Technology Brief

e-Construction and Partnering: *A Vision for the Future*

Peer-to-Peer Exchange

Alabama, Minnesota, Missouri, Nebraska, Oregon, and Utah Departments of Transportation

Huntsville, Alabama
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U.S. Department of Transportation
Federal Highway Administration

On-Ramp to Innovation
every day counts

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Background

The Alabama Department of Transportation (ALDOT) is among the few State departments of transportation (DOTs) that have committed to establishing a statewide unmanned aerial systems (UAS) program. Although ALDOT's UAS program is advanced, the agency continues to seek effective practices for using this versatile technology to improve workflows. ALDOT hosted a two-day, face-to-face e-Construction and Partnering (eCP) peer exchange to share UAS implementation ideas and learn from peers from the Minnesota DOT (MnDOT), Missouri DOT (MoDOT), Nebraska DOT (NDOT), Oregon DOT (ODOT), and Utah DOT (UDOT). Table 1 showcases different UAS program components at each DOT. The UAS program structure at MoDOT and NDOT is currently ad hoc. These agencies have not yet institutionalized specific UAS platforms, sensors, or software.

Table 1. UAS organization and technologies at participant DOTs.[1]

	ALDOT	MnDOT	ODOT	UDOT
UAS Program Proponent	Maintenance Bureau	Office of Aeronautics	Engineering Automation Section	Division of Aeronautics
Platforms	DJI PHANTOM 4 senseFly eBee senseFly albris	Altus LRX senseFly albris Flyability Elios	DJI MATRICE 210 DJI PHANTOM 4 DJI INSPIRE 2	senseFly eBee senseFly albris WingtraOne DJI PHANTOM 4 DJI INSPIRE 2 DJI MATRICE 210 3DR Solo
Sensors	High-definition imagery (still and video); thermal	High-definition camera (360° video and still)	High-definition imagery (still and video)	High-definition imagery (still and video)
Capture Software	senseFly eMotion DJI GO Pix4Dcapture	Altus Mission Planner senseFly eMotion	DJI GO	senseFly eMotion DJI GO Pix4Dcapture
Processing Software	Bentley ContextCapture Pix4Dmapper	Pix4Dmapper Trimble Inpho ESRI Drone2Map	Bentley ContextCapture Pix4Dmapper	Bentley ContextCapture Pix4Dmapper

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The Federal Highway Administration (FHWA) sponsored the eCP peer exchange, which was held October 17–18, 2018, in Huntsville, AL, as part of round four of the Every Day Counts (EDC-4) technical assistance program. In addition to the DOT participants, several representatives from Alabama's UAS Task Force attended, as did ALDOT's UAS consultant and FHWA staff from the Alabama Division and the Resource Center.

The peer exchange focused on the use of UAS for bridge maintenance inspection, surveying, and construction quantity measurements. It also included discussions on quantifying the benefits from UAS activities. The peer exchange concluded with a field demonstration.

Project Approach

Like many other DOTs, ALDOT has experienced workforce utilization challenges due to staff reductions and retirements during the peak growth of its construction program. To address this, ALDOT evaluated opportunities to use innovative technologies, such as UAS and e-Construction, to help automate processes and increase data collection efficiency for multiple applications.

The implementation of a statewide UAS program originated from an executive order by the Alabama Governor in 2015 that designated ALDOT as the authority for the operation. The statewide management plan for the use of UAS was developed by the Alabama UAS Task Force and approved by the Governor. Subsequently, ALDOT leadership embraced UAS technology and has continually sought to further develop its capability and improve services. Since that time, ALDOT's UAS program has matured, albeit through a deliberate "crawl, walk, run" approach.

In addition to establishing a statewide UAS Program, ALDOT created a position (e-Construction Engineer) within in its Construction Bureau in late 2016 to help identify and prioritize e-Construction measures for implementation. ALDOT identified the following initiatives:

- Mobile devices.
- Electronic plans.
- Electronic forms.
- e-Signatures and document management.
- Document submittals, workflows, and retention.
- e-Ticketing.
- e-Construction systems coordination.
- Radio-frequency identification/ barcodes for materials.
- Three-dimensional (3D) modeling for design and construction.
- Construction inspection with UAS.
- Construction manual and standard specification updates.
- Contractor education.

With the convergence of ALDOT's UAS directives and keen focus on e-Construction technologies, the agency's UAS program maturity accelerated in recent years through the purchase and use of at least five UAS platforms and a mobile command center. ALDOT staff have gained proficiency in UAS data processing and defined standard operating procedures.

Figure 1. ALDOT's mobile command center was used for the field demonstration.

Similarly, MnDOT, ODOT, and UDOT have matured their programs over the past several years through sponsored research, participation in national studies and initiatives, and a commitment to use UAS technology in support of their missions. MoDOT is looking at initiating research on UAS usage, and NDOT is evaluating its UAS strategy to identify timelines and opportunities.

The participant DOTs indicated that the implementation and proliferation of UAS technology resulted from creative solutions, such as taking advantage of pooled fund research, partnering across divisions and State agencies (law enforcement, etc.), cost-sharing, and working with academia and consultants.

Workflows

The consensus of the participant DOTs was that UAS have created many new opportunities for agencies through the versatility of various aircraft types (e.g. fixed-wing, multicopter, or helicopter) and interchangeable cameras/sensors for collecting imagery and light detection and ranging (LiDAR) data. Additionally, the ability to fly UAS in support of traditional workflows has resulted in cost savings for many applications, but also created programmatic and technical challenges related to automation and suitability. However, many State DOTs across the country are evaluating and piloting UAS technology to determine the most beneficial use cases for specific transportation applications.

The eCP peer exchange discussion on workflows focused on bridge maintenance inspection, surveying and mapping, and construction applications.

Bridge Maintenance Inspection

Inspection of bridges and structures is one of the more popular initial applications of UAS technology, given its ease of deployment and low cost of operations compared to traditional manned inspections. Other benefits expressed included improved safety and increased quantity and quality of documentation. For UDOT and MnDOT, bridge inspection contributed substantially to the adoption of UAS technology.

UDOT started testing UAS in coordination with Utah State University in 2010 and formalized the program in January 2016. The first step in establishing the program was to comply with regulatory requirements by acquiring the necessary permits. UDOT purchased three aircraft in June 2016 and established policy and procedures in March 2017. UDOT's UAS program now has nine certified remote pilots.

UDOT uses UAS for performing structure inspection for pavement delamination (figure 2) and mapping the locations (figure 3) and for capturing imagery for documentation. The technology has allowed UDOT to increase the frequency of bridge inspections and to improve and supplement documentation as well.

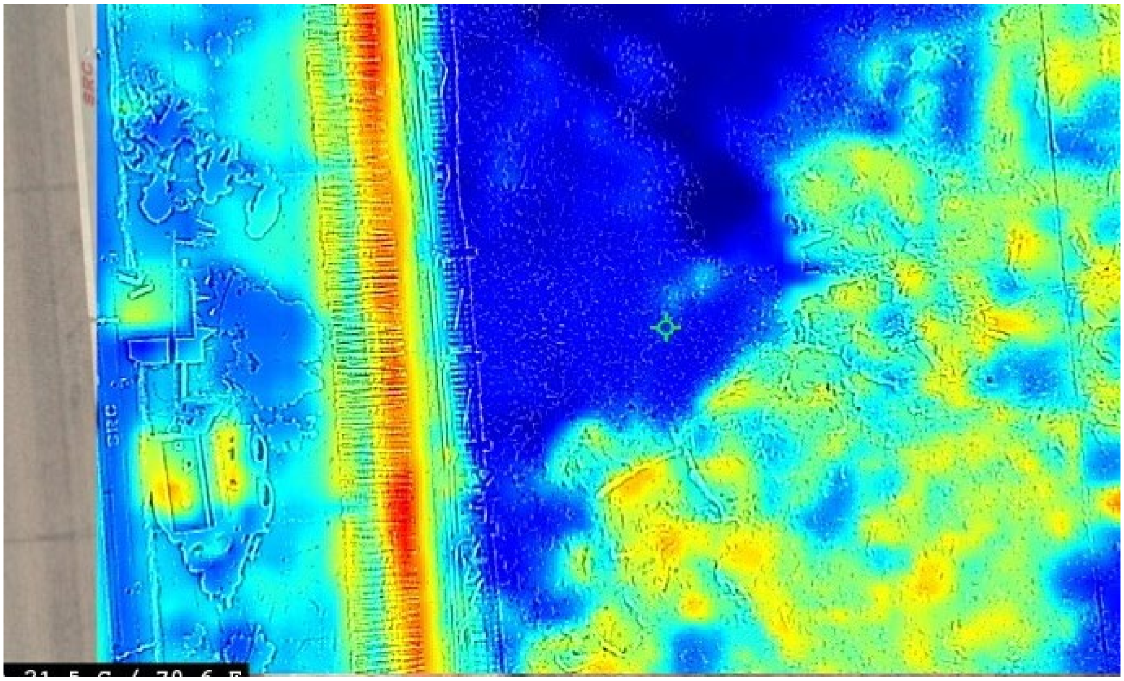

Figure 2. Thermal cameras can be used to identify pavement delamination. Source: UDOT

Figure 3. Location of delamination areas and structures can be documented using imagery GPS coordinates. Source: UDOT

MnDOT started looking at using UAS technology for bridge maintenance inspection in Spring 2015. The agency funded a three-phase research project to evaluate the technology's feasibility, select hardware appropriate for different use cases, and develop special provisions to enable the use of UAS for routine bridge inspections.

The study concluded that UAS technology is cost effective and safe for inspections of bridge decks and driving surfaces. Also, a specific type of UAS is needed for inspections of confined spaces within bridges. Georeferenced high-resolution video and still imagery improve documentation and decision-making, and post-processing software is able to deliver additional products (e.g., 3D models of the bridges and precise location of the deficiencies). Most importantly, the technology saved, on average, 40 percent of bridge inspection costs evaluated during the study compared to traditional methods.

While the UAS research was successful in determining the technology's feasibility, MnDOT is in the early stages of formalizing a statewide UAS program, which creates some challenges for moving forward. To address these challenges, the agency plans to pursue the following:

- Implement a UAS bridge inspection program at the Metro District.
- Develop a UAS-specific bridge checklist and manual for operations.
- Identify sustainable future funding streams.
- Develop a District-centric operating model for using UAS for MnDOT statewide bridge office inspections.

The UAS program for ODOT is administered by the Engineering Automation Section, which includes survey and geospatial staff. The driver for ODOT to adopt UAS was not bridge inspection, but rather surveying and mapping. However, ODOT worked with Oregon State University to conduct a benefit-cost analysis for using the technology for bridge inspections, which revealed that, on average, the agency can save more than $10,000 per bridge.

The consensus of the participating DOTs was that, before using UAS for bridge maintenance inspection applications, the bridge inspection manuals should be updated to allow for use of UAS as a support tool for inspectors. Additionally, thorough UAS-specific training on operational, technical, and procedural aspects (especially safety) is critical. Flying a UAS around bridges is a largely manual process that is influenced heavily by operator skills and the unpredictable wind conditions immediately surrounding the structure. Thus, before deploying a UAS, the remote pilot should understand the specific aircraft's capabilities and limitations as well as the unique operating environment (climate, wind conditions, etc.) in which it will be flying.

Surveying and Mapping

UAS technology has created opportunities for State DOTs to supplement surveying and mapping operations quickly and inexpensively for small and/or difficult to access areas. However, there is still some uncertainty with respect to achievable accuracies for specific applications, such as engineering design.

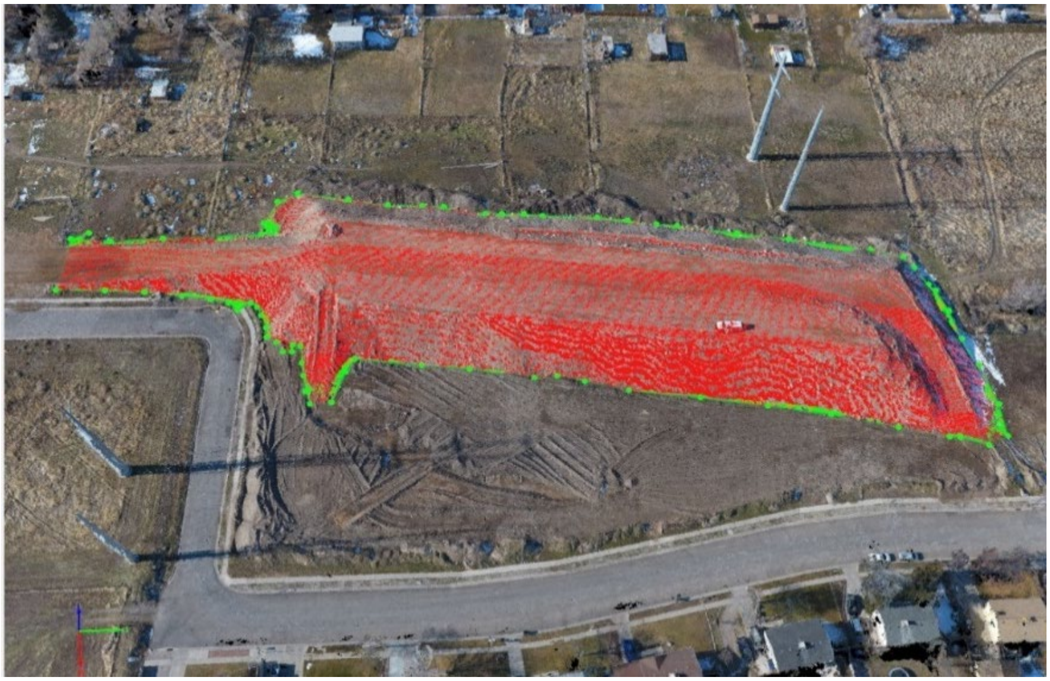

Figure 4. UAS mission for surveying and mapping. Source: UDOT

ALDOT is currently testing the capabilities of its UAS fleet to meet surveying and mapping needs based on the standard targeting methodologies and configurations, control specifications, and processing guidelines previously developed by the California DOT. ALDOT surveyors have found that the Global Navigation Satellite System (GNSS) positioning from the UAS can only provide 1- to 5-meter accuracy without real-time kinematic (RTK) corrections, depending on the hardware. ALDOT recommended peers enlist their respective survey staff to validate the vendors' claims when it comes to achievable accuracies.

ALDOT indicated that photo-identifiable control points are also needed for higher-accuracy data, but the number of such points depends on project requirements. Another effective practice is to design the layout of the control points on existing imagery or Google Earth™ maps during the mission planning phase. Lastly, ALDOT recommended validating results against pre-determined checkpoints and surveying protocols (e.g., RTK with dual observations or leveling loops).

ODOT and UDOT use a hybrid data collection approach for project requirements using UAS, LiDAR, GNSS rovers, and total stations. The technology is chosen based on obtaining the required accuracy while increasing productivity and safety. UDOT has observed an up to 60 percent increase in data collection productivity using this hybrid approach. MnDOT survey staff is investigating the use of UAS for surveying and mapping applications.

Advancements in integrating LiDAR technology with UAS show promise for higher-accuracy applications given its ability to penetrate vegetation. Aerial imagery accuracy from both unmanned and manned aircraft is limited by the features that can be seen in the image; thus, point clouds derived from images typically have high uncertainty with bare surface elevations in vegetated areas. Regardless of these limitations, the requirements for surveying and mapping applications will drive what technology will be used, which may or may not determine UAS is a suitable technology.

The workflow for surveying and mapping applications is informed by several conventional surveying principles, including:

- Staff and public safety is the primary consideration for any operation.
- Project requirements drive which technology will be used.
- Primary ground control/targeting is configured to encompass the area of interest.
- Technology is to be in good working condition.
- Data is validated against requirements and verified for completeness and quality in the field as well as before processing.

Specific UAS protocols that are notable include airspace authorizations, preflight briefings to flight participants and relevant stakeholders (airport, law enforcement, contractor, etc.), post-flight debrief with flight participants to capture lessons learned, and post-flight maintenance checks.

Construction Applications

The most common use case for UAS during construction is progress and site monitoring. UDOT is using UAS to assist with site analysis by flying missions before, during, and after the project. This documentation has helped UDOT compare datasets to settle discrepancies between parties. UAS are also being used to document everyday work zone traffic control, which assists the agency with related claims and lawsuits.

Another use case for UAS during construction is measurement of pay item quantities. Common measurements include earthwork and stockpile volumes and area and linear-type pay items. The task of measuring volumetric construction quantities has typically been performed by surveyors. Thus, the same workflows used for UAS surveying and mapping operations apply for measuring construction quantities. UAS mission crews, surveyors, and construction staff must work together throughout the project to understand requirements for deliverables and timing of flight missions.

It was noted that developing standardized procedures is important to ensure consistency, repeatability, and predictability when using UAS. The ability to conduct frequent flights over the same area to measure payment quantities requires workflows to be repeatable and reliable to avoid any disputes. There are certain pay items that are more conducive to using UAS technology than others, so it is important to understand those requirements before using UAS to measure quantities. For example, measuring earthwork quantities (i.e., small segments of roadway easily collected under visual line-of-sight flight requirements) with UAS may provide sufficient data for payment, whereas measuring final pavement quantities (i.e., longer segments of roadway beyond what visual line-of-sight flights can cover) may require data collection by another technology.

Figure 5. UAS mission to monitor construction progress. Source: ODOT

Regulatory Requirements

The DOTs noted that they operate under the Federal Aviation Administration (FAA) requirements (14 CFR part 107). UAS operators in both the public and private sectors must also adhere to statutory and regulatory requirements. Public aircraft operations (including UAS operations) are governed under the statutory requirements for public aircraft established in 49 USC § 40102 and § 40125. Additionally, both public and civil UAS operators may operate under the regulations promulgated by the Federal Aviation Administration. The provisions of 14 CFR part 107 apply to most operations of UAS weighing less than 55 lbs. Operators of UAS weighing greater than 55 lbs. may request exemptions to the airworthiness requirements of 14 CFR part 91 pursuant to 49 USC §44807. UAS operators should also be aware of the requirements of the airspace in which they wish to fly. The FAA provides extensive resources and information to help guide UAS operators in determining which laws, rules, and regulations apply to a particular UAS operation. For more information, please see https://www.faa.gov/uas/.

Safety Considerations

The DOTs noted certain safety considerations that should take place before, during, and after UAS flights. First, the remote pilot should brief the flight participants on what to expect during takeoff, flight, and landing, noting that takeoffs and landings will be verbally announced. During the flight, it is important to avoid interfering with or distracting the remote pilot. He or she will need to focus on piloting the aircraft by monitoring the telemetry and camera. The remote pilot and the observer should maintain contact with each other throughout the flight, both for awareness and coordination. Also, keeping a watchful eye on the aircraft behavior and surrounding airspace is important for avoiding incidents with other UAS or manned aircraft as well as ensuring the UAS command and control link is not compromised. After the flight, it is highly recommended that agencies hold a debriefing session to document what went right and wrong and how to improve the next mission.

It was also noted that airspace management is increasingly becoming an important consideration to ensure deconfliction. The DOTs discussed positive deconfliction being radar-based, procedural deconfliction by altitude and horizontal space, and time deconfliction by providing flight logs.

Cost and Benefits

Everyone agreed that using UAS for transportation applications includes the following benefits:

- Setting up minimal traffic control zones and reducing traffic impacts.
- Increasing accessibility to challenging terrain.
- Improving documentation through high-resolution imagery.
- Increasing efficiency through automated data collection and feature extraction.
- Improving data quality.

While many of these benefits have been validated through several studies and pilot projects, *it is important to note that the use of UAS for inspection is best suited as a supplement to the inspector's workflows.*

Only ODOT and MnDOT have formally quantified the costs and benefits specific to the use of UAS for bridge inspections. ODOT estimates more than $1 million in annual benefits for an investment of almost $130,000, which illustrates a high benefit-cost ratio. A breakout of the agency's estimated savings by UAS for bridge inspection is summarized in table 2.

The benefit variables used in the analysis included the average cost savings per bridge from the use of UAS, number of bridges inspected by ODOT annually, and the fraction of bridges suitable for the use of UAS. The cost variables used in the analysis included UAS equipment purchases, maintenance costs, and data storage costs. The information in table 2 indicates a positive return on investment (ROI) for implementing UAS for bridge inspection. However, given ODOT does not have a formal UAS inspection program, there were several assumptions and estimations used in the analysis. (Gillins, Parrish, Gillins, & Simpson, 2018)

Table 2. Breakdown of ODOT's estimated savings in using UAS for bridge inspections.

Savings Category	Estimated Savings
Personnel time	$3,900
Equipment rental	$2,800
Traffic control	$3,500
Total estimated savings	$10,200

MnDOT found results similar to ODOT's, with an average time savings of 10 percent; however, in some cases the savings were as high as 60 percent. As expected, the in-field inspection time was reduced substantially, but the post-processing added time.

UDOT applied a suite of geospatial technology (e.g., UAS, LiDAR, Global Positioning System [GPS], and 3D engineered models) on its first project using the 3D model as the legal document that resulted in an overall cost savings of about $82,672 (2.58 percent), with the workforce being 45 percent more productive. While no formal ROI calculation was presented, UDOT noted that the combined use of UAS with GPS technology for construction engineering and inspection resulted in a positive ROI. Furthermore, the use of UAS with other e-Construction technology contributed to a 25-day reduction in the construction schedule. UDOT also noted that it is difficult to quantify the cross-utilization of data within the agency.

ALDOT indicated that costs and benefits have not been formally quantified, but its investment generally paid off in the first two jobs from the perspective of consultant services and efficiency. Also, the tool proves highly useful when used as a supplement to other technologies and techniques, such as LiDAR and traditional inspection methods. Furthermore, when considering a contractor versus self-performing model, it was generally agreed upon that having subject matter expertise in-house aided negotiations with contractors and frequently led contractors to use the technology more effectively, with lower risks to projects and better project outcomes.

Lastly, some participants indicated there may be unique circumstances requiring further investigation to understand programmatic nuances with funding, license agreements, insurance savings, and effect on claims/dispute resolution. It was recommended that recurring software costs be calculated into the program budget.

Field Demonstration

ALDOT set up a field demonstration to allow participants to experience a flight mission. The ALDOT UAS staff and their consultant planned the field demonstration to simulate a typical mission. They selected a site and coordinated with appropriate authorities prior to the peer exchange. The ALDOT UAS staff gave participants an overview of what to expect during the mission before everyone arrived at the site.

ALDOT staff showed the different components inside a custom mobile command center that serves as the communication and data hub for UAS operations. ALDOT's command center is a fully enclosed trailer with an 8000-kilowatt generator, for which 35 gallons of fuel provides enough power for about 1 week. Other features include a server rack, Wi-Fi®, communication links, UAS repair area, storage areas for spare parts and tools (among other supplies), UAS take-off and landing pad, microwave and refrigerator, and workstation areas for data processing.

The demonstration started with a flight operated by MnDOT staff using the Flyability Elios UAS (figure 6), which is used for inspections of confined spaces (e.g., single box culverts). Then, ALDOT conducted several flight missions to showcase the capabilities of the DJI PHANTOM 4 and the senseFly Ebee UAS (figures 7) and two other systems owned by a consultant.

Figure 6. MnDOT's Flyability Elios UAS.

Figure 7. ALDOT's DJI PHANTOM 4 and senseFly Ebee UAS.

Key Takeaways

The experiences shared by the DOT representatives featured four key themes: program start-up, technical considerations, safety and regulations, and institutional challenges.

Program Start-up

Building capacity is critical given these programs are significant additions to DOTs, and it may take up to one year from commitment to formalizing a program. Steps for establishing a successful UAS program include appropriation of dedicated funds for purchasing equipment, software, and training services and adding staff to manage operations. Establishing policies and procedures and defining a long-term training curriculum are equally important. Planning and defining robust policies and strategies, along with standardizing procedures, ensures consistency, repeatability, and predictability. Lastly, the consensus among participants was that UAS technology requires moving beyond academic study and applying a hands-on approach to evaluating its usefulness, which is possible with a dedicated staff for managing all UAS activities.

Technical Considerations

State representatives indicated a critical success factor is to understand the limitations and capabilities of UAS equipment available in the market. Learning about the different platform options will help define suitability for specific applications and functional needs. Another key success factor is proper mission planning. It is during this phase of the mission that image overlap, flight altitude, and ground control placement are determined to ensure the resulting data will achieve accuracy and resolution requirements for imagery quality, quantity measurement, and monitoring purposes. It is also important during mission planning to prepare for potential loss of GPS signal by outlining mitigation procedures, such as switching to manual operation. Lastly, quality control and assurance protocols should be followed to ensure data integrity is not compromised and all requirements are met.

Collaboration with Information Technology staff is also critical to ensure proper data storage, accessibility, and management protocols are established to support the UAS program. ALDOT indicated that having a mobile command center has helped with interim data storage and post-processing, equipment management, and quick mission deployment.

Safety and Regulations

The prevailing theme was that safety and risk mitigation should take priority in all UAS programs and operations. Transparency and community engagement were also an enterprise imperative.

Recent and anticipated changes in the regulatory environment governing UAS operations were discussed at length due to the various UAS integration activities underway (e.g., the FAA UAS Integration Pilot Program). There is a clear need for the DOTs to work more closely with the FAA by enabling regulatory compliance for State DOT UAS operators, which will maximize operational efficiencies and enhancements through the use of UAS technology.

Institutional Challenges

Significant side discussions occurred during the peer exchange emphasizing the importance of thinking creatively about opportunities for DOTs to leverage this technology across the various DOT verticals as well as across State agencies (law enforcement, natural resource management, etc.) that support programmatic improvements ranging from data storage and management to collaborative procurement practices.

While nearly every DOT could speak to each topical area, it was clear that regional geographic demands influence their programs. For example, MnDOT and ODOT focus on using UAS for bridge maintenance inspections, given the number of bridges they maintain. ALDOT and UDOT use UAS frequently during construction, in part because both DOTs are accommodating significant construction program growth.

Nurturing a continuous learning environment and employing iterative improvement processes to program administration and technical capability were key for successful implementation and for staying abreast of advancements in technology and in the regulatory environment.

Finally, State DOTs' UAS programs are generally oriented toward addressing internal utilization of the technologies; however, as UAS technology develops into cargo and passenger capacity, there is a significant role for State DOTs in influencing the way these technologies are integrated into the existing transportation infrastructure. Taking prudent and deliberate steps now with evolving DOT capability and program maturity will further enable these future advancements.

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Contacts for More Information:
FHWA Office of Infrastructure, Chris Schneider — christopher.schneider@dot.gov
FHWA Resource Center, Kat Weisner — kathryn.weisner@dot.gov

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