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Developing a Plan for Using Unmanned Aerial Vehicles for Traffic Operations Applications in Virginia

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16. Abstract:

State departments of transportation are utilizing unmanned aircraft systems (UAS) in a variety of applications that support planning, construction, maintenance, and operations within their jurisdictions. As the use of UAS to support road-traffic-related applications is currently limited by a host of technical, regulatory, and operational issues, further exploration of these aspects is needed to inform the Virginia Department of Transportation's (VDOT's) plans to expand the use of UAS to improve travel safety and traffic operations. This exploration included conducting a comprehensive literature review to determine the current state of technology and practice, developing a conceptual plan for UAS implementation into VDOT operations, and performing a UAS application pilot demonstration. The state-of-practice review included VDOT's use of UAS, as well as that of other state DOTs that have employed UAS in their operations. As part of the implementation plan development, the researchers conducted a survey of state transportation agencies to assess the level of UAS usage, the types of applications that have been used, and impediments to implementation.

This work indicates that 36 out of 50 states (72%) are currently employing UAS for various transportation applications, and many are funding centers and programs for UAS operations. Moreover, each of the state DOTs is approaching the introduction and use of UAS technology differently. In many cases, states that had an advanced UAS program have also had a champion who achieved early adoption by leveraging available resources, knowledge, and experience. The experience of these agencies varies widely; some have a wide range of UAS application experience, while others have explored a much narrower range of uses. A preliminary implementation plan was developed that encompassed aspects of potential UAS traffic applications and metrics that could be used to assess an effective UAS deployment.

After review of numerous potential UAS applications, assessment of traffic flow at intersections was selected for pilot demonstration. UAS video data was collected at five intersections, and the data from one intersection was analyzed using an online computer vision tool to characterize traffic flow. This intersection was chosen for analysis due to the availability of data from an existing camera-based traffic monitoring system. The two methods of traffic video analysis were described and compared using a small segment of live traffic data. The existing traffic monitoring system uses cameras mounted on signal mast arms and relies upon highly oblique views of vehicles across multiple lanes of traffic, which often results in visual occlusion. In general, the improved view afforded by UAS data acquisition translated to a more accurate assessment of traffic flow. UAS acquisition also provides more flexibility with respect to deployment and a better, more expansive view of the intersection and approaching traffic. However, the UAS system is very limited with respect to viewing time as battery-powered flights are short, and flights over people and moving vehicles are currently restricted by regulations. Longer flight data collection may be accomplished using tethered UAS where power is provided to the aircraft directly from the ground.

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FINAL REPORT

DEVELOPING A PLAN FOR USING UNMANNED AERIAL VEHICLES FOR TRAFFIC OPERATIONS APPLICATIONS IN VIRGINIA

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This work indicates that 36 out of 50 states (72%) are currently employing UAS for various transportation applications, and many are funding centers and programs for UAS operations. Moreover, each of the state DOTs is approaching the introduction and use of UAS technology differently. In many cases, states that had an advanced UAS program have also had a champion who achieved early adoption by leveraging available resources, knowledge, and experience. The experience of these agencies varies widely; some have a wide range of UAS application experience, while others have explored a much narrower range of uses. A preliminary implementation plan was developed that encompassed aspects of potential UAS traffic applications and metrics that could be used to assess an effective UAS deployment.

After review of numerous potential UAS applications, assessment of traffic flow at intersections was selected for pilot demonstration. UAS video data was collected at five intersections, and the data from one intersection was analyzed using an online computer vision tool to characterize traffic flow. This intersection was chosen for analysis due to the availability of data from an existing camera-based traffic monitoring system. The two methods of traffic video analysis were described and compared using a small segment of live traffic data. The existing traffic monitoring system uses cameras mounted on signal mast arms and relies upon highly oblique views of vehicles across multiple lanes of traffic, which often results in visual occlusion. In general, the improved view afforded by UAS data acquisition translated to a more accurate assessment of traffic flow. UAS acquisition also provides more flexibility with respect to deployment and a better, more expansive view of the intersection and approaching traffic. However, the UAS system is very limited with respect to viewing time as battery-powered flights are short, and flights over people and moving vehicles are currently restricted by regulations. Longer flight data collection may be accomplished using tethered UAS where power is provided to the aircraft directly from the ground.

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INTRODUCTION

Background

In the past decade, non-military usage of unmanned aircraft systems (UAS) that employ unmanned aerial vehicles (UAVs), commonly referred to as drones, has increased significantly. Previously used primarily for military monitoring and offensive operations, inspection activities, and survey applications, UAS are seeing increasing application for a variety of civilian tasks, including infrastructure monitoring, precision agriculture, package delivery services, search and rescue operations, photography, and more. Among many public and private sector organizations, transportation agencies are in a unique position to leverage this emerging technology to improve safety, mitigate congestion, improve awareness, and provide cost savings. According to a recent survey by the American Association of State Highway and Transportation Officials (AASHTO) *(*AASHTO, 2019*),* 36 state departments of transportation (DOTs) have carried out or are exploring applications of UAS in various aspects of transportation, including inspecting bridges, collecting traffic data, and assisting with crash site clearance.

Operations divisions within transportation agencies are charged with keeping traffic moving efficiently and safely under a wide range of conditions that are constantly changing. Traffic Operations Centers rely upon a variety of tools to monitor and control vehicular flow.

These may include analysis of historical data, collection and assessment of real-time data, and predictive models of anticipated traffic. Timely assessment of the state of the roadway infrastructure is also critical to operations. These activities have relied upon acquisition of high quality and rich data, including that derived from roadside sensors such as cameras and radar, as well as crowdsourcing. The limitations of these data sources stem from their likely fixed locations, as is the case with radar and cameras, and from data quality issues inherent with the use of traffic sampling with vehicle probes. UAS are increasingly viewed as a tool for acquisition of data with capabilities that mesh well with more conventional systems. UAS offer the ability to quickly collect data on temporal disruptions, to fill in data gaps, and to provide more comprehensive and higher quality information to those managing and planning operations.

Moreover, transportation agencies and emergency responders are continually seeking new technologies and systems (especially for major traffic incidents) that can improve incident response, monitoring, and clearance (Stevens & Blackstock, 2017). Virginia's highway system experiences considerable traffic congestion—some from high traffic volumes such as on Interstates 95 and 81 and some from traffic incidents, both minor (e.g., crashes, stalls, and road debris) and major (e.g., vehicle rollovers, chemical spills, flooding, and hurricane evacuations). These incidents can literally bring the highway system to a standstill, which results in significant economic impact for drivers and businesses. Quick response and clearance of traffic incidents through traffic incident management practices are proven methods of restoring roadway capacity and increasing mobility on urban networks. UAS can play a major role in this process.

PURPOSE AND SCOPE

The primary objectives of this study were to:

- Compile a list of demonstrated and potential UAS road traffic applications and evaluate their viability for near-term deployment in Virginia with respect to technology, regulation, and operational limitations;
- Build on related UAS work that has already been performed by the Virginia DOT (VDOT) to develop a conceptual plan for VDOT's integration of UAS for support of their traffic operations; and
- Conduct pilot-scale demonstrations of those UAS applications determined to be the most salient with respect to VDOT's needs as determined by the Technical Review Panel (TRP).

Although this work was completed with a focus on VDOT's Operations Division activities, the findings presented may also have applications within other divisions of VDOT and other state agencies.

METHODS

The four major tasks that were conducted to achieve the research objectives are summarized as follows:

- Determine the current and near-future state of practice and technology. This task included conducting an extensive review of the literature on UAS used by various states, current Federal Aviation Administration (FAA) and state regulations, and assessing elements such as technology development, data collection, and other relevant information. This task also included a survey of various VDOT peer users to determine their views on what UAS applications were being used and how these were integrated within their operations.
- Development of a draft UAS implementation plan that would integrate the technology into VDOT's traffic operations safely and effectively. This task used findings obtained in Task 1 and further investigated design and operation features needed for potential system deployment.
- Perform UAS demonstration pilots. This task was based on the findings of Tasks 1 and 2, and guidance from the TRP following their review of the draft Interim Report.
- Develop recommendations for future deployment of new UAS technologies and applications in operations and, potentially, other divisions.

Task 1. Determine the Current and Near-Future State of Practice and Technology

A literature review was conducted to identify and assess available technologies and methods and their suitability for traffic operations deployment. The search for relevant studies covered primarily domestic publications and projects but also inquired into international case studies where similar systems were implemented. An online survey of UAS practitioners at other state transportation agencies was conducted to invite their input on their experience, significant benefits, and performance measures related to technology deployment and implementation programs. Inquiries were also conducted to identify other states' approaches to implementing UAS technology and potential issues experienced.

Task 2. UAS Draft Implementation Plan

The results of Task 1, reviews of publicly available literature, pertinent UAS regulations, and VDOT'S past and current UAS activities, as well as the knowledge of the research team, were used to develop a conceptual UAS implementation framework. The functional requirements for implementation of a UAS program were identified. FAA and other regulations pertaining to prospective VDOT UAS operations were identified and described. Implementation efforts at VDOT and peer agencies were reviewed. A core list of prospective UAS applications that are relevant to current and future VDOT operations was developed and included applicable area and functional descriptions. Also, a list of primary considerations for VDOT's UAS implementation process was compiled.

Task 3. UAS Demonstration Pilots

Based on the findings of Tasks 1 and 2, the researchers compiled a list of possible UAS traffic-related applications and submitted it to the TRP to review and rank as part of an Interim Report. A subsequent meeting of the TRP, Virginia Transportation Research Council (VTRC) staff, and research team members was held online to discuss potential demonstration activities that focused on roadway and traffic monitoring, incident management, driver assistance, and communication enhancement. Although many of the applications present a real-world solution to traffic problems, currently not all applications can be considered due to certain technology limitations, such as UAV battery life or software capabilities, as well as weather and regulations. This discussion was used to identify a use case for the pilot. The Results section provides an overview of the candidate pilot applications, a detailed description of the pilot selected, and the respective evaluation.

Task 4. Recommendations for Future UAS Deployment

The findings of this investigation and the combined experience of the research team were used to develop recommendations for VDOT's consideration with respect to future deployments of UAS to assist with its operations.

RESULTS AND DISCUSSION

Task 1. Determine the Current and Near-Future State of Practice and Technology

UAS Characteristics and Capabilities

UAVs are multi-purpose aircraft that may operate under the direct control of a remote pilot, or which may be flown autonomously via onboard or remotely located control systems. UAS more broadly include the UAV as well as any supporting systems including pilots, control hardware and software, and ancillary systems such as sensors (e.g., weather, radar) and communication equipment. It has been recognized that the benefits of UAS are wide ranging and impact many aspects of highway transportation, such as aiding with ground inspections, increased data accuracy, and expediting traffic data collection. Moreover, UAS technology provides DOTs with a new perspective on incident response for recurrent and non-recurrent roadway congestion while providing richer and more accurate data to informing decision making and planning.

Generally, there are two types of UAVs: fixed-wing and rotating-wing (i.e., rotorcraft). Rotorcraft such as helicopters and multi-rotor aircraft such as quadcopters, have a vertical take-off and landing capability. Fixed-wing UAVs typically takeoff from the ground along a horizontal trajectory, although some may be launched by hand or other mechanism. Rotorcraft UAVs are relatively easy to operate and capable, but they typically have relatively short flight times and a more limited range. Fixed-wing UAVs are typically smaller versions of airplanes having one or more propellers to provide constant forward propulsion. Their wings are rigid and are equipped with control surfaces that guide the vehicle to the intended location. Similar to rotary-wing UAVs, the fixed-wing UAVs can be manufactured in various sizes and can carry a wide variety of payloads for longer distances with respect to power consumed. Hybrid UAVs are also available; these combine vertical takeoff and landing capabilities with fixed-wing horizontal flight. Figure 1 shows Google Wing's hybrid UAV operating at the Virginia Tech Transportation Institute's (VTTI's) Virginia Smart Roads facility as part of a flight operations and marketing study.

Figure 1. Google Wing's Hybrid UAV Operating at the Virginia Smart Road at VTTI

Literature Review

A review of available literature was conducted to determine the current and near-future state of the practice and technology with respect to prospective DOT uses of UAS for operations and other tasks. It is worth noting that this is just a snapshot of the state of technology and applications in a field that is experiencing rapid growth. Included in Table 1 is a list of UAS applications that have been demonstrated by state DOTs or others that directly support highway transportation operations. Also included are respective regulations and/or exemptions, the type of equipment and sensors used, the area of operation, specific capabilities and technical limitations, and source information.

Table 1. UAS Traffic Applications and Related Aspects as Implemented or Investigated by other States

Application/DOT	Policies/ Regulations	UAV Type	Sensors	Operation Area	Capabilities	Technical Limitations	Observations/Source
Incident management and crash reconstruction	FAA regulations for small UAS	DJI Inspire 2 tethered	High-resolution camera	VTTI	Unlimited power and video streaming	None for this application	VTTI-VDOT project to test, Demo projects (2015)
Safety service patrol vehicle paired with tethered UAV for real-time video streaming to the Traffic Operations Center	FAA regulations for small UAS	DJI Inspire 2 tethered	High-resolution camera	VTTI	Unlimited power and video streaming	None for this application	VTTI-VDOT project to test, Demo projects (2017)
Enhancing the performance of traffic flow monitoring	FAA requirements for pilot-in-command (PIC)	Not specified	Various depending on application	Tethered/ untethered	Depending on application (high-resolution camera, long flight time)	Data logging	Three-dimensional models can be created from geo-referenced data Irizarry et al. (2017)
Traffic monitoring and incident management (Michigan DOT)	FAA compliance	DJI and others, multi-rotor and fixed wing	Various depending on application	Tethered/ untethered	Depending on application (high-resolution camera, long flight time)	Camera software	Brooks et al. (2015)
Traffic incident management (UAS-TIM) Traffic monitoring, crash scene mapping (Texas DOT)	Privacy exemption for UAS-TIM Ops	Multirotor, untethered, fixed wing	Various camera systems, long-range zoom electro-optical/infrared	Remotely piloted untethered UAS (autonomous flying)	Real-time enhanced video and photography, safe flight operation near or over live traffic	FAA limitations and use of information gathered from UAS	UAS provided real-time video to a traffic incident management central location; multiple states have developed various UAS programs Stevens (2017b)

Application/DOT	Policies/ Regulations	UAV Type	Sensors	Operation Area	Capabilities	Technical Limitations	Observations/Source
Traffic flow estimation at signalized intersections	Not needed	Custom-built octocopter UAV (Argus-One) GPS: DJI A2 GPS Compass Pro	Panasonic Lumix GH4 DSLM camera 16 MP	Remote	Provides stable and high-resolution (4K@25 fps); No fish-eye effects (curvature, wide field of view)	Short Flight time Detection software prone to various types of errors	Methodological study Khan et al. (2018)
New Hampshire DOT investigated UAS use for transportation applications and costs and benefits	FAA regulations and waiver application	DJI and SenseFly®	High-resolution cameras, image analysis software	Near intersections	Multiple camera orientations for oblique data collection	Weather and battery life	Applicability of UAS for transportation operations and implementation process O'Neil and Estabrook (2019)
Traffic data collection and information on driving behavior parameters (Italy, Calabria)	National regulations	Multirotor, small payload, flight time: 30 min	GPS, high-resolution camera able to capture videos up to 4k	Manual /flight planning driver mode	Provides high-resolution images.	Weather factors, modest autonomy, low payload	Can determine vehicle trajectories and driver behaviors Salvo et al. (2017)
Traffic surveillance and roadway incident; tests conducted in Newark (New Jersey DOT)	FAA compliance for flying a small UAS	Quadcopter UAVs (DJI Phantom 2)	Video camera system Supports First Person View	Remote	Fail-safe protocol (enabling the aircraft to automatically return to the initial point)	Short-range wireless communication	Software and hardware need improvement to increase image quality Lee et al. (2018)
Traffic flow estimation and analysis and vehicle classification (Singapore)	Local campus regulations	Quadrotor unmanned aerial vehicle	Downward looking camera, laser range finder	Remote	Eliminate the displacement incurred by camera jitter	Low image quality during nighttime	Proposed method works effectively on a wide range of complex scenarios Hong et al. (2019)
Safety and traffic patterns monitoring among other applications	Following FAA rules and regulations	Various UAS for different applications	Various sensors and cameras for traffic monitoring	Based on application	Assessment of traffic conditions in real time	High altitude vehicle recognition	Survey on civil applications and research challenges Shakhatreh et al. (2018)

Application/DOT	Policies/ Regulations	UAV Type	Sensors	Operation Area	Capabilities	Technical Limitations	Observations/Source
Traffic monitoring and emergency response	FAA and state requirements	BAT III® UAV, 6 hrs. flight duration, Telemetry 7 miles	High-resolution camera, thermal imaging	Autonomous/manual piloting	Transmit real-time high-quality video images and sensor data, can operate autonomously	Sensor and software	Traffic authorities can respond to traffic incidents in timely manner. Kamga et al. (2017)
Surveying various DOTs	FAA regulations	States use fixed-wing UAS	Albris TripleView® head (high-definition video, thermal)	Based on application	Enhanced camera resolution	Flying requirements (nighttime, inclement weather)	Reduced exposure to dangerous situations for surveyors. Banks et al. (2018)
Roundabout traffic monitoring, New Brunswick, Canada	Canadian regulations	DJI Phantom 3, rotor	High-resolution cameras, geo-positioning sensors	Roundabout	Multiple batteries for longer flight time	Battery life	Driver adaptation to two-lane roundabout Sowers (2017)
UAS use for transportation operations for Kansas DOT	General policies issued by FAA	General information	Not provided	Construction and surveying	Not available	Camera and data acquisition related	Kansas DOT has researched UAS use for routine operations McGuire et al. (2017)

DOT = department of transportation, GPS = Global Positioning System, UAV = unmanned aerial vehicle, UAS = unmanned aerial system, FAA = Federal Aviation Administration

Survey of Peer UAS Users

Further characterization of the current and near-future state of practice and technology with respect to prospective use of UAS by VDOT Operations was accomplished through a survey of practitioners at other state DOTs. The survey was conducted online using the Qualtrics® tool under license to Virginia Tech. Targeted survey participants were selected from a list comprising those attending the VDOT UAS Peer Exchange in 2018 and others identified as UAS program leaders or users at their respective agencies. A total of 49 potential participants were invited to provide input, and 13 representatives of 12 agencies from 11 states responded. Two participants responded for Utah DOT. The purpose of reaching out to the state DOT community was to gather information about their overall experience and to identify their perceived significant benefits of UAS usage. Participants were also questioned about their use of specific UAS applications, recommended performance measures, use of regulatory waivers, program evaluation criteria, perceived benefits, and lessons learned.

The 12 agencies that provided survey responses are listed below in alphabetical order. Two agencies from Pennsylvania are included.

- California DOT
- Florida DOT
- Georgia DOT
- Kentucky DOT
- Minnesota DOT
- North Carolina DOT
- North Dakota DOT
- Ohio DOT
- Pennsylvania DOT
- Pennsylvania Turnpike Commission
- Tennessee DOT
- Utah DOT (two respondents)

The survey questions as presented to the participants are shown in Table 2 below. Questions 1-4 pertain to personably identifiable data. Thus, responses to Questions 1-4 are not included in this report.

Table 2. State DOT Practitioner Survey Questions

No.	Question
1	Respondent's First Name (this information will not be shared)
2	Respondent's Last Name (this information will not be shared)
3	Respondent's email address (this information will not be shared)
4	Respondent's Phone No.- mobile or land line (this information will not be shared)
5	Respondent's Organization Name
6	Organization Type • State Agency • Commercial • Academic/Education • Other (please specify)
7	Please review the list of UAS traffic applications below and indicate your past, current, or future usage. (select all that apply) • Traffic characterization (type, speed, count, etc.) • Assessment of road hazards (sinkhole, road weather, fallen rocks, etc.) • First Responder Situational Awareness – Emergency event where a first responders can deploy an UAS to gain situational awareness before arriving to the scene. • Tethered UAV operations • Contaminant Level Sensing – Multi UAV coordination used for tracking contaminant levels of various areas. • Ground Vehicle Assistance – UAS can assist with navigation of ground vehicles whether manned or autonomous. • Ad-Hoc Communications Network – Multiple airborne hosts for temporary communications access points deployed in a daisy chain manner to allow communications where there may be no cellular or other communications network availability. • Roadway Emergency Alert – Deployable UAS that utilize visual warnings to alert drivers of upcoming emergencies on the roadway. • Illegal or unintended parking assessment (e.g., trucks along on ramps)
8	Please list other UAS traffic applications that your organization has used or plans to use that are not listed above.
9	If you operate UAS under an FAA waiver, please provide a brief description of each. (nighttime, beyond visual like of sight, etc.)
10	What are the significant benefits you are seeing by using UAS within your agency?
11	What metrics do you use to measure a successful UAS program or implementation procedures?
12	What advice do you have for others in selecting and implementing a UAS program within your agency?

UAS = unmanned aerial system, UAV = unmanned aerial vehicle

A summary of the participant responses to Question 7 is shown in Table 3 in the same order that they were presented in the survey instrument. In general, these results compare well with what was found in the literature review. However, with respect to the sixth traffic application, Ground Vehicle Assistance, it seems likely that the application was not described adequately in the survey, leading to irrelevant responses by three respondents.

Table 3. Summary of Survey Responses to Question 7 Regarding their Agency's Use of UAS Traffic Applications

Application	Used Previously (count)[a]	Using Now (count)[a]	Planned Use (count)[a]	Total Responses[b]
Traffic characterization (type, speed, count, etc.)	31% (4)	31% (4)	46% (6)	14
Assessment of road hazards (sinkhole, road weather, fallen rocks, etc.)	23% (3)	62% (8)	31% (4)	15
First Responder Situational Awareness – Emergency event where a first responders can deploy a UAS to gain situational awareness before arriving to the scene	15% (2)	54% (7)	31% (4)	13
Tethered UAV operations	0% (0)	8% (1)	54% (7)	8
Contaminant Level Sensing – Multi UAV coordination used for tracking contaminant levels of various areas	0% (0)	0% (0)	0% (0)	0
Ground Vehicle Assistance – UAS can assist with navigation of ground vehicles whether manned or autonomous	0% (0)	23% (3)	8% (1)	4
Ad-Hoc Communications Network – Multiple airborne hosts for temporary communications access points deployed in a daisy chain manner to allow communications where there may be no cellular or other communications network availability	0% (0)	0% (0)	23% (3)	3
Roadway Emergency Alert – Deployable UAS that utilize visual warnings to alert drivers of upcoming emergencies on the roadway	0% (0)	0% (0)	15% (2)	2
Illegal or unintended parking assessment (e.g., trucks along on ramps)	0% (0)	8% (1)	8% (1)	2

UAS = unmanned aerial system, UAV= unmanned aerial vehicle

[a]Percentages are calculated with respect to the total number of survey respondents (13).

[b]Responses totaling more than the number of respondents (13) are the result of multiple answer selections within one category.

Question 8 asked respondents to list other UAS traffic applications that their organization has used or plans to use that were not listed in Question 12. Nine respondents provided 29 responses overall, 15 of which related to UAS traffic applications. Those 15 responses are summarized below with notation in parenthesis of the number of times they were cited.

- Traffic Applications (12/15)
    - Control assessment
    - Traffic counts
    - Traffic maintenance
    - Ramp metering assessment

    - Special event traffic monitoring
    - Queue observation
    - Live streaming traffic video where cameras are not available
    - Roundabout assessment

- Incident Management Applications 3/15
    - Incident mapping
    - Incident management

The 14 other responses to this question included non-traffic applications, including bridge and bridge deck inspection, subaquatic vegetation monitoring, monitoring engineering design, airport obstruction survey, evaluation of closed-circuit television locations, earthwork and stockpile volume determination, overhead sign inspections, project evaluation, landslide assessment, and product deliveries.

Question 9 asked respondents to provide information on the types of FAA waivers that their agencies have used when operating UAS. Seven respondents provided 14 responses that are summarized below with notation in parenthesis of the number of times they were cited.

- Airspace (5)
- Nighttime flight (3)
- Flight over people (2)
- Beyond visual line of sight (1)
- Public Certificate of Authorization (1)
- Altitude, i.e., flights exceeding 400 ft. above ground level (1)

Question 10 asked respondents to list the primary benefits that UAS provide to their agencies. Twelve respondents provided 16 responses that are summarized below with notation in parenthesis of the number of times they were cited.

- Safety 7)
- Cost (4)
- Productivity (3)
- Expediency (1)
- Improved data quality (1)

Question 11 asked respondents to indicate what metrics of success should define a UAS program implementation. Ten respondents provided 14 responses that are summarized below with notation in parenthesis of the number of times they were cited.

- Return on investment (4)
- Safety events (3)
- Number of flights and or flight requests (3)
- Data quality (2)
- Productivity (1)
- Time savings (1)

Question 12, the last survey item, asked respondents what advice they would offer to others contemplating the use of UAS in their programs. Thirteen respondents provided 17 responses that are paraphrased and summarized below with notation in parenthesis of the number of times they were cited.

- Spend time to understand the capabilities and limitations of equipment and related software. Don't rely upon manufacturer/vendor marketing materials. Invest in the right UAS platform. (6)
- Develop good policies, procedures, and training programs that ensure a culture of safety (5).
- Share experience between agencies (3).
- Focus on what data are required rather than the collection tool (1).
- Fly under both FAA's Part 107 and Public Certificates of Authorization (1).
- If needed, hire or subcontract those with expertise in UAS (1).

Task 2. UAS Implementation Plan Development

One of the objectives of this research was to establish the state of the practice of UAS applications in the transportation area, with particular interest in integrating UAS activities to support VDOT's traffic operations. The purpose of this integration is to provide input on operational policies and procedures to promote the safe, effective, efficient, and lawful operation of UAS within VDOT's current organizational structure.

UAS Regulatory Requirements for Transportation Agencies

UAS can provide enhanced operational capability, safety, and situational awareness for first responders, traffic engineers, maintenance staff and affiliated partners, surveyors, and communities in general. They can operate in many types of environments or during critical incidents, natural or manmade, which might be hazardous to the safety of first responders or others. Current research indicates that over half of all U.S. states have employed UAS to tackle a transportation problem, whether it was traffic or infrastructure related (Stevens, 2017b). Approximately 80% of those states participated in a program that accelerated beneficial innovation by facilitating information sharing and technology exchange among the states and other transportation agencies and identifying actionable items of common interest (AASHTO, 2019). Regarding policies and procedures, knowledge of federal statutes and regulations related to UAVs is a critical starting point. In addition, each state agency must establish their own policies for acceptable use and operational guidelines for UAS, as they continue to develop and evolve rapidly. The research team recommends that each transportation agency should consider, at the minimum, the following functional requirements when developing new programs:

- Propose/design normal and emergency procedures, checklists, protocols, and UAS operational manuals for efficient implementation.
- Develop personnel requirements for UAS operators as well as procedures for securing and utilizing airspace authorization.
- Identify ways to use UAS with increased safety, reduced liability, significant cost savings, improved productivity, enhanced environmental protection, and reduced impact on the public.

- Follow standard operating procedures by using training to educate users on alternate methods of compliance for UAS operations, such as night operations, flight over people, or complex airspace.
- Request federal operations approvals such as Certificates of Waiver or Authorization (issued by FAA) and Section 333 Exemptions (operational approval and licensed pilot) to comply with FAA safety policies and state guidelines.

In addition, the transportation agencies in Virginia must ensure that other required certifications (e.g., pilot license renewal) and training (knowledge testing, industry formats on data collection) are provided in order to comply with federal regulations promulgated by the FAA or the U.S DOT (Quinton & Regan, 2018).

Importance of Policies and Regulations while Conducting UAS Operations

Government agencies are responsible for regulating and controlling UAS deployment for transportation applications and for ensuring that operators communicate effectively with federal, state, and local law enforcement to determine if a UAS operation poses any risks. The most important regulation was developed in 2016 by the FAA and implemented as Part 107 of Title 14 Code of Federal Regulations that allows for the operation of small UAVs (under 55 lb.) in the national air space (FAA, 2017). The rule requires operators to fly under 400 ft, keep a visual line of sight (VLOS), and only operate during daytime. Part 107 also establishes a process for issuing certificates to remote pilots and waivers to a small subset of the new regulations. A waiver is an official document issued by the FAA which approves certain operations of UAVs outside the limitations of the regulation (e.g., fly at night or beyond VLOS). These operational waivers allow pilots to diverge from certain rules under Part 107, but only if they demonstrate that flying can be performed safely when using alternative methods.

Typically, the FAA conducts a technical review of Certificates of Waiver or Authorization applications and, when necessary, provisions or limitations are imposed as part of the approval to ensure that the UAS can operate safely with other airspace users. Some examples of UAS operations not complying with FAA Part 107 rules that require waivers or specialized pilot training are listed in Table 4.

Table 4. UAS Operations that May Require FAA Waivers (adapted from FAA, 2017)

Operation	Relevant Part 107 regulation for which a waiver or special training is required
Fly UAS from a moving aircraft or a vehicle in populated areas	§ 107.25 – Operation from a Moving Vehicle or Aircraft
Fly UAS at night	§ 107.29 – Daylight Operations
Fly UAS beyond your ability to clearly determine its orientation with unaided vision	§ 107.31 – Visual Line of Sight Aircraft Operation
Using a visual observer without following all current visual observer requirements	§ 107.33 – Visual Observer
Fly multiple UAS with only 1 remote pilot	§ 107.35 – Operation of Multiple Small UAS
Fly UAS without having to give way to other aircraft	§ 107.37(a) – Yielding Right of Way
Fly UAS over a person/people	§ 107.39 – Operation Over People
Fly UAS: Over 100 miles per hour ground speed Over 400 feet above ground level With less than 3 statute miles of visibility Within 500 feet vertically or 2,000 feet horizontally from clouds	§ 107.51 – Operating limitations for Small Unmanned Aircraft

UAS = unmanned aerial system

Several states, including North Carolina, Michigan, Ohio, Oregon, Washington, and Vermont, have had experience with UAS implementation programs and are able to disseminate knowledge of their practices and the possible benefits. However, many programs do not have a system in place to monitor UAS usage or manage safety and FAA regulations, while other states have encountered difficulties when attempting to implement policies and procedures for UAS operations (Plotnikov, 2018). Specific applications that have been proposed or implemented by several state DOTs for operations include:

- Visual surveillance for traffic conditions, incidents, road conditions, and infrastructure status;
- Use of non-visual sensors for monitoring contaminant levels, environmental conditions (e.g., visibility), road weather, etc.; and
- Use of aerial data to perform crash scene reconstruction and support emergency response operations and assessments.

The review of the literature revealed that many states are currently pursuing research involving UAS deployment for transportation operations aimed at mitigating congestion and crashes (Barmpounakis et al., 2016; Ni & Plotnikov, 2016; Banks et al., 2018). Emergency responders and enforcement personnel will be the first to benefit from these studies, as real-time aerial views assessing damage will render critical information to deployed crews.

VDOT's Prior UAS Experience

Short summaries of some of the past UAS projects and/or demos undertaken by VDOT are included below. This list is not comprehensive and is provided here to provide background and context for development of a UAS Implementation Plan.

Acquisition and Sharing Aerial Video via a UAV Tethered to a Communication Cabinet

In December 2016, HoverFly® demonstrated a UAV tethered to a roadside traffic box located along the Eastbound side of I-64 near Williamsburg. Video of traffic along I-64 (Figure 2) was streamed to remote services for access via VA 511, mobile apps, and Skyline portals.

Figure 2. Aerial View of a Tethered UAV Above Traffic Along I-64 Near Williamsburg, VA

Incident Aerial Video Shared from a Tethered UAV Paired with a Safety Service Patrol Truck

In October 2017, a system comprising a tethered UAV paired with a VDOT Safety Service Patrol truck was demonstrated by VTTI along I-81 near Salem, Virginia (Figure 3 and Figure 4). Video acquired by the UAV camera was transmitted wirelessly to the control console and then via an HDMI cable to a cellular modem installed in the truck for real-time streaming to the Salem Traffic Operations Center and mobile devices accessing video sharing systems there. Power for UAV operation was transferred via the tether for persistent flights that were not constrained by onboard power capacity.

Figure 3. View of the Safety Services Patrol Truck and Paired, Tethered UAV Prior to Take-off

Figure 4. Video View Collected by the Tethered DJI Inspire 2 UAV (Inset) of I-81 Near Salem, VA

Implementation of Unmanned Aircraft System-Based (UAS) Digital Photogrammetry for Design, Risk Analysis, and Hazard Mitigation of Rock Slopes (2020)

In this VTRC project, a UAS using digital photogrammetry and point-cloud data analysis software was used to provide rock slope design and rock slope remediation recommendations of a quality comparable to existing traditional and ground-based methods. This research complements ongoing research designed to evaluate the use of emerging technologies for collecting the data required for rock slope investigations, remediation, and slope hazard inventories (Watts, 2021).

Crash Site Reconstruction Using UAS and Photogrammetry

VDOT has been working in collaboration with the Virginia State Police to train and equip officers with the knowledge, FAA certification, equipment, and software tools required to perform expedited crash incident site investigations. The benefits of this programs are improved safety and quicker incident clearance times.

Rapid Assessment of a Roadside Landslide

In May 2018, a UAV was used by VTTI to assess the extent of a landslide that occurred on US 460 in Giles County, Virginia. This slide resulted in the closing of one of two lanes of traffic. The slide area was difficult to access and view using conventional means such as climbing or remote viewing with binoculars. A DJI Phantom® was flown at the site for approximately 20 minutes, and 16 still images and three videos were recorded to assess site conditions (Figure 5). Subsequent review of the acquired data allowed the Salem District Materials Office to determine whether to reopen the closed lane once roadway cleanup was completed.

Figure 5. View of the Landslide Point of Origination Recorded by the UAV

UAS Integration Planning

When planning for the integration of UAS within VDOT's operations, the following primary objectives should be considered:

- Identify resource requirements related to funding, personnel, equipment, certification and training, data subscriptions, policy development, and other relevant attributes;

- Develop an implementation strategy of the requirements within the agency structure; and
- Perform a cost-benefit analysis to determine the feasibility of the most promising UAS applications.

These are the broad implementation goals that many state DOTs have established as part of their UAS programs that stem primarily from internal studies and peer exchanges. Additionally, a USDOT scan of UAS integration by surface transportation agencies identified seven key elements common to most UAS programs (Banks et al., 2018). Six of these elements that correspond to VDOT's needs are described below.

Executive Support

Key to the success of the implementation of any new program is support from upper management. Those unfamiliar with UAS may see them as an expensive and frivolous technology fraught with risk and public relations issues. Executives need to understand that state DOTs that have implemented UAS programs have realized benefits, including enhanced safety and efficiency, while saving time and money (Banks et al., 2018; Estes, 2014; Fischer et al., 2020; Quinton et al., 2018; USDOT, 2020; Tritsch, 2019).

The use of UAS for crash site mapping by the North Carolina Highway Patrol reduced mapping time from 2 hours to 25 minutes (USDOT, 2020). Washington State Police report that the amount of time required to assess situational awareness at crash sites was reduced by 80% using UAS (USDOT, 2020). Infrastructure inspection activities with UAS have demonstrated cost savings of 94% and 40% for the Michigan and Minnesota Departments of Transportation, respectively (USDOT, 2020). Cost benefits of UAS traffic applications are more often realized through reductions in vehicle crashes and congestion, although more direct cost reductions may be applicable where fixed surveillance systems can be replaced or augmented with UAS. Additional less tangible but important benefits may include improved data quality and enhanced environmental protection (Banks et al., 2018). With regard to executive support, effective transportation agency UAS programs typically share the following attributes (Banks et al., 2018):

- A focus on the benefits of a UAS program implementation, as noted above;
- Recognition that UAS programs do not necessarily require a large initial or continued financial investment;
- Recognition of the negative perceptions regarding UAS that may exist within or outside the agency; and
- Additional, continued assessment to quantify the benefits of implementation.

It is also incumbent on executives to ensure that adequate initial and continued funding is provided to support new and established UAS operations, that sufficient internal human resources are provided, and that primary program objectives are met using objective metrics, if possible.

Organizational Structure

The organizational structures for established state UAS programs vary widely in their implementations with respect to where responsibilities lie and what they entail. However, most programs include the following common structural elements that should be considered for successful implementation within or across agencies (Banks et al., 2018):

- A centralized, hierarchical oversight authority with defined roles;
- Recognition of the role federal regulatory agencies such as the FAA play and how they can enhance or negatively impact the program;
- Engagement with other agencies and tapping into pertinent (aviation) talent and capabilities that may be available and/or shared; and
- Recognition of the impact that regulations ranging from local to federal may have on the program.

VDOT developed its *Unmanned Aerial Systems (UAS) Operations Manual* as a governance document that is intended to ensure safe and appropriate UAS use for its operations in Virginia (2021). This document establishes a central authority with distributed support from regional/local coordinators and subject matter experts for areas of UAS application such as traffic operations, geotechnical investigations, infrastructure inspection, etc., as shown in Figure 6. VDOT currently relies primarily on contractors for respective aspects of UAS operations, including planning, staffing, regulatory compliance, training, data management, and actual flight operations.

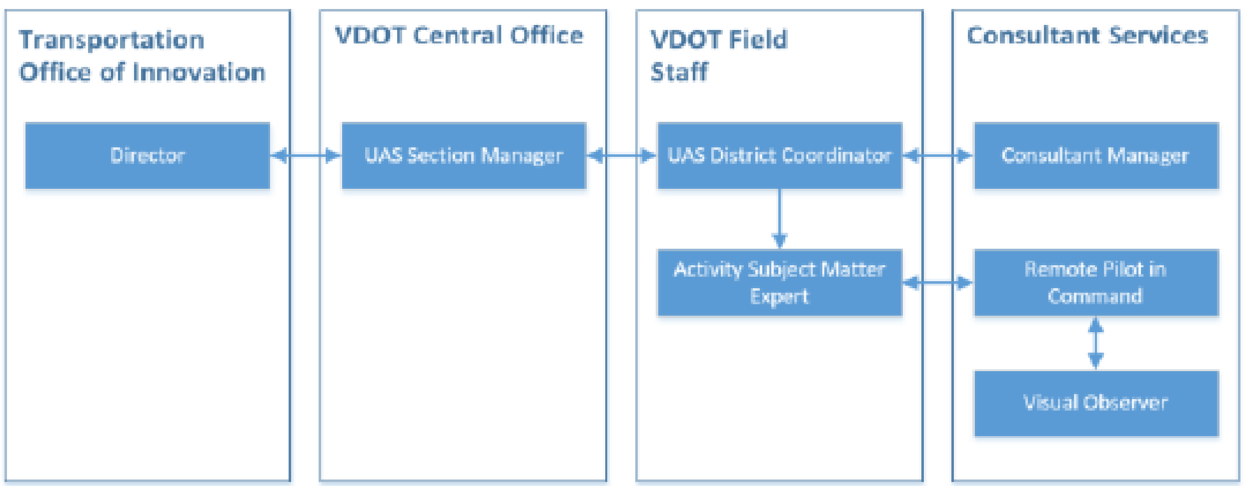

Figure 6. VDOT's Organizational Structure from its *Unmanned Aerial Systems (UAS) Operations Manual* (2021)

Safety assurance is the stated highest priority for most DOTs. This is also true within the aviation industry, where safety management systems were created to achieve the highest levels of safety practical (Banks et al., 2018). With the adoption of the use of unmanned aircraft to support surface transportation operations, it follows that aviation-based safety procedures are applied to UAS operations employed by DOTs. VDOT's *Unmanned Aerial Systems (UAS) Operations Manual* addresses the procedures required to assure safety and perform risk management in detail (2021). Safety and risk management programs implemented by state DOTs with UAS programs generally include the aspects listed below (Banks et al., 2018):

- An established safety policy and corresponding emergency response plan;
- Procedures for hazard identification and development of respective safety measures; and

- Establishment of a strong aviation safety culture both internally and externally.

In addition to the safety of flight operations, state DOTs must also consider the impact of UAS operations on the traveling public and their staff. For example, established aviation safety procedures may not account for such issues as potential UAS-induced driver distraction.

Policy and Regulation

Policies and regulations regarding UAS have evolved rapidly because of relatively recent technological advances that have enabled affordable and capable applications of these systems. Regulations have changed quickly to address and enable public users such as emergency services, law enforcement, and surface transportation operators (Banks et al., 2018; Estes, 2014; Fischer et al., 2020). Pertinent UAS regulations are described in detail in other sections of this document. Policies developed and applied at state DOTs with UAS programs include the following common attributes (Banks et al., 2018):

- Internal UAS guidance via an operations manual that focuses on procedures that ensure safe operations, adherence to policies, and compliance with applicable regulations;
- Internal resources to keep current with regulations and other developments to inform policy and operational changes;
- Guidance on applications that may require regulatory waivers or specialized equipment; and
- Consideration of policies that go beyond existing regulatory compliance in anticipation of potential future legislation and regulation.

Public Relations

The public has been exposed to UAS through a variety of military, commercial, government, and hobbyist applications, resulting in a mix of attitudes that may include misinformation, preconceived notions, and varying expectations. Primary public concerns regarding UAS include those relevant to safety and privacy. DOTs with successful UAS programs have employed strategic outreach and education efforts to address these concerns (Banks et al., 2018; Estes, 2014; Fischer et al., 2020; Quinton et al., 2018; USDOT, 2020; Tritsch, 2019). These programs typically include the following key elements (Banks et al., 2018; Fischer et al., 2020):

- Identification of a wide range of stakeholders that may include the public, vendors, other public entities, institutions of higher education, legislators, airspace regulators, and others;
- Inclusion of agency public relations department in adverse incident response plans;
- Tracking of pertinent legislation and regulations that may impact public perception of UAS programs; and
- Notification and inclusion of traditional and social media in UAS educational programs, workshops, demonstrations, and other events that will help assuage public concerns.

Applications and Operation

Prospective traffic and other UAS applications of potential interest to VDOT are described elsewhere within this section. Typical state DOT UAS applications range from relatively simple aerial reconnaissance operations to more complex applications such as those that require regulatory waivers, involve special payloads such as non-visual sensors, or require advanced support systems such as radar or terrestrial host base stations or beyond VLOS or augmented reality support technologies. In many cases, the UAS applications utilized by state DOTs share the following attributes (Banks et al., 2018):

- Initial simple, low-cost operations that do not require waivers or specialized equipment;
- Established workflow processes for data management, application use and development, and data reduction and analysis; and
- Consideration of the key benefits related to UAS usage such as improved safety, efficiency, and data quality, as well as environmental protection and liability reduction.

Training and Crew Requirements

Agencies that acquire and operate UAS must ensure that UAS operators on staff are qualified and that all training and certification is current. Since VDOT relies primarily on contractors for UAS operations, it is incumbent on those contractors to ensure that flight crew qualifications are current. Under this scenario, it is the obligation of VDOT staff to ensure that UAS service providers are vetted properly, and that part of this qualification includes continued training and certification of their flight crews. In general, UAS training and compliance programs, whether executed within the agency or externally, typically include the following (Banks et al., 2018):

- Conformity with all regulatory certification and training requirements;
- Continued training with respective record keeping; and
- Training tailored to the UAS application type and to special operations such as those that require additional certifications (e.g., night flight).

Initial and periodic follow-on training for those in agency management and support roles should also be considered. This will provide those in roles such as those shown in Figure 6 with the knowledge to ensure that UAS operations, whether internal or external, are performed appropriately, competently, safely, and in conformance with regulatory requirements.

UAS Integration Assessment

The research team proposes the following metrics that VDOT may potentially use to assess the success of their UAS implementation program. These recommendations are based on a general overview of the literature and the responses of those DOT personnel surveyed as part of Task 1.

- Safety
    - Counts of traffic incidents with consideration of severity
    - Counts of VDOT staff injuries with consideration of severity
- UAS usage quantification
    - Number of UAS operations
    - Number of internal requests for UAS support of normal activities
    - Number of internal requests for UAS support for new activities
    - Total expenditures on UAS operations

- Data quality
    - Ratings of data quality improvements (may be hard to quantify)
- Time savings
    - Person-hour reductions on activities
    - Traffic congestion reduction
    - Operation performance time reductions
        - Traffic incident clearance
        - Traffic flow assessment
        - Incident situational assessment
- Staffing and contracting
    - Completion of assignment of VDOT internal resources per the *Unmanned Aerial Systems (UAS) Operations Manual* (Figure 6)
    - UAS qualifications of existing contractors
    - Engagement with new contractors providing UAS services
- Adverse events related to UAS operations
    - Count of public complaints with respect to UAS deployment
    - Human injury
- Property damage
- Innovation
    - Research expenditures for UAS
    - Innovation program expenditures for UAS

It is expected that the findings of this project will identify additional opportunities for the application of UAS to VDOT's traffic operations that will cost-effectively enhance operations capabilities and efficiency while improving the safety of the driving public and VDOT employees and contractors.

Task 3. UAS Demonstration Pilots

The TRP selected three applications that were considered relevant for pilot demonstration as part of this study. These applications are described below.

Incident Site Aerial Surveillance

Activity: On-site aerial surveillance of an active traffic incident site. This application entails using UAS equipped with a high-definition camera (and other equipment if needed) to identify the incident site and coordinate the responding resources at the scene of the incident, which requires clear communication and feedback from the scene. Agencies traditionally monitor incidents on-site or from cameras at fixed locations. Using UAS, responders have the flexibility to monitor incidents from multiple angles and directly overhead to provide a better overall understanding of a complex crash scene to the command center.

In this demonstration, a vehicle crash or other emergency incident (e.g., spill) would be created and UAS and supporting equipment would be deployed to provide real-time aerial surveillance data to on-site responders and a remote operations center (e.g., Virginia Smart Road control room) via a wireless communications link. A tethered UAV might be used to demonstrate persistent operation within a restricted 3D flight envelope. In the real world, the data acquired in this way can be used to inform local and central traffic operations, assess infrastructure impacts, inform responder priorities and routing, and/or identify alternate traffic routing pathways.

Location: Within the response radius of the flight team in consideration of anticipated clearance time. Air restrictions will need to be verified prior to conducting the flying.

Regulatory Challenges/Waivers: Potential air space restrictions.

Potential Issues/Limitations: Privacy, weather, and time of day restrictions, timely law enforcement notifications to allow quick response by the flight team.

Product: On-site response with recorded video data of incident and response team activities.

Remotely Based and Piloted UAS Incident Surveillance

Activity: Demonstrate how UAS staged at a strategic location can be remotely activated and piloted to provide real-time aerial surveillance of an area of interest located within its operational area. This demonstration will employ "drone-in-a-box" technology to remotely deploy and operate a UAV to provide aerial surveillance of a simulated incident. The "box" enclosure functions as a secure weatherproof base for the UAV, a takeoff and landing pad, and a charging base. Some systems also provide for automated battery exchange to provide extended overall surveillance times with multiple flights to the incident site. The UAV can be piloted manually, semi-autonomously, or fully autonomously, where pre-programmed flight and data collection tasks are performed before returning to the base for repowering and/or data upload. Data acquired by the system may be used to:

- Confirm incident reports;
- Characterize incident characteristics such as vehicles involved, site setting, traffic impacts, responder presence;
- Reroute traffic;
- Identify on-site hazards such as chemical releases, downed power lines, and vehicle or roadside fires;
- Identify nearby sensitive receptors (human, environmental, etc.);
- Assess infrastructure damage;
- Determine towing and recovery equipment needs; and
- Direct responder routing

Data collected during surveillance may be streamed to operations centers in real time or uploaded once a data connection is available. The data may be shared with other groups to better inform response efforts.

Location: The UAS will be deployed in a controlled access area free of public traffic, such as the Virginia Smart Roads, to monitor a simulated crash incident site.

Regulatory Challenges/Waivers: None if demonstration is conducted under current FAA provisions for using a visual observer. May not be required unless operations will occur in controlled airspace or at night.

Potential Issues/Limitations: Since the purchase of one of these systems is outside the scope of this project, we would rely upon cooperation with a vendor for demonstration of their system. Weather is also a potential threat to any flight operation.

Product: On-site observation of the event using video feeds of the incident site from terrestrially based cameras, the first-person view from the UAV, and remote pilot interface screen capture.

Traffic Flow Assessment

Activity: On-site aerial surveillance of problem traffic areas with subsequent assessment of flow parameters and potential conflict zones.

Aerial video surveillance data would be acquired for an area of interest where acquisition using conventional methods may be unsuitable or require too much time. This data would either be shared in real time via a communications link to inform traffic operations or recorded for subsequent analysis where more time allows. Computer (machine) vision analysis of acquired video data could be used to automate the assessment of local traffic density, speeds, trajectories, conflict points, etc. If required, longer term aerial observation could be performed using a tethered UAV.

Location: UAS will be deployed to an area such as a roundabout, highway on-ramp or off-ramp, or other intersections (Figure 7) where acquisition of traffic flow data would provide detailed information about traffic patterns, vehicle counts, and potential conflict points.

Regulatory Challenges/Waivers: May not be required unless operations will occur in controlled airspace or at night. Flight over moving vehicles will be avoided.

Potential Issues/Limitations: Adverse weather.

Potential Issues: Weather and time of day restrictions, adequate field of view and parallax effects on computer analysis.

Product: Video data of traffic, analysis of potential and observed vehicle conflicts, determination of misuse of infrastructure or violation of controls.

Figure 7. Travel, Crossing, and Merge Lanes at a Restricted Crossing U-Turn Intersection

UAS Demonstration Pilot(s)

In a TRP meeting held February 26, 2021, the three UAS traffic applications described above were presented and reviewed. The research team also presented preliminary work where aerial video was collected and used in the DataFromSky® (DFS) license-free data viewer to determine traffic flow parameters completed at two intersections in Blacksburg, Virginia. In consideration of the complications created by the COVID-19 pandemic, concerns over the accuracy of existing intersection traffic data collection systems, and recognition of the potential future uses of traffic analysis tools such as DFS, the research team was directed to focus their future efforts on a single type of demonstration where aerial video data would be used with the DFS application to assess traffic flow at certain VDOT intersections and compare the results with data produced by the GRIDSMART® (GS) detection systems used at those intersections. A description of the work conducted at these intersections follows.

In discussion with TRP members at, and following, the February 26 meeting, six locations of interest were identified. UAS video data were collected at five of the six locations near Blacksburg. GS data were collected from four intersections in anticipation of concurrently collecting UAS data at these sites. The locations of these six sites are shown in Figure 8, and respective information regarding signalization and what type of types of data were collected are provided in Table 5. UAS data were not collected at Site 4 because of its location within a no-fly zone near the end of a runway at the Virginia Tech Montgomery Executive Airport. This area is also subject to frequent temporary flight restrictions respective to special events hosted on the Virginia Tech campus, such as football games. Additional information for Site 5 is presented in the following section with respect to the traffic data comparison performed. Descriptions and UAS data from Sites 1, 2, 3, 4, and 6 are included in the Appendix.

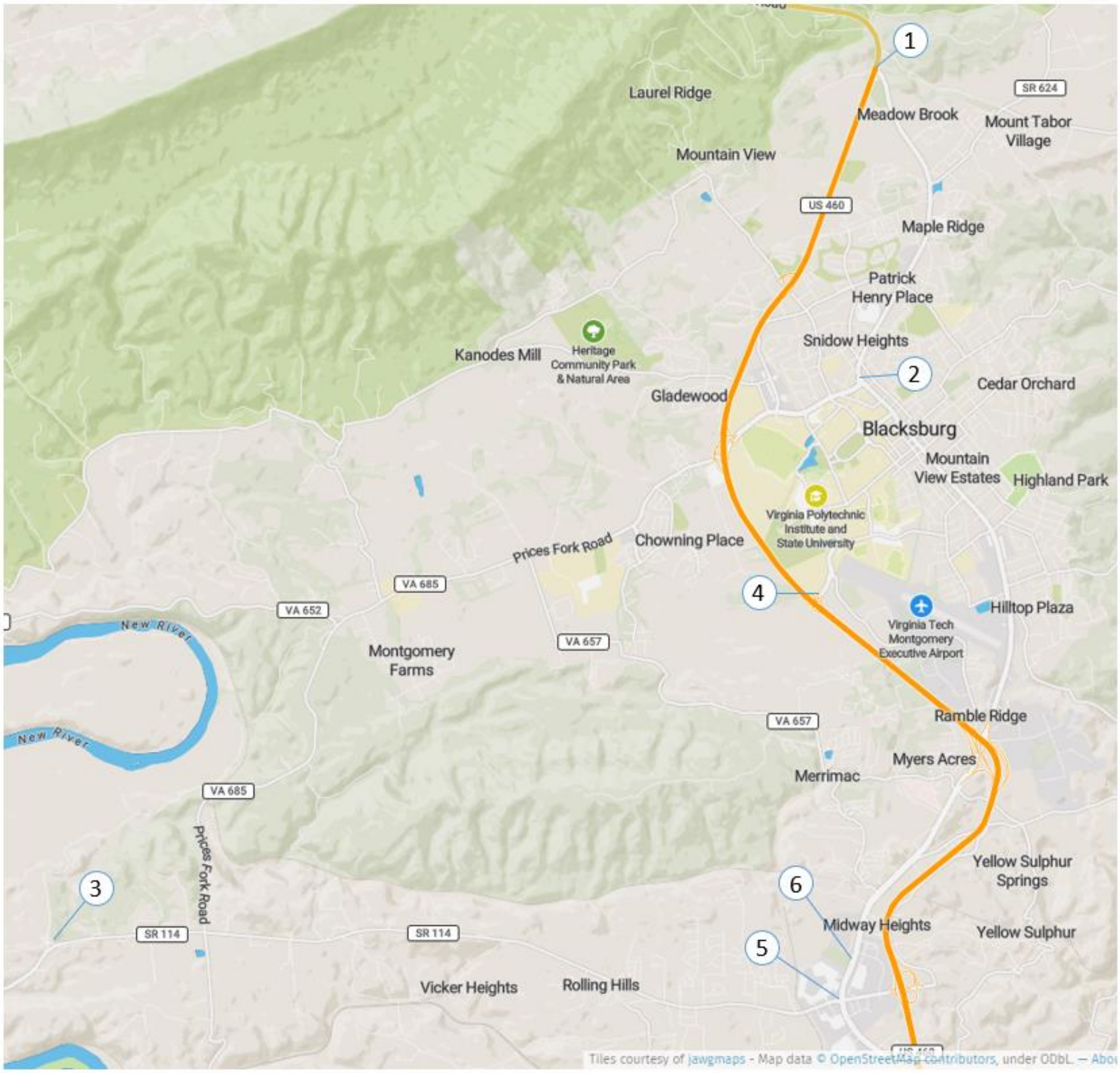

Figure 8. Map Showing the Locations of the Six Demonstration Sites Near Blacksburg, VA

Table 5. Intersection Information for the Locations Shown in Figure 8

Site No.	Location	Signalized	UAS Data	GS Data
1	US 460 at North Main Street (Business 460)	No	Yes	No
2	Prices Fork Rd. at Main Street (Business 460)	No	Yes	No
3	SR 114 at Constitution Rd. (near the entrance to the Radford Army Arsenal)	Yes	Yes	Yes
4	US 460 at Southgate Dr. (entrance to Virginia Tech)	Yes	No	Yes
5	SR 114 at North Franklin St.	Yes	Yes	Yes
6	North Franklin at Shoppers Way	Yes	Yes	Yes

UAS = unmanned aerial system, GS = GRIDSMART

Intersection Traffic Data

UAS Data Collection

All aerial video was collected using a DJI Mavic Air® UAV equipped with a fixed focal length color camera with an 85º horizontal field of view (Figure 9). The camera gimbal varies camera pitch while rotation of the aircraft provides for camera yaw and roll. This is a small UAV that has a relatively short flight times of about 25 minutes, which varies based upon battery capacity and encountered winds. Significant winds were encountered during flights, but the aircraft was able to maintain its lateral position and altitude and maintain a steady platform for video acquisition, although flight times were consequently limited to about 12 minutes to ensure adequate maneuverability for safe landing. While larger and more capable UAVs were available that offered extended flight times, the team decided to use this smaller model due to the close proximity of passing vehicles and the increased safety that a lighter aircraft provides should an adverse event occur.

Video data were recorded at a resolution of 3840 × 2160 pixels and a rate of 29.97 frames/second and encoded using an H264 codec. Due to the file size limitations of the secure digital card storage media used on the aircraft, a computer utility was used to join multiple video files into a single larger file that was subsequently used for data reduction.

Figure 9. DJI Mavic Air® UAV of the Type Used for Aerial Video Collection at the Intersections

Aerial Video Processing

UAS video files collected during the flights were uploaded to the DFS website for computer vision analysis. Once analysis was completed, the user was prompted to download the tracking log file for use in the DFS desktop application that was provided free of charge. DFS charges for video processing based on video length and services performed. The cost for standard analysis of UAS-based data was $16.71 (USD) per hour of video as of the time of this work. Additional data reduction services were also available for a fee. These include services such as human review for confirmation of vehicle type classification or traffic counts.

As illustrated in Figure 10, the tracking log file and the video file that were used to generate that data were opened together in the DFS application, where tracking data are overlain over the video in a player window. At this point, all tracking data is provided with respect to pixels rather than a distance. A geo-registration utility within the application can be used to define the real-world locations of at least four reference points, as shown within the viewing program. This is accomplished using a mapping utility such as Google Maps® to derive latitude and longitude coordinates in commonly used coordinate systems. Use of more permanent and distinct reference landmarks, such as drainage structures or manholes, is recommended. Conversely, georeferenced points such as lane markings that may change with repaving and repainting are not recommended. It should be noted that video collected from elevated locations such as towers and buildings may also be analyzed similarly within a sister DFS utility to provide traffic characteristics data.

Aerial video data from all intersections except Intersection 4 were uploaded to the DFS website for analysis, and respective tracking log files were downloaded. UAS data from Intersection 4 were not collected due to flight safety considerations as mentioned previously.

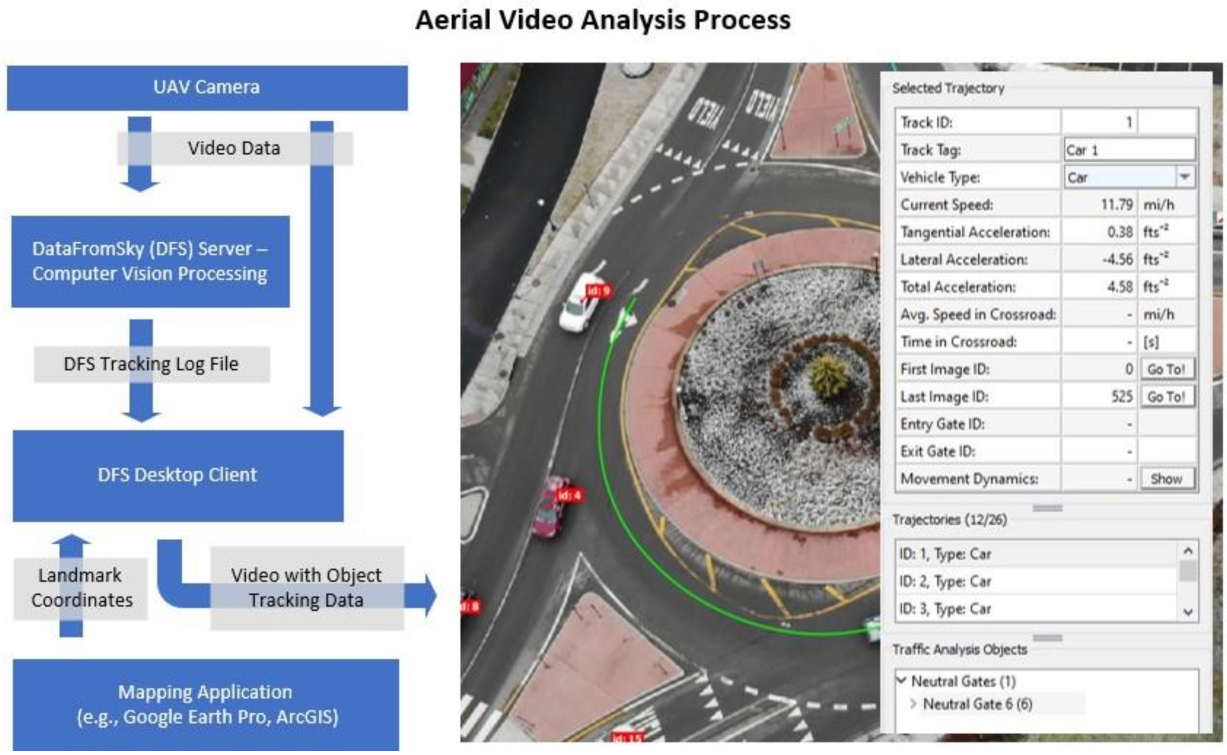

Figure 10. Process Used to Analzye and Display DFS and a View of the Desktop Interface with Corresponding Object Tracking Data (Inset Right)

GRIDSMART® Data

GS is deployed by VDOT to provide traffic data at certain signalized intersections. GS can determine traffic characteristics such as vehicle presence, count, classification, and tracking. GS uses downward facing cameras that provide a full hemispherical view of the intersection that is analyzed in real time using machine vision algorithms to characterize the presence and movement of objects within the view. This may include vehicles, bicycles, pedestrians, and other objects as determined by system configuration. The video is not customarily recorded unless it will be used for a specific study, nor is it suitable for human viewing unless a de-warping utility is used to create a recognizable two-dimensional format. GS provides a desktop program that allows for post hoc viewing, processing, and analysis of recorded camera imagery. Processed data may also be exported in standard data formats for external analysis. GS imagery and data may also be accessed in real time from remote installations equipped with suitable high-speed communications, such as broadband internet.

In coordination with the research team, VDOT personnel installed external hard drives at signalized Intersections 3, 4, 5, and 6 to record GS data. Since hard drives fill rapidly with data including many images, corresponding UAS aerial video data for comparison needed to be collected within a time window of about four days after hard drive installation. Once respective

UAS flights were completed, VDOT personnel removed the hard drives and provided them to the research team. Data from all four intersections were copied to another external hard drive and the original hard drives were returned to VDOT.

The GS desktop program was used to review the data from each intersection while paying particular attention to those times when flights were conducted. Unfortunately, the GS image data required to view recorded traffic data were not recorded for the corresponding flight times at Intersections 3 and 6. As previously noted, UAS data were not collected at Site 4 because of its proximity to a no-fly zone near the end of a runway at the Virginia Tech Montgomery Executive Airport. Therefore, time-synched data from both flight and GS sources were available only at Site 5, which is the intersection of SR 114 and North Franklin Street in Christiansburg. Significant difficulties with reviewing the GS data for Site 5 were also encountered and eventually overcome after extensive correspondence with GS support and the eventual release of a new version of their viewing software in August 2021.

Comparison of DFS and GS Output

An exploratory comparison of DFS and GS program output at Intersection 5 (Figure 11 and Figure 12) was conducted to demonstrate the potential utility of UAS for traffic flow assessment. The eastbound leg of the intersection was chosen as a basis for method comparison, as the GS cameras provided a good view of traffic for manual validation. It should be noted that this intersection features right-turn slip lanes (Figure 13) that were not targeted by VDOT staff for GS system monitoring. Consultation with GS support personnel indicated that analysis of traffic in those lanes is possible if the system is configured respectively.

Figure 11. Aerial View of Intersection 5 at North Franklin St. and Peppers Ferry Rd NW (SR 114) in Christiansburg, VA (Looking Northeast)

Figure 12. Aerial View of Intersection 5 at North Franklin St. and Peppers Ferry Rd NW (SR 114) in Christiansburg, VA (Looking Southeast)

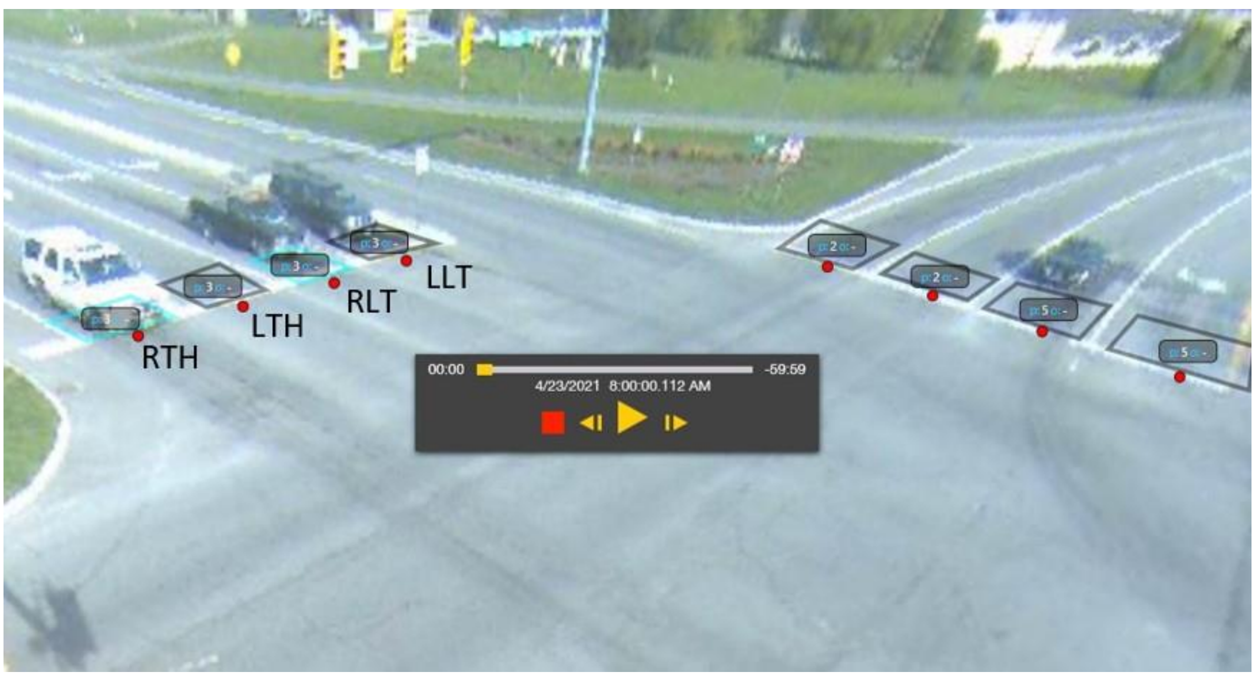

Figure 13. GS Camera View of SR 114 Eastbound and North Franklin Southbound Approaches Looking Northwest and Showing Vehicle Detection Zones, Viewing Tool Play Controller with Time and Lane Labels

Aerial video data collected for the intersection were reduced using the process outlined in Figure 10, and virtual gates corresponding to those already configured in GS were created to enable vehicle counts (Figure 14). The time offset between aerial and GS data were determined visually using the presence of an uncommon yellow vehicle to allow synchronization. All vehicle count data were verified manually via human observation of video within each system's viewing tools.

Figure 14. Screen Capture from the DFS Viewer of the SR 114 Eastbound Approach Looking Southeast and Showing the Four Virtual Gates and Respective Vehicle Identification Numbers in Red and Vehicle Count Numbers Embedded Within the Green Gates

A comparison of GS and DFS traffic data at Intersection 5 located at SR 114 and North Franklin St. in Christiansburg was conducted. The vehicle count results are shown in Table 6. It should be noted that the reporting intervals provided for by GS software and limited UAV flight times resulted in only a 5-minute time window where data were available from both systems. However, researcher observation of the recorded video and vehicle counts and classifications from both systems provided some revealing insight on the advantages and disadvantages of each system.

Table 6. Vehicle Count Data from GS and DFS Testing at Intersection 5

	Minutes 0–5			Minutes 5–10					Minutes 0–10		
	Manual	GS		Manual	GS		DFS		Manual	GS	
Lane	Count	Count	Error[a]	Count	Count	Error[a]	Count	Error[a]	Count	Count	Error[a]
Right Through	11	11	0 (0%)	6	8	2 (33%)	6	0 (0%)	17	19	2 (12%)
Left Through	6	5	1 (17%)	3	2	1 (33%)	3	0 (0%)	9	7	2 (22%)
Left Left Turn	3	3	0 (0%)	2	2	0 (0%)	2	0 (0%)	5	5	0 (0%)
Right Left Turn	12	12	0 (0%)	9	10	1 (11%)	9	0 (0%)	21	22	1 (5%)
Totals	32	31	1 (3%)	20	22	4 (20%)	20	0 (0%)	52	53	5 (10%)

GS = GRIDSMART, DFS = DataFromSky
[a]The error is calculated with respect to the manual count.

GS Performance Observations

Inaccurate detection of vehicles was noted in several instances, resulting in both false negative and false positive counts. This is shown in the graphical indication of vehicle detection and counts in the GS software. In Figure 15, the white pickup truck at the lower left was detected, as indicated by the change of color of the detection zone box from black to aqua. In subsequent data frames, the box color changed back to black and then to aqua again, and the vehicle count for that lane was incremented higher accordingly.

Figure 15. GS Software View of the Intersection Approach Showing Vehicles and Detection States

In Figure 16, a detection box color change and corresponding count increase, indicating that a vehicle is present although none is.

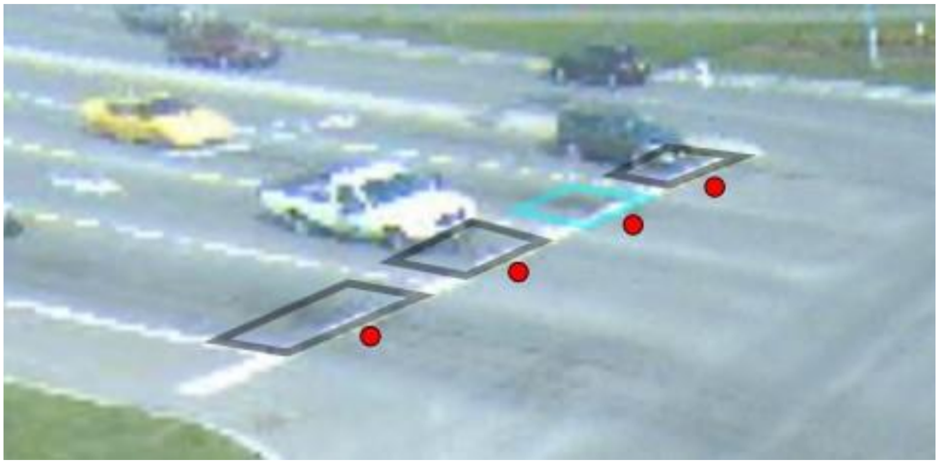

Figure 16. GS Software View of the Intersection Approach Showing Vehicles and Detection States

In Figure 17, a large white truck creates detection events in two lanes even though the second adjacent lane is empty.

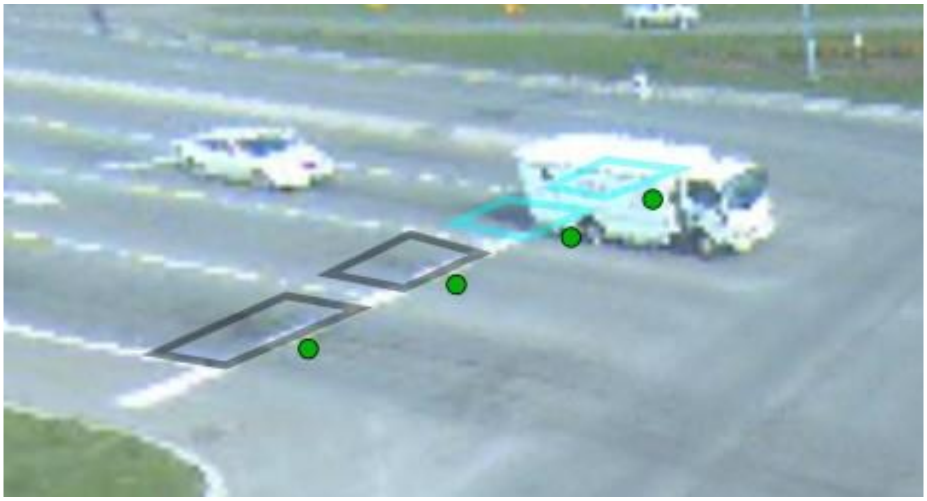

Figure 17. GS Software View of the Intersection Approach Showing Vehicles and Detection States

In Figure 18, a black truck prevents detection of a white minivan in the adjacent lane, as indicated by the lack of color change of the detection box from black to aqua.

Figure 18. GS Software View of the Intersection Approach Showing Vehicles and Detection and Count States

In Figure 19, a false positive vehicle count results when a darker colored vehicle is not recognized within the detection box.

Figure 19. GS Software View of the Intersection Approach Showing Vehicles and Detection States

It should be noted that these results are preliminary in nature. A single intersection approach was subjectively chosen to provide the best view for comparison of GS and DFS results over a relatively short, 10-minute period.

DFS Performance Observations

While no DFS errors were observed during the analysis at Intersection 5, issues were evident in DFS data collected at one of the unsignalized intersections. As shown in Figure 20, DFS analysis of UAS video collected at Intersection 1 revealed that larger vehicles may mistakenly be classified as multiple smaller vehicles. This is evidenced by the assignment of three unique vehicle identification flags and numbers with corresponding count data effects.

Figure 20. View of Intersection 1 (US 460 at North Main Street (Business 460) in the DFS Software Showing Vehicles and Respective Identification Tags (Red)

Comparison of GS and DFS

The GS count data presented in Table 6 are somewhat misleading in that observed false positives and false negatives tended to negate each other, which resulted in high overall accuracy numbers despite individual errors. The DFS data, as analyzed using their standard online machine vision methods (no human oversight), tended to overcount vehicles, as single vehicles were sometimes recognized as multiple vehicles, basically providing false positives. No false negatives were observed during testing, although those might be expected under certain conditions where there is a lack of contrast between object and background.

In general, the DFS method using aerial UAS video benefits from the improved view provided by higher camera elevation and flexible positioning. Visual obscuration of vehicles by nearby vehicles observed in the GS data was not evident in the DFS data. Also, the DFS method provides for a single view of the entire intersection where all traffic can be viewed simultaneously. The GS method may require the use of multiple cameras to cover larger intersections, and the current GS software does not provide for fusing traffic data from multiple cameras for whole-intersection analysis and viewing. Although fog or smoke was not encountered during testing, respective deleterious effects would likely be more pronounced with an increased distance between cameras and vehicles. This may impact the DFS method when compared to GS if UAS flight elevations are high enough.

A limitation of the UAS method of data collection, flight time, combined with certain data collection and data reduction capabilities of the GS system resulted in a singular and relatively short period of data comparison. Thus, the results of this investigation are not likely to be generally representative since analysis was limited to one approach on one intersection over a short time span. More robust evaluations might utilize multiple flights or tethered UAVs to allow extended flight times and include multiple intersections with a comprehensive scope that includes all approaches across a variety of environmental and traffic conditions.

DISCUSSION

The literature review and practitioner survey conducted in Task 1 primarily reflect those UAS technologies and applications that have already been demonstrated in some form. During the kick-off meeting for this project, VDOT instructed the research team to consider also those UAS applications that might not have been demonstrated or that are not currently possible because of technological, regulatory, or other constraints. A summary of some of these types of applications is included in Table 7. The contents of this list are based both on the literature review and the combined expert knowledge of the research team.

Table 7. Potential UAS Applications for Future VDOT Operations Implementation

Category	Application	Description
Infrastructure Augmentation	Ad Hoc Communications Network	Multiple airborne hosts for temporary communications access points deployed in a daisy chain manner to allow communications where there may be no cellular or other communications network availability.
	Roadway Emergency Alert	Deployable UAS that utilize visual warnings to alert drivers of upcoming emergencies on the roadway.
	Temporary/Emergency Traffic Lights	UAS equipped with traffic signal that can be deployed in the event of lost stationary traffic signals or for areas when traffic signals are needed for brief periods of time.
Vehicle/Driver Assistance	Autonomous Vehicle Assistance	UAS can assist with autonomously operated vehicles' route planning miles ahead of the vehicle's current location.
	Heavy Vehicle (Truck) Rerouting	Vehicle rerouting during congestion or truck rerouting if reaching a restricted roadway.
	Parking Monitoring	UAS deployment to assess parking lot utilization.

Category	Application	Description
Roadway Monitoring	Road Surface Monitoring	Road surface evaluation using specially equipped (multispectral technology) UAS.
	Sinkhole Monitoring	Using UAS to monitor sinkhole impact on roadway traffic.
	Animal Movement Monitoring	UAS deployment to assess animal movement to prevent animal-vehicle conflicts.
	Weather Condition Analysis	Non-visual and visual monitoring of roadway environmental conditions/weather (flooding, landslide, high winds).
	Contaminant Level Sensing	Multi UAV coordination used for tracking contaminant levels of various areas.
Traffic Monitoring	Traffic Flow Characterization	UAS deployment to monitor recurrent/non-recurrent congestion, work zone traffic flow, merge behavior.
	Intersection Vehicle Movement	UAS deployment to track intersection traffic flow.
	Traffic Speed Analysis	Radar-equipped UAS for speed survey.
	Vehicle Behavior Monitoring During Inclement Weather	Monitoring traffic patterns during adverse weather conditions. Aid with winter maintenance activities.
	Measure Gap Acceptance	Deployed UAS collect video data to estimate the driver's gap acceptance at intersection for use in capacity analyses.
	Traffic Monitoring for Hazardous Material Transport	Using UAS to assist with hazard identification and development of safety measures during an incident.
	Evacuation Management	Monitoring traffic during extreme weather evacuation.
	Lane Merging Monitoring	Monitor driver behavior after merging and/or changing lanes.
	Truck Monitoring in Enforced Areas	Monitor areas where trucks need to stay in the right lane.
Incident Management	Traffic Incident Management	UAS deployment for quick response and clearance of traffic incidents to restore roadway capacity.
	First Responder Situational Awareness	Emergency event where first responders can deploy UAS to gain situational awareness before arriving at the scene.
	Crash Site Reconstruction	Done in cooperation with law enforcement officers to expedite crash site surveys and incident clearance.

UAS = unmanned aerial system, UAV = unmanned aerial vehicle

CONCLUSIONS

- *UAS technology is currently seeing wide and rapidly increasing adoption by DOTs in a wide variety of applications. As this technology develops and regulations mature, the scope and* *magnitude of UAS applications that support traffic operations are expected to grow significantly and become much more mainstream.* DOTs are including UAS within their standard operations, whether utilized by their own personnel or contractors, and within guidelines established to ensure safety, efficiency, and regulatory compliance.

- *A demonstration of a UAS-based traffic flow analysis system has shown that it may be used to collect traffic flow data such as vehicle counts and classification as well as speed and trajectory data quickly and efficiently.* Limitations of these types of UAS technologies include short data collection (flight) times when untethered; constraints related to environmental conditions such as wind, precipitation, and light; and regulatory restrictions and uncertainty that may impact the value of apparent benefits. UAS-based tools are especially well suited for sporadic, critical, short term, data gathering efforts where flexibility of operation is beneficial.

- *Specific UAS capabilities such as operation beyond visual line-of-sight (VLOS) and/or remote piloting, the ability to fly over people and moving vehicles, and remotely based and piloted UAS incident surveillance (drone-in-a-box) hold specific promise for support of future DOT traffic operations, with the primary benefit of expedited data acquisition without many of the limitations associated with collection of this type of data using conventional methods.* It should be noted that conducting these types of UAS operations currently requires a regulatory waiver from the FAA.

RECOMMENDATIONS

1. *VDOT's Operations Division and Traffic Engineering Division should consider utilizing UAS, and potentially, associated automated video analysis tools, to characterize traffic conditions for critical short duration data collection efforts not amenable to traditional data collection.*

2. *The VDOT Office of Strategic Innovation and the VTRC should support research and experimental (pilot) implementations to determine how innovative UAS technologies may be used by VDOT personnel and/or contractors to support VDOT's traffic operations.* Examples could include, but are not limited to, the following:

   - Small, lightweight, and frangible UAVs for rapid data collection. These aircraft may allow safe operation over moving vehicles and people by personnel not certified as pilots.
   - Aerostats (e.g., blimps) for extended aerial observation of areas of interest.
   - Remotely based and piloted UAS incident surveillance (drone-in-a-box).
   - Tethered and hybrid-powered (i.e., battery and fuel) aircraft for extended flight times.
   - Fixed-wing and/or hybrid (i.e., fixed- and rotary-wing) aircraft for extended distance flights such as linear infrastructure.

   Waivers of current FAA regulations may be required to perform this work.

3. *The VDOT UAS section should acquire and analyze further information on UAS usage by other state DOTs for traffic operations to provide objective data on how UAS programs have been funded, their associated costs, and the respective return on investment realized through their implementation. Any gaps and deficiencies in UAS program implementation and funding should also be characterized.*

IMPLEMENTATION AND BENEFITS

Researchers and the technical review panel (listed in the Acknowledgments) for the project collaborate to craft a plan to implement the study recommendations and to determine the benefits of doing so. This is to ensure that the implementation plan is developed and approved with the participation and support of those involved with VDOT operations. The implementation plan and the accompanying benefits are provided here

Implementation

With regard to Recommendation 1, the VDOT UAS Section Manager will lead the development of guidance on contracting specifications and modified proposal evaluation processes that better accommodate the use of UAS for traffic monitoring applications. The modified proposal evaluation criteria will be structured to take into consideration those factors that may be of particular benefit when using UAS such as safety, deployment flexibility, improved data quality, and expediency of data collection. The Operations Division will support the development of this guidance and policy in collaboration with the UAS Section Manager from the Location and Design Division. This will begin within 18 months of the publication of this report.

With regard to Recommendation 2, VTRC and VDOT's Office of Strategic Innovation will work with relevant divisions to identify current UAS research needs and develop potential research needs statements (RNSs) for a pilot UAS implementation program. A pilot traffic operations UAS implementation will be identified and conducted to demonstrate the usefulness of UAS and better characterize the associated benefits and potential challenges and pitfalls with respect to their use. VTRC will work with the UAS Section Manager to develop the RNS for discussion in relevant VTRC research advisory committees for possible funding within 18 months of the publication of this report.

With regard to Recommendation 3, VDOT's UAS Section Manager will consult with peers at other DOTs to obtain the relevant information regarding UAS program agency funding mechanisms, costs, quantifiable benefits, and potential pitfalls to avoid. This information will be used to inform VDOT's UAS program implementation decisions. This activity may be supported by VDOT's OSI. Depending on the results of these discussions, follow up national work such as an NCHRP synthesis, may be needed. A decision on whether to proceed with an NCHRP problem statement will be made within 18 months of the publication of this report.

Benefits

The benefits of implementing Recommendation 1 include:

- Expediency – Use of UAS for collection of traffic characteristics shows significant potential for providing required information very quickly under circumstances that may be challenging for traditional methods. This may be especially impactful on the assessment of sporadically occurring events such as crash and weather incidents.
- Safety – The use of UAS may provide safety benefits derived from the extension of remote sensing outside the zone where traffic and other hazards may present elevated risks to those installing or operating data collection equipment. Typical UAS operations allow both the aircraft and the pilot to operate clear of roadside areas where traffic and other hazards exist.
- Improved data quality – The vantage point offered by an elevated camera platform may provide an improved view of the roadway environment. Also, the location of the aircraft may be changed quickly depending upon data collection requirements and changes in conditions.

The implementation of Recommendation 2 will allow VDOT to obtain a better understanding of how UAS usage may benefit their operations, while also developing insight on the respective limitations and costs based on its own experience. It will also allow VDOT to contribute to the greater body of knowledge that informs how UAS may be used to support surface transportation.

The implementation of Recommendation 3 will provide VDOT with the objective empirical data needed to inform future decisions on whether the use of UAS for traffic operations makes sound financial sense and how that investment might be funded within the agency.

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APPENDIX: ADDITIONAL DATA FOR OTHER INTERSECTIONS OF INTEREST

Location 1 (Figure A1) is a restricted crossing U-turn intersection that was built by VDOT as an alternative to a signalized intersection. It was chosen by the research team as a preliminary demonstration site because of its relative novelty and interesting turning and merging traffic flows.

Figure A1. Aerial View of Intersection 1 at US 460 and North Main Street Near Blacksburg

Location 2 (Figure A2) is a roundabout located at a busy intersection in Blacksburg, Virginia. It was chosen by the research team as a preliminary demonstration site because it is somewhat unique in design and because of the complex traffic flow and high potential for merging traffic conflicts.

Figure A2. Aerial View of Intersection 2 at Prices Fork Rd. and Main Street in Blacksburg

Location 3 (Figure A3) is a diverging diamond intersection. It was noted by the TRP as a potential demonstration site. UAS data were not collected at this site due to safety concerns over nearby air traffic.

Figure A3. Aerial View of Intersection 3 at US 460 and Southgate Dr. in Blacksburg

Location 4 (Figure A4) is a signalized intersection located at the entry of the Radford Army Arsenal along Peppers Ferry Road. This site was suggested by the TRP. This site provided flight challenges related to the presence of a restricted, no-fly zone immediately north of the intersection, but aerial video was successfully collected without adverse incident.

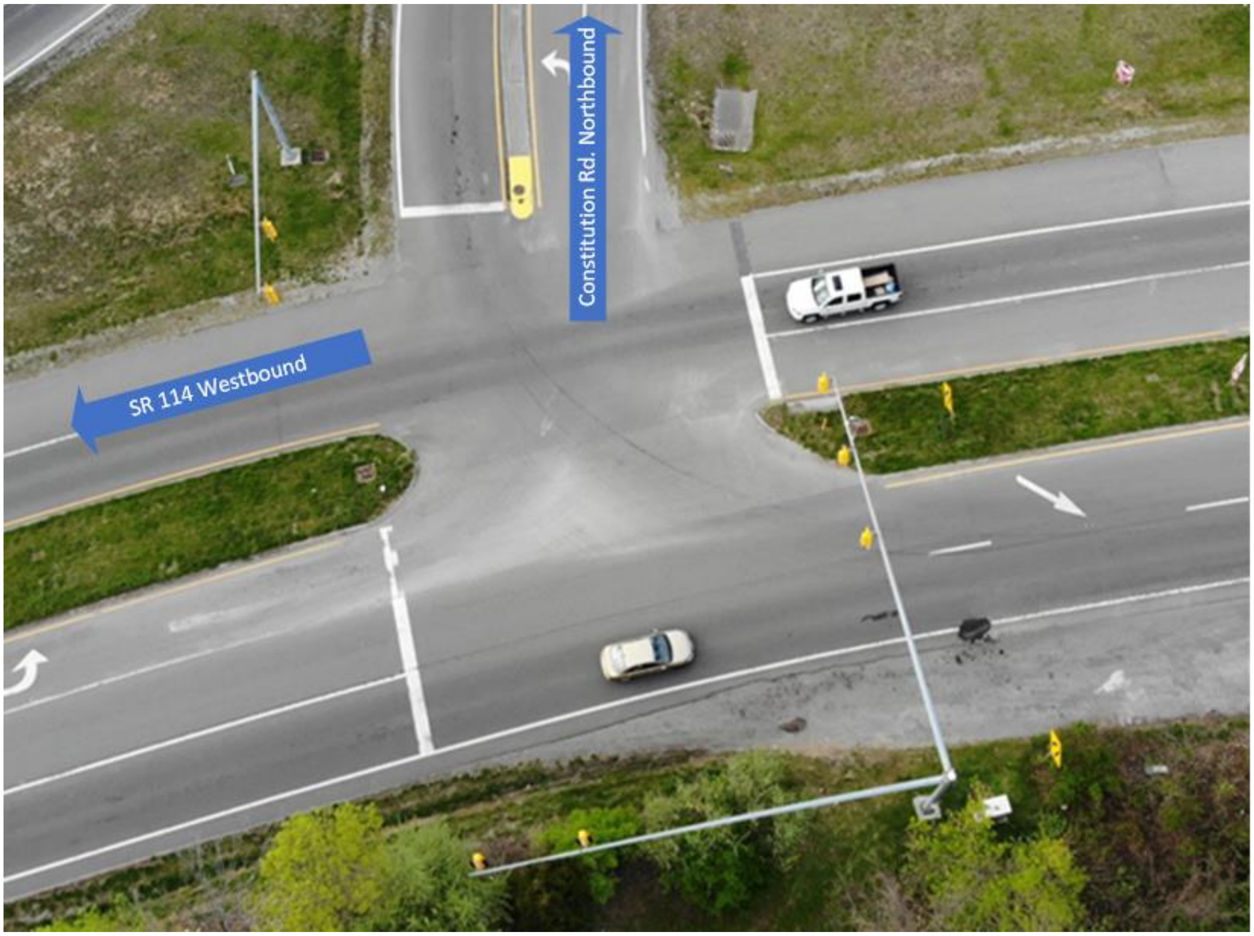

Figure A4. Aerial View of Intersection at Peppers Ferry Rd NW (SR 114) and Constitution Rd near Fairlawn, VA

Location 6 (Figure A5) is an intersection located just north of, and adjacent to, Location 5. This intersection was recently constructed to provide better access to a shopping area located east of the site. Challenges at this site included maintaining safe lateral clearances between flight areas and areas where people and moving vehicles might be present.

Figure A5. Aerial View of Intersection 6 at North Franklin St. and Shoppers Way in Christiansburg, VA