Unmanned Aircraft System (UAS): Purchase and Training

State Transportation Innovation Council (STIC) Incentive Project

Final Report
January 2021

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EXECUTIVE SUMMARY

The NJDOT created a brand-new unit in the Bureau of Aeronautics to pursue the benefits of innovative drone technology. The new unit (called the UAS Program) required startup funding for equipment and training to support the evaluation of transportation missions. Funding through the Federal Highway Administration (FHWA) State Transportation Innovation Council (STIC) Incentive program provided the equipment required for field operations and included training for an initial cadre of 10 UAS Remote Pilots.

LIST OF ACRONYMS

AGL - Above Ground Level
ATC - Air Traffic Control
BOA - Bureau of Aeronautics
CAI - Center for Accelerating innovation
CFR - Code of Federal Regulations
COA - Certificate of Waiver or Authorization
FAA - Federal Aviation Administration
FHWA - Federal Highway Administration
HMLP - High Mast Light Pole
ICAO - International Civil Aviation Organization
NAS - National Airspace System
NJDOT - New Jersey Department of Transportation
NJIT - New Jersey Institute of Technology
RPIC - Remote Pilot in Command
STA - State Transportation Agency
STIC - State Transportation Innovation Council
sUAS - Small Unmanned Aircraft System
TFR - Temporary Flight Restriction
TMC - Traffic Management Center
UAS - Unmanned Aircraft System

INTRODUCTION

The use of drones by public sector agencies such as the New Jersey Department of Transportation (NJDOT) is progressing at an exponential rate. Each state has funded ground breaking research and is expanding their Unmanned Aircraft System (UAS) capability with limited funding and guidance.

In 2016 the Division of Multimodal Services sent a survey to all NJDOT Directors asking them to identify areas in their routine operations where UAS technology had the potential to improve safety and efficiency. The Bureau of Aeronautics (BOA) UAS Program was then able to develop several potential use cases to fly missions in support projects such as:

a. Traffic Management
b. Structural Inspections
c. Crash Scene Documentation
d. Periodic real-time assessment of crew performance on the job
e. Check for flooding post storm or drainage issues pre storm
f. Drainage outfall inspections
g. Inspect for Right of Way Incursions
h. Pre-construction surveys
i. Supplemental project data for presentations to local municipalities
j. Photos to supplement project reports

STIC PROCESS

Funding provided through the FHWA STIC Incentive program enabled the purchase of UAS equipment and training to establish a new unit within the Bureau of Aeronautics (BOA) called the UAS Program. This incentive funding provided the initial equipment and training funding required to establish the NJDOT UAS Program.

STIC resources foster a culture for innovation and help develop innovations into standard practices in their States. Through the program, funding up to $100,000 per State per Federal fiscal year is made available to support or offset the costs of standardizing innovative practices in a State Transportation Agency (STA) or other public sector STIC stakeholder. The program is administered by FHWA's Center for Accelerating Innovation (CAI).

GOALS AND OBJECTIVES

To provide the initial equipment and training required to establish the NJDOT UAS Program.

PROJECT ABSTRACT

The State Transportation Innovative Councils (STIC) Incentive program funding will enable the New Jersey Department of Transportation's (NJDOT) to purchase sUAS (small Unmanned Aircraft Systems) and tablet computers to be operated by the Bureau of Aeronautics. NJIT and Rutgers University have conducted studies to determine the feasibility of using small Unmanned Aircraft Systems to assist our Bridge Inspection and Traffic Management teams. NJDOT Directors responding to our recent survey have identified a number of additional areas in their operations where sUAS technology has the potential to improve safety and efficiency in their routine operations.

They include:

a. Bridge Inspection
b. High Mast Light Pole Inspection
c. Traffic Management

d. Crash Scene Documentation
e. Emergency management
f. Identify areas of large potholes or longitudinal joints that are separating.
g. Identify areas of litter or vegetation needs.
h. Periodical assessment of performance by crews on the job. Live.
i. Check for flooding post storm or drainage issues pre storm.
j. Monitor pre winter storm brine spreading.
k. Monitor during storm; position of resources. If possible?
l. Bridge inspections.
m. Bridge scouring monitoring post storm.
n. Better identify vegetation in need of spraying during spring campaigns to stop vegetation spread.
o. Identify center barrier hits and guiderail hits.
p. Drainage outfall inspections.
q. Normal, IR or thermal images of concrete surfaces to identify spalling.
r. Inspection or Drainage outfalls.

<u>Project Description</u>

The research from NJIT and Rutgers indicate that utilizing this innovative technology will improve safety and efficiency while reducing costs. Initially we plan to start integrating this technology into conducting bridge inspections and traffic incident management. Based on that experience we will systematically advise and assist the other Directors to integrate sUAS technology into the operations they identified above. (See items a. through r.) The Multi-Modal Division is creating a policy regarding the use of sUAS. Two examples follow.

1. Traffic Management

   sUAS are being considered to help with accident investigations by mapping the entire crash scene from above. The quicker the scene can be mapped the faster the accident can be cleared to reduce congestion. A live video feed from the drone can also be sent to the NJDOT Traffic Operations center in real time to monitor congested highways and assist in providing alternate routes.

2. Bridge Inspections

   The use of a sUAS to aid high mast inspections and under deck bridge inspections will be trialed to improve the quality of routine inspections. This will enable us to gather data that cannot be readily obtained without expensive access methods. Defects can be identified and viewed with a level of detail equivalent to a close-up photo. The safety risks associated with traffic control and working at height can be minimized with a drone. The risk of having NJDOT personnel working under a bridge deck while over a waterway can also be eliminated.

<u>Develop Guidance</u>

- Implement inspection-specific sUAS technology into NJDOT applications.

- Explore the use of a sUAS in the planning of an inspection.
- Incorporate sUAS technology into actual inspections.
- Compile a best practices document.
- Provide guidance in drafting state sUAS policies and procedures.

Standards and Specifications

The FAA regulations under 14 CFR Part 107 outline the minimum training and certifications required to operate a sUAS, however, New Jersey is a densely populated state with a uniquely complicated airspace structure. NJDOT operations are near active roadways so a clear set of standards and specifications will need to be developed to ensure a high degree of safety.

Implement System Process Changes

While UAS cannot replace many of the current activities that NDOT performs, it can greatly enhance them both from a safety and technical point of view.

Organize Peer Exchange

NJDOT Aeronautics is establishing a peer partnership with the Aviation sections in several other states. We will combine our knowledge and experience to develop a set of best practices with the following states;

- Kansas
- North Carolina
- Florida
- Georgia

End Result

sUAS will increase safety and save time while reducing costs in the following areas:

For Traffic incident Management:

- To map an accident scene to assist crash investigations to clear roads faster
- To provide a “bird’s eye view” for monitoring congestion in remote areas
- To provide the Traffic Management Operations Center with better information for decision making.

For Bridge Inspections:

- To eliminate the safety risk to NJDOT personnel performing high mast inspections
- To eliminate the safety risk to NJDOT personnel performing under deck bridge inspections
- To provide inspection detail that effectively replicates some of the detail learned through use of snooper trucks without the traffic control requirements and at significantly lower cost in equipment and traffic control needs.

Other efficiencies will be investigated as we actively employ our innovative sUAS technology to assist other NJDOT Divisions.

Applicant Information

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Funding Request

$59,945.00

Quantity: Five sUAS (drones)

This cost is based on estimates equipment similar to the following:

Quantity	Equipment Description	Cost
One	Hexacopter Drone, ready to fly including Gimbal Mounting Bracket	$7,000
One	Gimbal Mounting Connector	$199
One	RTK-G + Datalink Pro Pack	$4,999
One	A3 Upgrade Kit	$460
One	Gimbal, RAW capable Camera MFT 15mm	$1,999
One	Two set of Intelligent Flight Batteries (6PCS)	$1,598
One	Custom Protector Hard Case	$1,100
Two	Mini Tablets (Tablet App is part of the Navigation system)	$540
Four	256 GB Memory Cards	$800
Three	Professional Quad Copters ready to fly with Hi-Res RAW Capable Camera and 3-axis gimbal	$14,997
Twelve	64GB Memory Cards	$600
Three	Intelligent Flight Batteries	$477
Three	Mini tablets	$747
Three	Three sets of cables and accessories	$450
Three	Sets of professional pixel mapping software to convert drone images in order to deliver highly precise, georeferenced 2D maps, 3D models, Orthomosaic maps, volumetric, or GIS data with survey grade accuracy	$8,000
Four	Remote Pilot in Command training ($3,495/person)	$13,980

Quantity	Equipment Description	Cost
One	Training sUAS with obstacle avoidance, subject tracking technology, dual compass, dual IMU, a Pro Travel Case, 3 Intelligent Batteries total, and Triple Parallel Charger. 3 Axis stabilized camera with 12MP still shot and 4K video at 30 fps.	$1,600
One	Aeronautical Knowledge Test	$399
	TOTAL	**$59,945**

The repair and future maintenance costs will be borne by the NJDOT. The 20 percent matching share for the funds will also be borne by the NJDOT.

Eligibility and Selection Criteria

NJDOT is eligible to apply for and receive funding. NJDOT recently received STIC Incentive Program funding for a Data Driven Safety Analysis initiative; however, enough remains to fund this project in FY 17. The project is eligible under 23 USC for Construction. The project is ready within 6 months to receive funds. Innovation aligns with the stated TIDP goal. The innovation is being utilized by Michigan's Department of Transportation. The NJDOT Division of Multimodal is currently not utilizing this technology routinely. NJDOT will be happy to participate in monitoring and evaluation activities and will be willing to share the process, benefits and lessons learned with regards to this innovation. We are seeking federal participation in funding this proposal through the State Transportation Innovation Council (STIC)'s e-Construction Incentive.

TRAINING PROGRAM

PURPOSE OF TRAINING

1. To increase the staff capability of the Bureau of Aeronautics to support a wider range of Division requests.
2. To infuse UAS knowledge and expertise throughout the NJDOT Divisions to expand the internal knowledge of UAS regulations and capabilities.
3. To standardize operational methods and practices for all personnel.

Most UAS training vendors offer Computer Based Training or online preparation courses for the FAA Part 107 written test. A single written exam may be adequate for certain academic subjects, but UAS Remote Pilot training must also include practical training to ensure the risk management objectives of the department are achieved.

Practical UAS training for transportation missions was a brand-new concept that was previously not available through the normal channels of NJ state contract vendors. New curriculum was developed by the NJDOT UAS Program and delivered through a consultant with funds from the STIC grant.

CURRICULUM

The curriculum has two sections. The first is the Initial Course which is based on FAA Part 107 and includes practical training and skill building exercises. The second section is Recurrent Training which is taken after the initial course to maintain a high level of knowledge and practical skills.

INITIAL TRAINING CANDIDATES

The ten NJDOT candidates nominated by Division Directors for the Initial Course were:

	Division	Name
1.	UAS Program	Glenn Stott
2.	UAS Program	Koree Dusenbury
3.	Construction Project Mgmt	Ashley Davis
4.	Traffic Operations	Dennis Caltagirone
5.	Traffic Operations	Elizabeth Falcon
6.	Emergency Mgmt	Richard Crockett
7.	Aeronautics	Gerard Leipfinger
8.	Aeronautics	Christropher Rinaldi
9.	MultiModal	William Henderson
10.	MultiModal	Shadman Mohammed

INITIAL TRAINING

The four-day UAS Initial Training Course was held in Ringoes, NJ from Sep 18th – 21st, 2018. Several New Jersey State agencies were very interested in this training program because the NJDOT is regarded as having a leading role in the implementation of UAS technology. Observers from the New Jersey State Police, NJ Department of Corrections, and the NJ Office of Homeland Security & Preparedness were invited to observe the training sessions from the back of each class. They were not provided training materials, did not receive course credit, nor were they permitted to participate in any training activities.

Initial training is designed in three phases. The first two phases were designed to be generic packages that could be used as a template for all NJ state agencies. Below are the three distinct phases of UAS Initial training for NJDOT employees:

Phase I	FAA Part 107 Certification
Phase II	Best Practices & Practical Training
Phase III a	Skill Building Training
Phase III b	Mission Specific Training

INITIAL TRAINING PHASE I

a. Phase I - FAA Part 107 Certification
   The first component of training is to learn the pertinent FAA UAS regulations and then successfully pass the 14CFR Part 107 written test for FAA certification.

   i. FAA Part Regulations
   ii. National Airspace System and Sectional Charts
   iii. Operations near aviation facilities
   iv. Aviation Weather
   v. Loading and Performance
   vi. Human Factors, Crew Resource Management
   vii. Emergencies and contingencies
   viii. UAS Maintenance
   ix. Practice Exam and FAA test

Figure 1. Phase I Ground School Training

INITIAL TRAINING PHASE II

Phase II consists of best practices and practical training. This practical training phase is designed to supplement the trainee's academic knowledge with skills and hands-on flight experience such that the trainee can safely fly without supervision. These skills shall include, but are not limited to the following:

i. Pre-Mission Planning
ii. Site Survey and Risk Assessment
iii. PreFlight equipment checks

iv. Personnel Mission briefing
v. Take off/Landing and basic flight maneuvers
vi. Camera controls and software
vii. Recordkeeping
viii. Data Management
ix. Pre Mission and Flight planning
x. OnSite survey and mission briefings
xi. Battery Technology and Charging
xii. Operations and maintenance
xiii. Photo and Video production
xiv. Waivers and Authorizations

Figure 2. Phase II Equipment Inspection

Figure 3. Phase II Checklist Preparation

Figure 4. Phase II Battery Change for Quick Turnaround

Figure 5. Phase II Almost Ready for Takeoff

INITIAL TRAINING PHASE III

Phase III training must be conducted in a controlled environment that allows a trainee to concentrate on the current task in an area that does not endanger other personnel or property. The training area must also be free from the potential to create driver distractions or congestion. The busy NJDOT office complex in Ewing, NJ is in FAA Class D airspace and lies beneath the final approach for Runway 34 at Trenton Mercer Airport. An agreement was reached with the NJDOT Operations unit to utilize their facilities and Class G airspace at the Bordentown Training Center.

Figure 6. NJDOT Bordentown Training Center

Phase III training has two parts: Skill Building and Mission Specific.

a. Phase III a - Skill Building

   The newly certified UAS Remote Pilot will be assigned a mentor and authorized to practice their UAS flying skills without requiring an instructor to be present. A visual observer is still mandatory.

   i. Using a UAS simulator, students will practice quadcopter flying in a controlled indoor environment
   ii. Students will perform a preflight and configuration checks
   iii. Students will present a Mission brief
   iv. Student will fly and perform depth-perception exercises
   v. Student will use the drone camera to capture photos and video
   vi. Student will plan and fly an autonomous flight.

b. Phase III b - Mission Specific

   This training is mission specific to the Division's objectives. The skill and proficiency required to fly over a marshland at high altitude is distinctly different than the skills required for an under-deck bridge inspection. This training will likely be developed and conducted within NJDOT.

i. Traffic Incident Management
ii. Structural Inspections
iii. Aerial 3D Corridor Mapping
iv. Emergency Response Assessment
v. Real-time Construction Project Monitoring
vi. 3D Reality Modeling
vii. Landfill Volume Calculations

RECURRENT TRAINING

Recurrent training is only conducted for graduates of the initial course. It is defined as the training required to maintain an employees' high level of knowledge and practical skill over time. It is conducted at periodic time intervals,, such as annually, and should consist of:

1. A written UAS systems exam
2. An Oral Exam regarding emergency procedures
3. An oral delivery of a mission briefing
4. Demonstration of practical skills

Remote Pilots must also fly or practice three UAS missions every 90 days. If they do not meet the three-mission requirement, a demonstration of practical skills is required before assuming the duties of a Remote Pilot for the NJDOT.

USE CASE DEVELOPMENT

The primary focus of use case development is for Traffic Management and Structural Inspections

1. Traffic Management: The Route 495 Project

   An example of a Traffic Management use case was the Route 495 Bridge Construction (NJ 495 Project) in Secaucus, NJ.

   This section of Route 495 leads into the Lincoln Tunnel towards NYC and is one of the busiest roadways in the country. Urgent bridge repairs required several detours and the closure of two out of four lanes. The challenge for the Traffic Operations Division was to continually refine their traffic operations plan to maximize traffic throughput. Traditionally a high-level overview for a project of this magnitude would require the use of a manned helicopter because traffic cameras have a limited field of view over a large area. The project area lies within Class Bravo airspace and manned helicopters are a more expensive option than a UAS team.

   Both the photos below were taken from exactly the same horizontal location. The only difference is the height of the camera Above Ground Level (AGL). Figure 7 shows the field of view from a traffic camera mounted on a 50-foot mast compared to the UAS flying at 400 feet in Figure 8.

Figure 7. Traffic camera field of view from a 50-foot mast

Figure 8. View of from a UAS at 400 feet

The UAS Program was tasked to enhance the situational awareness of the NJ 495 Command Post and the Woodbridge Statewide Traffic Management Center (TMC) by providing live video coverage of the entire project area.

Both Inspire 2 drones purchased through STIC funding flew dozens of missions in support of the NJ 495 project. Flights were conducted continuously at 400 feet AGL between 6:00am to 9:30am, and from 3:30pm until 7:00pm. The drone provided nearly continuous live-streaming video to the TMC during those peak time periods. It was nearly continuous because the UAS landed every 25 minutes for a fresh set of batteries. A daily flight summary video was also provided to the Director of Traffic Operations and the Director of Communications.

Overall, the Director of Traffic Operations and the TMC Manager were very satisfied with the data and situational awareness provided by the UAS Program.

2. Structural Inspections

   See the High Mast Drone Inspection white paper attached as Appendix A.

3. Crash Scene Documentation

   See the NJIT ITS Resource Center Final Report attached as Appendix B titled, Standard Operating Procedure for the Safe Operation and Maintenance of UASs for Traffic Operation and Traffic Incident Management.

LESSONS LEARNED

1. Take-off and Landing Pads

   Many take-off and landing areas in the transportation industry are located in environments containing dust, dirt, leaves, sand, or loose debris. Even a small UAS can create enough down wash from the propeller blades to stir up a cloud of contaminants. These contaminants will coat the UAS in a fine layer of dust and can damage the leading edges of the propeller blades. The NJDOT sign shop created 30 inch by 30-inch landing pads made out of white plastic that is 3/16 inch thick. They are placed on the ground and ensure that small quad copters can be operated in a more sterile environment. Landing pads can also give a quick reference for the relative size of objects because they provide a 30-inch scale that can be seen in deliverable

   Powering up a quad copter on uneven ground could cause the camera and gimbal assembly to strike the ground during the power-on self-test sequence. Using a landing pad on uneven ground offers a perfectly flat surface to prevent this from happening.

2. Importance of Checklists

   The aviation industry has demonstrated the importance of checklists to ensure that a complex series of critical tasks are conducted efficiently, thoroughly, and in the correct order. NJDOT has developed several operational checklists based on this proven concept. A sample set of checklists are provided in the Best Practices section.

3. Thorough Briefing

   The Remote Pilot in Command must deliver a thorough briefing in a standardized format to ensure that all participants are familiar with the mission. The briefing should outline all mission parameters and include the duties and responsibilities of everyone present. A sample of a briefing is provided in the Best Practices section.

BEST PRACTICES

1. Checklists are tailored to a specific model of UAS. Best practices include strict adherence to the manufacturer's stated specifications and limitations, and must incorporate the emergency procedures recommended for that specific model of UAS. The following are examples of a set of quadcopter operational checklists:

Preparing for Flight
Pre-Flight Checklist Choose Staging Point……………………………..……..……………..Aircraft in Clear Area Assemble UAS Legs………………………………………….…………………….…..…………Installed Props…………………………………………………………….…White/White. Red/Red Cameras……………………….………………...X5S installed SD Card……………………………………………………….………………....Confirmed SD Card ……………………………………………………..…………………..Installed Camera……………………………………..…………………A (Auto) Correct Exposure Batteries………………………………….………………….....Odd(Left)/Even(Right) Check for structural damage **Manage Settings** Flight Mode……………………………..………………………………………………..**P** RTH……………………………………………………..………………....Set (Max 100m) Max Altitude…………………………..………………..……………..…..Set (Max 120m) Max Distance…………………………………………………..……….Set(Max 1200m) Compass……………………………………………………………..………...Calibrated SD Card……………………………………………..………………………Formatted Batteries………………………………………………………………………………Paired **Crew Briefing** Roles & Responsibilities…………………………………..……………Roles, expectations Discuss location…………………………………..….explain why this is the selected location Safety concerns…………………….……………………………….………Discuss obstacles Mission & deliverables……………….…………………….…Discuss route of flight and why Weather……………………………………………………………....…All aspects of weather Current Airspace……………………………...........…………………………….….Check Standard Call outs……………………………………………………..Go through all of them Sterile Cockpit……………………………………………………………….…………Check Emergency Procedures…………………….……………………………RTH, Safeguards, settings Questions?...

Normal Takeoff
Auto Takeoff Aircraft Status Bar………………………………..……………… …Ready To Go (GPS) Motors……………………….…………………..…Press Sticks in downward to Start Motors Homepoint…………………………………………………..……Verified Set as Desired Clear Airspace……………………….…………………….……………..…”Clear Airpspace” “TAKE OFF”……………………..………..……Tap Up Arrow( ) to Loiter Loiter 1.5M Height **Manual TakeOff** Aircraft Status Bar………..…………………….……………………….….Safe to Fly (GPS) Motors……………………..…………………………………………..…………Start Homepoint……………………..……………………………………..Verify Set as Desired “TAKE OFF”………………………………..………………..Slowly Push Left Stick up Transformation Switch……………………………………..………………………UP Dual Controller- Single Controller-
Normal Landing
Returning to Home……………………….…………….…………….”Returning to Home” Landing Area………………………………..…………Check Clear and Safe of People Gear Down……………………….…………………………..………………Gear Down Gimbal up……………………………………………………………....……..”Gimbal Up” “LANDING”……………………………….…………………………..……..…”LANDING” Power Off aircraft……………………………………………..…...”Powering off Aircraft” **If in Automatic Mode** Landing Area…………………………………….…………..…Check Clear and Safe of People “LANDING”……………………………………….………..……Transformation Switch Down “LANDING”……………………………..……………………...…………Tap up arrow( )
Quick Turn Around **Pilot Flying** UAV………………………………………………………………..………Take Control No fly zone(s)……………………………………………..……...……………Re-Verified **Pilot non Flying/Observer** Map………………………………………………..……..Displayed and centered on UAV Telemetry………………………….…………………….…………………………......Verified GPS lock & precision……………….…………………………………………………...Verified Battery power………………….………………………………………………Minimum 70% Control camera picture………………….……………...……Verify using on screen controls Remote Control…………………………………………….………….Re-Verify Installed Homepoint…………………………..…..Set – Open flat ground, clear of people or obstacles

Landing for Battery change and Quick Departure

Complete After Landing Checklist
Depleted Batteries……………………………………………………..…………...Remove
Replacement Batteries……………………………..…...Securely attached, inserted until "click"
Batteries………………………….……………………….………………Fully loaded above 80%
Copter……………………………………….....POWER ON (wait for self-check to complete)
Short music……………...…………………………...…………………………………Played
RC Status LED………..……………………………………………………...……….GREEN
Copter Status LED……..…………………………………………………………Blinking Green
RC and Tablet…………..…………………………...Connected and DJI Pilot App Launched
Pilot App………………………………….……….….Set and verify desired flight parameter
Compass……………..……………………...……………………………….……Calibrated

Do not attempt to engage motors yet
Pilot Flying
UAV………………………………..………………………...….….…………Take Control
No fly zone(s)…………………………..…………………………...…..…………Re-Verified
Pilot non-Flying/Observer
Map…………………………..…………………………….…...Displayed and centered on UAV
Telemetry…………………….…………….……………………………………….....Verified
GPS lock & precision……………………………….……………………………...Verified
Measured altitude versus accrual altitude (from Maps)………………….………...Verified
Battery power………………………………………………………….………Minimum 70%
Data and video Links………………………………………….……………………Alive
Control camera picture…………………….…………………Verify using on screen controls
Remote Control…………………………………….……………………..Re-Verify Installed
Homepoint…………………………..…...Set – Open flat ground, clear of people or obstacles

After Landing

Remote PIC……….…………….………………….……….……………"Power aircraft Off"
VO…………………………....…………….……………………………"Powering aircraft Off"
Batteries……………………….……..…………………Disconnect, Temperature check, Log
Motor temperatures………………………………………………………………...Check

Disassembly and Store Checklist
Propellers……………………………………………...…………………………Remove
Camera and Gimbal……………………………………………Removed, cleaned, and Stored
Copter……………………………………...…………………….…………Travel Mode

2. Standardized Crew Briefings

The RPIC should discuss the following topics during a mission briefing:

i. Crew roles and responsibilities
ii. Flight location
iii. Safety concerns (obstacles, wires, traffic, radio interference, etc.)
iv. Current and forecast weather conditions
v. Current airspace (including flying under a COA)
vi. Review the flight profile and deliverables
vii. Review the NJDOT standard callouts
viii. Review sterile cockpit procedures
ix. Review UAS controller contingency settings (max alt, max distance, RTH settings, low battery warnings, etc.)
x. Review emergency procedures
xi. Answer questions

A sample mission briefing for the inspection of a high-mast tower near a major highway is as follows:

i. Crew roles and responsibilities:

   "*Hi everybody, this is the briefing for UAS Mission number 19-140. I am Glenn, the RPIC, and I am responsible for the safe operation of this flight with the assistance of John as our visual observer (VO). The VO is the crewmember responsible for keeping the UAS in sight at all times and notifying us of potential safety issues during the flight. Bill is the structural engineer who will be operating the camera and directing the UAS into proper positions to conduct the evaluation."*

ii. Flight location:

   "We will be flying this mission in Hamilton, NJ on Route 130."

iii. Safety concerns (obstacles, wires, traffic, radio interference, etc):

   "*There are two high-tension power lines to the west and east of the mission area. Keep an eye on Route 130 traffic to ensure we aren't creating a distraction or causing congestion."*

iv. Current and forecast weather conditions:

   "The temperature is 75 degrees, the sky is overcast at 1600 feet, and the wind *is 220 degrees at 10 knots."*

v. Current airspace (including flying under a COA):

   "*We are in Class G airspace."*

vi. Review the flight profile and deliverables:

"*Our goal today is to inspect four high mast light poles near the highway. We will be conducting four flights today gathering high-definition photos."*

vii. Review the NJDOT standard callouts:

"I am going to review the standard verbal callouts. The VO will acknowledge each command by repeating it during the mission.

- *'Power on Aircraft': The VO will turn on the aircraft and I will load the mission commands.*
- *'Clear Airspace': The VO will ensure the takeoff area is clear of any potential threats during the takeoff.*
- *'Taking off': After hearing the response to "take off" from VO, I will take off.*
- *'Controllability check': I will check to ensure the aircraft is properly executing the maneuvering commands from the remote control.*
- *'Landing gear up': I will raise the landing gear, if applicable.*
- *'Climbing 50, 100, …' (every 50 ft.): I will say the UAS altitude every 50 ft. until the mission altitude.*
- *'Proceeding to mission': I will start flying the aircraft to the mission location.*
- *'Battery Call out (every 10%)': I will read the remaining battery percentage every 10%. The aircraft must be on the ground with no less than 20% battery remaining.*
- *'Returning home': Either when the mission is complete or the battery percentage reaches 30%, I will command the aircraft to start proceeding home. I will stabilize the aircraft in a hover approximately 15 ft. above the landing site.*
- *'Gear down': I will activate 'gear down'.*
- *'Gimbal up': I will raise the camera gimbal.*
- *'Landing"': I will commence a descent to touchdown. The VO will monitor potential hazards to ensure a safe landing.*
- *'Going around': If anyone observes a hazard during landing, he/she will call 'Go around' and I will repeat 'going around'. I will immediately initiate a climb to a safe altitude. Once at a safe altitude, we will discuss the hazard and attempt another landing.*
- *'Power off aircraft': The VO turns off the UAS."*

viii. Review sterile cockpit procedures:

"The sterile cockpit procedure is in effect once the "clear airspace" command is given. This means that only conversations essential to safely complete the mission are permitted."

ix. Review UAS controller contingency settings (max alt, max distance, RTH settings, low battery warnings, etc):

"*I have set the 'return-to-home' maximum altitude to 300 ft in the event of a lost link. I have set the controller to a maximum altitude of 125 ft and a maximum distance of 1000 ft The low battery warning is set at 30%, and the critical battery warning at 20%. The compass is calibrated, and the SD card is formatted."*

x. Review emergency procedures:

"In case of an emergency, we will utilize the following emergency procedure:

- *I will announce the emergency.*
- *We all remain calm.*
- *In case of Loss of Power, I will try to regain control of the UAS. Everybody should maintain visual contact with the UAS.*
- *In case of an airspace intrusion, I will suspend the operation and maneuver or land to avoid the conflict.*
- *In case of a flyaway or loss of control, I will try to put the aircraft in 'return-to-home' mode. If the aircraft is going to enter controlled airspace, I will contact ATC immediately.*
- *In case of any impending impact causing injuries, the VO will call 911 and I will notify the NJDOT Bureau of Aeronautics."*

xi. Answer questions:

"Briefing complete. Any questions?"

3. Driver Distraction and Congestion Mitigation

Road side UAS operations have a higher potential to distract passing motorists when the UAS is flying low, slow, or in plain view.

Keep the UAS out of plain view as much as possible during assembly and daily equipment checks.

Place staging vehicles strategically to block the view of the take-off and landing pad to passing motorists. Two vehicles are better than one and will shield the view from both directions.

Make use of the natural terrain and surrounding structures to shield the takeoff area from being observed by passing traffic.

On initial take-off fly climb to approximately four feet for an airborne equipment check. Four feet is suggested so the UAS is below the roof line of the staging vehicles and not in full view to traffic.

From four feet climb rapidly to an altitude of at least 100 feet. The higher the altitude of the UAS the smaller it will appear from the ground. A higher altitude also presents a higher viewing angle which further assists by keeping the UAS above a driver’s normal field of view.

Ensure that Visual Observers are continually monitoring traffic for signs of distraction and congestion. Passing motorists are somewhat used to seeing staging vehicles and personnel in reflective vests so some slowing of traffic is to be expected. The known presence of a UAS operation may lead to more curiosity and distraction that a routine roadside maintenance crew. This can slow down traffic flow and quickly lead to congestion. Slow moving traffic has a higher potential for distraction because drivers have more time to focus on what’s happening in the work area.

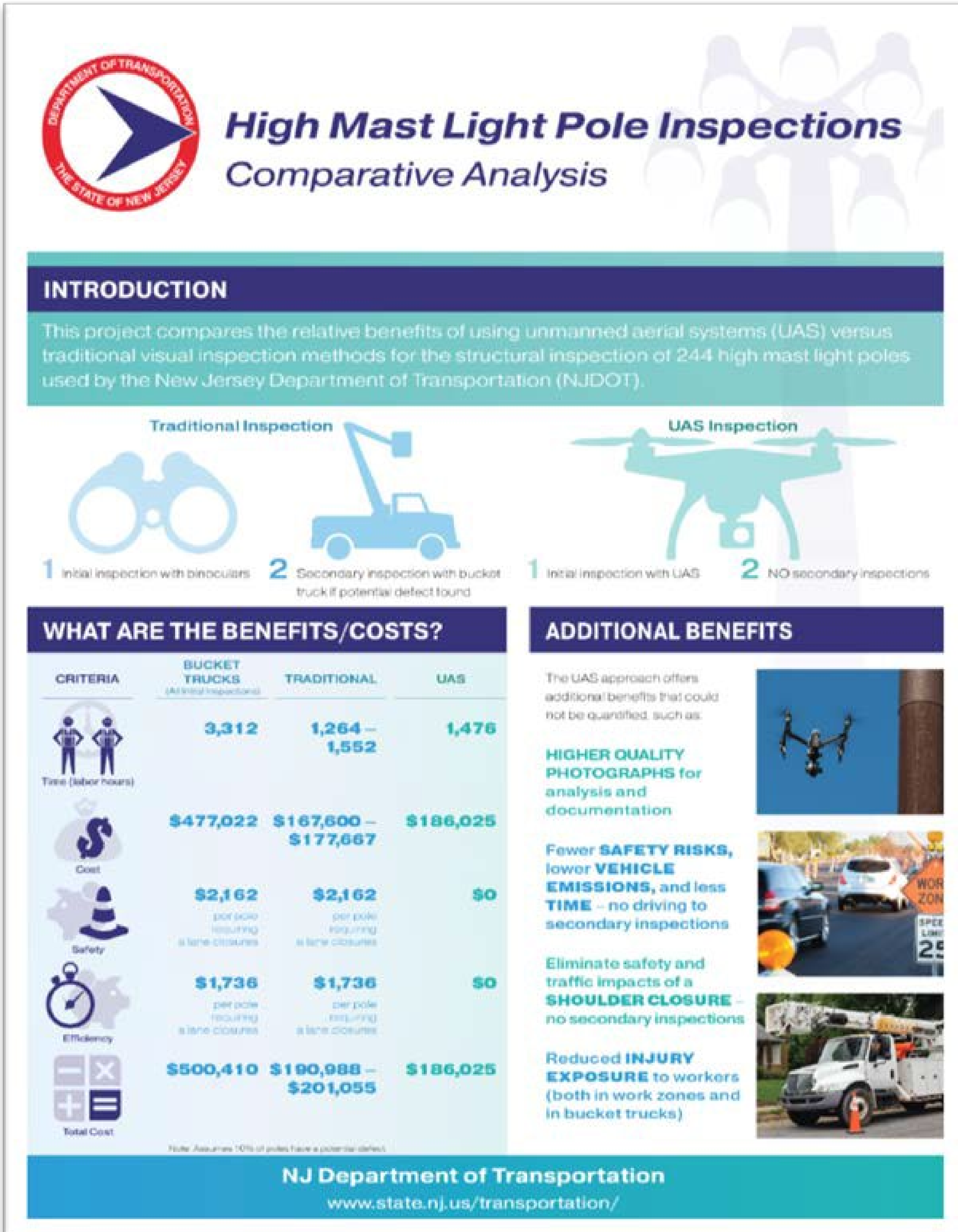
QUANTIFIABLE BENEFITS

In 2018 the department commissioned a white paper to provide a comparative analysis of the various methods for conducting the structural inspections of 244 High Mast Light Poles (HMLP).

The traditional inspection approach requires an initial inspection of high mast light poles by two engineers with binoculars. If any potential defects are noted, a second inspection using a bucket truck is required. Depending on the location of the pole, the secondary inspection may require a shoulder or lane closure and disturbance of a guiderail with associated impacts on highway safety and efficiency, personnel time and cost. The UAS inspection approach has a higher time requirement and cost during the initial inspection phase but eliminates the need for a secondary inspection and any associated traffic or safety impacts, leading to an overall cost savings. Finally, these approaches are briefly compared to a prior bucket truck approach which required a bucket truck for every high mast light pole initial inspection in the state.

A traditional, ground-based asset management approach was compared against UAS technology across four project evaluation criteria: safety, efficiency (highway and data), time, and cost.

A comparative analysis is depicted in Figure 9. A copy of the complete report is attached as Appendix A: Structural Inspection.



Note: * Assumes 10% of high mast light poles require a secondary inspection using the traditional approach.

Figure 9. Summary of UAS Benefits/Costs

CONCLUSION

The field of UAS technology for the transportation industry is rapidly evolving as State DOTs take advantage of the safety, efficiency, and cost savings this technology can provide.

Generous funding through the STIC incentive program has provided the training and equipment needed to jump start the new NJDOT UAS Program in the Bureau of Aeronautics. The unit has created policies, procedures, and many best practices through lessons learned, and has institutionalized UAS technology under EDC-5. The program continues to flourish and has become one of the leading state DOT UAS programs in the nation.

APPENDIX A: STRUCTURAL INSPECTION

Memorandum – High Mast Drone Inspection

TO: Federal Highway Administration (FHWA)
FROM: NJDOT Bureau of Research
DATE: October 5, 2018

Executive Summary

The purpose of this report is to provide a comparative analysis between a traditional, ground-based asset management approach and an approach utilizing unmanned aerial systems (UAS) for the structural inspection of 244 high mast light poles as conducted by the New Jersey Department of Transportation (NJDOT). The goal of this research was to document and, to the best extent possible, quantify the benefits of using UAS compared to a traditional approach across four project evaluation criteria: safety, efficiency (highway and data), time, and cost.

The traditional inspection approach requires an initial inspection of all high mast light poles in the state by two engineers with binoculars. If any potential defects are noted, a second inspection using a bucket truck is required. Depending on the location of the pole, the secondary inspection may require a shoulder or lane closure and disturbance of a guiderail with associated impacts on highway safety and efficiency, personnel time and cost. The UAS inspection approach has a higher time requirement and cost during the initial inspection phase but eliminates the need for a secondary inspection and any associated traffic or safety impacts, leading to an overall cost savings. Finally, these approaches are briefly compared to a prior bucket truck approach which required a bucket truck for every high mast light pole initial inspection in the state. These benefits and costs are summarized in Table 1.

Table 1 - Summary of Benefits/Costs

Criteria	Bucket Truck Approach (For all Initial Inspections)	Traditional Approach (Bucket Truck for Secondary Inspection Only)	UAS Approach
Time (Labor-hours)*	3,312	1,264 – 1,552	1,476
Cost*	$477,022	$167,600 - $177,667	$186,025
Safety (cost)	$2,162 per pole requiring a lane closure (6)	$2,162 per pole requiring a lane closure (maximum 6)	$0

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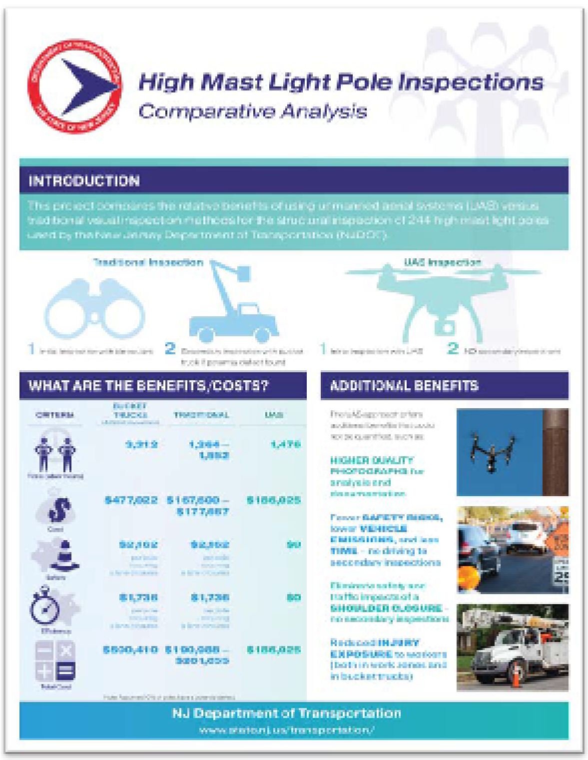
Criteria	Bucket Truck Approach (For all Initial Inspections)	Traditional Approach (Bucket Truck for Secondary Inspection Only)	UAS Approach
Efficiency (cost)	$1,736 per pole requiring a lane closure (6)	$1,736 per pole requiring a lane closure (maximum 6)	$0
Total Cost	$500,410	$190,988 - $201,055	$186,025

Note: * Assumes 10% of high mast light poles require a secondary inspection using the traditional approach.

In addition, the UAS approach provides a number of benefits not quantified in this report, including collection of higher quality data for analysis and future comparison, reduced time, safety risks, environmental impacts, and costs associated with driving to secondary inspections, and reduced injury exposure for workers related to traffic closures and bucket truck deployments.

Figure 1 - High Mast Light Pole Inspection Overview



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Introduction

The purpose of this report is to provide a comparative analysis between a traditional, ground-based asset management approach and an approach utilizing unmanned aerial systems (UAS) for the structural inspection of high mast light poles as conducted by the New Jersey Department of Transportation (NJDOT). The goal of this research was to document and, to the best extent possible, quantify the benefits of using UAS compared to a traditional approach across four project evaluation criteria, including:

- Safety;
- Efficiency (both for inspection personnel and motorists);
- Time; and
- Cost

Figure 2 - Unmanned Aerial Vehicle and High Mast Light Pole

Source – NJDOT Aeronautics, 2016

This report is organized by first offering an introduction to high mast light poles in New Jersey, then providing an explanation of the inspection process using three case studies, and lastly a calculation of benefits using the four project evaluation criteria.

High Mast Light Poles Overview

NJDOT is responsible for inspecting and maintaining 244 high mast light poles in the State. These light poles are typically located at major interchanges and are intended to provide illumination over a large area. These deployments generally provide a uniform level of illumination and reduce glare.[1] The greatest concentration of high mast light poles in New Jersey are located along State Route 3 (SR 3) west of Union City (Hudson County) and along U.S. 46, U.S. 202, and Interstate 80 in Wayne (Passaic County). Figure 3 highlights the location of these poles.

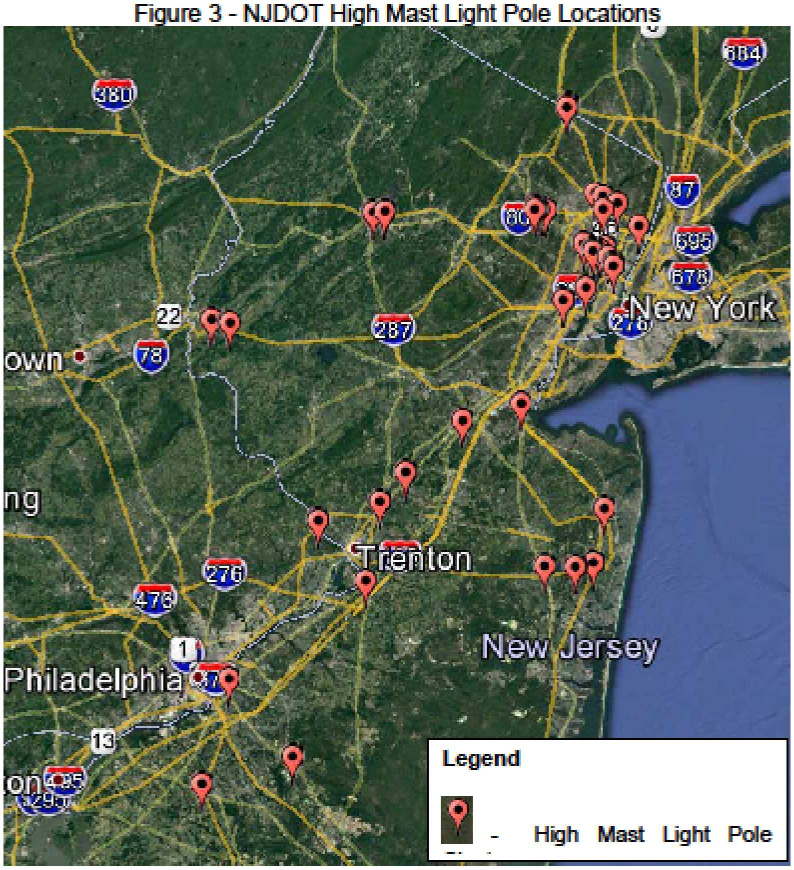
These high mast light poles are inspected once every five years, with all inspections being conducted within the same year. The last inspection cycle occurred in 2016. The design lifespan of a high mast light poles is approximately 30 years. Six of the 244 light poles are in locations that are not reachable by UAS, either due to ground cover, flight

[1] https://www.dot.state.mn.us/trafficeng/lighting/2010_Roadway%20Lighting_Design_Manual2.pdf

restrictions, or the inspection would require the UAS to cross active traffic lanes which is not currently allowed by NJDOT.

The inspection of high mast light poles has evolved over the years. Historically, all initial inspections of high mast light poles were done by bucket truck. However, following a tradeoff analysis that compared the cost of this approach, the inspection quality, and the potential risks to public safety, an approach using binoculars for the initial inspection and a bucket truck only for high mast light poles with a potential defect (traditional approach) was implemented. UAS offers a new option, one that balances direct cost to NJDOT and the public, safety risks, and the ability for NJDOT to obtain high quality data and make better-informed maintenance decisions for every high mast light pole in the state.

Figure 3 - NJDOT High Mast Light Pole Locations



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Source – NJDOT, Google Earth.

Case Studies

The following section details the UAS and traditional initial inspection process for all high mast light poles. It then discusses three scenarios where a secondary inspection would be required to highlight the differences between the traditional and UAS approaches.

Initial Inspection

All high mast light poles are subject to an initial inspection. The initial inspection process using the traditional approach and UAS approach are described in the following sections.

Traditional Approach

Using the traditional approach, the initial inspection of each high mast light pole is conducted by a pair of engineers, typically contractors working for NJDOT. The inspection of the high mast light pole covers a number of elements including:

- Concrete base;
- Anchor bolts;
- Lighting elements; and
- Light pole.

The inspection of the light pole itself takes approximately 15-20 minutes and is conducted from the ground with binoculars and photographs of the pole are taken from the ground using a hand-held camera. The entire inspection, including all pole elements, takes approximately two hours to complete.

This initial inspection using the traditional approach has minimal impact on highway safety or efficiency as the inspection team is able to perform the inspection completely off the roadway. There may be a limited issues associated with driver distraction as a result of motorist taking their eyes off the road and looking at the inspectors and vehicles involved in the inspection. However, NJDOT considers this risk to minor.

If no potential defects are detected on the light pole, this is the end of the inspection process. If a potential defect on the pole is identified, a return visit using a bucket truck would be required. Historically, approximately 10% of the light poles require a return visit during each inspection cycle. The impact of this second inspection on the four project criteria can vary depending on the characteristics of each pole and is discussed in the scenarios below.

Unmanned Aerial System (UAS) Approach

Using a UAS approach, the initial inspection of each high mast light pole is conducted by a team of three people including two engineers and a UAS pilot, again typically contractors working for NJDOT. Similar to the traditional approach, multiple elements of each light pole are examined. The UAS is used specifically for inspection of the light pole. The inspection of the concrete base, anchor bolts, lighting elements, etc. is *not* conducted by UAS.

Figure 4 - High Mast Light Pole Inspection Team

Source – NJDOT Aeronautics, 2016.

The UAS is deployed from a flat base set near the high mast light pole. Using a video camera to provide constant feedback to the team on the ground, the UAS makes a pass up the pole, rotates 135 degrees and comes down, rotates 135 degrees and goes up, then has a final pass back down to examine any issues if needed. Still photographs are taken of any potential defects. These photographs can be examined on-site by the team or examined back in the office in order to determine if maintenance work is required.

Each high mast light pole inspection requires approximately 2 hours to complete, with the UAS portion of the inspection lasting approximately 15-20 minutes. This initial inspection using UAS has minimal impacts on highway safety or efficiency as the inspection team is able to conduct the inspection completely off the roadway. Similar to the traditional approach, there may be minor concerns due to the presence of a vehicle and people conducting the inspection. Additional concerns due to the deployment of UAS are also minimal. On takeoff, the UAS is immediately flown to a height of approximately 20 feet to minimize potential distractions and the UAS is not allowed to cross moving traffic lanes.

Similar to the traditional approach, if no potential pole defects are detected during this initial inspection, this is the end of the process. The operational case studies below become relevant if a potential defect was detected during the initial inspection.

As detailed below, the traditional approach requires a second inspection if the initial inspection identifies a potential defect. If a UAS is used during the initial inspection, a second inspection is not necessary.

Secondary Inspection

The following scenarios discuss the secondary inspection process for high mast light poles where a potential defect is identified during the initial inspection. The process for inspecting these poles using the traditional approach varies depending on the specific location and operational characteristics of the highway facility in proximity to each pole.

Second Inspection Scenario 1 - No Access Impediments

In this scenario, a potential defect is found during the initial inspection of a high mast light pole in a location that is reachable by bucket truck **without disturbing traffic lanes or requiring the removal of the guiderails**. This scenario accounts for approximately 194 (80%) of the high mast light poles inspected by NJDOT. An example light pole is #1201801, located at the interchange of U.S. 1 and College Rd. West in Plainsboro Township.

Using the traditional approach, if a potential defect was found during the initial inspection, a second inspection would be required. This second inspection would require the use of a bucket truck in order to raise inspectors off the ground and provide a better vantage point to inspect the potential defect. The two engineers involved in the initial inspection join the bucket truck operator and the second inspection can take up to four hours to complete, not including travel time to and from the inspection site. The two engineers use the bucket truck to make a closer examination of the pole, take photographs using a hand-held camera, and then determine if maintenance work is warranted.

If the initial inspection is done using a UAS, there is no need for a second inspection. The initial inspection provides sufficient information to the engineers to determine if maintenance work is required.

Second Inspection Scenario 2 – Shoulder Closure

In this scenario, a potential defect is found on a light pole that **requires a shoulder closure** to inspect with a bucket truck. Within this, there are two potential sub-scenarios. In the first, the inspection does not require removing the guiderail to access the light pole. An example light pole is #1201814 which is located south of U.S. 1 at the interchange with U.S. 130 in Milltown. In the second, the inspection requires the guiderail to be removed in order to access the light pole. An example light pole is #1601808 located at the interchange of SR 3 and SR 21 in Clifton (Passaic County).

This scenario accounts for approximately 44 (18%) of the high mast light poles in the state. Sixteen of the poles are in locations that do not require a guiderail opening, 28 light poles do require guiderail removal.

In this scenario, the second inspection requires a number of additional personnel:

- The two engineers who conducted the initial inspection;
- A bucket truck operator; and
- Two additional traffic safety personnel who set-up the shoulder closure.

All of these personnel must be on-site during the entire inspection process which typically last approximately 4 hours, not including any travel time associated with going to and from the inspection site.

If the guiderail must be opened to allow access, two additional staff are required. Due to liability concerns, only NJDOT maintenance personnel can remove and replace the guiderails that run along the highway. It takes approximately 30 minutes to remove and 30 minutes to replace the guiderails, but NJDOT staff do not have to remain at the work zone during the entire inspection. This does not include any potential travel time associated with driving to and from the site.

Using the UAS approach, this secondary inspection including shoulder closure and possible guiderail removal is not required. The initial inspection with UAS provides sufficient information to make a decision regarding additional maintenance needs.

Second Inspection Scenario 3 – Lane Closure

The final scenario envisions a potential defect being found on a high mast light pole in a location **requiring a lane closure** to access the pole. Similar to the shoulder closure scenario, in some cases a guiderail must be removed to provide access. An example of this is light pole #0204802 located at the interchange of SR 3 and SR 17 in Rutherford (Bergen County). This scenario accounts for only six high mast light poles in the state, four of which require a guiderail removal to access.

Similar to Scenario 2 above, the second inspection using a traditional inspection approach requires a number of additional personnel including:

- The two engineers who conducted the initial inspection;
- A bucket truck operator; and
- Two to three additional traffic safety personnel who set-up the lane closure.

All of these people are required to be at the high mast light pole during the 4 hours it takes to conduct a secondary inspection, in addition to any travel time to/from the site. For the sites where the guiderail must be removed, NJDOT maintenance personnel must be present to remove and replace the guiderail. They do not have to remain on-site for the entire 4 hours, but typically spend approximately 1 hour total per inspection at the site, again not including any travel time.

The UAS approach eliminates the need for this secondary inspection and associated lane closures and potential guiderail removal. As discussed in the following section, secondary inspections of these light poles have the greatest potential impact on highway users in terms of both safety and travel time.

The historic approach which used a bucket truck for the initial inspection of all 244 high mast light poles (no secondary inspections) utilized a similar process as a traditional inspection outlined in the three scenarios above. The corresponding impacts to time, cost, safety and efficiency are summarized at the end of the comparative analysis section.

Comparative Analysis

This section provides a comparative analysis of costs and benefits across the four project evaluation criteria for the two approaches for high mast light pole inspection, and includes a brief summary of benefits/costs for historic, bucket truck approach at the end. The simplest criteria to quantify, time and cost, are detailed first, followed by safety and efficiency.

Time

For the initial inspection, the UAS approach requires more labor-hours than the traditional approach due to the presence of an additional person (the UAS pilot). The traditional approach requires 976 labor-hours (2 people, 2 hours per pole, 244 poles). In this initial phase, the UAS approach requires an additional 476 labor-hours (1 additional person, 2 hours per pole, 238 poles that can be inspected by UAS) versus the traditional approach.

Time savings accrue during the second round of inspections which are not required using a UAS approach. The total amount varies depending on which of the 244 light poles require a secondary inspection. Assuming 10% (24) of poles in a given cycle require a secondary inspection, both a low and high estimate of additional time can be calculated. At the low end, if the 24 poles are all in locations which do not require guiderail removal or a road closure, the second inspection utilizing a bucket truck would require the following:

- 2 engineers and 1 bucket truck operator for 4 hours per pole.

This would entail an additional 288 labor-hours of work, 12 labor-hours per pole.

At the high end, if all 24 light poles required a guiderail removal and a shoulder/lane closure, the following would be required:

- 2 engineers, 1 bucket truck operator, 2-3 personnel (averaged to 2.5) to handle lane/shoulder closure for 4 hours per pole; and
- 2 NJDOT maintenance staff to remove and replace guiderail for 1 hour per pole.

This would entail an additional 576 labor-hours, 24 labor-hours per pole.

Based on 2016 data, if 24 poles require a secondary inspection and half of those required a shoulder/lane closure and guiderail removal, the secondary inspections required an additional 432 labor-hours. This means that the 2016 inspection cycle which utilized drones required an additional 44 labor-hours of time.

These time benefits are summarized in Table 2 below. It should be noted that travel time represents a potentially significant savings but is not included in this analysis. Travel time is highly variable depending on the locations of staff (both contractors and NJDOT maintenance staff) and the particular high mast light poles which require additional inspection.

Table 2 - Time (Labor-Hours) Required For Traditional and UAS Approach to High Mast Light Pole Inspections

Scenario	**Traditional Approach**	**UAS Approach**	**Notes**
Initial Inspection	976	1,476	238 poles can be inspected by either method, 6 by traditional method only
Secondary Inspection – Low Estimate	288	0	Assumed 10% defect rate, all defects are on poles that do not require guiderail removal or traffic closure
Secondary Inspection – High Estimate	576	0	Assumed 10% defect rate, all defects are on poles that require traffic closure and guiderail removal
Secondary Inspection – Medium Estimate	432	0	Assumed 10% defect rate, 12 poles require traffic closure and guiderail removal (6 lane closures, 18 shoulder closures)
Total Time	*1,264 – 1,552*	*1,476*	
Total Time per Pole	*5.18 – 6.36*	*6.05*	

Cost

Using the traditional approach, the estimated cost for the initial inspection of 244 high mast light poles by two engineers is approximately $122,000, for a cost of $500 per pole.[2] Using UAS, the initial inspection cost for 244 high mast light poles by two

[2] Approximate cost of $125/hour for each engineer, 2 hour inspection

engineers and a UAS pilot is approximately $186,025.[3] This includes inspecting six light poles using the traditional approach where UAS operation is not feasible. For the 238 poles that can be inspected by UAS, the cost per pole is $738. If none of the inspected poles had a defect, this initial inspection would be the end of the process. Under this scenario, UAS would cost approximately $64,000 more than the traditional approach per inspection cycle due to the presence of a third person (the UAS pilot) at each inspection.

However, because UAS inspections do not require a second inspection with a bucket truck, there are substantial cost savings versus the traditional approach if a potential defect is detected. NJDOT estimates that approximately 10% of poles (24) are found to have defects in any inspection cycle. There is no additional cost to inspect these poles using the UAS approach, since the initial inspection is sufficient to determine if maintenance work is required or not. The cost for a secondary inspection using a bucket truck varies from approximately $1,800 per day ($900 per pole) in locations without a guiderail or traffic disruption to $2,400 per day ($1,200 per pole) for the bucket truck and support crew needed for work zone setup. At the low end, if all 24 poles with a defect do not require removal of a guiderail or a highway closure (Scenario 1 above), the additional cost is approximately $45,600. At the high end, if every pole requires guiderail removal and a lane or shoulder closure (6 poles from Scenario 3, 18 poles from Scenario 2), the additional cost is approximately $55,667. Based on the distribution of defects discovered during the 2016 cycle where 12 poles required a shoulder/lane closure and 12 did not, the additional cost of the secondary inspections was approximately $50,633. These costs are summarized in Table 3 below.

Table 3 – Cost of Traditional and UAS Approach to High Mast Light Pole Inspections

Scenario	Traditional Approach	UAS Approach	Notes
Initial Inspection	$122,000	$186,025	238 poles can be inspected by either method, 6 by traditional method only
Secondary Inspection - Low Estimate	$45,600	$0	Assumed 10% defect rate, all defects are on poles that do not require guiderail removal or traffic closure
Secondary Inspection - High Estimate	$55,667	$0	Assumed 10% defect rate, all defects are on poles that require traffic closure and guiderail removal
Secondary Inspection - Medium Estimate	$50,633	$0	Assumed 10% defect rate, 12 poles require traffic closure and guiderail removal (6 lane closures 18 shoulder closures)
Total Cost	*$167,600 - $177,667*	*$186,025*	
Total Cost per Pole	*$687 - $728*	*$762*	

[3] Approximate cost of $238/hour for UAS pilot in addition to two engineers, 2 hour inspection

Based on the above information, if an additional 7 poles in locations that did not require any highway closures or guiderail removal had a defect in 2016, the direct costs for using UAS would have been comparable with that of using the traditional approach, not including any safety or efficiency benefits from the UAS approach.

Safety

Safety benefits from deploying UAS to inspect high mast light pols accrue in two different ways. The first is a safety benefit for highway users, the second is a safety benefit to NJDOT and its employees.

Highway Safety

Work zone related crashes are an emphasis area in NJDOT's 2018 Highway Safety Plan. Between 2011 and 2015 there were 30,702 reported crashes in construction, maintenance, and utility zones in New Jersey.[4] Approximately 60 of the 244 high mast light poles in the state require either a shoulder or lane closure during a secondary inspection if traditional inspection methods are used. These closures are not required if a UAS is deployed for the initial inspection.

Information on the impact of a work zone closure on highway safety provides a wide range of values. For example, the Crash Modification Factors Clearinghouse shows CMF ranging from 1.12 to 1.87 for "Active work with temporary lane closure (compared to no work zone)," indicating an increased potential for crashes in work zones. Due to project constraints, the team employed a traffic incident management (TIM) proxy to calculate the increased risk of crashes. TIM literature on secondary crashes due to a primary crash and subsequent lane closure is extensive but again can vary depending on numerous factors including weather, time of day, time of year, vehicle type, etc. The increased risk of a crash due to the closure of a lane following a primary crash ranges from 3% to approximately 15%. To be conservative, this analysis assumes a 3% increased risk of a crash due to a lane closure.[5]

To calculate the potential safety benefits from not deploying work zones, NJDOT's Crash Rates by Crash Severity Statewide statistics provided a basis for crash rates per million vehicle miles by severity. These rates were multiplied by a vehicle occupancy rate[6] and the statistical cost for each crash severity level[7] was inflated to 2018 using the

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[4] https://www.nj.gov/oag/hts/downloads/HSP_2018_web.pdf

[5] Moore, J.E., Giuliano, G. and Cho, S. Secondary accident rates on Los Angeles freeways, Journal of Transportation Engineering, Vol. 130, No. 3, 2004, pp. 280-285.

[6] Fatality crashes are 1.065 (based on 607 deaths in 570 fatal crashes in 2016 in NJ). Injury crashes are 1.39 based on CBA guidance for average occupancy of passenger vehicles (assumed injury to all persons involved). Property Damage Only crashes are 1.0 (conservative estimate).

[7] FHWA: Benefit-Cost Analysis Guidance for Discretionary Grant Programs, Office of Secretary of Transportation, June 2018.

Consumer Price Index (CPI). These values are then summed and divided by one million to produce a safety cost per vehicle mile of $8.01.

Assuming that each work zone closure associated with a secondary inspection of a high mast light pole is 1 mile long and the total volume of vehicles at the light poles identified by NJDOT as requiring a closure during the non-peak period when work is conducted averages 9,000 vehicles over the 4-hour work time[8], **the safety benefit of avoiding a lane closure is approximately $2,162 per pole**. With 6 light poles in the system that could potentially require a lane closure, the maximum additional safety cost is $12,972. If the added crash risk due to a closure is increased to 15% instead of 3%, the cost per closure rises to $11,412.

There are also an additional 44 high mast light poles which require a shoulder closure in order to provide the bucket truck with access to the pole for the secondary inspection. Data on the impacts to safety of shoulder closures is much less robust and was not included in these benefit calculations. However, it should be assumed that shoulder closures have some negative impact on traffic safety, if for no other reason than they can be a distraction for drivers and limit the amount of space vehicles have to maneuver.

Finally, in addition to the direct safety and financial impacts of work zone crashes, these crashes create delay above and beyond that which would be associated with a work zone and also raise the possibility of additional crashes upstream from the initial incident. This additional crash avoidance and reduction in delay is not included in this analysis, but should be considered when examining the overall impact of UAS and traditional approaches to high mast light pole inspections.

Workplace Safety

Working at height in a bucket truck and working near traffic are both dangerous activities. The need for a secondary inspection using traditional inspection methods for high mast light poles places workers at a higher risk. Personnel working from bucket trucks and those working in roadway work zones are at risk of injury from numerous causes, but falls and being struck by vehicles in the work zone are the most prevalent.

Though data exists to quantify the occurrence and severity of injuries to workers, data on the level of exposure is lacking. Without this, it is difficult to calculate the risk level for any one work zone or operation using a bucket truck is. Additionally, the occurrence of injuries for lift or boom truck operators on a national level is low, therefore risk of injury on any given deployment of a boom truck is miniscule.

[8] Based on average AADT of highway segments from 2016 HPMS data within 250 feet of an identified high mast light pole requiring a closure (43,700 AADT). AADT distributed according to NJ Road User Cost Manual, 2015 (Table 3.1). These values were summed over 4-hour increments starting between 9am and 10am and lasting until 3pm to 4pm to represent hours the work zone would be active. The average 4-hour volume between 9am and 4pm is 9,000 vehicles.

The United States Department of Labor Occupational Safety and Health Administration (OSHA) maintains records of "lift truck" injuries in the workplace. These records indicate a total of 13 incidents in 2017 (5 fatal), 8 in 2016 (8 fatal), and 13 in 2015 (12 fatal) across the U.S.

These values are too low to calculate a statistic risk of incident per truck deployment so the benefit is not included in the overall calculations in this white paper. However, the seriousness of the incidents (74% fatalities) emphasizes the potential danger involved with operating a bucket truck.

Worker injuries at work zones are far more common. Between 2011 and 2015, 609 workers were killed at road work zones in the United States.[9] However, similar to bucket truck deployments, quantifying the risk of work zone injuries or fatalities for any one work zone deployment is complicated by a lack of information on the total number of work zones deployed in the U.S., their overall length, and other critical factors. For this reason, a specific benefit for avoiding work zone personnel injuries is not included in the white paper. This notwithstanding, the potential of work zone injury is real and the consequences are severe. Eliminating the need for establishing a work zone to conduct a pole inspection removes the potential for such injuries and is a large benefit of utilizing the UAS approach.

Efficiency

The final project criteria for examining the use of UAS versus traditional methods to examine high mast light poles is efficiency. Similar to safety, efficiency benefits can accrue from a number of sub-categories. The two main ones are increased efficiency for highway users, and an improvement in data quality and storage which leads to more efficient internal processes at NJDOT.

Highway Efficiency

High mast light poles are typically deployed on near high volume roads and interchanges. Closures of a lane due to a work zone associated with the deployment of a bucket truck will have a negative impact on traffic flow, a cost that is avoided by the use of UAS technology during the initial inspection.

To estimate the road user cost (RUC) of delay caused by a lane closure, the team utilized the New Jersey DOT's Road User Cost Manual (2015) and accompanying spreadsheet. As described in the manual, "Road User Costs are directly related to the traffic demand, facility capacity, and the timing, duration and frequency of work zone induced capacity restrictions." For our calculations, the following assumptions were made:

[9] Bureau of Labor Statistics, 2017. https://www.bls.gov/opub/ted/2017/fatal-injuries-at-road-work-zones.htm

- Work zone length of 1 mile;
- Work zone speed of 35 miles per hour (free flow speed of 55 miles per hour);
- 9,000 vehicles travel the queue over 4 hours during authorized work times (see Safety section above for methodology);
- 10% truck volume;
- Highway capacity of 2,300 passenger cars per hour per lane (based on "Freeway – 6 or more lanes" in Table 3.2 of the NJDOT RUC Manual);
- Used RUC values for vehicle length;
- Value of time are from FHWA: Benefit-Cost Analysis Guidance for Discretionary Grant Programs (2018) and values are inflated to 2018 dollars; and
- Vehicle operating costs (VOC) are based on the RUC model inflated from 1970 to 2018 using the CPI from the U.S. Bureau of Labor Statistics

Based on these assumptions, **the efficiency benefit of avoiding a lane closure is approximately $1,666 per pole.**[10] Similar to the safety calculations described above, shoulder closures also likely have an impact on highway efficiency, though at a lower level than a full lane closure. The NJDOT RUC worksheet does not provide a method to calculate the impact of shoulder closures and any benefits from avoiding them are not quantified in this white paper.

Improving highway efficiency will also have environmental benefits through the reduced emission of pollutants including carbon dioxide, nitrogen oxide, particulate matter (2.5), volatile organic compounds, sulfur dioxide, and carbon monoxide. Based on the reduced travel speed associated with the work zone, **avoiding a lane closure adds approximately $70.46 in environmental benefits per pole**, a total of $422.75 for the six poles with a lane closure.

Additional environmental benefits would accrue from not sending out a bucket truck for the secondary inspection. The impact of the 24 additional trips are not included in the quantifiable benefits due to the range of possible drive times, driving conditions, and other factors that influence the calculations depending on the location of the poles with potential defects.

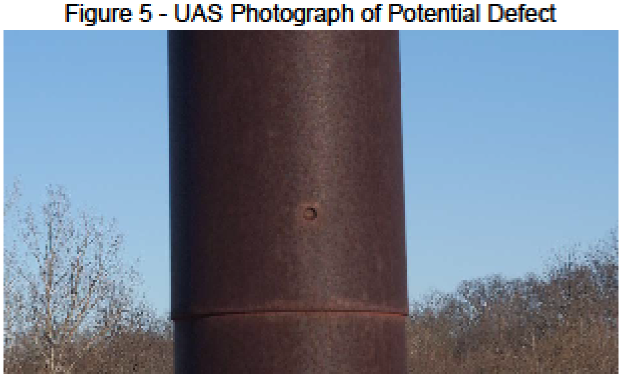
[10] This estimate may be conservative. A 2015 study by Michigan DOT found that user delay costs for closing one lane for 10 hours on a four-lane highway over a bridge in a metro area totaled $14,600, or $1,460 per hour. See: http://asphaltmagazine.com/wp-content/uploads/2016/05/Dronesss.pdf

Data Efficiency

NJDOT staff indicated that one of the largest benefits they see from using a UAS approach is the higher quality of data. This information is useful both during the initial review process to determine if maintenance work is necessary and as a historical marker to identify and track changes over time.

The UAS uses a high definition video camera during the inspection process to identify in real-time potential defects on the high mast light pole. The flight path of the UAS is consistent from pole-to-pole, reducing the variability between inspections. The UAS pilot and engineer on the ground monitor the feed and can take 20 megapixel (mp) photographs of any potential defects from close range (approximately 10 feet) during the initial inspection.[11] Figure 5 below shows a picture taken via UAS of a potential defect. The traditional approach relies on engineers on the ground using binoculars or taking photographs from a camera with zoom during the initial inspection, or engineers in a bucket truck with a single vantage point to the pole using a hand-held camera during the secondary inspection. During both phases, the image quality is lower than available using UAS due to the need to utilize a zoom feature. While sufficient to meet inspection requirements, the higher quality data available from UAS is preferred and offers a better record to compare against future inspections.

Figure 5 - UAS Photograph of Potential Defect



Source: NJDOT Aeronautics, 2016.

The still images captured by the UAS also provides more redundancy during inspections as multiple people can examine the photographs in the office after the inspection. This helps control for differences in experience, eye strength, and other human factors that could impact the inspection process as well as provides consistency between inspection cycles to protect against personnel turn-over. The high resolution images are also potentially useful as training tools.

Bucket Truck High Mast Light Pole Inspection

Historically, NJDOT deployed a bucket truck to inspect every high mast light pole in the state. This process and the associated costs are very similar to those accrued during a

[11] This data is compressed to a 5mp image for storage.

secondary inspection using the traditional approach, except they apply to every high mast light pole in the state instead of a selection with potential defects. A total of 212 high mast light poles would not require a guiderail removal, 32 would require a guiderail removal. The costs of this across the four project criteria were[12]:

- Time: 3,312 labor-hours total, average of 13.6 labor-hours per pole
- Cost: $477,022 total, average of $1,955 per pole
- Safety: $2,162 per pole requiring a lane closure (6 total). Total cost = $12,972
- Efficiency: $1,736 per pole requiring a lane closure (6 total). Total cost = $10,416

Summary

As detailed above, there are numerous differences between a traditional and UAS approach to conducting high mast light pole inspections. The quantifiable benefits across the four project criteria are summarized in Table 4 below.

Table 4 - Summary of Benefits/Costs

Criteria	Bucket Truck Approach (For all initial Inspections)	Traditional Approach (Bucket Truck for Secondary Inspection Only)	UAS Approach
Time (Labor-hours)*	3,312	1,264 – 1,552	1,476
Cost*	$477,022	$167,600 - $177,667	$186,025
Safety (cost)	$2,162 per pole requiring a lane closure (6)	$2,162 per pole requiring a lane closure (maximum 6)	$0
Efficiency (cost)	$1,736 per pole requiring a lane closure (6)	$1,736 per pole requiring a lane closure (maximum 6)	$0
Total Cost	$500,410	$190,988 - $201,055	$186,025

Note: * Assumes 10% of high mast light poles require a secondary inspection using the traditional approach. The range of values in the traditional approach accounts for the possible locations and access requirements of the poles requiring a secondary inspection.

At a quantifiable level, the UAS approach balances NJDOT's need to comprehensively manage and inspect high mast light pole assets in the state with cost considerations. In addition, the traditional approach values assume a 10% defect rate to determine benefits; as the high mast light poles in New Jersey age, this defect rate may rise which would increase the benefits of a UAS approach compared to the traditional approach.

[12] Using the same cost data as applied for the secondary inspections using the traditional approach

Finally, the benefits of using UAS are not fully captured in the above numbers. For example, the following considerations are not included:

- Value of higher quality photographs of potential defects for analysis and documentation;
- Fewer safety risks, lower vehicle emissions, and less time spent due to reduced trips to/from poles for secondary inspections;
- Eliminate safety and traffic impacts of a shoulder closure due to no secondary inspections; and
- Reduced injury exposure to workers (both in work zones and in bucket trucks).

For some of these potential benefits, such as the cost of additional travel time to and from a work site for a secondary inspection, the potential variance in each inspection cycle makes it difficult to provide a numerical benefit.

For other categories, such as the value of capturing higher quality photographs where numerical values cannot be calculated, the qualitative impact for NJDOT is still very high. The UAS approach provides better photographs that can be examined by multiple people in an office setting and compared to historical photographs to track change over time. This redundancy improves the quality of the inspection process and can save time and money, especially as the existing inventory of high mast light poles in the state continue to age and the possibility of secondary inspections using a traditional approach rises. In addition, as technology and UAS experience evolves, the UAS approach will likely become faster and cheaper to deploy helping ameliorate cost concerns.

Finally, this program can serve as a test bed for future UAS deployments in construction project management and incident response and management, providing NJDOT with valuable experience and lessons learned that can be applied across multiple programs in the years to come.

Figure 6 - UAS Inspecting a High Mast Light Pole

Source: NJDOT Aeronautics, 2016.

APPENDIX B: STANDARD OPERATING PROCEDURE FOR THE SAFE OPERATION AND MAINTENANCE OF UAS FOR TRAFFIC OPERATION AND TRAFFIC INCIDENT MANAGEMENT

NJIT
New Jersey Institute of Technology

ITS Resource Center

Activity 6A: Technology Evaluation and Deployment

Standard Operating Procedure for the Safe Operation and Maintenance of UASs for Traffic Operation and Traffic Incident Management

Prepared for
NEW JERSEY DEPARTMENT
OF TRANSPORTATION

FINAL REPORT
December 2017

ITS Resource Center | NJIT

Activity 6A: Technology Evaluation and Deployment

Standard Operating Procedure for the Safe Operation and Maintenance of UASs for Traffic Operation and Traffic Incident Management

FINAL REPORT

December 2017

This report has been prepared as part of the CY 2017 work program for the ITS Resource Center at the New Jersey Institute of Technology.

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STATE OF NEW JERSEY
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Executive Summary

UAS operations must comply with all operational requirements and regulations as described by 14 CFR Part 107 and FAA Circular AC 107-2. FAA has provided the summary guidance indicating the essential elements to conduct UAS flights with respect to: 1) pilot requirements; 2) aircraft requirement; 3) location requirements; 4) operational rules; 4) comply with regulations and 14 CFR Part 107.

At this time, New Jersey has no regulatory requirements for UAS - this report does not speculate on what those may require. UAS technology and policies are evolving, therefore this is not an all-inclusive document but a rudimentary framework based on past experiences and best practices to supplement Part 107 requirements; thereby supporting the NJDOT initiation of UAS operations for traffic operations and incident management.

Within the context of traffic operations and incident management, the primary objectives of this report are as follows:

- To conduct a review of other states best practices;
- To make initial recommendations for operating altitudes, operational distances, minimizing distraction to drivers, and wind limitations to design future years flight operations at the testbed location;
- To develop procedures that can be used to design future flight operations at the testbed with the ultimate goal that these can be expanded in the future years to cover statewide flight procedures; and
- To develop risk assessment checklist.

As discovered in Chapter 3 presenting the best practice reviews, a majority of the state DOTs do not have a formal procedures document and rely solely on FAA regulations; only a few of state DOTs who do have formal operational procedures instruct users to follow FAA regulations but provide additional guidance on preflight planning, operations, post-flight, etc. Furthermore, within the context of traffic operations and incident management some of the operations documents have information that is not applicable to unplanned activities such as crash scene investigation. The recommendations for UAS operational procedures are presented in Chapters 5, 6, and 7 for day of flight procedure, flight operations procedure, and emergency procedure, respectively. Risk assessment and maintenance guidelines for UAS operations are addressed in Chapter 8 and 9.

1 Introduction

1.1 Background

This document has been prepared within the context of providing the New Jersey Department of Transportation (NJDOT) with a basic Unmanned Aircraft Systems (UAS) procedure for traffic operations and Traffic Incident Management (TIM). Therefore, there is a specific emphasis on UAS operations most likely encountered during these types of activities. For example, incident management (crash scene investigation) would require low altitude data in close proximity to the roadway. As a result, it is envisioned that a vast majority of these operations can be conducted at altitudes below 400ft within the NJDOT Right-of-Way (ROW). In the future this may expand and require updates to this document.

Traffic operations compared to incident management are significantly different from each other from an operational perspective. For example, for incident management there would already likely be any number of vehicles onsite such as police, fire, ambulance, and SSP; and would inherently be creating a distraction and possible roadway closures. Therefore, a UAS operation may contribute to the distraction, but not be the primary cause. It could be argued that the usage of a UAS for incident management would not substantially add to the existing level of distractions, and that no mitigation would be required. Whereas with traffic operations the UAS could indeed be a primary cause of distraction as there wouldn't be flashing lights, etc. already on the side of the road. It's likely that based on field of view and typical driver behavior, that there would be some altitude at which the UAS would cause little or no impact on driver distraction. A small UAS operating at a couple of hundred feet off the ground may appear to only be a dot in the sky - no larger than typical distractions such as a passing bird. Similarly, high speed traffic may only catch a glimpse of UAS and not be impacted; whereas slow moving traffic may have longer time to observe and react to the distraction. This effort will also provide some guidance to minimize distraction, however without reported incidents of UAS distracting drivers this will be difficult to quantify at this time. As more empirical data becomes available in the future this will likely require updates.

UAS operations must comply with all operational requirements and regulations as described by 14 CFR Part 107 [1] and FAA Circular AC 107-2[1]. This document does not review the FAA policies in detail and the reader is advised to refer back to the FAA (source documents) for more detailed information regarding these requirements. FAA has provided the summary guidance indicating the essential elements to conduct UAS flights [1].

- Pilot requirements ,
  - Must have Remote Pilot Airman Certificate
  - Must be 16 years old

  - Must pass TSA vetting
- Aircraft requirement,
  - Must be less than 55 lbs.
  - Must be registered if over 0.55 lbs.
  - Must undergo pre-flight check to ensure UAS is in condition for safe operation
- Location requirements
  - Class G airspace*
- Operational rules.
  - Must keep the aircraft in sight (visual line-of-sight)*
  - Must fly under 400 feet*
  - Must fly during the day*
  - Must fly at or below 100 mph*
  - Must yield right of way to manned aircraft*
  - Must NOT fly over people*
  - Must NOT fly from a moving vehicle*
- Comply with regulations and 14 CFR Part 107

At this time, New Jersey does not have regulatory requirements for UAS - this document does not speculate on what those may require. UAS technology and policies are evolving, therefore this is not an all-inclusive document but a rudimentary framework based on past experiences and best practices to supplement Part 107 requirements; thereby supporting the NJDOT initiation of UAS operations for traffic operations and incident management.

1.2 Research Objectives

Within the context of traffic operations and incident management the objectives of this evaluation study are:

- Conduct a review of other states' best practices.
- Make initial recommendations for operating altitudes, operational distances, minimizing distraction to drivers, and wind limitations to design future years flight operations at the testbed location.

- Develop procedures that can be used to design future flight operations at the testbed with the ultimate goal that these can be expanded in the future years to cover statewide flight procedures.
- Develop risk assessment checklist.

2 Literature Review

Unmanned Aircraft Systems (UAS) have seen a rising number of applications in a variety of domains such as policing and firefighting, nonmilitary security work, surveillance of pipelines, land management, earth observations, and infrastructure inspection. In recent years, UAS have received special attention in the field of transportation research, and there has been a trend to incorporate UAS in infrastructure management activities such as bridge and roadway inspections. State DOTs have also begun reviewing, testing, and deploying UAS technologies for a variety of tasks. According to a recent survey conducted by the American Association of State Highway and Transportation Officials (AASHTO) in March 2016, thirty-three state DOTs have or are investigating, testing, researching, or using UAS for their operations [2]. Such activities include bridge inspections, accident clearance, surveying, photography, or for identifying, monitoring, and mitigating risks posed by landslides and rockslides. Seventeen state DOTs have studied and/or used drones, while an additional sixteen state DOTs are either developing drone policies or working to conduct drone research, as shown in Figure 1.

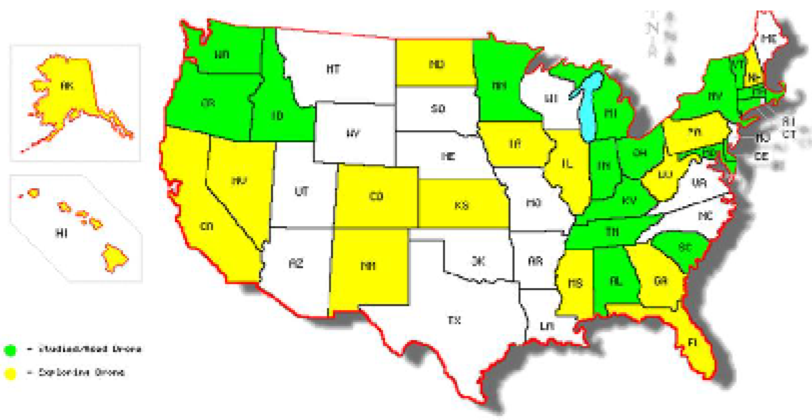

Figure 1. State DOTs that have studied and/or are currently studying drone applications

However, UAS adoption is moving quickly that the AASHTO Survey (March 2016) is now significantly out of date as many States not included such as North Carolina, Texas, and New Jersey are conducting transportation research or already deploying UAS in some capacity. Conversely, other States appear to have pulled-back on UAS efforts, this could be for any number of reasons including adjusting to the new UAS regulations released in August of 2016.

The state of practices among various state DOTs across the nation are concerning the applications of UAS in the transportation industry related to ITS. Such UAS applications include:

1) traffic surveillance and traffic management; 2)speed sample measurement; 3) traffic count measurement; 3) turning movement measurement; 4) special event supervision; 5) post-incident inspection; 6)traffic monitoring; 7) tracking vehicle movements; 8) parking lot utilization monitoring; 8) real-time traffic monitoring; and 9)traffic signals monitoring.

Furthermore, there is significant national research regarding the usage of the data produced from UAS; including traffic flow estimation, analysis of the traffic parameters, optimizing interchanges, road noise estimation, multi-vehicle trajectory prediction, and many others.

Within the context of NJDOT establishing a UAS testbed for traffic monitoring and incident management research there were three research papers that were relevant and published after the new FAA UAS rules went into effect in August 2016. Although some older papers may have useful information, the newer FAA rules were specifically written for newer UAS technology based on and several committees comprised of subject matter experts. This comprehensive overhaul of how FAA treats and regulates UAS significantly changes how and where UAS can be used.

Considering the limitation of visualizing data such as time and expense cost, Kwasniak [3] explored the potential benefits of applying drone to data collection. The drones are well known as their light weight, stability, easy to use and affordable price. DJI is the largest drone design and sale company in the worldwide drone market. Based on the frame type, the drone can generally be distinguished into tri-copter, quadcopter, hexacopter, and octocopter. The average flight time varies from 15 minutes to 40 minutes depending on the equipment added. In recent years, the Federal Aviation Administration has drafted several regulations for the operation of drones. The way the pictures or videos are taken and the operation speed of the drone are keys to drone-based projects. A list of example projects was discussed such as intersection design or operating safety, construction zone safety, and other conditions that insufficient information can be obtained from traditional map information system or platform (Google Maps/Earth). Kwasniak [3] also implied that drones could be useful in safety projects which were limited to human inspection [3].

Khan et al. [4] concluded an overview of the current usage and illustrated the future implementation of UAVs. A proposed UAV framework including flight planning, flight implementation, data acquisition, data analysis, data interpretation, and optimization was introduced. A review of the existing traffic-related UAV studies was presented. The related low-cost technology provided high-resolution video data while covering a large area. However, limitations such as battery time, weather condition, and privacy should be considered [4].

Kim et al. [5] surveyed a total of 435 professionals from 98 different cities and 45 states. Near 20% reported drones operating close to traffic. More than 85% believe that drones should be regulated over roadways. The paper pointed that there is an urgent need to focus on drones and traffic safety. More traffic conflicts, accidents, and collisions related to drones could be reported in the future [5].

3 Best Practice Review

There have been many surveys to collect UAS information, however none of the surveys reviewed provide details on procedures. A majority of the past surveys collected information such as if a DOT is using a UAS, what the DOT is using UAS for, number of UAS, etc and not operational aspects.

To outline the best operational practices and prepare this document, the research team reviewed the past surveys and identified State DOTs who appear to be using or researching UAS (specifically for traffic operations and TIM). The team identified DOTs and contacted each, requesting information about their UAS program and operational procedures documents. A summary of the responses can be found in Table 1.

Table 1. List of DOTs Contacted for UAS Procedural Documentation

#	State DOT	Response
1	Arkansas	"We do not have any procedure documents at this time. For the project you're referring to, we used other measures for collecting data, which did not include a UAS because of FAA regulations and restrictions at the time of the project."
2	Colorado	"draft not ready for public release."
3	Florida	"Right now we do not. The Department's current position is that we will not purchase any since the technology is improving. Our Office of Information Technology has determined that if we do decide to purchase any approval has to go through them. Our requirement is that if a contractor wants to use a UAS on a Department project we add a requirement that they follow all FAA and State and Local Regulations and Statutes."
4	Georgia	Was unable to make contact.
5	**Kentucky**	**Received documentation.**
6	Massachusetts	Was unable to make contact.
7	Michigan	"We do not. We are currently in our phase II of research to generate applications for data collected from a UAS. Also, MDOT only requires pilots follow FAA law/regulations for use of UAVs."
8	**North Carolina**	**Received documentation.**
9	**Ohio**	**Received documentation.**

#	State DOT	Response
10	South Carolina	Was unable to make contact.
11	**Tennessee**	**Received documentation.**
12	**Utah**	**Received documentation.**
13	Virginia	"Thanks for reaching out regarding the potential of VDOT sharing its defined UAS best operational practices, unfortunately to date these efforts remain under consideration and development therefore I have nothing to convey at this immediate time. "
14	Washington	"I don't have any documents like that, but I have forwarded this message to our winter operations manager and he may have something. [Name redacted] doesn't either, but he can provide some observations from a public agency perspective if that is helpful."

Some general observations:

- a majority of the DOTs do not have a formal procedures document and rely solely on FAA regulations.
- the few DOTs who do have formal operational procedures instruct users to follow FAA regulations but provide additional guidance on preflight planning, operations, post-flight, etc.
- within the context of traffic operations and incident management some of the operations documents have information that is not applicable to unplanned activities such as crash scene investigation.

The three most comprehensive documents secured from other DOTs are the North Carolina DOT UAS Operational Procedures Guide, Tennessee DOT Small Unmanned Aircraft Systems Standard Operating Guidelines, and the Ohio/Indiana Flight Operations Manual. These operational documents, the research teams past UAS operational experience, and input received from NJDOT Division of Aeronautics served as the basis for this report.

3.1 Key Elements of North Carolina DOT UAS Operational Procedures Guide

The North Carolina DOT UAS Operational Procedures Guide has a general introduction that indicates that all flights must comply with 14 CFR Part 107, along with 8 sections that cover Pre-flight Operations, During Flight Operations, Post-flight Operations, Emergency Procedures, Flight Area/Perimeter Management, Accident/Incident Reporting, Flight Crew Communications, and External Communications [6].

The Planning and Inspection sections are provide below as reference:

- Planning
  - The flight crew should be familiarized with all available information pertaining to the flight such as; take-off/landing, including but not limited to the operational limitations of Part 107, weather conditions, hazards, no fly zones, etc.
  - North Carolina state statues require land-owner approval before operations take place.
  - RPIC will ensure the location for take-off and emergency landing is adequate upon arrival at the location. At least one emergency landing area should be identified before the start of operations.
  - RPIC should be aware of all surroundings in the event that an emergency landing is necessary. This includes the ability to recover the UAS."

- Inspection
  - Before the first flight of the day, verify all batteries are fully charged.
  - Check the airframe for signs of damage, and its overall condition.
  - Check the entire aircraft per the pre-flight inspection instructions in the manual for the specific aircraft to make sure it is in good structural condition and no parts are damaged, loose, or missing.
  - Check the propeller or rotor blades for chips, cracks, looseness and any deformation.
  - Check that camera(s) and mounting systems are secure and operational.
  - Perform an overall visual check of the aircraft prior to arming any power systems.
  - Repair or replace any part found to be unsuitable to fly during the pre-flight procedures prior to takeoff."

Within the operating procedures, the only other items noted that add requirements beyond compliance with Part 107 are:

- The weather section includes a discussion of using a pocket anemometer to check for onsite weather conditions.
- A sample checklist is provided:
  - Required documentation, Pilots Certificate, NC State Operators Permit, Aircraft Registration, UAS Flight Manual, Proof of Insurance.

- Weather conditions suitable.
- Check air frame for cracks and check all screws are tight.
- Propeller(s)/Rotor(s) not damaged and tightly fixed.
- Propulsion system mounting(s) secure.
- Batteries fully charged and securely mounted.
- Communications (datalink) check.
- Ensure the GPS module (if any) has GPS "fix."
- Check mission flight plan.
- "Return Home" and/or "Emergency Landing" locations (if supported by the particular UAS) are selected, located appropriately, and loaded to the GCS and aircraft.
- Ensure sensors are calibrated and that the right setting is loaded.
- Complete flight crew briefing.
- Ensure the launch site is free of obstacles.
- Recheck wind direction before launch.
- Confirm phone number for nearest Air Traffic Control facility in event of emergency.

- Emergency procedures are clearly outlined.
- Flight areas and perimeter managements section covers a number of items, of note is that it includes:
  - Alternate landing sites - The RPIC shall designate at least one alternate landing site. In the event that a landing is not possible and the primary landing site is deemed unsafe, procedures to utilize the back-up site will be invoked.
  - Landing Safety & Crowd control - All landing sites shall be maintained and operated in the same manner as the launch sites. A buffer of at least 50 feet shall be maintained at all times between aircraft operations and all nonessential personnel (all personnel other than the UAS Operator/RPIC and the Visual Observer).

3.2 Key Elements of Tennessee DOT Small Unmanned Aircraft Systems Standard Operating Guidelines

The Tennessee DOT Small Unmanned Aircraft Systems Standard Operating Guidelines has a general introduction and a review of FAA Part 107. The document discusses the roles and responsibilities of the flight crew, which covers many compliance aspects of Part 107 such as holding a remote pilots license. Some additional items to note are [7]:

- the RPIC must have a valid Tennessee drivers license,

- the RPIC must have read and be familiar with the operators manual for the UAS they are flying,
- must be approved by Tennessee DOT,
- "The remote PIC must be trained on the ability to safely operate the sUAS in a manner consistent with how the sUAS will be operated including evasive and emergency maneuvers and maintaining appropriate distances from persons, vessels, vehicles, and structures. "
- "In order to be current, the remote PIC must have conducted and logged at least 3 launch and 3 recovery operations within the previous ninety 90 days. These operations must have been conducted on a registered sUAS of the same class as the sUAS to be flight tested, and in a comparable environment."

Within the operating procedures, the only other items noted that add requirements beyond compliance with Part 107 are:

- "Flight Operations shall be conducted from a stationary position except in sparsely populated areas. Prior approval shall be granted by TDOT prior to conducting any flight operation from mobile (non-stationary) platforms (i.e. vehicle or boat)."
- "Flight operations are performed without affecting moving traffic. Traffic control including temporary traffic closures shall be arranged in advance with the responsible TDOT office for the area."
- "The sUAS control station shall be in a safe stable location to allow for the flight crew direct attention to the flight operations without possible distraction."
- Maximum airspeed of 45mph
- Flight operation to avoid bad weather such as rain, snow, and excessive wind.

3.3 Key Elements of Ohio/Indiana Flight Operations Manual

The Ohio/Indiana Flight Operations Manual has a general introduction and a review of FAA Part 107. The document also has language to operate under a COA or 333 exemption. The document discusses the roles and responsibilities of the flight crew, but also included a detailed list of items for accident /incident notification which included [8]:

- Type, nationality, and registration of the UAS.
- Name of owner, and operator of the UAS.
- Name of the pilot in command.
- Date and time of the accident.

- Last point of departure and point of intended landing of the aircraft.
- Position of the UAS with reference to some easily defined geographical point.
- Number of persons killed and/or injured.
- Nature of the accident, the weather and the extent of damage to the aircraft, so far as is known.

In general, the document is succinct and places considerable responsibility (decision making) on the RPIC. "The PIC is directly responsible for control over all flight operations from permission planning through debriefing, and is the final authority for the safe operation of the UAS. The PIC is responsible to ensure that the UAS is in an airworthy condition prior to flight. The PIC is directly responsible for the safety of the crew and equipment. The PIC will comply with all Federal Aviation Regulations, this manual, and the appropriate manufacturer's UAS Operating Manual." It was the research team's opinion that this document was primarily written for someone with an aviation background. We reached back out to the ODOT UAS Program Director and confirmed that this is being used by traditional pilots.

It's also interesting to note that there is a safety risk assessment under on the last two pages of the operations manual. The UAS program manager indicated that there is a team that internally that reviews: mission objectives, UAS platform, airspace (congestion, 107, 333, public COA), and location (traffic/non participants). From that they derive risks and mitigation strategies.

3.4 Best Practices Identified Gaps

It was noted that while these manuals were useful references, there was no guidance provided to help set limits for operating altitudes, operational distances, minimizing distraction to drivers, wind limitations, or developing a risk assessment checklist. Furthermore, discussions of safety review board and pre-flight approval process seemed to imply that these documents were developed for planned operations. These documents appeared to be written within the context of someone who may already be familiar with aviation practices. For example, there lacked an explanation of Meteorological Terminal Aviation Routine Weather Report (METAR) weather data that a Remote Pilot In Command would be required to understand, but in practicality someone new to aviation may be unfamiliar. Also, a common concept was that RPIC has to use significant judgement during operations; however this subjectivity may be awkward for a less experienced RPIC, as each person's risk level may be different. Since this project has an emphasis on traffic operations and incident management, the research team thought it best to provide more information on these components for someone who may be less familiar with these concepts.

4 Methodology

It is common practice to have a written flight plan prepared before a flight and submitted for internal agency (NJDOT) review. However, for many (unplanned) activities this is not realistic due to the timing of fast moving operations. Using the test-bed helps control the following variables:

- Unplanned activities – preflight planning activities limited to those that can reasonably be conducted in the field.
- Access rights for takeoff and landing - operational area limited to NJDOT ROW.
- Local ordinances – operational area limited to test-bed location so the flight area has already been prescreened for compliance.
- Flight operations within Class G unrestricted airspace - references to waivers and airspace authorizations are not applicable.

Establishment of a UAS test-bed location is a separate section of this report under the Intelligent Transportation Systems Resource Center (ITSRC) project. The test-bed provides a prescreened known location (or corridor) where conditions can be controlled and UAS flights can be pre-approved within the context of following the concept of operations prepared herein. This is an important component because it allows the research team to control the location and prepare a rudimentary operational practice.

4.1 VLOS Distance Recommendations

There is much debate regarding UAS and VLOS. FAA requires that the UAS be operated within Visual Line of Sight (VLOS), however this distance is not defined. The ability to see or detect a UAS may fall within operator's line-of-sight. However, the operator must clearly "see" the aircraft and have situational awareness to make decisions based in the followings:

- Review of FAA visual flight rules (VFR) states that there needs to be a three statue mile visibility. This has little relevance to UAS as they are typically substantially smaller than manned aircraft; it is assumed that UAS pilots would agree that a small DJI UAS is too small to see at 3 miles. However, regarding larger-manned aircraft, the 3 miles does assist the RPIC to identify aircraft approaching the operational area and take corrective action.
- In 2014 FAA published a report "A review of Research Related to Unmanned Aircraft System Visual Observers" which summarized past VLOS research efforts [9].
    - "When expressed in terms of angular size, the most commonly accepted resolving ability of humans is 1 min of visual arc (1/60th of a degree) (O'Hare & Roscoe,

1990). For example, an object that has a visual cross-section of 1 ft and is 3,438 ft from an observer subtends 1 min of visual arc, so an object that has a 1 ft visual cross-section can theoretically be recognized from as far away as 3,438 ft."

- "One of only two studies of visual observer capabilities is reported by Crognale (2009). Crognale conducted a series of four experiments looking at the effectiveness and capabilities of visual observers." This study was interesting as it used a UAS with a 10ft wingspan and tested at what distance and how quickly an observer could detect the UAS and make decisions to "see and avoid." The results indicated 13 seconds at an average distance of 1,073ft. However further efforts to evaluate reacquisition of a UAS that was flown out of range yielded 2,946ft. It could be inferred that from the Crognale 2009 experiments that indicate a detection distance somewhere between 1,073ft and 2,946ft would be appropriate.
- Ultimately, the FAA researchers concluded that VLOS "For smaller systems, this is probably no more than ¼ mile, depending on atmospheric and lighting conditions."

- In Europe, the maximum VLOS is defined as 500m or approximately 1640ft [10].

The European definition and the 2014 FAA report closely agree. Therefore, it is recommended to adopt ¼ mile (1,320ft) maximum distance for VLOS which is just slightly more conservative than the European requirement. The research team would like to acknowledge that the ¼ mile VLOS distance is conservative. Without knowing actual site and environmental conditions as well as size and color of the UAS to be deployed that this distance is a conservative basis and can be used as a maximum for incident management and traffic operations uniformity.

4.2 Operational Altitude Recommendations

The FAA, under Part 107, allows for operations up to 400ft Above Ground Level (AGL); however, this does not imply that there are no risk factors. Within this range, there are areas of increased risk. At the lowest altitudes (i.e. 10ft) there is a higher risk of distracting drivers leading to car-crashes as well as a higher probability of physical contact (UAS-crashes) with vehicles or obstructions. As the altitude increases, the ground-based risks may decrease, but the potential to interfere with manned aircraft increases. According to 14 CFR section 91.119, Minimum Safe Altitudes manned aircraft generally operate above 500ft but that is not always the case [11]. That section also allows a helicopter to operate at less than 500ft given certain safety considerations as well as provision for low flying agricultural crop spraying and insect mitigation.

Generally speaking, 13ft 6in is the maximum truck height without requiring overheight permits. Flight operations would not be over moving vehicles as this is prohibited, but this legal truck height restrictions link back to many infrastructure features such as bridge clearances. The Academy of Model Aeronautics National Model Aircraft Safety Code states that "excluding takeoff and landing, no powered model may be flown outdoors closer than 25 feet to any individual [12]." Therefore, 40ft height (approx 13.6ft + 25ft) was set as the recommended minimum hovering height of any operation, anything below 40ft would qualify as elevated risk and require additional mitigation.

One of the few legal cases that has resulted in guidance regarding disruptive operational heights of low flying aircraft is United States v. Causby, 328 U.S. 256 which dates back to 1946 [13]. In this case a threshold of 83ft was cited for various geometric reason (67 feet above the house, 63 feet above the barn and 18 feet above the highest tree). For this reason, the research team recommends that 83 ft should be set as the threshold for moderate/low risk flight heights.

As discussed in the previous section, by adopting a ¼ mile (1,320ft) recommend maximum distance for VLOS, it can be cross referenced to manned aircraft approach floors. Helicopters are allowed to operate at less than 500ft and in the case of incident management may even be required to provide medivac directly on the highway. According to FAA requirements for VFR approach/departure for a helicopter, "The approach/departure path starts at the edge of the FATO and slopes upward at 8:1 (8 units horizontal in 1 unit vertical) for a distance of 4,000 feet" [14]. By dividing 1,320ft by 8 (the approach floor) it results in a height of 165ft. This results in two likely scenarios:

- Helicopter providing support to incident, in this case the helicopter is providing support directly to the first responders and it would be expected that the "safety area" around the scene to support a medivac would be free of aircraft and other mobile objects. Thereby the operating area for a UAS would be extremely small and the possibility to interfere with manned aircraft deemed too great of a risk to allow operations.
- Operator is unaware of nearby heliport landing area, although the operator should always check for nearby aviation facilities it is possible that this scenario could occur.
    - For context, based on an 8:1 helicopter approach path a helicopter would intersect the drone zone 400ft ceiling at (400ft x 8 = 3200) 3,200ft. This means that an approaching helicopter could enter the UAS flying area as far away as 3,200ft from the RPIC (or landing zone). Given that the helicopter is much larger than a UAS and would likely be detected at 1000's of feet away (as opposed to 1,320ft VLOS).Therefore conceptually the RPIC would "see and avoid" the helicopter once it crossed below the 400ft threshold even at 3,200ft.

For "see and avoid" within the 1,320 radius, the UAS and manned aircraft would both be clearly visible giving the operator time to react. It can also be assumed that a helicopter would not be descending directly on the RPIC's location (i.e. RPIC would be standing directly on top of helipad) nor within the immediate 1,320ft VLOS radius. However, for worst case analysis let's assume the heliport is just outside the 1,320ft radius and that approach passes directly over the RPIC. Without a visual observer the RPIC would detect the helicopter as it was passing directly overhead resulting in a worst case detection height of (1,320 /8 = 165) 165ft as shown in Figure 2. However, with a visual observer who could be looking behind the RPIC, for the helicopter to traverse the RPIC diameter of 2,640 at an approach path of 8:1 would result in entering the drone zone at 330ft (2,640 / 8 = 330) as shown Figure 2. It is possible for a helicopter approach path to be within this zone but it would have to be in very close proximity to the operator. Although the UAS ceiling is 400ft, operations close to the ceiling (and manned aircraft) could be more risky than a lower altitudes. Therefore when using a visual observer the recommended zone for the operator to see and avoid would be below 330ft.

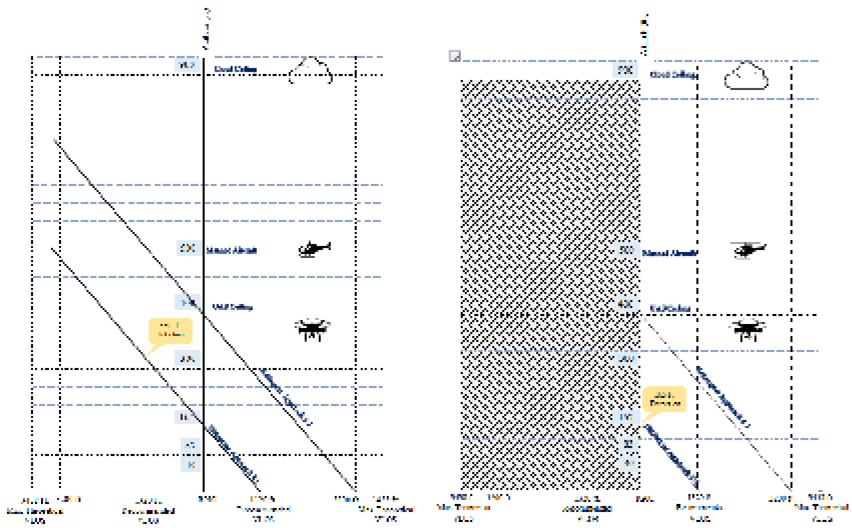

Figure 2. Helicopter Approach Path Detection With (Left) and Without (right) Visual Observer

It could be argued that the Part 77 glide path for fixed wing aircraft could also be used in this analysis. However, runways to accommodate fixed wing are better documented and more obvious than heliports which may be seldom used or only documented as part of emergency procedures. Using a 20:1 glide path would result in a very conservative height that given the UAS proximity to the operator would be unrealistic.

It's possible to use multiple visual observers and to extend the range that a UAS can be flown from an operator. For traffic operations and incident management, this type of daisy-chained observers does not appear to be practical as it would require additional staff resources.

Within the context of operating in Class G airspace, the final recommendations are as shown in Figure 3. There are several recommended zones of operation based on risk. The green zone of 83ft to 165ft would appear to have the least likelihood of interacting with vehicles/obstacles or manned aircraft, this might be a zone that NJDOT considers allowing UAS operations without a visual observer.

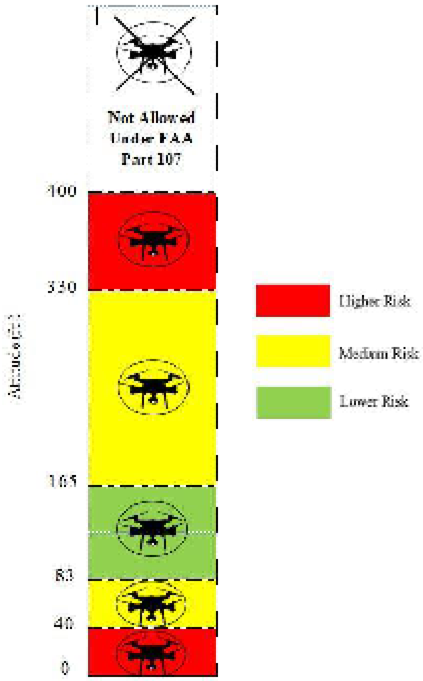

Figure 3. Recommended Operation Attitude vs. Risk Level

4.3 Wind Recommendations

Safety is a primary concern of any UAS operation. Similar to manned aircraft, UAS are sensitive to inclement weather condition. Small unmanned aerial systems can be even more sensitive to weather conditions such as wind or rain than larger aircraft. Obstructions on the ground can influence the flow of wind and be an invisible danger. Ground topography and large buildings can break up wind flow and produce wind gusts, which usually change rapidly in direction and speed. High speed winds can not only compromise the safe operation of a UAS, but may also result in potential motion blur. Given these facts, it is required to identify the range of wind speeds for safer drone operations. Table 2 illustrates the different Beaufort Wind Force Scale identified by the Roya Meteorological Society [15].

Table 2. Beauport Wind Force Scale [16]

Wind Force	Description	Wind Speed (Knots)	Specifications
0	Calm	Less than 1	Smoke rises vertically
1	Light Air	1-3	Direction shown by smoke drift but not by wind vanes
2	Light Breeze	4-6	Wind felt on face; leaves rustle; wind vane moved by wind
3	Gentle Breeze	7-10	Leaves and small twigs in constant motion; light flags extended
4	Moderate Breeze	11-16	Raises dust and loose paper; small branches moved
5	Fresh Breeze	17-21	Small trees in leaf begin to sway; crested wavelets form on inland waters
6	Strong Breeze	22-27	Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty
7	Near Gale	28-33	Whole trees in motion; inconvenience felt when walking against the wind
8	Gale	34-40	Twigs break off trees; generally impedes progress
9	Strong Gale	41-47	Slight structural damage (chimney pots and slates removed)
10	Storm	48-55	Seldom experienced inland; trees uprooted; considerable structural damage
11	Violent Storm	56-63	Very rarely experienced; accompanied by widespread damage
12	Hurricane	64 and more	Devastation

According to the advisory circular AC-107-2, the Remote Pilot In Command (RPIC) must ensure that the small unmanned aircraft does not exceed a groundspeed of 87 knots (100 mph) during flight operations [16]. In addition, according to the Remote Pilot-Small Unmanned Aircraft Systems Study Guide FAA-G-8082-22 published by the FAA in 2016 [16], low-level wind shear, which is dangerous to an aircraft, is commonly associated with passing frontal systems, thunderstorms, temperature inversions, and strong upper level winds (greater than 25 knots or 28.7 mph). Hodgson et al. tested the ScanEagle UAS within a range of wind conditions, and concluded that the UAS was capable of maintaining a parallel line flight pattern in wind conditions up to 26 knots (29.9 mph) [17].

Based on several test flights of a UAS, Yau et al. concluded that wind speed should be less than 8 meters per second (15.5 knots) [18]. In another study, the Florida Institute of Technology reported that the control of a UAS would be an issue in wind speeds higher than 15mph (13 knots) [19]. It should be noted that these studies used the UAS for bridge and high mast pole inspections, requiring close proximity to the infrastructure. For ITS applications the minimum distance between the sUAS and any non-participant or obstruction will likely be 25ft or more. It is likely that incident response activities may come close to this minimum distance, while traffic monitoring activities may far exceed the threshold. Since the inspection activities noted in the studies would have involved flights at a closer proximity to objects, the wind speed of 13 knots is likely overly conservative compared to the application of drones for ITS.

In order to gain a better understanding of the UAS manufacturer's recommendations regarding maximum wind speeds, the team reviewed the most common, commercially available UAS, as illustrated in Table 3. For the majority of commonly available units, the team found that the maximum recommended wind speed should generally not exceed 19.4 knots (10 m/s or 22 mph).

Table 3. Maximum Recommended Wind Speeds for Drone Operations

Type	Maximum Wind Speed (Knots)
DJI Phantom 4 Pro	19.4
DJI Phantom 4 SPECS	19.4
DJI Inspire 2	19.4
DJI Phantom 3 Standard	19.4
DJI Mavic Pro	19.4
DJI Phantom 3 Advanced	19.4
DJI Spark	19.4
3DR Solo	21.7
SenseFly Albris	19.4

Based on past research efforts, manufacturers maximum operational wind speeds, and FAA documentation the research team developed a three-tiered wind risk matrix for UAS operation. Low risk wind conditions are those wind speeds from 0 – 13 knots. At these speeds, it is unlikely for the wind to have a noticeable effect on the control or flight path of the UAS. Wind speeds from 13 – 20 knots constitute a medium risk for a UAS flight. The upper threshold of this range which generally aligns with common manufacturer recommended maximum wind speeds. However, there are less common UAS that may indeed operate safely under more windy conditions, and given the context of incident management they may be required to operate in less ideal conditions in the future. Therefore, a higher risk range was established from 20 to 25 knots. The wind speed becomes a significantly higher risk to the flight operations as 25 knots is the FAA (FAA-G-8082-222016) threshold before potential wind shear damage to the UAS[Error! Bookmark not defined.].

Furthermore, according to the Beauport Wind Force Scale at 28 knots "Whole trees in motion; inconvenience felt when walking against the wind Error! Bookmark not defined.." If the wind is sufficient to impact walking, this would also likely impede the RPIC from comfortably standing in such conditions. For the purposes of the initial testbed locations, the team does not recommend performing any flights above the 25 knot limit. The recommended ranges for the wind risk matrix are shown in Figure 4 below.

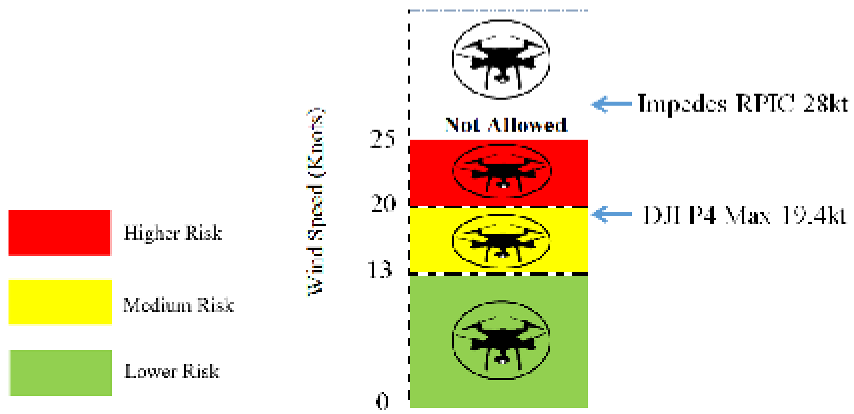

Figure 4. Recommended Wind Speed vs. Risk Level

4.4 Temperature Recommendations

Most quadcopters use lithium-polymer (LiPo) batteries. Batteries should be stored as per the manufactures recommendations, typically in a cool and dry place. Batteries should not be stored in excessively hot or cold locations such as the trunk of a car during the summer or winter months. An overheated battery pack can result in thermal runaway leading to fires. Conversely, during colder temperatures useful battery charge may be reduced. A fully charged battery that provides 25 minutes of flight time during normal weather condition may only provide a fraction of that flight time in cold weather. Many modern drones are designed to fly in temperatures that range from roughly 32°F – 104°F (0°C – 40°C), providing the opportunity to safely fly in a variety of climates [20].

Therefore, it is recommended that UAS operators refer to the equipment user manuals for safe operating conditions for the drone, gimbal, and battery. In lieu of a manufactures recommendation, the research team considered 5°C warmer than the minimum and 5°C cooler than maximum temperature for a typical Lithium Ion battery charge temperature. This range would roughly be between 41°F and 104°F (5°C and 40°C); and closely aligns with common DJI temperature considerations.

Fundamentally, at lower temperatures the RPIC should plan for shorter flights as a result of decreased battery performance. It may be possible to reduce the cold impact by keeping the battery packs warm in a vehicle. At a minimum, during colder temperatures the research team recommends launching and hovering at a low altitude for 1 to 2 minutes to allow the battery pack to internally warm as a result of the chemical reaction (battery packs warm during use). This may help to bring the battery pack into a more optimal temperature range resulting in better battery performance. Failure to warm the pack may result in a greater chance of low battery mid-flight causing unexpected power loss.

Also of note, parts can become fragile at low temperature. For instance, overtightening of hardware/nuts in the cold weather when some materials are more brittle can result in breakage.

4.5 Cloud Ceiling and Visibility

FAA Part 107 requires a minimum visibility of 3+ statute miles (sm) and the minimum distance from clouds being no less than 500ft. Since the maximum altitude of a UAS is 400ft and it must at least be 500ft below the clouds (400ft +500ft=900ft); conservatively it can uniformly be stated that the cloud ceiling must be above 900ft for all UAS operations.

4.6 Distraction Caused by UAS

Distracted driving is a topic of much research, especially with the advent of cellphones. A recent study conducted by Huisingh et al. [21] estimated the prevalence of distraction among passenger vehicle drivers using a roadside observational study [21]. The authors conducted a cross-sectional survey at 11 study intersections. Based on the results of this study, more than 32 percent of drivers were involved in distracted activities. To be specific, compared to external distractions such as roadway environmental factors, internal vehicle distractions such as interacting with other passengers and talking on the phone were higher among the studied drivers. To get a better understanding of distracted driving activities on safe driving, Sosa et al. [22] also analyzed external and internal driving distractions. The external distractions included the construction zones and accident scenes, and internal distractions consisted of talking on the phone and using a touchscreen panel in the vehicle. The authors concluded that the external distractions due to the crash and construction scenes are not as significant as the internal distractions. According to the results obtained from previous studies [22-25], internal distractions result in more adverse effects on safe driving compared to the external distractions.

If the leading cause of distraction is not the external factors, such as crash scenes, then it is possible the usage of a UAS (an external distraction) at any altitude would not contribute to distracted driving any more than current NJDOT roadside activities. However, currently there is no data available to quantitatively analyze and validate what if any distraction a UAS may pose to drivers. This question if further compounded by the 3-dimensional nature of UAS, which can operate far above a driver or close to the ground immediately adjacent to the roadway.

It is possible that based on field of view and typical driver behavior that there would be some altitude at which the UAS would cause little or no impact on distraction. A small UAS operating at a couple of hundred feet off the ground may appear to only be a dot in the sky - no larger than typical distractions such as a passing bird. Similarly, high speed traffic may only catch a glimpse of UAS and not be impacted; whereas slow moving traffic may have longer time to observe and react to the distraction. In the case of incident management one might expect that all the flashing lights and activity of a crash scene would already be a significant distraction and thus outweigh the additional potential distraction caused by a small UAS – this is unproven. Within a drivers normal field-of-vision there is a centralized focus area; at a minimum the research team recommends that when using a UAS for traffic operations and incident management to avoid this zone as much as feasible. The following sections of the report, within the context of trying to minimize the UAS distracting the driver, provide more information regarding the focus zone, operating altitudes, and potential flight patterns.

4.7 Flight Safety Parameters

The proposed UAS-based congestion and incident data collection plan is a supplement data collection and monitoring system for Traffic System Management and Operations (TSM&O). The collected video will be used to the detection, diagnostics of congestion and incident impact and support decision-making regarding congestion relieve and incident response.

4.7.1 Congestion Monitoring

Purpose: Detect and investigate potential congestion for bottleneck segments.

Congestion phases and UAS Operations: Traffic congestion can be classified into 4 phases according to the timeline, as shown in Table 4. Various tasks are required in different phases.

The initial planning will be conducted prior to the congestion investigation. Three tasks need to be done during the initial planning:

- Task 1: Identify the bottleneck segments and the impact area of the congestion;
- Task 2: Determine the takeoff and landing site;
- Task 3: Design the survey pattern and altitude holding considering driver distraction and safety.

Then schedule the flight according to the location and time of congestions.

Table 4. Congestion Phases and Corresponding TSM&O Activities, Field Experiments

Phase	TSM&O Field Operations	Proposed Field Experiments
Planning	- Bottleneck Identification - UAS Preparation / Pre-flight checklist /Site setup: Prepare required equipment, have a pre-flight check on UAS and setup the takeoff/landing site.	- Select Candidate Sites.
Pre-Congestion	- UAS Takeoff - UAS Collection of off-peak traffic condition (Baseline)	- Prepare required equipment Travel Preparation / Pre-flight checklist / Site setup - Collect basedline free-flow traffic conditions
Congestion Activation	- UAS Continuing Collection of peak hour data - Video Support for Traffic Operational Center - Communication support for disseminating queue warning messages	- Execute flight pattern and altitude holding for overlooking - Hover to observation point and state congestion data collection.
Congestion Continuation	- UAS Continuing Data Collection - UAS Battery Swapping and Retake off - UAS monitoring of incidents and bottleneck activities	- Execute flight pattern and altitude holding - Video Stream / Archive: Data collection (static) and Event Investigation (PTZ)
Congestion Recovery	- Conclusion of UAS Flight - Close of Flight Site - Data Exporting and Analysis	- Battery Swapping / UAS Swapping / Charging - Landing / Recollection of field equipment

4.7.2 Incident Response

Purpose: Detect, investigate incident, and archive incident data.
Incident phases and UAS Operations: Traffic incidents can be classified into 6 phases according to the timeline, as shown in Table 5. Compared with Congestion Monitoring, Incident Response has more TSM&O Activities and more complicated flight planning.

Table 5. Incident Phases and Corresponding TSM&O Activities, Field Experiments

Phase	TSM&O Activities	Field Experiments
Incident Detection	Acquire incidents information from TMC or service patrols	Select Candidate Site
Incident Verification	Confirm incidents from TMC or service patrols	Drone Video Feedback to Observer Monitors and Laptop
Incident Response	DMS Warning / Notification	Draw and Load Flight Survey Pattern
Incident Survey	Investigate Incidents	Conclude Flight Survey
Incident Clearance	Clean Incidents related debris	Conclude Site Monitoring
Traffic Clearance	DMS Removal	Conclude Congestion Monitoring

- Phase 1: Incident Detection
  - Once an incident is confirmed by service patrols and TMC, UAS will be sent to the incident site.
  - Travel to the site with UAS and pilot.
- Phase 2: Incident Verification
  - Aerial Video Support: Design a hovering pattern where is off-people, can provide overall observation of incident, and provide exact coordinates and milepost of the incident.
- Phase 3: Incident Response
  - Flight Survey Pattern: Design a flight pattern for incident data collection.
- Phase 4: Incident Survey
  - Flight Survey conclude
- Phase 5: Incident Clearance
  - Site Monitoring conclude
- Phase 6: Traffic Clearance
  - Congestion Monitoring conclude

Detailed UAS operation plan is discussed in the following sections.

4.8 Operational Plan

4.8.1 Congestion Monitoring

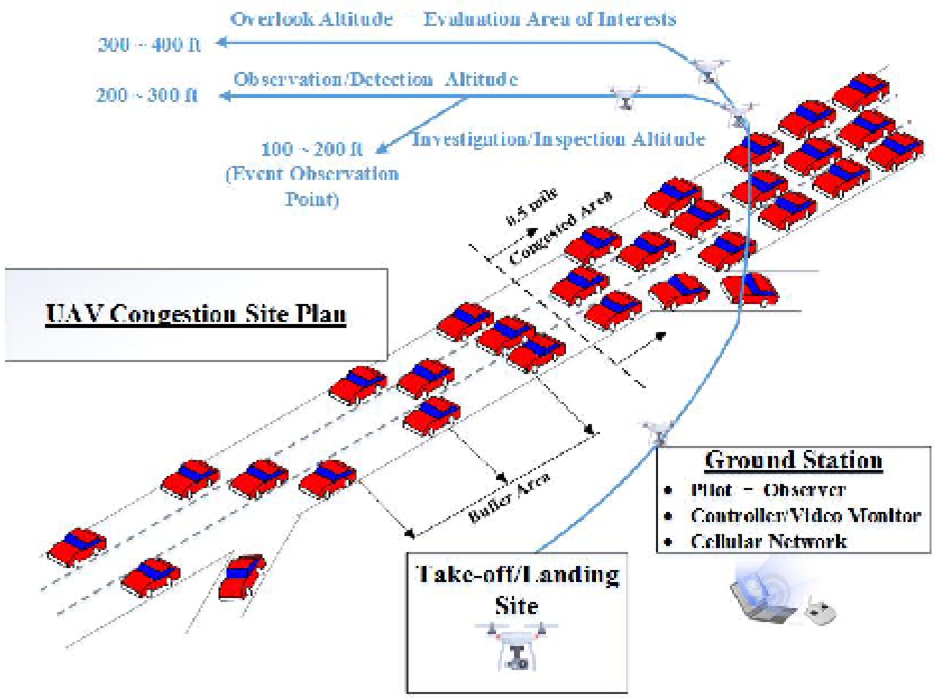

Figure 5. Congestion Monitoring

Figure 5 illustrates the site plan of congestion monitoring including 3 flight patterns, position of take-off/landing site, position of ground station and related altitude/distance settings.

The take-off and landing site of UAS can be either on congestion site or off congestion site. If it is off-site, the UAV needs additional flight time to establish the specified altitude and then travel to the congestion site.

Ground Station will be located off-site. Pilot/observer controls and monitors the UAS along the pre-designed flight pattern; video monitor and controller serve as tools for pilot/observer to control the UAS.

During the operation, the UAS first raise up to the Overlook Altitude (300 to 400ft) to evaluate the area of interests. Then, lower it to the observation/Detection Altitude (200 to 300ft) to keep monitoring the area of interest. Another altitude option is the Investigation/Inspection Altitude (100 to 300ft), where the UAS can look at a specific bottleneck segment or event point. The Investigation/Inspection Altitude considering the human factors is the lowest limit of altitude to prevent driver's distraction. Accordingly, the buffer area is the area that UAS should not be flying.

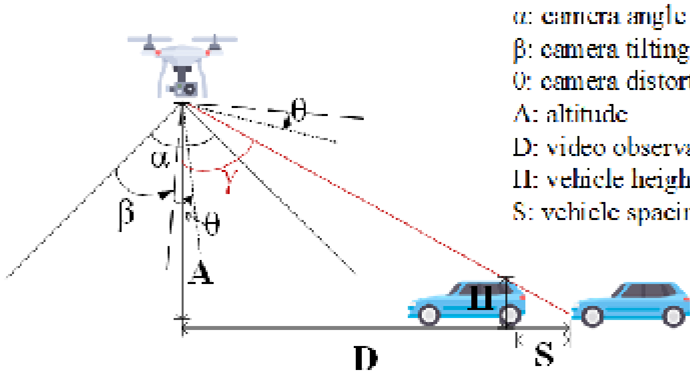

Figure 6. UAS Camera Angle and Line of Sight for Car Separation

Figure 6 illustrates that the camera has an angle range α called Field of View (FOV), a tilting angle which can change the direction of camera by controlling gimbal. However, at the edge of FOV, video/photo distortion may provide bad data for analysis, thus a camera distortion buffer θ needs to be considered to reduce the distortion impact during the traffic investigation.

As shown in Figure 6, to fully acquire vehicle status, a certain angle γ needs to be covered by camera FOV to make vehicles in video/photo separate. This needed angle and altitude could be calculated as below,

$$\gamma = Arctan(S/H)$$

Where S is the vehicle spacing, H is the vehicle height, D is the horizontal distance for UAS to the investigated vehicle, and A is the holding altitude of UAS.

The camera tilting angle range is considered as 0 while pointing down and 90° while pointing parallel to ground. The camera FOV varies from different types of UAS, as shown in Table 6 below.

Table 6. Popular UAS Camera Specifications Experiments

Type	Lens FOV (Field of Vision)	Camera Tilting Angle Range
DJI Phantom 4 Pro	84°	Integrated with Gimbal (0° to 120°)
DJI Phantom 4	94°	Integrated with Gimbal (0° to 120°)
DJI Phantom 3 Standard	94°	Integrated with Gimbal (0° to 120°)
DJI Mavic Pro	78.8°	Integrated with Gimbal (0° to 120°)
DJI Phantom 3 Advanced	94°	Integrated with Gimbal (0° to 120°)
DJI Spark	81.9°	Integrated with Gimbal(5° to 90°)
PARROT BEBOP 2	90°	Integrated without Gimbal
PARROT DISCO	90°	Integrated without Gimbal
Yuneec Typhoon H Pro	98°	Integrated with Gimbal : 360° view
3DR Solo	76° (Sony R10C)	Integrated with Gimbal : (0° to 90°)
Albris: SenseFly	63° (Main Camera), 100° (Thermal, Head Camera)	0° to 90°

The FOV is an important parameter that affects how far the camera can see. The number of Pixels on Target (PoT) is used to evaluate the recognition level of target in video image. The larger the PoT is, the clear the image is. To determine the PoT, the camera's image resolution, the camera/lens FOV, and the object size are needed [26]. As shown in Table 2, the maximum FOV is the length of road that can be covered according to of different PoT. PoT is set to different levels according to the objectives at different altitudes and FOV of 94° (DJI Phantom 4) is used as an example for calculation.

In Table 6, targeted investigation ranges are typical ranges used for bottleneck assessment including 300 ft for the typical length of an acceleration lane for detailed inspection of bottleneck factors, 0.5 mile for data collection and observation, and 1 mile for overlook the entire impact segment of a bottleneck. It is easy to see that the target investigation range can be easily covered by the camera since the target investigation range is much smaller than the Max FOV.

$$\text{Diagonal Resolution} = \sqrt{\text{Camera Horizontal Resolution}^2 + \text{Camera Vertical Resolution}^2}$$

$$\text{Max FOV} = \frac{\text{Diagonal Resolution}}{\text{PoT}} * \text{Vehicle Length}$$

$$\text{Altitude} = \frac{\text{Target Investigation Range}}{\tan\left(\frac{\text{Camera FOV}}{2} - \text{Camera Tilting Angle}\right) + \tan\left(\frac{\text{Camera FOV}}{2} + \text{Camera Tilting Angle}\right)}$$

Table 7. Max FOV and Tilting Angle

	Pixels on Target (PoT)	Vehicle Length (ft)	Diagonal Resolution	Max FOV (ft)	Target Investigation Range (ft)
Overlook	2	20	2203	22029	5280 (1 mile)
Observation	8	20	2203	5507	2640 (0.5 mile)
Inspection	14	20	2203	3147	300

According to altitude and target investigation range, the Camera Tilting Angle can then be calculated. The Relationship between Altitudes versus Camera Tiling Angles are as the flowing Table 7 and Table 8.

Table 8. Camera Tilting Angle at Altitude 300ft, 200ft and 100ft

Altitude (ft)	Camera Tilting Angle (degrees)
300	40
200	39
100	21

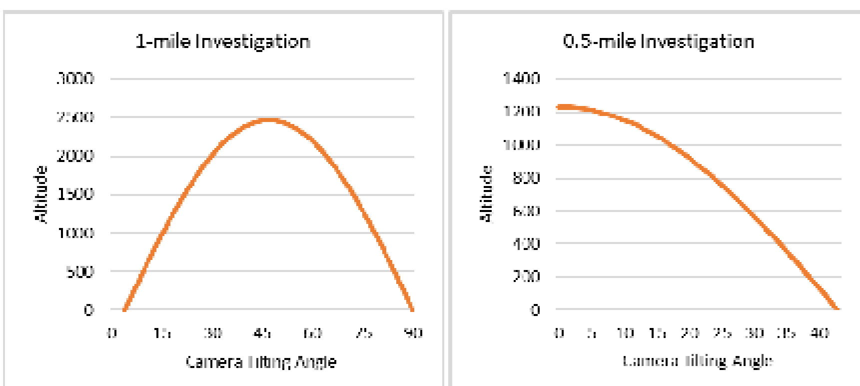

Figure 7. The Relationship between Altitudes versus Camera

4.8.2 Incident Response

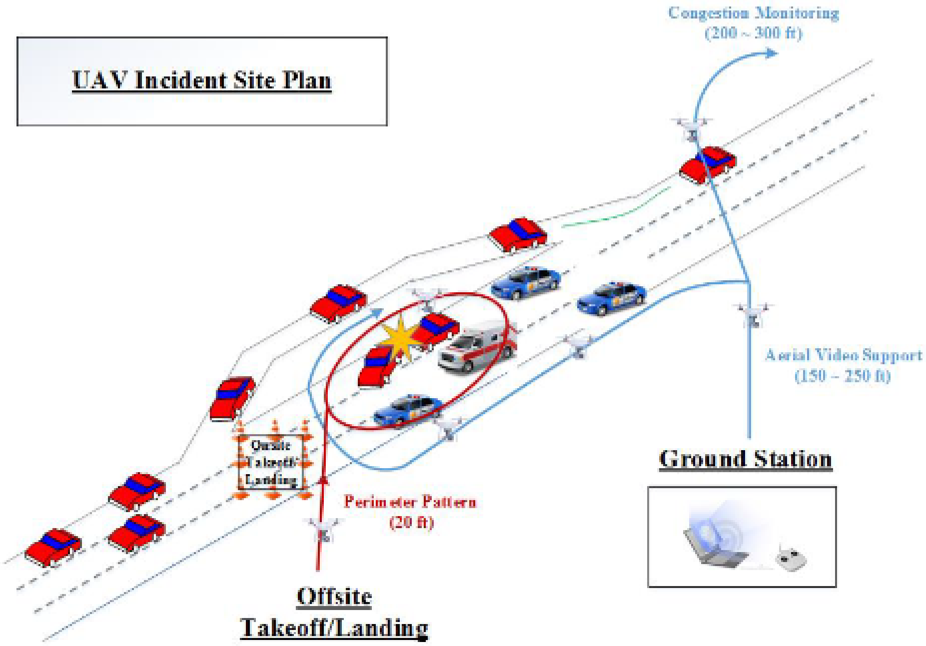

Figure 8. Incident Site Plan

Figure 8 illustrates the site plan of incidents including 3 flight patterns, position of take-off/landing site, and position of ground station. After the detection and verification of incidents, Aerial Video Support Flight Pattern, Perimeter Flight Pattern and Congestion Monitoring Flight Pattern will be designed according to the incident position, severity and lane closure. Same as Congestion Monitoring site plan in Figure 5, the ground station needs to be out of the buffer area, whereas the takeoff/landing site can either be off incident site or be inside the incident site with an area around 10ft by 10ft.

The UAS flying with Aerial Video Support Pattern keeps at a certain boundary towards the incident site yet has the flexibility of moving around. As shown in Figure 8, if all lanes are closed for the incident segment, the UAS can cross the segment to another side to have a full view of the incident. Perimeter Flight Pattern provides a closer overlook of the incident scene while Congestion Monitoring Pattern captures the traffic growth upstream of the incident site.

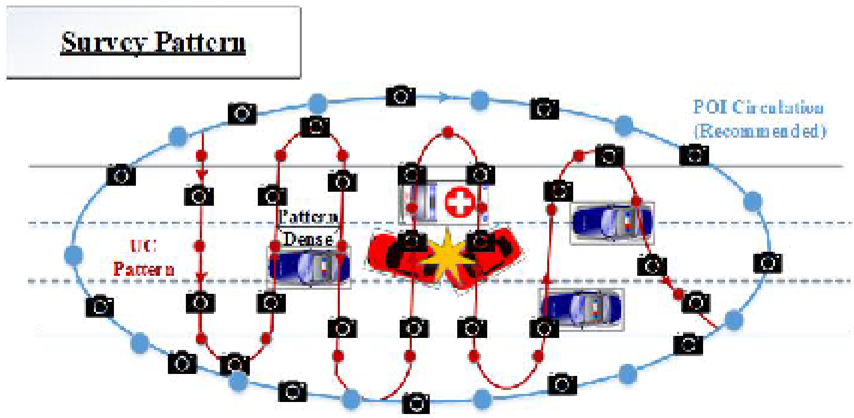

Figure 9. Survey Pattern

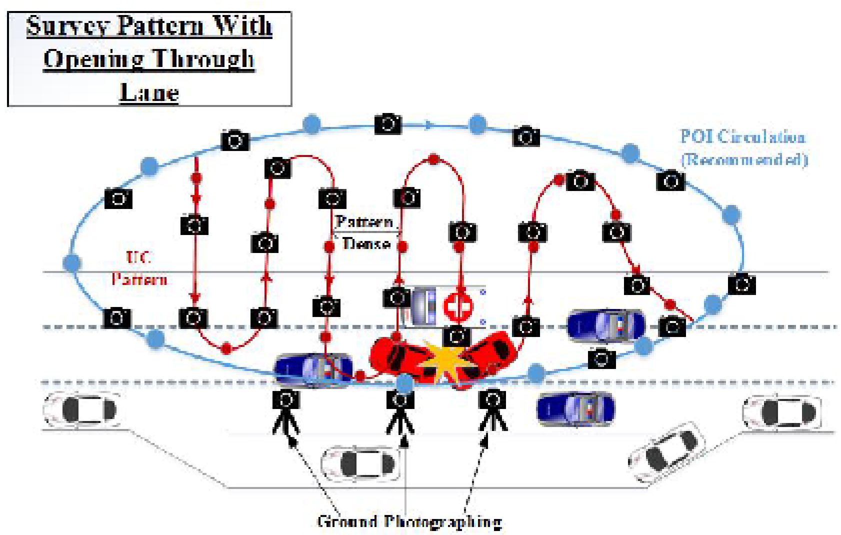

Figure 10. Survey Pattern with Opening through Lane

As shown in Figure 9 and Figure 10, red and blue dots are the control points of survey flight patterns. Photos from different angles and positions are needed to fully 3D reconstruct the incident scene. POI Circulation Pattern and UC Pattern are proposed to meet the needs of photos. Circulation Pattern stays at a relatively higher altitude *A* while UC Pattern stays at a relatively lower altitude *B*. The dense of UC Pattern keeps at a distance of *C* to ensure sufficient overlaps among photos. Note that altitude *A*, *B* and dense *C* needs to be determined according to UAS characteristics, flight time and site geometry.

Considering the scenario that several through lanes are still opened, survey pattern will be different from all-lane closed scenario. As shown in Figure 6, the survey pattern with opening through lane shall avoid flying over the diverting traffic, which leads to a lack of observations from some angles. To compensate for the lack of observations, ground photographing is needed on the side of diversion.

4.8.3 Focus Cone Analysis

Peripheral vision is vision outside of the range of stereoscopic vision. It can be conceived as bounded at the center by a circle 60° in radius or 120° in diameter, centered around the fixation point, i.e., the point at which one's gaze is directed [27]. In common usage, near peripheral visions refer to the area outside a circle 30° in radius and bounded by a circle 60° in radius [28-29]. The dividing boundary of peripheral vision at 30° radius is based on several features of visual performance. Visual acuity declines by about 50% every 2.5° from the center up to 30°, at which point visual acuity declines more steeply [30]. Color perception is strong at 20° but weak at 40° [31]. 30° is thus taken as the dividing line between peripheral vision and central focus zone.

Drivers' most accurate field of vision is known as the central cone of vision, as represented by the red area in Figure 11. The further away from the central cone, the less the driver focuses on the object. Converting the angle of circle into horizontal plane and vertical plane, 15° is the boundary of central focus cone, 30° is the boundary of near peripheral and angles larger than 30° is in far peripheral, as shown in Figure 11. Moving objects in the near peripheral could cause a certain level of distraction, while objects in the far peripheral could hardly cause distraction.

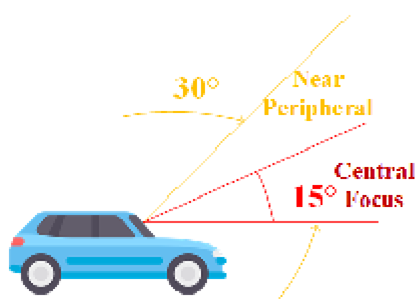

Figure 11. Driver's Focus Cone

According to the calculation, a UAS having around 10 inch length becomes a pixel when the distance is larger than 2500ft, i.e., it will not cause any distraction. According to studies from Apple Inc., 300 pixels per inch (PPI) is the magic number that when you hold something around to 10 to 12 inches away from your eyes, is the limit of the human retina to differentiate the pixels [32]. With this, an UAS with dimension of 10 inch becomes one pixel in human retina when the UAS is 2500 ft away, as calculated below:

$$\begin{aligned} \text{Retina Distance} &= \text{Distance}_{\text{phone}} * \frac{\text{PPI}}{\text{Number of Pixels of UAS in Human eye}} * \text{UAS Dimension} \\ &= 10\ \text{inch} * 300\ \text{ppi} * 10\ \text{inch} \\ &= 30000\ \text{inch} = 2500\ \text{ft} \end{aligned}$$

It is assumed that at 300 ft altitude, the UAS is looking at 5280ft (1mile) of traffic for the purpose of overlook; At 200 ft altitude, the UAS is looking at 2640ft (0.5mile) of traffic for the purpose of observation; At 100 ft altitude, the UAS is looking at 300ft of traffic for the purpose of investigation.

According to[Error! Bookmark not defined.], 14 pixels on target makes the target identifiable, 8 pixels on target makes the target recognizable and 2 pixels on target makes the target detectable. Thus, based on the different altitudes and investigation ranges assumed above, the following table shows different zone ranges along the investigation range. The Zone Ranges divide the horizontal distance between vehicles and UAS into several zones, as shown in Table 9. The horizontal distance is calculated by

$$\text{Horizontal Distance} = \sqrt{\text{Retina Distance}^2 - \text{Altitude}^2}$$

In addition, the Focus Zone is the overlap of the Identifiable Zone and the zone that UAS is inside driver's focus cone (15°); Acute Focus Zone the overlap of the Identifiable Zone and the zone that UAS is inside driver's near Peripheral (30°).

Table 9. Zone Ranges

Altitude (ft)	Investiga-tion Range (ft)	Impact Zone*	Pixels of UAS in Human Eye	Retina Distance (ft)	Horizontal Distance (ft)	Zone Range (ft)
300	5280	Identifiable Zone	14	179	N/A	None
		Recognizable Zone	8	313	88	0-88
		Detectable Zone	2	1250	1213	88-1213
		Focus Zone	14		520	None

Altitude (ft)	Investiga-tion Range (ft)	Impact Zone*	Pixels of UAS in Human Eye	Retina Distance (ft)	Horizontal Distance (ft)	Zone Range (ft)
		Acute Focus Zone	14		1120	None
200	2640	Identifiable Zone	14	179	N/A	None
		Recognizable Zone	8	313	240	0-240
		Detectable Zone	2	1250	1233	240-1233
		Focus Zone	14		346	None
		Acute Focus Zone	14		746	None
100	300	Identifiable Zone	14	179	148	0-148
		Recognizable Zone	8	313	296	148-296
		Detectable Zone	2	1250	1246	296-300
		Focus Zone	14		173	None
		Acute Focus Zone	14		373	None

* Impact zone definitions are as follows:

- Identifiable Zone: Equivalent to 14 observable pixels on a retina display by drivers
- Recognizable Zone: Equivalent to 8 observable pixels on a retina display by drivers
- Detectable Zone: Equivalent to 2 observable pixels on a retina display by drivers
- Focus Zone: Equivalent to 14 observable retina pixels and within 30 degree focus cones of drivers
- Acute Focus Zone: Equivalent to 14 observable retina pixels and within 15 degree focus cones of drivers

Figure 12 shows the zone ranges graphically. Drivers in Detectable and Recognizable Zones may hardly be distracted by UAS because the UAS is only a small object in their view. Drivers in Focus Zone and Acute Focus Zone can both identify (with more than 14 pixels in retina) and draw attention to UAS (with in driver's focus cone). However, as the UAS altitude goes up, Focus Zone and Acute Focus Zone disappears.

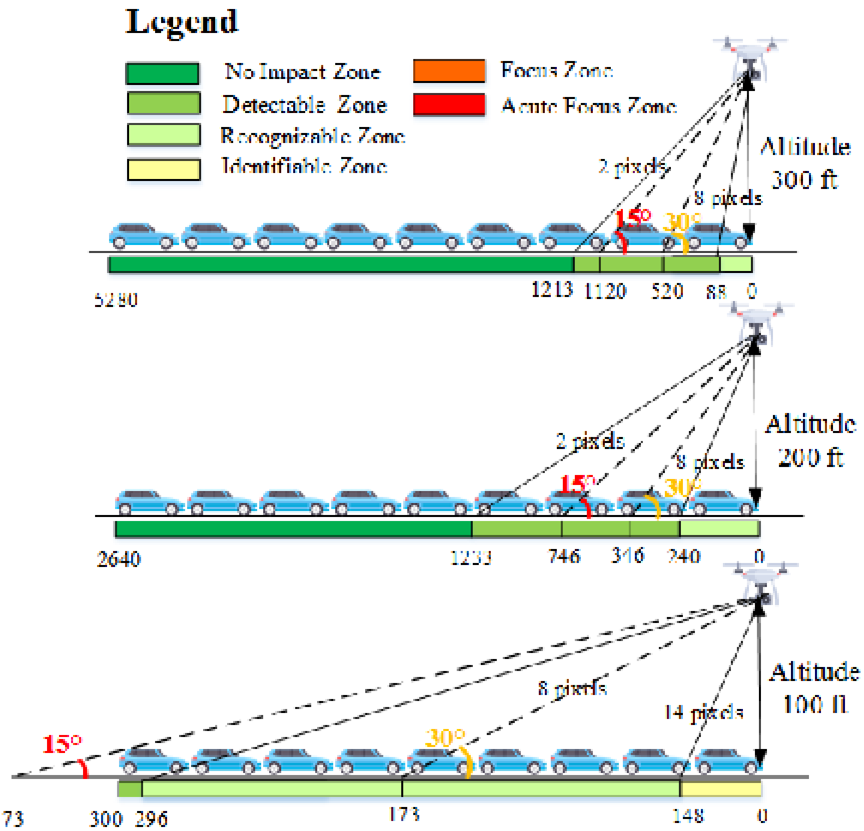

Figure 12. Zone Ranges along Investigation Range

4.8.4 Major Findings and Future Work

Based on the above theoretical analysis, several observations can be obtained as well as the evaluation needs in field experiment.

- Based on geometric calculation, high-resolution video camera (e.g. 1080p+) will ensure sufficient FOV (field of view) for the targeted missions for overlooking (300ft), observation and data collection(200ft), and detailed investigation (100ft) (See
- Table 7, Table 8, and Figure 7). Further field experiments on the quality and resolution of images for different applications are still needed to verify the proposed altitude levels and camera tiling angles.

- Different survey patterns may be applicable for different bottleneck or incident scenarios. Different factors such as the application (site monitoring or 3D reconstruction), the restrictions on flying over people, vehicle, or accident scene, site layout and setup, and the location of through lane for traffic diversion (See Figure 9 and Figure 10). The optimal flight patterns still need to be adjusted and optimized in field experiments for safety and efficiency.
- To investigate the potential risks for the distraction, several optical and geometric studies are conducted including the focus cone models (Figure 11), the needs for pixels on target (PoT) and camera FOV(field of view) based on different detection-recognition-and-identification requirements (
- Table 7 and Table 8), and the visual impact analysis of UAS in human retina based on parameters (Retina distance equation). The theoretical numbers resulted in the estimated range of different zonal characteristics based on distance from the UAS at different altitude levels (Figure 12). The results indicate that in higher altitude levels, e.g. 200 and 300 ft. The distraction to drivers is light with most of the roadway segments are in No Impact to Recognizable Zones. At low altitude (e.g. 100 ft), there is an identifiable zone within 148 ft to the UAS site. At 100ft, the UAS will be outside of a typical Driver's focus cone (less than 30 degree) unless the drivers stop and look towards the UAS. More detailed field experiments still need to be conducted to verify some of the thresholds and boundary values and the resulting human factor impact.

5 Day of Flight Procedure

As part of the planning activities within the test-bed location the RPIC must assess the test-bed conditions at the time of the flight, inspect UAS for airworthiness, and verify weather conditions are suitable for flight.

- Identify primary takeoff and landing location: flat, level, free of obstacles or brush that could damage propellers, free of overhead obstructions, and free of non-participants.
- Identify emergency landing location(s): all efforts shall be made to avoid death, injury, or damage to personal property even if it means destroying/damaging the UAS by landing in an alternate landing location such as brush or water.
- Review surrounding area for elevation changes, proximity to adjoining properties, obstructions, towers, trees, power lines, etc. Note: By using a known test-bed location major concerns have been prescreened, however it is a given that common obstacles will be present.
- Visualize flight path and altitudes for obstacles and compliance with including but not limited to requirements of Part 107.
- Review Weather, Notice to Airmen (NOTAM), and Temporary Flight Restrictions (TFR)Error! Bookmark not defined.
    - Environmental Conditions – Weather - Review aviation weather information from an FAA approved weather service such as www.1800wxbrief.com or www.aviationweather.gov that provides Meteorological Terminal Aviation Routine Weather Report (METAR). At a minimum the RPIC must review: 1) Cloud Ceiling; 2) Visibility; 3) Wind speed; 4) Temperature; and 5) Other conditions (weather advisories, rain, etc)
    - Review NOTAM's and Temporary Flight Restrictions (TFR's) from an FAA approved site such as tfr.faa.gov and pilotweb.nas.faa.gov
- Estimate flight time to confirm batteries are sufficiently charged. Ensure that batteries are sufficiently charged including the UAS, controller, phone (or radio) in event of emergency, and payload (camera etc).
- UAS Airworthiness: Inspect the UAS in accordance with manufacturer guidelines, assemble UAS, check airframe for cracks, tighten screws, check propellers are secure and not damaged (cracks, chips, deformations, and dings), check batteries for damage or bubbling, secure payload and batteries, confirm GPS fix, confirm controller is communicating with UAS, and if applicable ensure "return home" position, flight path, and altitude setting are properly set,.

- Crew briefing: If using visual observers or other crew members - conduct a crew briefing prior to the flight covering the mission (flight path), safety concerns, communication procedures, assigned tasks, and emergency procedures.
- Ensure paperwork is onsite including Remote Pilots license, UAS registration card, insurance card (if appropriate), UAS has registration number affixed, and phone number for nearest ATC.
- Review emergency procedures.
- Complete risk assessment form.

5.1 Environmental Conditions - Weather

Aviationweather.gov provides a simple graphical interface. By clicking on the nearest station the RPIC can review METAR data from a reporting station. As the flight may occur between stations there are some errors that may occur, this error increases the further the flight occurs from a reporting station. As shown in Figure 13 there are more than a dozen reporting stations within New Jersey with many more in the surrounding states to provide a RPIC with a basis to determine environmental conditions. For example, as shown in Figure 13 the cloud ceiling at the Somerville station was 5000ft with a 10-mile visibility.

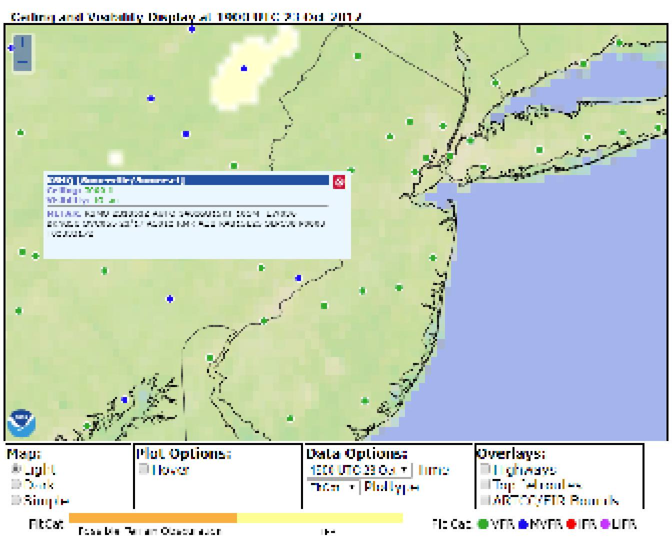

Figure 13. Sample Environmental Data from aviationweather.gov [33]

The METAR data shown in Figure 13 has all the necessary information to determine weather conditions at this site. The major components of the METAR data is defined as follows:

- KSMQ = Station id = Somerset Airport in Bedminster, NJ
- 231853Z = date and time in universal Greenwich Mean Time (GMT) = 23rd day (no month or year is indicated) 1853 GMT which is 4 hours ahead of Eastern Time (ET) therefore 2:53pm ET.
- Auto = automated station
- 14006G15KT = wind heading and speed = wind from 140degrees 6 knots and gusts up to 15 knots
- 10SM = visibility = 10 statute miles
- FEW036 BKN050 = Cloud ceiling = there can be multiple codes reported here. FEW, SCT, BKN, and OVC refer to the amount of sky coverage denoting few, scattered, broken, and overcast relating to 1/8-2/8, 3/8-4/8, 5/8-7/8, and 8/8 of sky coverage respectively[Error! Bookmark not defined.]. However, the lowest cloud ceiling will be reported as BKN for broken or OVC for overcast and is reported in hundreds of feet = 5,000ft cloud ceiling
- 23/17 = Temperature in Celsius and dew point = 23 degrees C is 73 degrees F
- The rest of the codes relate to other weather conditions that will not be discussed at this time

Aviationweather.gov also has the ability to show weather advisories such as severe weather shown in Figure 14 and radar showing precipitation as shown in Figure 15.

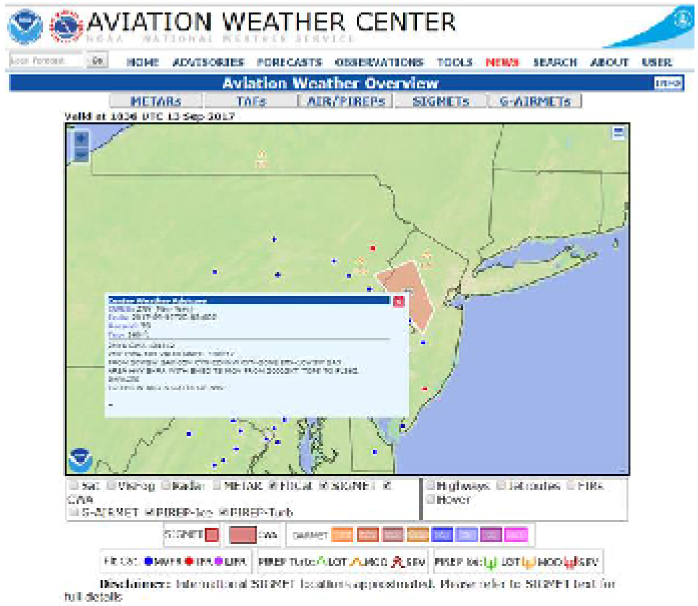

Figure 14. Sample of severe weather moving into area

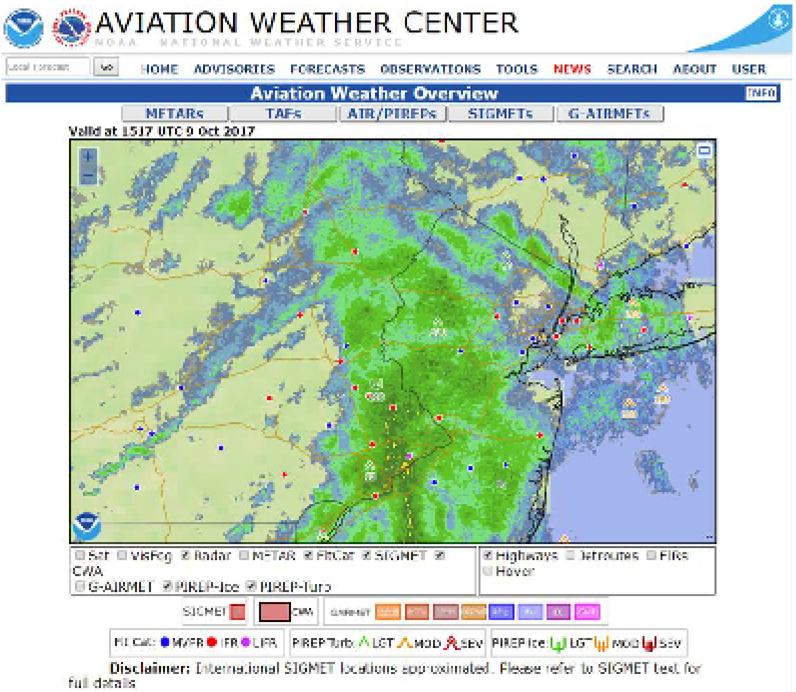

Figure 15. Sample radar map showing precipitation

5.2 Notice to Airmen (NOTAM), and Temporary Flight Restrictions (TFR)

The pilotweb.nas.faa.gov site provides a number of search options including latitude/longitude and "around me" options to check for NOTAMs. A typical search may result in well over 100 entries, many of which are facility or permanent NOTAMs. The RPIC will need to review all NOTAMS, keeping in mind that the UAS may only operate within the visual line of sight. Thus, 1- or 2-mile radius is well beyond the expected UAS operational distance therefore limiting the search may result in more manageable results. Figure 16 shows a typical result from pilotweb.nas.faa.gov along with a map display for the NOTAMs as shown in Figure 17.

Figure 16. Typical NOTAM search result from pilotweb.nas.faa.gov [34]

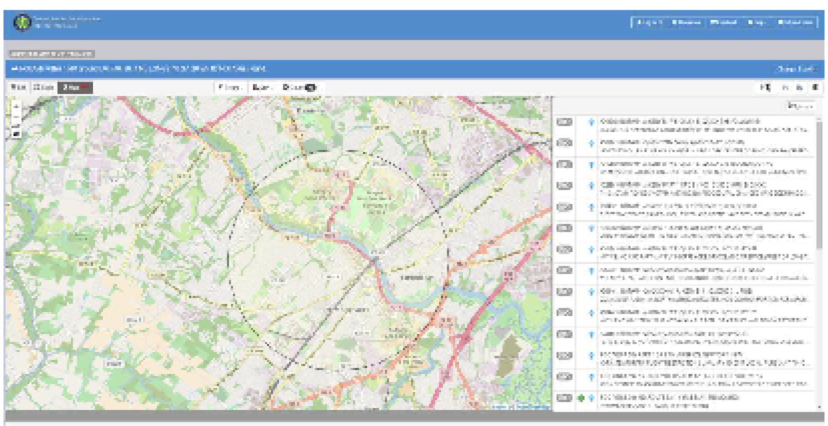

Figure 17. NOTAM mapping feature from pilotweb.nas.faa.gov

The tfr.faa.gov site provides a simple search tool to find Temporary Flight Restrictions. For example the RPIC may select New Jersey and view all current TFR's as shown below in Figure 18.

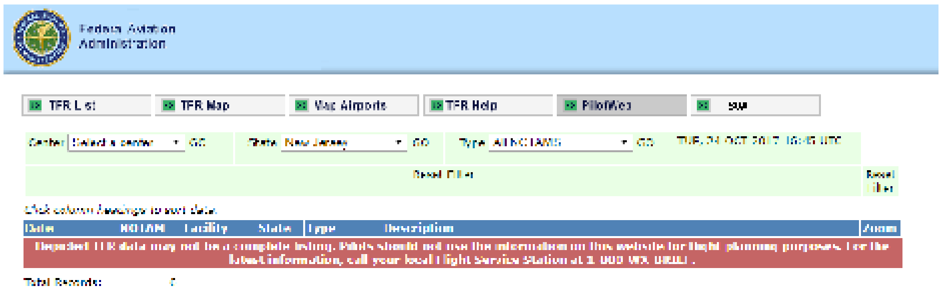

Figure 18. Typical Temporary Flight Restriction (TFR) search result from tfr.faa.gov site [35]

6 Flight Operations Procedures

This chapter summarizes the procedure of UAS flight operations as follows:

- Unpack the UAS and all necessary flight components. Components typically include: controller, flight computer/cell phone/tablet, propellers, launch/landing pad, etc.
- Assemble UAS in accordance with the manufacturer's assembly instructions
- Attach all necessary payloads, ensuring correct placement and weight distribution. Payloads may include camera systems, LiDAR, etc.
- Position UAS at launch site. If landing pad is needed, place landing pad on ground first, ensure it is stable, then place UAS on top
- Perform pre-flight inspection of UAS. Inspect propellers for cracks, check battery life, check all connections are secure, etc.
- Power on Controller and UAS in accordance with the manufacturers power-on instructions. Typically, the controller will power on first, followed by the UAS
- Proceed to a safe distance away from the launch site to ensure the RPIC and crew are a safe distance from the UAS and propellers, while remaining close enough to perform takeoff procedures (typically 10-15ft)
- Ensure all communication links are established and in reliable working condition. This may include: checking the controller can control the UAS/gimbal/payload, that the UAS has a successful GPS lock, etc
- Set "Return to Home" location if applicable. Many commercially available units will set the RTH point automatically upon start up.
- Verify flight crew are prepared for operation; verify cleared surrounding area and airspace
- Announce the take-off of the UAS
- Perform take-off procedures as defined by the manufacturer's instructions. The UAS may take off via RC controller commands, or by tablet interface
- Maintain a low altitude hover (~10 ft) to ensure all communication links are connected and that UAS is able to maintain stable flight prior to executing flight plan
- Perform flight operation in accordance with previously defined flight plan
- Maintain Visual Line of Sight with UAS at all times
- Be aware of the airspace surrounding the UAS at all times. Check for manned aircraft, birds, obstructions, etc.
- Ensure that landing location is clear and accessible

- Announce the landing of the UAS and it's landing location
- Land UAS at defined landing site
- Perform shut down sequence as defined by manufacturer's operating manual. Generally, power off UAS first, followed by controller, then tablet
- Remove batteries and store them in safe location. Do not leave batteries in UAS during storage
- Remove all additional payloads form unit
- Disassemble and re-pack UAS

7 Emergency Procedure

In the event of an emergency, it is the responsibility of remote pilot in command (RPIC) to perform all necessary emergency procedures to reduce the risk of additional property damage or injury as a result of the situation. The emergency procedure process occurs in three distinct phases: pre-flight phase, in-flight emergency situation, and post-flight reporting. It is important for the RPIC to address an emergency situation in all three phases in order to both limit the potential for, and the damage from an in-flight emergency.

The potential emergencies and actions taken to respond that are listed below are not an all-encompassing list, there are many type of failures. The RPIC may only have a few seconds to respond. There may be other instances in which the RPIC will wish to perform an emergency procedure. These instances include: the UAS is not functioning properly, manned aircraft has entered the flight zone, birds have interfered/entered the flight zone, etc. It is up to the RPIC to perform the emergency procedure and land the UAS in a safe location. All efforts should be made to avoid death, injury, or damage to personal property even if it means destroying/damaging the UAS by landing in an alternate landing location such as brush or water.

7.1 Pre-Flight

During the pre-flight phase, the pilot identifies potential hazards and risks that could negatively affect the safety of a flight. It is important the RPIC has a plan on how to avoid these hazards, and what to do should a situation emerge. Prior to the flight, the RPIC should review emergency procedures with the flight crew, and should consult with the crew to identify any additional flight risks. This phase is also where the RPIC and crew should identify at least one emergency landing location, should the sUAS be unable to return to its primary landing location. Depending on the make and model of the sUAS, the RPIC should also ensure the unit has a set "Return to Home" point, and that the location is in a safe, accessible area. The RPIC should also have the phone number of the nearest ATC as well as the NJDOT UAS manager, so that should an emergency situation arise, they can contact emergency personnel as soon as possible.

The NJDOT UAS Manager is:

Glenn G. Stott
Aeronautical Operations Specialist
NJDOT UAS Manager
New Jersey DOT
609-530-2743

Numbers for the nearest ATC in testbed locations are summarized in Table 10:

Table 10. Nearest ATC

Airport	Phone Number
Newark Liberty Airport (EWR)	973-961-6161
Northeast Philadelphia (PNE)	215-937-7968
Morristown (MMU)	973-538-6400
Philadelphia International (PHL)	215-937-6914

7.2 In-Flight Emergency Situation

Ultimately, it is up the Remote Pilot in Command to make the final decision on how to address an emergency situation. Every situation will have its own unique set of complications and additional factors contributing to the overall decision. It is the responsibility of the RPIC to determine how to react to the situation, and what emergency procedures to implement. Some in-flight situations that may require emergency procedures include, but not limited to:

- Lost link
- Fly Away
- Lost GPS Signal
- Low Battery
- Lost Visual Line of Sight
- Non-Participant entering flight area
- In-air Collision
- Crash Landing

7.2.1 Lost Link

A lost link situation can occur in two ways:

- If there is a failure with ground station equipment in sending commands to the UAS
- If there is an issue with the UAS in receiving commands from the ground station

In either event, the RPIC should make every effort to reestablish connection back to the UAS. Procedures to reestablish this connection may be found in the UAS's operating manual. In the event the RPIC is unable to communicate with the UAS, many models provide a "Return to Home" fail-safe should the unit lost connection for a pre-determined amount of time. In this case, the UAS will fly itself to the "Return to Home Point" and land itself. If the "return to home" function fails, and the UAS continues to fly uncontrolled, the situation will have advanced to a "Fly Away."

7.2.2 Fly Away

In a fly away situation, the pilot is unable to regain control of the UAS, and the unit continues to fly in the airspace uncontrolled. Should this event happen, the RPIC should make note of the last known altitude, location, heading, and battery life of the UAS. The RPIC should then contact the nearest ATC to notify them of the lost UAS. The RPIC will also contact the NJDOT UAS manager to report the event.

7.2.3 Lost GPS

Many commercially available UAS have GPS capabilities. The GPS lock may assist the UAS with in-flight operations, including as navigation, heading, and semi-autonomous flight paths. While GPS lock is a useful tool when operating a UAS, it is not always necessary depending on flight operation. Should the UAS lose the GPS signal, it will be up to the RPIC to determine whether to abort the operation and manually return the UAS to an acceptable landing zone.

7.2.4 Low Battery:

Battery life is an important element to UAS operations. The RPIC should keep note of the current battery status of both the UAS and the controller through the duration of the flight. Many UAS have built-in functions that will instruct the UAS to fly back to it's "Return to Home" point should the battery life become too low.

7.2.5 Lost Visual Line of Sight:

Maintaining Visual Line of Sight is an important safety parameter for both the UAS and for the safety of non-participants. Maintaining VLOS with the UAS allows the RPIC and flight crew to know where the UAS is in the airspace, what obstacles are nearby, and what hazards could pose a potential risk to the UAS. Should the RPIC lose VLOS with the unit, the RPIC should make every attempt to safely fly the UAS back to a safe location within the airspace where the RPIC and visual observers can regain visual contact with the UAS.

7.2.6 Non-Participant entering flight area:

Avoiding UAS flight directly over non-participants is important from both a FAA compliance and safety standpoint. FAA CFR 14 Part 107: 107.39 states that:

> *"No person may operate a small unmanned aircraft over a human being unless that human being is:*
>
> *(a) Directly participating in the operation of the small unmanned aircraft; or*
>
> *(b) Located under a covered structure or inside a stationary vehicle that can provide reasonable protection from a falling small unmanned aircraft."*

Should a non-participant enter the flight area, the RPIC should attempt to safely maneuver the UAS so as to avoid flight directly overhead of the non-participant. Available flight crew not directly operating the UAS should notify the non-participant of the UAS operation occurring overhead. Should it become impossible to operate the UAS without flying directly overhead of non-participants, the RPIC should abort the mission and land the UAS in a safe landing location.

7.2.7 In-air Collision

An in-air collision with an object other than a person is a serious event that may result in damage to the UAS, other property damage, or physical injury. Should an in-air collision occur, and the UAS is still able to maintain flight, the RPIC should immediately bring the UAS to a safe landing site, and conduct a full inspection of the unit. The RPIC should look for any damage resulting from the collision, and check the propellers, rotors, etc to ensure they are functioning properly. It is then up to the RPIC to determine whether the UAS requires additional repair, or if it is clear to fly. If the collision was with public or private property (ex: house, power line, street light), the RPIC will contact the NJDOT UAS Manager and take steps to inform the property owner of the incident. If the in-air collision causes the drone to malfunction, or need additional repairs, the RPIC will abort the mission, unless a secondary UAS is available.

If the UAS has an in-air collision with a person, the RPIC should assess the injury, and if necessary, call 9-1-1 for emergency assistance. The RPIC should also contact the NJDOT UAS Manager to inform the department about the incident, regardless of injury level.

7.2.8 Crash Landing

A crash landing may be the result of a previous emergency situation, such as a dead battery or in-air collision. In the result of a crash landing, it is likely that the UAS will sustain some damage. Upon a crash landing, the RPIC should perform a full inspection of the UAS to assess the damage. If minimal damage (such might be the case of a "hard" landing) is found, and the UAS is deemed airworthy, it is up to the RPIC to determine whether to proceed or abort the mission. If the unit is deemed inoperable after the crash, the RPIC will abort the mission unless a secondary UAS is available. If the crash landing results in an injury to a crew member or non-participant, the RPIC will assess the injury and call 9-1-1 should emergency responders be necessary. Regardless of injury level, if contact with a person, participant or otherwise, results from a UAS crash, the RPIC will contact the NJDOT UAS Manager to inform the department about the incident.

7.3 Post Flight

Should an emergency situation occur, the RPIC should be prepared to produce a report to the NJDOT UAS Manager of the incident, including the circumstances leading up to the emergency, measures taken as a result of the emergency, and resulting damage/injuries. Furthermore, the RPIC must follow the FAA regulation regarding accident reporting as outlined in 14 CFR Part 107: 107.9. This regulation states:

> *"No later than 10 calendar days after an operation that meets the criteria of either paragraph (a) or (b) of this section, a remote pilot in command must report to the FAA, in a manner acceptable to the Administrator, any operation of the small unmanned aircraft involving at least:*
>
> *(a) Serious injury to any person or any loss of consciousness; or*
>
> *(b) Damage to any property, other than the small unmanned aircraft, unless one of the following conditions is satisfied:*
>
> *(1) The cost of repair (including materials and labor) does not exceed $500; or*
>
> *(2) The fair market value of the property does not exceed $500 in the event of total loss."*

8 Risk Assessment

Risk assessment is driven by likelihood and severity; FAA recommends developing a framework for levels of likelihood and severity to evaluate and mitigate the safety aspects of a flight. FAA also indicates that "It is also very easy to get quite bogged down in trying to identify all hazards and risks. That is not the purpose of a risk assessment. The focus should be upon those hazards which pose the greatest risks[Error! Bookmark not defined.]"

Given that this effort is to be conducted within the confines of the test-bed for initial UAS deployment the research team felt it appropriate to simplify this approach to a binary matrix instead of a multi-level rubric, identifying only those items of elevated risk and using a "yes this is likely" or "no its not likely" approach. This approach does not address mitigation strategies as it categorically places any negative response into a high-risk operation which would result in cancellation of the flight operation. This is a conservative approach and would appear to be more stringent than FAA requirements. However, the flight planning process and safety assessments would be intrinsically linked; thereby meeting or exceeding the flight safety assessment process, and providing a rudimentary questionnaire/rubric to grant a RPIC authority to assess an operation.

This approach does not have developed levels of severity or address mitigation strategies, however since the flights are limited to test-bed location within the NJDOT ROW these mitigation strategies can be developed in the future as the UAS usage expands and the research team has additional historical flight concerns to review.

Location of Flight (GPS coordinates):

Date: Start Time End Time

Mission Overview:

Remote Pilot in Command (RPIC) (Name and Remote Pilots License):

Visual Observer:

Aircraft (Make, Model, and Registration)

Closest Airport (Name and Number)

Closest Air Traffic Control (ATC) (name and phone number):

#	Compliance and Items of Elevated Risk	Yes	No
1	Is this flight at an NJDOT approved UAS testbed location?		
2	Do you think it's likely the UAS will travel beyond 1,320ft (1/4 mile) from Remote Pilot in Command (RPIC)? *Maintain visual line-of-sight including but not limited to going behind an object.		
3	Will your primary flight activities occur between 40ft and 330ft? * Excluding take-off and landing.		
4	Do you think it's likely the operation will extend beyond daylight hours?		
5	Do you think it's likely the operation will exceed 100 mph?		
6	Have you observed aircraft (manned or unmanned) in the vicinity of the UAS flight path? *Within 1,320ft (1/4 mile) vertical and horizontal radius of the RPIC.		
7	Do you think it's likely the UAS flight path will pass over people or moving vehicles? * Including people or vehicles (EMS, police, fire, or general public) that may enter the flight path during the operation.		
8	After reviewing the surrounding location, is it likely that any obstructions, towers, trees, power lines, etc will hinder the operation?		
9	Please list any obstructions* identified even if they won't hinder operations: *Trees and power lines are common, however it's important to make note that you have assessed their presence		
10	After visualizing the flight path and altitude is there likelihood that you will violate the requirements of Part 107?		
11	Do you have any reason to believe that this flight should be canceled? * Including but not limited to hazards, crew, UAS problems, pressure, stress, anxiety, illness, medication, alcohol, fatigue, and lack of sleep or food.		

If any of the above questions are RED the flight is to be cancelled.

#	Activities to reduce risk	Yes	No
1	Launch – Landing Zone		
1a	Have you identified a primary takeoff and landing location?		
1b	Are you using a rigid panel for a landing pad; alternatively is it flat, level, free of obstacles or brush that could damage the propellers		
1c	Is it free of overhead obstructions?		
1d	Is it free of non-participants?		
2	Have you identified a suitable emergency landing location(s)? **All efforts should be made to avoid death, injury, or damage to personal property even if it means destroying/damaging the UAS by landing in an alternate landing location such as brush or water.*		
3	Environmental Conditions and Weather		
3a	What is the visibility? ________ statute miles Is the visibility greater than 3 statute miles?		
3b	What is the cloud ceiling? _____ ft Is the cloud ceiling greater than 900ft AGL?		
3c	What is the temperature? ____ Is the temperature within the UAS manufactures recommendation? ** In lieu of a recommendation, temperature must be within 41°F and 104°F (5°C – 40°C) to answer yes.*		
3d	What is the wind speed? ______ knots Is the wind speed below the UAS manufactures recommendation? ** In lieu of a recommendation, wind must be below 13 knots to answer yes.*		
3e	Are you comfortable flying in the forecasted weather conditions?		
4	Have you reviewed NOTAMs for the area in which you will be flying?		
5	Are there any Temporary Flight Restrictions (TFR's) for the area in which you will be flying?		
6	Did you ensure batteries are charged? Including the UAS, controller, phone (or radio) in event of emergency, and payload (camera etc).		
7	Did you inspect the UAS in accordance with manufacturer guidelines? ** Including assemble UAS, check airframe for cracks, tighten screws, check propellers are secure and not damaged (cracks, chips, deformations, and dings), check batteries for damage or bubbling, secure payload and batteries,*		
8	Did you conduct a crew briefing? ** Crew briefing should include mission (flight path), safety concerns, communication procedures, assigned tasks, and emergency procedures.*		
9	Do you have copies of your Remote Pilots license, UAS registration card, insurance card (if appropriate), UAS has registration number affixed, and phone number for nearest ATC?		
10	Did you review emergency procedures?		
11	Did you confirm GPS fix?		
12	Did you confirm controller is communicating with UAS?		
13	Did you set "return home" location?		

If any of the above questions are RED the flight is to be cancelled.

9 Maintenance Guidelines

The RPIC should follow manufacturer's recommendations, in lieu of manufacture recommendations here are some overall recommendations from various sources:

- UAS is free of visible defects [36]
- Inspect batteries for damage [37]
- Verify battery charge or fuel (count in weight) &Keep batteries separated, non-touching, and log them [37]
- Inspect Antenna positioning and wear [37]
- Inspect all rotors for wear [37]
- All propellers in good condition are free of cracks, holes, dings, or other defects [36]
- Tighten any parts e.g., lug-nuts, rotors, etc. [37]
- Check that camera(s) and mounting systems are secure and operational [38]
- Perform any necessary maintenance [37]
- Log all maintenance or repairs in logbook[37]
- Ensure any attachments maintain Center of Gravity (CG) [37]
- Ensure paperwork is complete and up-to-date [39]
- Ensure UAS Registration is Visible on Craft [37]
- Pack secondary controller/buddy box [37]
- Set UAS for Home/Safety Return [37]

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