualified) agency personnel to accomplish the mission safely?	☐ Yes	☐ No	☐ NA
UAS Flight Operations	☐ Yes	☐ No	☐ NA
16. Are all aerial hazards identified and known to all participants?	☐ Yes	☐ No	☐ NA
17. Can terrain, altitude, temperature, or weather that could have an adverse effect be mitigated?	☐ Yes	☐ No	☐ NA
18. Have mitigating measures been taken to avoid conflicts with military or civilian aircraft?	☐ Yes	☐ No	☐ NA
19. Have adequate landing areas been identified and or improved to minimum standards?	☐ Yes	☐ No	☐ NA
20. Has ditch point locations been discussed in the event of a power loss?	☐ Yes	☐ No	☐ NA
21. Have the proper approvals been given by FAA?	☐ Yes	☐ No	☐ NA
22. If flying in restricted airspace, has notification been made with the controlling authority prior to launching sUAS?	☐ Yes	☐ No	☐ NA
23. Have the retrieval instructions been discussed in the event of a loss of aircraft?	☐ Yes	☐ No	☐ NA
24. Will adequate briefings be conducted prior to flight with all participants?	☐ Yes	☐ No	☐ NA
25. Is there an alternative method that would accomplish the mission more safely?	☐ Yes	☐ No	☐ NA
Other Special Cases			
26. Remember; maps of areas/sites, handheld radios, cell phones	☐ Yes	☐ No	☐ NA
27. NOTAM on file	☐ Yes	☐ No	☐ NA
28. Have all phone calls and contacts been made with Range Control?	☐ Yes	☐ No	☐ NA
Identify Corrections (if any):			
PIC Signature:	Date:		

Project Aviation Safety Briefing

This checklist will be completed for each operation/currency/training event.

Briefing Leader: Day 1________Day 2_________Day 3_________Day 4__________

Briefing Date(s):______________Time:____________Location: ___________________

Discussion Items:

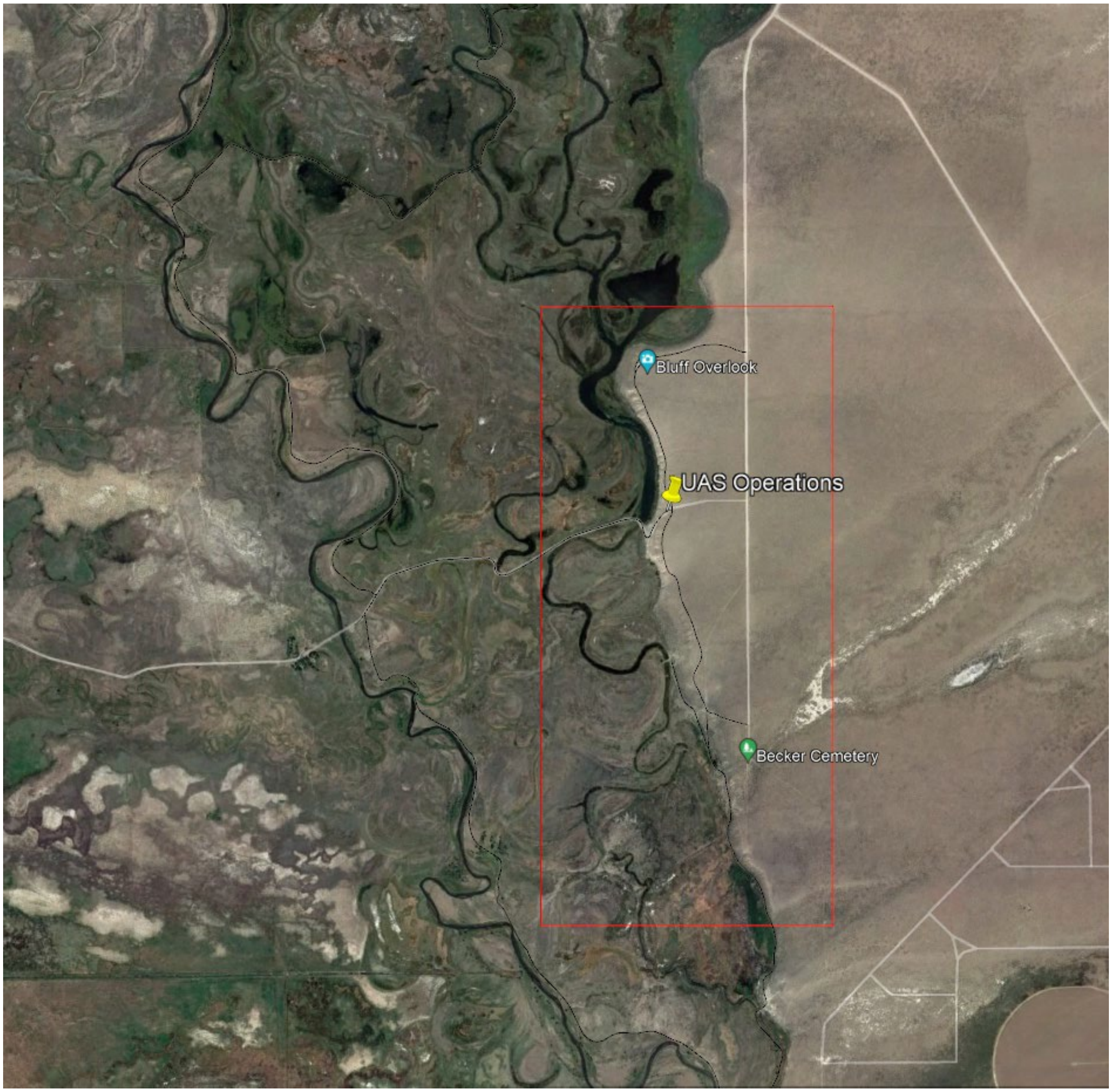
________A. Hazard Analysis (as outlined in plan)
________B. Safety Air Ops (Ground)
________C. Safety Air Ops(Flight)
________D. Military Training Routes/Restricted Airspace Deconflicted
________E. Flight Following
________F. Frequencies and Communication Plan
________G. Lost Link Procedures
________H. Emergency Evacuation Plan
________I. Authorities (Airspace and Landowner)
________J. Weather Considerations
________K. Review applicable JHAs/Risk Assessments
________L. NOTAM on file
________M. Other

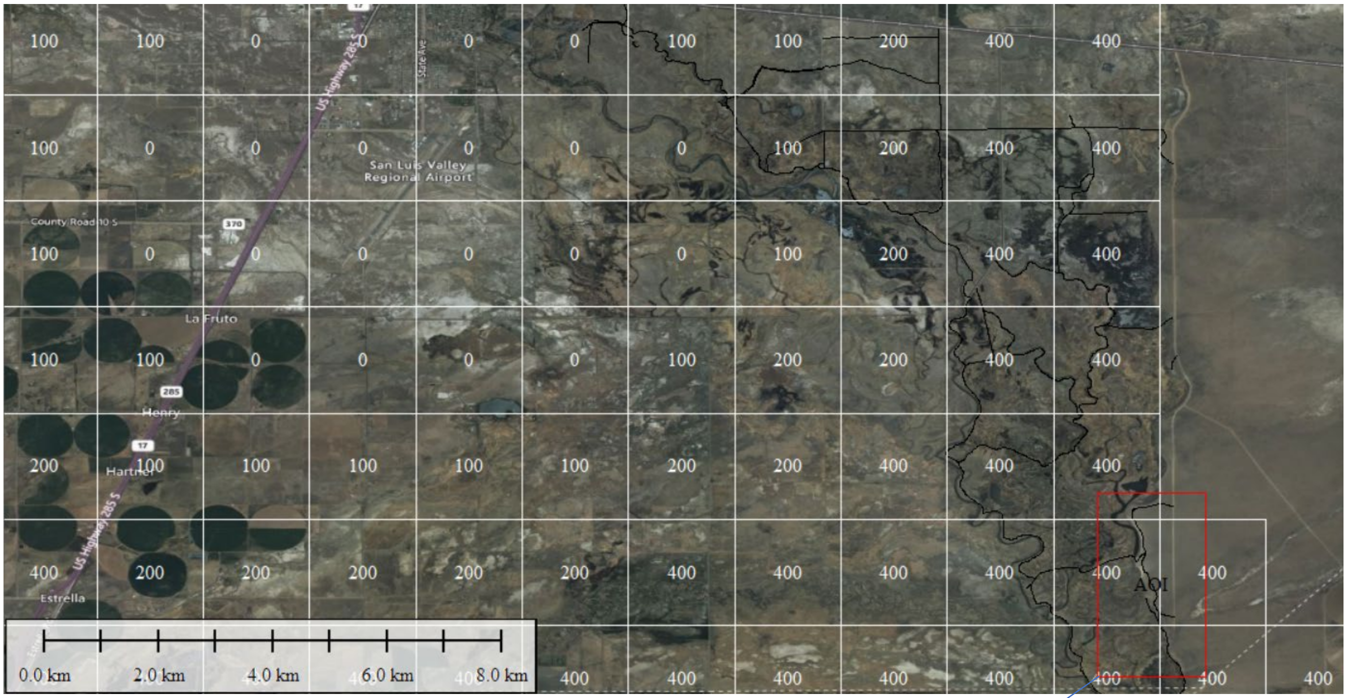
All briefing attendees sign beside their name to indicate concurrence. Sign for each day of operation.

Name (print):	**Signature:**

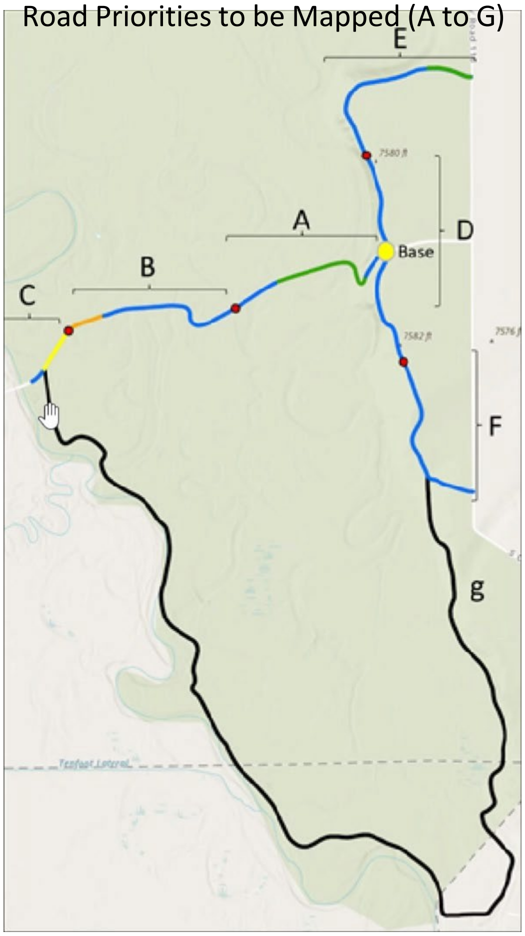
A - Mission Area(s) Map

- Red or Blue Polygon is potential AOI for collecting UAS data.





Road Priorities to be Mapped (A to G)



B – Medical Response Plan

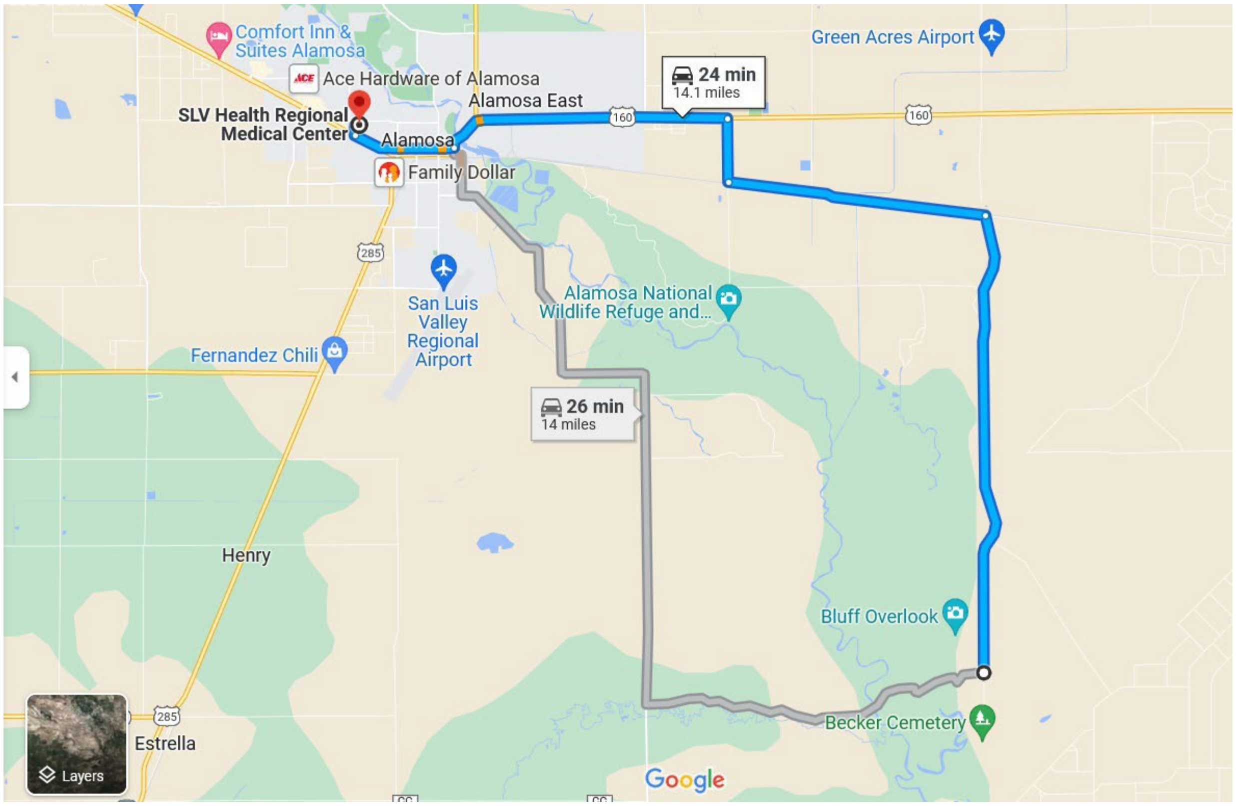
In case of a medical emergency: **CALL 911**

Nearest Medical Facility: San Luis Valley Health Regional Medical Center 106 Blanca Avenue

Alamosa, CO 81101

(719) 589-2511

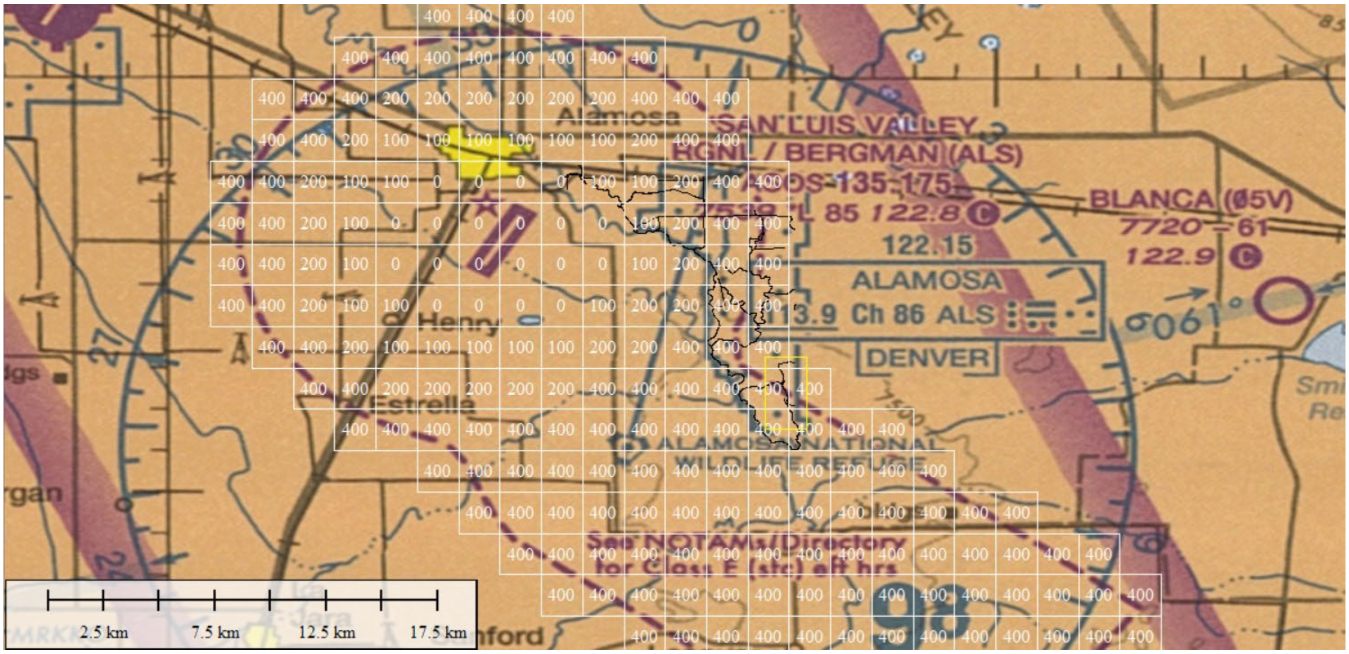
Open 24 hours



sanluisvalleyhealth.org

C – FAA Sectional

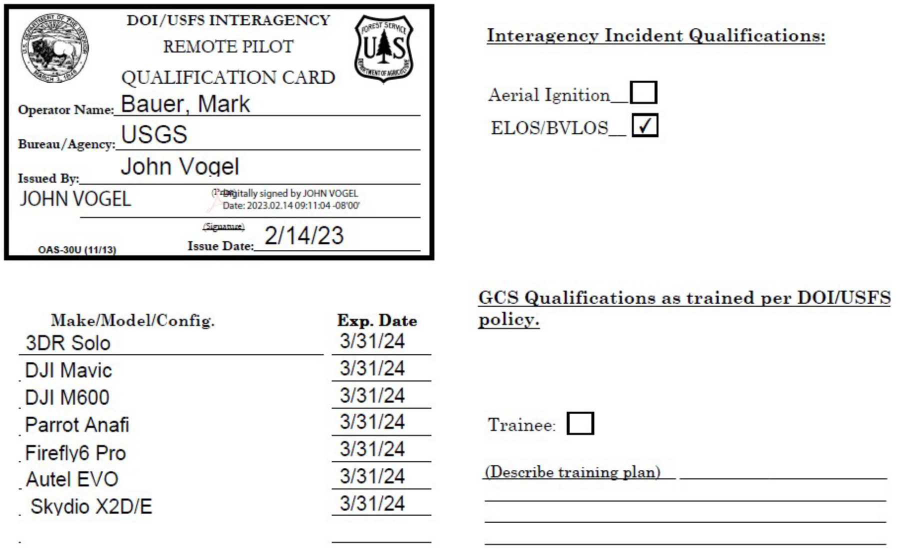
LAANC Grid shown in White AOI shown in Yellow.



D – Contact Information

Include any phone numbers listed in the PASP, as well as any other pertinent phone numbers.

Name	Number
Interagency Aviation Mishap Response	1-888-464-7427 (1-888-4MISHAP)
Denver ARTCC (ZDV)	303-651-4100
Will Hickman - San Luis Valley Regional Airport	
Carson Poe – Volpe Nat Trans System Center	
Scott Gilman - Volpe Nat Trans System Center	
Remit Work - Volpe Nat Trans System Center	
Jake Butler - Volpe Nat Trans System Center	
Mark Bauer – USGS NUSO	
Lance Brady – USGS NUSO	
Bob Bell – FHWA	
Steve Short - FHWA	
Bill McQuiston - FHWA	
Brandon Strohl - FHWA	
Katie Lyon FWS	
Mike Smith FWS	



DOI/USFS INTERAGENCY
REMOTE PILOT
QUALIFICATION CARD

Operator Name: Bauer, Mark
Bureau/Agency: USGS
Issued By: John Vogel
JOHN VOGEL (Print) Digitally signed by JOHN VOGEL Date: 2023.02.14 09:11:04 -08'00'
(Signature)
Issue Date: 2/14/23
OAS-30U (11/13)

Interagency Incident Qualifications:

Aerial Ignition__☐
ELOS/BVLOS__☑

Make/Model/Config.	**Exp. Date**
3DR Solo	3/31/24
DJI Mavic	3/31/24
DJI M600	3/31/24
Parrot Anafi	3/31/24
Firefly6 Pro	3/31/24
Autel EVO	3/31/24
Skydio X2D/E	3/31/24

GCS Qualifications as trained per DOI/USFS policy.

Trainee: ☐

(Describe training plan) ____________________