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OPERATIONAL EVALUATION OF UNMANNED AIRCRAFT SYSTEMS FOR CRASH SCENE RECONSTRUCTION

Operational Evaluation Report

Version 1.0

Prepared for:
National Institute of Justice

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STRENGTHEN SCIENCE. ADVANCE JUSTICE.

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EXECUTIVE SUMMARY

As the provider for the National Institute of Justice's (NIJ's) National Criminal Justice Technology Research, Test, and Evaluation Center (RT&E Center), the Johns Hopkins University Applied Physics Laboratory (JHU/APL) conducted an operational evaluation of Unmanned Aircraft Systems (UAS) for crash scene reconstruction (CSR). The operational evaluation focused on the effectiveness and utility of UAS in reconstructing crash scenes in an operational setting – that is, how effectively they perform their assigned roles and whether they represent a substantive improvement over other methods in the context of the entire investigation. The scope of the study was limited to US law enforcement agencies.

The RT&E Center conducted a literature search and several interviews with law enforcement officers to determine how UAS are currently deployed for CSR by various agencies and to develop appropriate criteria for evaluating the performance of UAS in CSR. The RT&E Center also submitted a Request for Information (RFI) to the Federal Register seeking information on UAS use for CSR and organizations willing to participate in this operational evaluation study.

Michigan State Police (MSP), Illinois State Police (ISP), and Arlington, Texas, Police Department participated in the interviews. An RFI response was received from the Major Crash Assistance Team (MCAT) of Lake County Illinois. The RT&E Center has worked with MSP, ISP and MCAT to collect operational performance data, and then analyzed the collected data.

The main finding of the study is that utilizing UAS for CSR can significantly reduce the data collection time at a crash scene, resulting in shorter road closure times and officer on scene times, if logistical, administrative and technology challenges associated with UAS use are resolved. Operational data collected in the study shows that data collection by UAS is on average one hour shorter than data collection by a robotic total station and two hours shorter than data collection by a manual total station. However, these gains can be realized only if UAS can replace total stations. Although several agencies currently use UAS in crash investigations, the main usage is to obtain aerial photographs to complement total station measurements – not as a replacement for the total station.

The study also found that the availability of UAS to be deployed for a crash scene investigation is affected by several factors. Time to deploy was the primary issue that held back UAS usage during the operational data collection for the study. Federal Aviation Administration (FAA) rules requiring a pilot's license to operate UAS prevent most reconstructionists from operating the UAS themselves and necessitate a separate unit on scene. If the UAS assets and operators are far from the crash scene, UAS may not be deployed since waiting for them can delay the investigation. Expiration of UAS operator's medical certificates also prevented UAS deployment for several investigations throughout the study period. New FAA Small Unmanned Aircraft (Part 107) Regulations (Ref. [1]) can partially mitigate availability issues related to the pilot's license requirement. With the introduction in August 2016 of FAA Part 107, which establishes new rules for non-hobbyist small UAS operations, there is now an alternative to the (manned) pilot's license, called a remote pilot airman certificate with a small UAS rating. There are fewer requirements for the remote pilot airman certificate as compared with a traditional manned pilot's license. The primary requirement for the remote pilot airman certificate is

passing an aeronautical knowledge test. By comparison, a manned pilot's license requires a knowledge test, a practical test comprising an oral test and flight test (check ride), a logbook documenting specific aeronautical experience, and medical certification.

Another common issue holding back UAS usage was scene darkness. UAS sensor limitations as well as FAA rules limit UAS use for law enforcement to daytime operations; therefore UAS was not deployed for several nighttime crash investigations. In some of these cases UAS operators came to the scene later to take the aerial pictures.

Despite these challenges for UAS use for CSR, the benefits of UAS are recognized by the law enforcement agencies. Even with the current usage complementing total station measurements, the UAS provides a bird's eye view that may encompass the entire crash scene in one photograph. Both ISP and MSP mentioned the ability to create the entire picture within an hour of the crash, which enables them to see crash scene details and to overlay them on scene imagery to better understand the process of the crash, including the movement of the vehicles and the direction of travel. ISP also highlighted the additional potential benefit for presenting crashes in court, where the overhead view from UAS can make it easier to explain the crash to the jury.

Full benefits of UAS for CSR can be realized by using aerial photographs for measurements, which would negate the need for total stations at least in some crash investigations. This requires established trust in the accuracy, precision and repeatability of UAS measurements and an increased availability of UAS for timely deployment. When used for measurement purposes, UAS require photogrammetry software that can combine the aerial photographs and calculate distance between points of interest. Although previous results demonstrated that these techniques have sufficient accuracy for CSR, improving the evidence base in favor of these techniques is necessary to ensure that they can be used as evidence in court. Independent studies are required that fully consider the variety of conditions and compare UAS measurements with total station measurements. It would be important to identify equipment, software, environment, weather and operational factors that may impact measurement accuracy, precision and repeatability so that the criminal justice community can determine the capabilities and the limitations of these techniques.

1. INTRODUCTION

1.1 Purpose

As the provider for the National Institute of Justice's (NIJ's) National Criminal Justice Technology Research, Test, and Evaluation Center (RT&E Center), the Johns Hopkins University Applied Physics Laboratory (JHU/APL) conducted an operational evaluation of Unmanned Aircraft Systems (UAS) for crash scene reconstruction (CSR). To accomplish this task, the RT&E Center first conducted a literature search and several interviews with law enforcement officers to determine how UAS are currently deployed for CSR by various agencies and to develop appropriate criteria for evaluating the performance of UAS in CSR. The RT&E Center also submitted a Request for Information (RFI) to the Federal Register seeking information on UAS use for CSR and organizations willing to participate in this operational evaluation study. The RT&E Center has worked with the participating organizations to collect operational performance data, and then analyzed the collected data.

This document describes the evaluation criteria, methodology, and the findings of this study.

1.2 Scope

The operational evaluation focused on the effectiveness and utility of UAS in reconstructing crash scenes in an operational setting – that is, how effectively they perform their assigned roles and whether they represent a substantive improvement over other methods in the context of the entire investigation. The scope of the study was limited to US law enforcement agencies. Although there are agencies with well-established UAS programs in other countries, UAS use by these agencies was out of scope for this study.

1.3 Document Organization

This document is organized into the following sections:

Section 2 provides an overview of traffic incident management showing how investigation and reconstruction fit into the overall activity. Investigation tasks are identified. Current approaches to crash scene reconstruction, independent of whether a UAS is used, are delineated, along with legal considerations.

Section 3 describes the criteria used to evaluate UAS effectiveness. Since reducing the clearance time after a crash and minimizing the exposure of personnel to traffic are important considerations, evaluation criteria include roadway clearance time, incident clearance time, and personnel exposure time. Data quality was assessed for suitable accuracy. Operational factors such as weather and environmental constraints were characterized.

Section 4 discusses the interviews conducted with law enforcement agencies. Arlington, Texas, Police Department, Michigan State Police, and Illinois State Police agreed to participate in the interview process. Several interviews were conducted with these agencies, including both UAS operators and reconstructionists. Additionally, an RT&E Center team visited the Michigan State Police for interviews and a UAS demonstration.

Section 5 describes the operational testing and the findings. The data collection methodology is described. Sources of data included an online data collection tool, flight logs, and Request for Information (RFI) response data. The data is analyzed and presented as text and figures. Data types are compared and contrasted.

Section 6 summarizes the study findings from the interviews and the operational testing.

2. BACKGROUND

Crash scene reconstruction is the systematic practice of investigating, analyzing, and drawing conclusions about the origins and sequence of events for a traffic incident. Reconstructionists are engaged to perform in-depth collision analysis to ascertain the cause of the crash and contributing factors. For this operational evaluation, the focus was primarily on the investigation activities performed at the crash scene.

Crash scene reconstruction typically requires images of the scene from many different angles to capture all relevant aspects of the scene including the vehicle(s) at final rest position, evidence of the area of impact, collision debris distribution, road evidence, operator's and witness's views, and vehicle damage (Ref. [1]). These photographs can also be used for creating scaled diagrams of the scene, modeling objects, and measuring various distances. Traditionally, taking these photographs involves law enforcement personnel performing on-scene investigations, which consumes time and also may expose the law enforcement personnel to secondary collisions. Many different technologies are utilized to reduce the clearance time after a crash and the exposure of personnel to secondary collisions (Ref. [2]), including total stations and photogrammetry. Some of these technologies are discussed briefly in Section 2.3.

2.1 Traffic Incident Timeline

The U.S. Department of Transportation (USDOT) has produced a traffic incident timeline (Ref. [5]), shown in Figure 1, which describes the sequence of events occurring as a result of a traffic incident from the time the incident occurs until the time that normal traffic flow returns. The timeline breaks down the events without attaching any absolute measures of time, but only showing the order in which the activities progress.

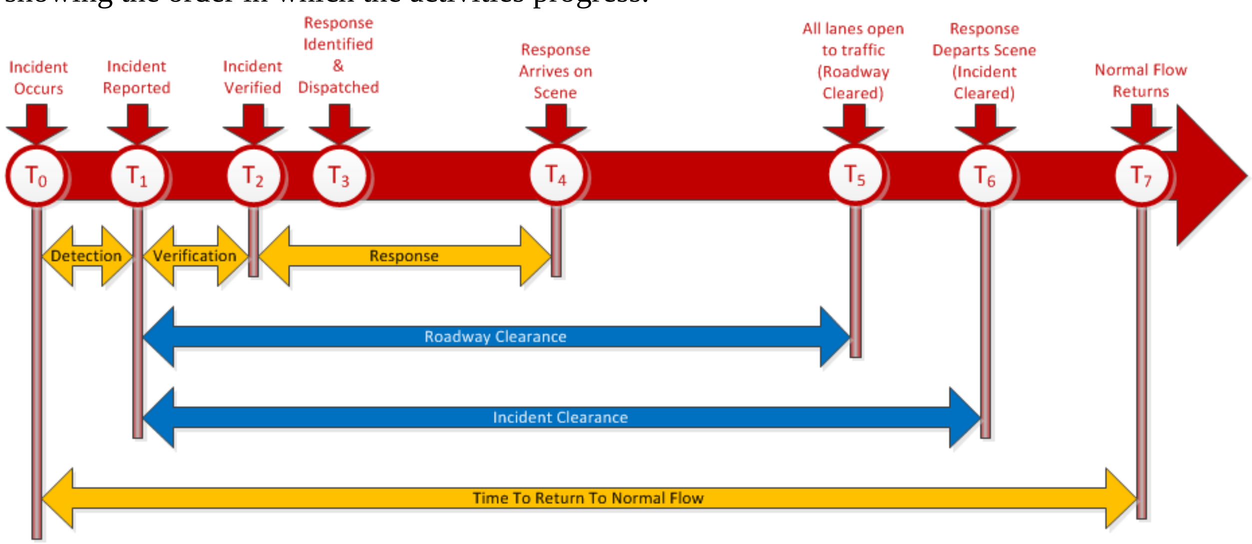

Figure 1: Traffic Incident Timeline

Responders arrive on scene at time T4 with the priority of making the scene safe, caring for any injured, and then performing an investigation of the incident as shown in Figure 2 below. Figure 2 is derived from Figure 1 and shows these activities in the interval between T4 and T6, at which point the response departs the scene. For the operational evaluation, our interest is in the "Investigate" portion of this timeline. Observe that the "Investigate" portion of this timeline crosses time T5 where all lanes become open to traffic and the roadway is cleared. This means that the portion of the Investigate activities that requires access to the roadway needs to be done earlier in the investigation where possible in order to reduce the roadway clearance time. Sometimes most of the investigation must occur prior to T5. At other times, most of the investigation may occur after T5. The topography and unique conditions of each incident help determine the investigation timing.

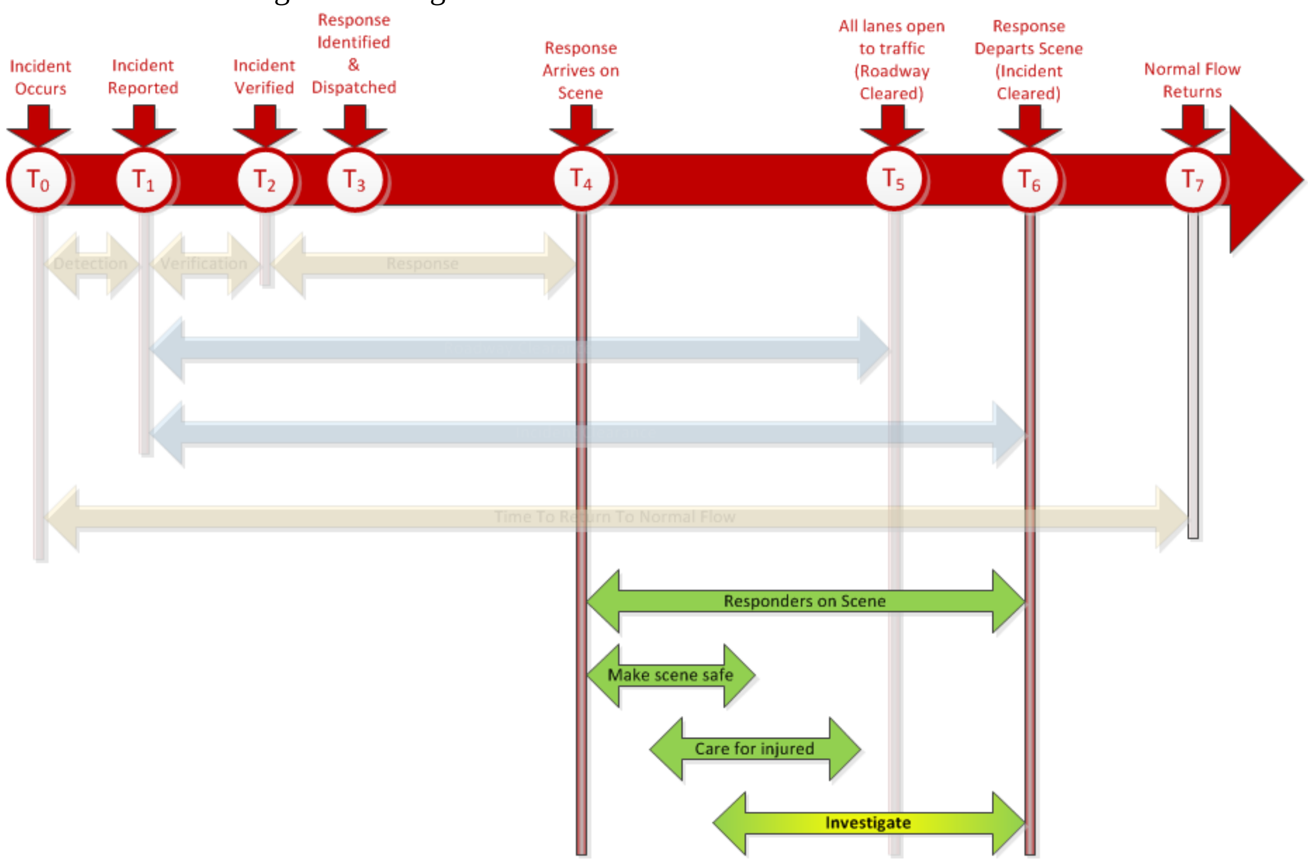

Figure 2: Timeline with Responders on Scene Detail

2.2 Investigation Tasks

The severity and circumstances of a collision will determine the proper level of investigation. In their order of complexity, the levels are usually called at-scene investigation, advanced (technical) investigation, and reconstruction (Ref. [6]).

The at-scene investigation documents evidence at the scene, takes measurements, and creates a field sketch. Interviews are done with witnesses, drivers, and passengers along with checking drivers for intoxication or other impairment. Detailed inspections of the vehicles are performed. Marking of the scene is done to support measuring and to preserve the locations of evidence. Marking materials can include paint, chalk, cones, flags, nails, and other supplies that are able to highlight spots of interest.

Crash scene photography is fundamental to the preservation, evaluation, interpretation and presentation of physical evidence (Ref. [7]). Photographs are taken to show the situation when vehicles came to rest after the crash. They show how objects were arranged and how things were related to each other. The portfolio of photographs typically includes the following:

- Overall views of crash scene taken from long range
- Entire roadway width at or near area of impact from medium range
- Photos to represent each driver's/participant's view as they approached
- Photos reflecting what shows on the roadway, such as tire marks and debris
- Photos of vehicles (each side plus front and rear plus details of damage and vehicle ID)

Measurements are taken to capture the locations of evidence relative to features of the roadway and nearby landmarks. The method used depends on the attributes of the scene as well as the measurement tools available. Two of the common methods are known as the Coordinate Method and the Triangulation Method. Variations of these methods may also be used.

In the Coordinate Method, a straight baseline (reference line) is established (edge of road or similar) along with a reference point along the baseline. Two measurements are taken: (1) the shortest distance from the spot to be measured to a point along the baseline (at right angle to the baseline); and (2) the distance from the right angle point along the baseline to the reference point. For a scene with a straight road edge near much of the evidence this can be the preferred method. For reasons of safety, the edge or side of the roadway is used as a baseline whenever possible (Ref. [8]).

In the Triangulation Method, two reference points are established. Then each spot to be measured becomes the third point of a triangle. The lengths of the three sides of the triangle are measured, which are the distance between the two reference points plus the distance between the spot and each of the two reference points. The Triangulation Method is preferred when there is no straight line available or the straight line is far away from the spot to be measured. It is useful when there are at least two fixed landmarks near the evidence.

Variations of the Coordinate or Triangulation Methods may also be used. Sometimes a combination of the two methods is the most effective way to capture measurements at a scene. Some measurement tools, such as the total station (see Section 2.3.2), can measure accurate angles as well as distances to enable locating the spots more efficiently from the setup point of the total station.

The field sketch (also known as a "preliminary field sketch") is a rough drawing that "maps" the crash scene as observed by the crash investigator (Ref. [9]). It assists the investigator in recording the measurements. Included in a field sketch are the following items:

- Outline of roadways
- Features of roadways
- Positions of vehicles, bodies, debris, blood, etc.
- Positions for traffic control devices
- Environmental factors (snow, ice, standing water, etc.)
- Items or terrain features that may have been contributing factors
- Names of streets and addresses
- Type of road surface
- Vision obstructions
- Types and locations of road lights (night)
- Skid marks and other relevant marks
- Debris related to accident
- Road grade
- Lane and road widths
- Reference points / baseline

An advanced (technical) investigation includes further data gathering and analysis tasks that may be performed during the traffic incident timeline or at a later time. These tasks include:

- Determining the drag factor of skid surfaces
- Determining time-distance relationships and solving momentum problems
- Matching marks on the road with parts on the vehicle
- Determining what is induced damage to vehicles and what is contact damage
- Determining the principal direction of force
- Correlating injuries with the part of the vehicle impacted by occupants
- Determining if vehicle lights were on or off at impact
- Determining if any fire damage occurred before or after impact
- Determining if mechanical or electrical failure contributed to crash
- Preparing a scaled drawing of the scene from measurements and notes

The highest level of investigation complexity is reconstruction. The reconstruction analysis tasks are predominantly done at a later time rather than during the traffic incident timeline but they depend on data gathered earlier. These tasks include:

- Determining how the collision occurred
- Identifying direct and immediate causes of crash
- Performing experiments to ascertain performance and other capabilities of a vehicle
- Performing experiments to determine driver and pedestrian behavior
- Assembling all technical data required to build a court case

2.3 Measurement Approaches

As discussed above, there is a significant amount of data that is required for crash reconstruction. Various tools and approaches have been used to support the gathering of the data needed. Options include traditional manual distance measurement methods, total stations, photogrammetry, and 3D laser scanning. Photogrammetry and 3D laser scanning have typically been performed on the ground but more recently they have become possible using UAS.

2.3.1 Manual Measurements

Traditional manual distance measurement methods are commonly used due to the simplicity, compactness, and low cost of the tools necessary. Manual distance measurement uses the Coordinate and/or Triangulation Methods described earlier. Materials needed include a tape measure (~25 foot), roll-up tape (100 to 200 foot) and sometimes a rolling wheel measuring device for longer distances. Also needed are a clipboard, paper, and a writing instrument.

2.3.2 Total Stations

Total stations combine electronic distance measuring (a.k.a. laser range finder) and an electronic transit (a.k.a. theodolite) for angle measurement. The electronic distance measuring is done by sending a laser signal out from the total station aimed at the spot of interest. A portion of the reflection from the spot returns to the total station. Since the signal travels at the speed of light, the round trip time of the signal may be used to determine the distance between total station and the spot. For situations where the reflection signal strength is inadequate or the spot is not visible, a prism pole is used as a target for the laser to provide a strong reflected signal. A key characteristic of the corner cube prism used on a prism pole is that it reflects a signal directly back to its source. This provides the strongest return signal back to the total station.

The other basic feature of a total station is the electronic transit used for angle measurement. Angles are measured both in the horizontal and the vertical axes. Part of the total station assembly is a leveling mechanism to ensure that angle measurements are truly horizontal and vertical. The prism pole also includes a leveling mechanism.

The total station captures and stores data as measurements are taken. Software processes the data to create scaled diagrams. The software may be embedded in the total station or remote.

Total stations typically allow all spots at a scene to be measured from a single setup location. Sometimes, due to the layout of the scene, more than one setup location is necessary. The total station can often be safely located away from traffic to protect the operator at the total station. However, when a prism pole is used, a person is still needed at the crash scene to position the prism pole at the various spots being measured.

Advanced total stations are available which include additional capabilities. Robotic total stations function with just one operator at a prism pole, where the total station automatically tracks the prism pole. The operator is able to remotely control the total station from the prism pole.

However, there is a possibility that the total station loses track of the prism pole, requiring re-acquisition of the pole before measurements can be resumed.

Standard and robotic total stations are limited by visual line of sight and laser range finder capability to ranges up to 3.5 km when using prism pole reflector and 1 km without using the reflector (Ref. [10]). Total stations with GPS capability enable longer measurement distances, because they don't require a visual line of sight between the total station and the prism pole. They function with one operator at the prism pole, which includes a GPS receiver. The location information provided by the GPS signal enables measurements at locations out of sight from the total station; however the prism pole must have line of sight with the GPS satellite constellation in the sky. Since GPS accuracy alone is not sufficient for the majority of total station applications, a locally placed base (reference) station or a remote reference station is needed to provide GPS error correction data over a radio link to the GPS receiver (rover) on the prism pole. Reference stations support separations of up to approximately 30 km (Ref. [11]) with the rovers and don't require visual line of sight between the reference station and a rover. It should be noted that GPS is degraded by environments with tree cover, large buildings, mountains, or similar items that block visibility of the GPS satellite constellation, so GPS-based measurements may not be possible for some crash scenes.

2.3.3 Photogrammetry

Photogrammetry is the science of making measurements from photographs. The output of photogrammetry is typically a map, drawing, measurement, or a 3D model of some real-world object or scene. Two types of photogrammetry are Close-Range Photogrammetry (CRP) and Aerial Photogrammetry. In CRP the camera is close to the subject and is typically hand-held or on a tripod. In Aerial Photogrammetry the camera is mounted in an aircraft and is usually pointed vertically towards the ground. Multiple overlapping photos of the ground are taken as the aircraft flies along a flight path.

The materials needed to support photogrammetry include a calibrated camera, mapping software to process the photographs, and a computer to host the software. Only the camera is necessary on the scene. While the computer and associated software used for post processing the photographs may be located elsewhere for later use, processing on the scene enables confirmation that the photographs are adequate and complete.

The photogrammetric approach depends on having multiple images with overlapping content. Typically, multiple photographs are taken from different angles containing reference points as well as spots of interest. Post processing using the mapping software calculates distances using photographic triangulation.

More sophisticated software automatically or semi-automatically renders 3D models and/or can stitch together mosaics of "orthorectified" images from the photographs. Orthorectification is the process of removing the effects of image perspective (tilt) and relief (terrain) effects for the purpose of creating a planimetrically correct image. The resultant orthorectified image has a constant scale wherein features are represented in their true positions. This allows for the accurate direct measurement of distances, angles, and areas (i.e., mensuration).

Photogrammetry is a relatively new technology. As recently as 2009, it was observed in a Wisconsin crash investigations training guide (Ref. [7]) that “Anyone who has ever tried to make a map from a photograph knows why photos are not adequate substitutes for measurements. It is true that by photogrammetry, maps can be made from photos, but this is a tedious and expensive process.” However, photogrammetry software has been rapidly evolving to ease usage and to provide a richer set of data products. On the basis of software license sales data, there are in excess of 2,000 users of CRP among the traffic accident reconstruction and forensics community in the US alone, the vast majority being police and highway patrol departments (Ref. [10]).

Most crash investigations today that use photogrammetry use ground based CRP with the operator holding the camera or a tripod mounting the camera. Only one operator is needed. Many overlapping photographs are required for CRP, so that all spots that have to be measured are captured and these spots are viewed from multiple angles to support triangulation.

Aerial Photogrammetry hosted on UAS is becoming more common for several applications. One advantage of airborne cameras in CSR is that they have a vantage point similar to that of a scaled drawing of the scene, which is one of the work products that has to be produced by the reconstructionist. Therefore, fewer photographs are needed to capture the spots needing a measurement. The aerial vantage point enables compelling photos of the crash scene supporting visualization of key aspects of the scene. Many UAS already include GPS functionality and can provide camera orientation data. This knowledge about the position of the camera in airborne systems supports additional automation in the data capture and post processing, reducing operator workload.

A set of photos covering the entire crash scene suitable for aerial photogrammetry tools has the following characteristics:

- 70% overlap between photos
- All photos at approximately the same altitude
- All photos with the same field of view (zoom often at widest setting)
- Metadata with geometry information included in the photographs
- All photos with consistent lighting
- Boundaries of a scene typically have lower measurement accuracy due to fewer overlapping photos, thus when planning one must be sure that the photo capture boundaries extend beyond the crash scene boundaries to maintain accuracy throughout the scene

Photogrammetry post processing tools produce various data products from the photographs. A commonly desired work product is an orthorectified mosaic of the entire crash scene. Photogrammetry tools can correct the geometry of images so that they appear as though each pixel was acquired from directly overhead (orthorectification). The tools stitch together adjacent images into a seamless single large image.

Another possible use for the photogrammetry tools is making measurements from the photographs. Distance and crush measurements are a common need in reconstruction. Photogrammetry tools can calculate the locations of selected points within a scene relative to each other. Having a complete set of overlapping photographs of the scene also allows points not originally thought to be of interest to be measured later.

Another photogrammetry capability is the rendering of 3D imagery. This allows one to virtually "fly through" the crash scene, potentially providing insights into the reconstruction activities or compelling evidence for explaining a crash.

2.3.4 Laser Scanning Systems (Lidar)

A laser scanning system (lidar) performs a 3D scan of a large volume of space. The laser is slewed and measures the distances to all items within the volume that can be seen from the setup location. The term "lidar" is a portmanteau of "light" and "radar" sometimes used for this technology. Lidar is similar to radar but uses light waves instead of radio waves to perform detection and ranging.

In lidar, a laser beam is swept horizontally and vertically and measures the distances to all surfaces within the volume that can be seen from the setup location. The range of motion in the slew and the distances to all the surfaces that the laser "sees" determine the size of the volume. The volume is also limited by the range capability of the laser, which depends on the strength of the return signal that reflects from the surfaces being scanned back to the lidar. Higher power lasers result in stronger return signals and thus longer range. The scan produces a very large data file that renders a 3D model of the scene and the ability to measure distances between any two locations in this "point cloud."

Many lidar systems also include cameras that take photographs from the setup location in the direction of the volume being scanned. The photographic data is combined with the 3D model to provide color information for all of the points in the point cloud. This gives systems the capability of rendering images that look like photographs.

Typical lidar systems are ground based. Once emplaced and started, the scan is automated and does not require active operator monitoring, freeing up the operator for other tasks. Depending on the topography of the crash scene, one emplacement or multiple emplacements are necessary to capture all data. The equipment may be located away from the crash scene and away from traffic as long as there are adequate lines of sight to the scene and the range to the scene is within the capabilities of the lidar. When multiple emplacements are necessary, overlap between the scans is required, with common reference points to register one scan with respect to another.

Lidar systems are commercially available for integration on UAS platforms. Challenges for UAS with lidar include the requirements for small Size, Weight and Power (SWaP) as well as compensating for the motion of the UAS. Emerging miniaturization of technology enables lidar systems that can be carried by a small UAS. The inclusion of precise motion sensing equipment resolves the moving platform issues and enables a continuous point cloud capture while moving, rather than the multiple point clouds created by the ground based systems. However, the resulting system requires somewhat larger and more complex UAS than a comparable UAS that uses photogrammetric technology.

2.4 Judicial Proceedings

There are several standards for the admissibility of scientific evidence into a court of law. Two of these standards are the Daubert standard and the Frye Standard. Any measuring tools used by the reconstructionist for gathering evidence are subject to scrutiny under these standards.

According to the Cornell University online Legal Encyclopedia (Ref. [13]) the Daubert standard is used by a trial judge to make a preliminary assessment of whether an expert's scientific testimony is based on reasoning or methodology that is scientifically valid and can properly be applied to the facts at issue. Under this standard, established in Daubert v. Merrell Dow Pharmaceuticals, Inc., 509 U.S. 579 (1993), the factors that may be considered in determining whether the methodology is valid are as follows: (1) whether the theory or technique in question can be and has been tested; (2) whether it has been subjected to peer review and publication; (3) its known or potential error rate; (4) the existence and maintenance of standards controlling its operation; and (5) whether it has attracted widespread acceptance within a relevant scientific community.

The Frye Standard is used to determine the admissibility of an expert's scientific testimony, established in Frye v. United States, 293 F. 1013 (D.C. Cir. 1923) (Ref. [13]). A court applying the Frye standard must determine whether the method by which that evidence was obtained was generally accepted by experts in the particular field in which it belongs. The Frye standard has been abandoned by many states and the federal courts in favor of the Daubert standard, but it is still used in some states.

Court acceptance is strongest for manual measurement systems followed by total stations. Less accepted are ground based photogrammetry and 3D laser scanning systems. UAS based solutions are the least mature and thus least established among the considered measurement techniques, regarding court acceptance (Ref. [14]).

2.5 Using UAS for Crash Investigations

Recent advances in UAS motivate consideration of these systems among the plethora of solutions for more efficient crash scene investigation. Coupled with advances in imaging systems and the Global Positioning System (GPS), UAS can potentially take multiple high resolution images of a scene from the air, reducing the time law enforcement personnel has to perform on-scene investigations. Captured images can then be processed by specialized image processing algorithms to create models of the crash scene and make various measurements. Recent studies show that images captured by UAS can provide measurements with generally acceptable levels of errors using photogrammetric techniques (Ref. [3]).

A recent NIJ-sponsored study compared the performance of using UAS for crash scene investigations against traditional methods using a mock crash scene (Ref. [4]). Two teams equipped with different UAS and a third team without UAS investigated the same scene. The findings show that the time taken to clear the scene was reduced by 35 and 45 minutes (56% and 73%) by the use of UAS. Furthermore, the time officers were at risk in the roadway was reduced by approximately 28 minutes (78%). The study also compared the accuracy of measurements made by the three teams and found that UAS slightly reduced some measurement errors.

The results reported in the study report (Ref. [4]) are encouraging for using UAS in CSR. Since these results were obtained in controlled experiments using a mock crash scene, the next question to consider is whether similar benefits of using UAS can be observed in actual operations. There are many possible operational conditions that were not included in the above study that may impact the UAS benefits. These include adverse weather conditions, obstacles around the roadway that block UAS view or prevent their use, and the presence of other time consuming tasks that reduce the significance of image capture time. The work described in this document is an evaluation of UAS benefits in an operational setting to help address these concerns.

3. EVALUATION CRITERIA

This section describes the criteria that were used to evaluate the effectiveness and suitability of using UAS in crash scene reconstruction by Law Enforcement Agencies (LEAs). The criteria span multiple dimensions of operational effectiveness and efficiency. Specifically, the criteria include time metrics, such as how quickly vehicles can be cleared from the roadway and the time spent by response personnel in crash investigation, data quality metrics, such as collecting data with the accuracy needed for CSR, and applicability metrics, such as whether the UAS can be effectively used in a variety of environments and weather conditions. These criteria were used to compare the utility of UAS with other CSR methods. The evaluation criteria are explained in the sub-sections below.

3.1 Roadway Clearance Time

The traffic delay associated with major traffic incidents is one of the most commonly cited concerns related to traffic incident management (Ref. [15]). These delays result in many negative impacts, including lost time and a reduction in productivity, increased cost of goods and services, increased fuel consumption, and reduced quality of life. In major metropolitan areas across the United States delay related to traffic incidents is estimated to be between one-half and two-thirds of the total congestion-related delays (Ref. [15]).

There are differences in the definition of Roadway Clearance Time among different agencies. For instance it is defined by the Florida Department of Transportation (FDOT) as the time between arrival of a service patrol and when travel lanes are cleared (shoulders may continue to be blocked) (Ref. [15],[16]). The Maryland State Highway Administration defines it as the time between the arrival of a service patrol or other responders and when the incident is completely cleared including all travel lanes and shoulders (Ref. [16],[17]). The RT&E Center has adopted the USDOT's definition of the Roadway Clearance Time for this study. As shown in Figure 1, USDOT defines the Roadway Clearance Time as the time between the first recordable awareness of the incident by a responsible agency (incident reported) and the first confirmation that all lanes are available for traffic flow. This definition adds the incident verification and law enforcement response time to the FDOT definition.

3.2 Incident Clearance Time

Incident Clearance Time is defined by the USDOT as the time between the first recordable awareness (incident reported) of the incident by a responsible agency and the time at which the last responder has left the scene, as shown in Figure 1. It is always larger than the Roadway Clearance Time, since it includes the time for law enforcement activities after the roadway is cleared. While Roadway Clearance Time correlates with the traffic backups and delays due to the incident, the Incident Clearance Time correlates with the officer time and manpower required to clear the scene.

3.3 Personnel Exposure Time

Another serious impact of traffic incidents is the exposure of responding personnel to roadway traffic. "Struck-by" incidents, when a responder is struck by a passing vehicle while doing their job at a crash scene, are one of the leading causes of death among fire/rescue and law-enforcement personnel (Ref. [14]).

3.4 Data Quality

Data collected by any method during crash scene investigation must be accurate enough to enable reliable reconstruction of the scene and the sequence of events leading to the crash. Distance measurements between various objects are used in the reconstruction for the estimation of crucial factors such as vehicle speed and driver response time. Excessive errors in collected data compromise the reliability of these estimations.

In addition to accuracy, the usability of collected data for processing and as evidence in court are important factors. In this context usability refers to whether the data collected can readily be used for various CSR tasks. For example, the look angle changes with the use of UAS, since photographs are typically taken from the ground and the UAS take aerial or bird's eye view photographs. While an aerial view can be useful to provide an overall view of the crash scene, it may not provide adequate detail about the vehicles.

Operational testing in this study did not include the gathering of appropriate data for quantitative evaluation of measurement accuracy. The law enforcement agencies supporting the evaluation were typically not using the UAS data for measurements but instead used the images to supplement measurements taken using the total station. The aerial or bird's eye view photographs helped provide an overview of the scene. The RT&E Center gathered responses on the types and the purpose of the UAS data from the agencies.

3.5 Operational Factors

Crash scene reconstruction may be required at any time (day/night), under any weather conditions, and in any environment. The suitability of technology to operate under variable environment characteristics can influence the reduction in incident and clearance time for an incident by facilitating quick data collection techniques. Challenging topography (wooded area, slopes, high-rise structures in immediate vicinity, congested area) can affect the ability of responders to get to the site and to collect data.

4. INTERVIEWS WITH LAW ENFORCEMENT AGENCIES

The RT&E Center conducted a series of interviews with the Law Enforcement Agencies (LEAs) to understand the procedures and limitations of current UAS use in CSR. Members of the RT&E Center study team also visited Michigan State Police for a demonstration of their UAS. This section describes the interviews, the Michigan visit, and the findings from the interviews.

It should be noted that FAA Small Unmanned Aircraft (Part 107) Regulations (Ref. [1]) were not in effect when the interviews were conducted; therefore, statements about FAA rules or requirements in the subsections below don't encompass these newer regulations.

4.1 Agency Selection

The RT&E Center study team conducted research to identify LEAs with UAS programs throughout the US. The study team contacted these LEAs by phone or e-mail to request their participation in discussions on UAS use for CSR. Arlington, Texas, Police Department, Michigan State Police, and Illinois State Police agreed to participate. When applicable, separate interviews were conducted with a reconstructionist and a UAS pilot from the same LEA. In addition to the interviews, the RT&E Center requested historical data and participation in operational data collection from these LEAs.

4.2 Interview Questions

Interviews captured the way CSR is currently conducted by the LEAs. Similarities and differences in methods were captured in interview summaries to develop an operational data collection method suitable to the participating LEAs. Information obtained during the interviews also served to better interpret the operational data collected later.

Interviews were also valuable for understanding the preferred CSR equipment and tools, as well as the criteria that are valued by each agency, such as safety, data reliability, time to clear the scene, etc. The interviews also highlighted several problems that the agencies face.

A sample set of interview questions is shown in Table 1.

Table 1: Interview Questions for Law Enforcement Agencies Using UAS

General Name of the Agency and the Department? Years/Months worked in law enforcement? Years/Months in current position? What is your role for crash scene investigations and reconstructions? Years/Months Experience with crash reporting? Years/Months Experience with UAS?

About Your Team
How are traffic investigations conducted within your agency?
How many crash teams are within your Department?
Do all crash teams include UAS operators?
How many individuals make up a team?
How is the team manned with and without UAS?

Training
How are your UAS operators selected/hired?
What kind of training do UAS operators receive?
How long does it take to train a UAS operator?
Does your agency have a COA (Certificate of Authorization) for your UAS?
Was there additional training needed for your operators to obtain the COA?
What refresher training is required, and how often?
What is the typical cost to train a UAS operator?

Equipment
What kind of UAS do you have?
Please describe the process of selecting your UAS.
How many UAS do you have?
How much did each UAS cost?
What additional hardware is needed to support the UAS?
What sensor or sensor packages are deployed?
What software is needed to support the UAS?
What data analysis tools do you use?
What data outputs are available?
What is the cost of the support hardware and software?
Please describe common types of maintenance and repair for the UAS.
What is the annual cost of owning and operating UAS?

Operation of UAS
Are there state/local laws or guidelines UAS operators must follow?
Approximately how many flights were made last year?
How many operators are needed to fly UAS?
How long can your UAS fly?
Any safety considerations for the public?
Any safety considerations for the officers?
What are typical UAS setup, flight, and tear down times for crash investigations?
How are sensors and UAS calibrated? How often?
Is data downloaded real-time or post flight?
How is data transmitted on site and post flight?
How long does it normally take to download and process data collected by UAS?
How are collected data archived?
What are the memory limitations?
How frequently do you encounter weather conditions that prohibit UAS use?

How frequently do you encounter obstacles that prohibit UAS use?

Response Team Process
Please describe the process for responding to traffic incidents.
How many teams are deployed to a scene?
How many members are in the teams deployed?
Are extra team members required for operation of UAS?
How do you decide whether to send UAS to a scene?
Can you briefly describe how you/your agency collects data at the crash scene?
How does involvement of hazardous material in a crash change the procedures and analysis of an incident?
What are the most critical types of data to collect at a scene?
What unique benefits does each type of data bring forward?
What tools do you typically use to collect data at a crash scene?
What is the best possible combination of tools to collect crash scene evidence?
Please tell me about the benefits of your UAS program.

Analyze Crash Data
Please describe the method of processing evidence after a crash.
What is the basis for performing a reconstruction of a traffic incident?
What measurement methods do you use? Are they formally documented?
How/when do you usually combine data collected across tools to create a picture of or reconstruct a crash scene?
How long does it take to process the UAS data into something meaningful?
What do you typically create/produce for an incident?
How many fatal crashes does your agency investigate per year?
What percentages of those are reconstructed?

Judicial Process
Have you ever been called to court to testify in a crash case?
Have you presented data collected by UAS to court? Were the data accepted?
How frequently are you called to court?
What kinds of evidence does the court typically accept?
What kinds of evidence does the court typically reject?
What admissibility standard does the court use in your jurisdiction?

4.3 Summary of Findings from the Interviews

Phone interviews were performed between the RT&E Center team and representatives from several law enforcement agencies. Lieutenant Brook Rollins, Special Operations Division, with the Arlington, TX Police Department, was interviewed on March 25, 2016. Sergeant Allan Avery, reconstructionist with the Michigan State Police, was interviewed on April 26, 2016. Mr. Brian Miller, Unmanned Aircraft System Coordinator/Pilot with the Illinois State Police, was interviewed on April 26, 2016. Sergeant Robert Ventura, Traffic Crash Reconstruction Resource Officer with the Illinois State Police, was interviewed on April 28, 2016.

Members of the RT&E Center team also visited Michigan on March 30-31, 2016 to meet with representatives from the Michigan State Police (MSP) and the Michigan Department of Transportation (MDOT). Interviews were conducted with Ms. Angie Kremer, Sgt. Matt Rogers, and Mr. Steve Cook. Ms. Kremer is a Traffic Incident Management Engineer for MDOT who works closely with the MSP. Sgt. Rogers is a Tactical Flight Officer (TFO) for the MSP Aviation Unit and also runs the MSP Unmanned Aircraft Systems program. Mr. Cook is an Operations Engineer for MDOT and Project Manager for the MDOT program called Implementation of Unmanned Aerial Vehicles (UAVs) for Assessment of Transportation Infrastructure.

Main findings from the interviews are organized into five categories and discussed in the subsequent subsections below. Appendix B provides more details about each interview.

4.3.1 UAS Usage

UAS use varies significantly across LEAs. In general UAS is considered for adoption to any scenario where it can help to keep law enforcement personnel out of harm's way. The uses reported during the interviews are crime scene investigation, missing persons, SWAT team hostage scenarios, fire scene investigation, natural disaster investigation and crash scene investigation.

LEAs that reported using UAS for crash scene investigation required a minimum of two operators to pilot the UAS and to be an observer per FAA guidelines. These operators are in addition to the reconstructionist and other crash scene investigators.

The UAS operators are recruited from various departments across the agencies. Aviation background is almost always essential since FAA requires the operators to have a pilot's license or a remote pilot airman certificate with a small UAS rating.

The UAS team is generally deployed for more severe crash scenes. A fatal crash scene requires the presence of a reconstructionist, who may call the UAS team to the scene.

FAA and Certificate of Authorization (COA) requirements dictate many of the rules and regulations that LEAs must follow in order to operate UAS. The following is a summary of the steps prior, during and post flight that was recorded during the interviews. The order of the steps varies between agencies but many of them are common.

Pre-Flight

- Identify personnel who will respond
- Check weather, location relative to local airports, and other potential barriers to deploying UAS
- File FAA clearance
- Identify areas and objects of interest together with the reconstructionist
- Determine takeoff and landing zone, flight path, flight parameters
- Setup UAS for flight

Flight

- Launch UAS
- Record the scene from the pre-identified vantage points (e.g., driver view, birds eye view, vehicles from different angles)
- Land UAS

Post Flight

- Review data and determine if subsequent flights are required
- Back up data and provide reconstructionist with a copy
- Determine if a return visit is necessary for additional data capture
- Import captured data into software tools (at the office)
- Process data and generate reports

4.3.2 UAS Characteristics

UAS come in a variety of shapes and sizes and serve diverse purposes. Some of the key parameters that differentiate UAS performance are weight, maximum altitude, cruise speed, endurance, maximum range of operation, and the payload capabilities. The available budget and the types and complexities of missions must be considered in the selection of UAS. The following sections summarize the selection criteria, aircraft type, model and accessories that are used by the three agencies participated in the interviews.

4.3.2.1 Arlington, Texas, Police Department

The Arlington, Texas, Police Department (APD) acquired their UAS primarily for crash reconstruction purposes, although they are currently using the UAS also for additional missions such as crime scene search and missing persons search and rescue. The current model in use by the department is a Leptron Quad Copter shown in Figure 3 (Ref. [18], [19]). It was selected after multiple vendors were contacted. Some of the attractive features of this UAS were the ability to fly with only 1 pilot (versus 3 that was required by a previous model), rapid battery charging, easy maintenance, and ease of transportation. APD uses a GoPro camera and GoPro editing software for video capture.

Figure 3: Leptron Quad Copter

The Leptron Quad Copter can operate within the temperature range of -10F to 100F with a maximum flying time of 20 minutes. It supports a variety of camera configurations, including high definition (HD) video, still pictures, and infrared. Other features include auto-takeoff and landing, return home after lost communication, and a simple drag and drop user interface. Detailed specifications for the Leptron Quad Copter are presented in Appendix A.

4.3.2.2 Michigan State Police

The Michigan State Police (MSP) use UAS for various missions, including SWAT team use in hostage situations, natural disasters, and in traffic crash reconstruction especially for multi car pileup crashes. MSP used operational assessments provided by the Department of Homeland Security Science and Technology Directorate (DHS S&T) Robotic Aircraft for Public Safety (RAPS) Project Office for selecting their UAS. The model in use is the Aeryon SkyRanger shown in Figure 4 (Ref. [20], [21]).

Figure 4: Aeryon SkyRanger

The Aeryon SkyRanger has 6 batteries on board, allowing flight times up to 50 minutes. The system can be used at extremely low temperatures down to -22F. It has wind tolerance to 40 mph sustained or 55 mph gusts. It can be used with a laptop computer for processing while at scene and supports attaching artificial lighting if required. Detailed specifications for the Aeryon SkyRanger are presented in Appendix A.

4.3.2.3 Illinois State Police

The Illinois State Police (ISP) use DJI Inspire 1 quadcopter shown in Figure 5 (Ref. [23]). It has a dual controller system that can be operated by two people to get more complex camera shots. It also has a smart phone application that allows control using a variety of smart phones and tablets.

Figure 5: DJI Inspire 1

The DJI Inspire 1 has extra power and range compared to its predecessors in the DJI family of drones and it is more resistant to winds. It has a maximum flight time of 18 minutes. It adds an extra layer of optical and ultrasound technology to keep it in position more accurately when closer to the ground and also in situations where there is no GPS signal. The operating temperature range of DJI Inspire 1 is from 14F to 104F. Detailed specifications for the DJI Inspire 1 are presented in Appendix A.

4.3.3 Data Capture

The interviews with APD, MSP and ISP included discussions regarding the methods by which these law enforcement agencies capture, store, and analyze data. Also revealed in the interviews were the types of data law enforcement agencies capture.

Data capture is typically done by flying the UAS over the crash scene and taking digital photographs. Sometimes a video of the scene is captured either in addition to or instead of the digital photographs. Data capture is a manual process with many UAS. The operator flies the UAS to suitable locations, points the camera to observe the desired scene, and snaps the photos. Some more advanced UAS support automated data capture. Prior to the UAS taking off, the operator brings up a map of the scene on the UAS controller. A polygon is drawn on the map to indicate the desired area for photographs. Settings are adjusted for the desired amount of overlap between the photos and the desired ground resolution. The controller takes inputs from the operator and creates an automated mission plan. The operator approves the mission plan, and then the UAS is launched and performs the mission automatically with the operator monitoring and adjusting as needed.

Some data gathering may be deferred to later due to several reasons. At night, the camera cannot see the objects unless there is sufficient artificial lighting of the scene. During a rush hour investigation, law enforcement may want to defer taking some pictures to open the road to traffic earlier. Finally, weather conditions may impair visibility, or high winds may preclude UAS flight.

If some data gathering is deferred, then the scene is marked during the initial investigation to show where evidence is located. The investigators mark the location of the cars and highlight evidence that would be short lived. Control points are sometimes added to the scene and manually measured as a reference. The distance between the control points can be used to confirm/correlate with other measurements. Paint, cones, and/or survey markers can be used for marking.

Maximum flight duration for a single flight ranges from approximately 15 to 45 minutes depending on the UAS. If more time is needed to gather data, then multiple flights are performed back-to-back. UAS are typically battery powered. Multiple batteries are kept charged up so that back-to-back flights can be performed after swapping out the batteries. Battery recharging can be performed at the station or by a support vehicle at the scene. Required storage for captured data depends on the image resolution, imager mode, and maximum flight duration. Typically, the data (video, still images, metadata) is stored on an SD card in the aircraft or in the ground controller. The UAS also support exporting data to another device. This could be in real time during a flight or during post processing. Various interfaces are supported for data export, including USB, Wi-Fi, and microSD.

Post processing is typically done on a separate computer at the office, however a laptop computer is often used at the scene to validate that adequate data was captured.

Data is archived on servers upon return from the crash scene. Data retention policies vary widely from state to state and city to city. MSP retains data indefinitely. In Illinois, if a law enforcement agency uses UAS for crash scene photography, the agency must destroy all information within 30 days, except that a supervisor at that agency may retain particular information if there is reasonable suspicion that the information contains evidence of criminal activity, or the information is relevant to an ongoing investigation or pending criminal trial.

Analysis of the captured data most often involves correlation of UAS images with other measurements for verification. A commonly desired work product is an orthorectified mosaic of the entire crash scene. This single large image is the primary UAS data product utilized by the reconstructionists.

Another possible use for the photogrammetry tools is making distance measurements from the photographs. The three law enforcement agencies are not utilizing this capability routinely. Instead, it is used occasionally as a backup to measurements normally taken by a total station.

Still images are the most common type of data captured by UAS for crash reconstruction. They include bird's eye views of the scene from approximately 100 to 400 feet. The maximum altitude is utilized to possibly get the entire scene in one photo and also to minimize distractions to onlookers. Lower altitudes are used to reveal more detail. Lookdown shots from about 10 feet may be necessary to get the crush information, which allows determination of direction of force.

Video is the other type of UAS data product commonly utilized in reconstruction. Video images include a bird's eye view of the scene. The operator will zoom in on relevant details using camera zoom capability or by lowering the altitude of the aircraft. A "fly through" from the perspective of each of the vehicles involved in the crash from each direction is performed. Note that real time video downlinked from the aircraft to the ground may be lower resolution than the video recorded within the aircraft.

4.3.4 Benefits

The LEAs interviewed by the RT&E Center outlined several benefits of using a UAS for Crash Scene Reconstruction. The first benefit mentioned was a reduction in the overall time of the investigation. This leads to opening highways sooner and reducing the amount of time that officers are in harm's way. All agencies interviewed mentioned the time component as being a benefit of UAS. ISP added that the time component outweighs the cost of operating the UAS.

The UAS also provide a bird's eye view that may encompass the entire crash scene in one photograph. Both ISP and MSP mentioned the ability to create the entire picture within an hour of the crash, which enables them to see or to overlay crash scene details to better understand the process of the crash, including the movement of the vehicles and the direction of travel. ISP highlighted the additional potential benefit for presenting crashes in court, where the overhead view from UAS can make it easier to explain the crash to the jury. Prior to acquiring their UAS, ISP used an Air Operations Division manned aircraft flying at 1200 feet to capture aerial photos. Those photographs were often blurry due to the altitude of the aircraft and quality of the camera. The UAS photographs were mentioned as a significant improvement over the previous method.

The last benefit mentioned during the interviews was data quality. UAS data paired with photogrammetry software is expected to improve accuracy of measurements, including crush. While the accuracy of a total station measurement is based on assumptions of lane line width and tire width, the UAS takes measurements without these assumptions. The UAS data can also be used to supplement other data. For example, total station measurements for tire marks and other debris can be overlaid on UAS data to substantiate the data and to confirm the vehicle's path of travel. On the downside, because measurements are completed after the fact, if any data are missing, there may not be an opportunity to get the information. Therefore the investigators must make sure they got what they needed before the UAS operators leave the scene.

MSP mentioned the importance of getting into the UAS game early, ahead of industry, in order to stay ahead of the technology. They raised the concern that the private companies will begin using the technology, and then the agencies will need to "play catch up" if they are late.

4.3.5 Barriers

Interviews with LEAs also focused on potential barriers and difficulties in using UAS for crash scene reconstruction. Common barriers are rules and weather conditions that constrain when, where, and how UAS can fly.

FAA rules limit UAS use for law enforcement to daytime operations; therefore nighttime crash investigations require the UAS operators to come to the scene later to take the aerial pictures. In these cases the reconstructionist or other investigators mark the locations of the vehicles and other evidence during the initial investigation. That way UAS can still produce a good representation of the scene several days later. The LEAs find the top down views of the scene very valuable even if they are taken a few days later. It is also common to measure the markings by a total station during the initial investigation so that the UAS pictures that are taken later can be scaled properly.

FAA rules also require at least two officers to operate UAS – a pilot and an observer. The aircraft must be in line of sight during the flight. Moreover the UAS pilot needs a license, which requires special training. This prevents UAS use directly by the reconstructionists and necessitates a separate unit to operate the UAS.

LEAs are not allowed to operate UAS close to airports. They have to notify the airports when and where they are going to fly the UAS, which adds some delay to their response to an incident.

Weather conditions can also be a limiting factor in UAS use. UAS have varying tolerances to wind speed and temperature, and cannot be operated if the wind speed or temperature is beyond the permissible range.

False public perception can also be a barrier. LEAs mentioned that people may think of offensive systems or surveillance systems jeopardizing their privacy when they hear UAS, although this is not the case. Therefore managing public perception would be important for UAS use by law enforcement.

4.4 Michigan State Police UAS Demonstration

Members of the RT&E Center team visited Michigan on March 30-31, 2016. In addition to the interviews, MSP performed a demonstration of their UAS for the RT&E Center team at the department's Precision Driving Unit track on Canal Road in Lansing, MI. The UAS along with supporting equipment were shown to the team. Ground and flight demonstrations were performed.

Figure 6: UAS Demo performed at MSP Precision Driving Unit Track

An Aeryon SkyRanger was used in the demonstration along with the Aeryon HDZOOM30 Imaging Payload. There were two support vehicles, a Chevrolet Suburban and a Ford Utility Body pickup truck. The Suburban was outfitted specifically to support UAS operations and is the vehicle that Sgt. Matt Rogers uses to go to a crash scene. The Ford was outfitted to support the MSP Aviation Unit, and it supplements the Suburban at some crash scenes.

The Suburban carries all equipment needed to provide UAS coverage at a crash scene, including the UAS, multiple payloads, multiple batteries, battery chargers, ground station, radio for voice communications, other supporting equipment and spare parts. Payloads carried include the Aeryon HDZOOM30 electro-optical imaging zoom payload, Aeryon SR-3SHD electro-optical imaging fixed field-of-view payload, and Aeryon SR-EO/IR combination electro-optical / infrared imaging fixed field-of-view payload. Six UAS battery packs are carried, with three of them actively being charged from the Suburban's electrical system. As each battery provides up to 50 minutes of flight time and takes under 60 minutes to charge, this complement of batteries and charging capability provides constant availability of batteries regardless of the length of the mission. All equipment fits into the trunk of the Suburban, leaving two rows of seating for the driver and the passengers.



Figure 7: Primary support vehicle was Chevrolet Suburban with UAS load-out and battery charging capability

The Ford Utility Body pickup truck supports data display and dissemination for the MSP Aviation Unit. It includes receivers and transmitters mounted to the roof of the Utility Body to receive video from an MSP helicopter and relay it to others. It is also outfitted with multiple large monitors for viewing the video. A hard-wired interface between the UAS ground station and the truck enables display and dissemination of the UAS video when the truck is collocated with a UAS ground station.

Figure 8: Secondary Support Vehicle was Ford Utility Body with display and dissemination capabilities

The UAS equipment was set up on an unused section of the track at the MSP Precision Driving Unit. An area was marked off with cones and designated as the launch and recovery site. The UAS was assembled at the back of the Suburban. For the demo, the Aeryon HDZOOM30 electro-optical imaging zoom payload was installed. This payload provides the best video but uses more power and weighs more than the other electro-optical payload, reducing the flight time. Since the demo was planned for only 15 minutes, power and weight were not an issue. The ground station was mounted to a tripod and was connected by cable to the Utility Body truck. Two people performed the set up in less than 10 minutes.

Figure 9: UAS Assembly and Setup

The completely assembled aircraft was placed in the middle of the launch and recovery site. For the demo, there was one UAS operator and one observer. The operator was responsible for maintaining control of the aircraft. The observer was responsible for panning the airspace around the site and alerting the operator for any conflicted airspace issues. Voice communications were direct with no radio or intercom utilized for the demo.

Figure 10: Launch / Recovery Site

A preflight checklist was used to verify that the Aeryon SkyRanger was ready for launch. The aircraft took off and flew to locations commanded by the operator. Video was sent down from the aircraft to the ground. The video could be seen on the operator's tablet. It could also be seen on the displays in the back of the Utility Body truck. At one point during the flight, the operator received a high winds alert. Towards the end of the flight, the operator received an aircraft subsystem failure message. At this point the aircraft was commanded to land and landed without incident at the launch and recovery site. The aircraft was then disassembled and stowed in crates in the back of the Suburban. Tear down of the system was quick. No tools were needed for assembly or disassembly of the aircraft. Sgt. Rogers told the RT&E Center team that the subsystem failure issue would be reported to Aeryon for further investigation and determination of a course of action. MSP maintains a support contract with Aeryon to address these sorts of issues.

5. OPERATIONAL DATA COLLECTION

The purpose of the operational data collection was to collect crash investigation data that will directly enable calculation of the evaluation criteria described in Section 3. The data collection required the cooperation of law enforcement agencies that can provide the data together with some baseline for comparisons. Ideally a participating law enforcement agency would collect data from crash scenes using both UAS and another method, which would enable a direct comparison of the efficiency of the two methods. In practice such data collection using two methods simultaneously was not often possible due to the additional burden this would place on the crash investigators. Furthermore in many cases where two methods are used simultaneously, they complement each other rather than measuring the same objects independently. For instance a total station (TS) may be used for distance measurements while a UAS is used only for obtaining an aerial view of the scene. To handle such cases correctly it becomes essential to understand what exactly each tool is used for in each crash case.

Two agencies, ISP and MSP, agreed to participate in operational data collection. The RT&E Center asked ISP and MSP for existing CSR data to assess whether existing crash records contained timing information and details that would be useful for the operational assessment. Unfortunately existing crash records did not uniformly have such critical information as start and stop times for TS measurements and lane closure times.

In addition to the operational data collected from ISP and MSP, the RFI response submitted by the Major Crash Assistance Team (MCAT) of Lake County Illinois provided useful information. According to the RFI response, MCAT is a multi-jurisdictional agreement among 35 Illinois municipalities whereby resources are shared for the purposes of investigating and recording serious crashes. MCAT reported investigating sixteen major crash scenes with UAS technology, including both daytime and nighttime operations. For each of these scenes they created a full digital three-dimensional model of the scene using photogrammetry. Total stations were also used in the investigation for all sixteen scenes. MCAT shared their existing data with the RT&E Center. The data were used to complement the newer data collected by ISP and MSP.

5.1 Data Collection Methodology

The RT&E Center developed a set of questions to collect crash investigation data using an online tool. The two participating agencies, ISP and MSP, were requested to answer these questions after each major crash investigation. The requested data was different for UAS operators and reconstructionists. The questions only relevant for UAS operators were not displayed to the reconstructionists and vice versa. Some questions were conditional on an answer to a previous question and may or may not be asked depending on that answer. Questions used to collect data are described in the following subsections. The conditional questions are marked with “(C)” at the beginning.

5.1.1 Incident Overview

The first section collects general data about the incident, including the agency and the officer providing data, the role of the officer (i.e., reconstructionist or UAS pilot/observer), the crash identifier, any specific challenges for data collection, weather conditions, tools used to collect crash data, and the reason UAS was requested (or not) for the investigation. Questions in this section are common for both the reconstructionist responders and UAS pilot/observer responders. The questions in this section are listed below.

- Agency
  - ❍ ISP
  - ❍ MSP

- Role at this scene
  - ❍ Reconstructionist
  - ❍ UAS Pilot/Observer

- Name/Initials

- Crash identifier/Report #

- Crash type
  - ❍ New
  - ❍ Historical

- Would you like a research team member to call you to talk through this crash or would you prefer to enter data yourself?
  - ❍ Yes, please give me a call.
  - ❍ No, I'll complete the data sheet myself.

- Describe any characteristics of the crash, scene or environment that posed challenges for reconstruction data collection.

- Please describe the weather conditions/visibility.

- Which tools were used to collect crash data at this scene, and when:

	Manual Total Station	Robotic Total Station	Hand-held camera(s)	Sled	Tape measure	UAS	Other
First response	❑	❑	❑	❑	❑	❑	❑
Second site visit	❑	❑	❑	❑	❑	❑	❑
3rd and subsequent site visits	❑	❑	❑	❑	❑	❑	❑

- (C) Which additional data collection tool(s) did you use?
- (C) Why did you decide to request UAS support on this crash?
- (C) Why wasn't the UAS deployed with the first response team?
- (C) Why did you decide to not use the UAS support on this crash?

5.1.2 First Response and Subsequent Site Visits – Pilot

Questions in this section are only asked to UAS pilot/observer responders. This section collects data about the timeline of the crash investigation, the number of UAS flights, the number of officers for flying/observing the UAS, estimate of the road closure time, and estimate of UAS pilot/observer exposure to flowing traffic. If there were subsequent site visits after the first investigation to collect additional data, the same questions are repeated for each site visit. The questions in the First Response section are listed below. Questions for subsequent site visits are identical with the addition of one question about the reason for additional site visit.

- Please describe the UAS team time line for this visit to the scene in military time (HH:MM).
  - Learned about incident:
  - Arrived on scene:
  - UAS setup start:
  - UAS flight start:
  - UAS flight complete:
  - UAS tear down complete:
  - Left scene:

- How many officers were deployed to operate/observe the UAS?
  - Pilot(s):
  - Observer(s):

- How many flights were logged?
  - ❍ 1
  - ❍ 2
  - ❍ 3 or more

- Estimate the road closure times.
  - All lanes closed:
  - Some lanes closed:
  - All lanes open:

- Were UAS operators/observers directly exposed to flowing traffic at any point (e.g., while some lanes were open)?
  - ❍ Yes
  - ❍ No

- (C) How long were UAS operators/observers exposed to traffic... Only enter data for the roles on the scene: If no one filled that role (e.g., 3rd observer), leave the column blank. If roles were not exposed to flowing traffic, enter 0s.

	Pilot	Observer 1	Observer2	Observer3
In the roadway On the shoulder Somewhere else (Please describe location)				

- How many, if any, secondary accidents occurred?
  - ❍ 0
  - ❍ 1
  - ❍ 2
  - ❍ 3
  - ❍ 4 or more

5.1.3 First Response and Subsequent Site Visits – Reconstructionist

Questions in this section are only asked to reconstructionist responders. This section is similar to the first response section for UAS pilot/observer responders but asks information about total station and other measurement tool usage instead of UAS usage. It collects data about the tools that were used for several types of measurements in the investigation, the timeline of the crash investigation, the number of total station tripod locations and total station data points, the number officers for operating the total station, estimate of the road closure time, and estimate of total station operator exposure to flowing traffic. If there were subsequent site visits after the first investigation to collect additional data, the same questions are repeated for each site visit. The purpose of the detailed tool usage information is to assess whether UAS can replace total station usage either partially or completely. If a complete replacement is possible comparing the timelines may reveal several benefits of the UAS. The questions in the First Response section for reconstructionists are listed below. Questions for subsequent site visits are identical with the addition of one question about the reason for additional site visit.

- Which tools were used to collect crash data at this scene, and when:

	Manual Total Station	Robotic Total Station	Hand-held camera(s)	Sled	Tape measure	UAS	Other
Scene overview	❑	❑	❑	❑	❑	❑	❑
Skid marks, scrub marks and gouges	❑	❑	❑	❑	❑	❑	❑
Roadway objects (Vehicles, debris, etc.)	❑	❑	❑	❑	❑	❑	❑
Stationary objects	❑	❑	❑	❑	❑	❑	❑
Permanent pavement markings (Road and lane markers, etc.)	❑	❑	❑	❑	❑	❑	❑
Road surface and grade	❑	❑	❑	❑	❑	❑	❑
Drivers' perspective	❑	❑	❑	❑	❑	❑	❑

- Please describe the Total Station/Recon team time line for this visit to the scene in military time (HH:MM).
  - Learned about incident:
  - Arrived on scene:
  - Started Total Station set-up:
  - Started Total Station data collection:
  - Completed Total Station data collection:
  - Completed Total Station tear down:
  - Left scene:

- How many officers were involved in setting up and collecting Total Station data?
  Setting up the Total Station:
  Collecting Total Station data:
  Breaking down the Total Station:

- How many tripod locations were used to collect the Total Station data?
  - ❍ 1
  - ❍ 2
  - ❍ 3 or more

- How many data points did the Total Station collect?

- Estimate the road closure times.
  All lanes closed:
  Some lanes closed:
  All lanes open:

- Were Total Station operators directly exposed to flowing traffic at any point (e.g., while some lanes were open)?
  - ❍ Yes
  - ❍ No

- (C) How long were Total Station operators exposed to traffic? Only enter data for the roles on the scene: If no one filled that role (e.g., 3rd observer), leave the column blank. If roles were not exposed to flowing traffic, enter 0s.

	Pilot	Observer 1	Observer2	Observer3
In the roadway On the shoulder Somewhere else (Please describe location)				

- How many, if any, secondary accidents occurred?
  - ❍ 0
  - ❍ 1
  - ❍ 2
  - ❍ 3
  - ❍ 4 or more

5.1.4 Data Analysis

This section is for reconstructionist responders only. It is intended for a direct comparison of the usefulness of total station data with UAS data for reconstruction report development. The questions ask whether any data in the report will depend uniquely on total station data or uniquely on UAS data. These questions are listed below.

- Think about the analysis and reconstruction report you will develop for this crash. Which data will you use in your reconstruction report?
  - ❍ Total Station data
  - ❍ UAS data

- What, if any, data/images will you use or create that depend uniquely on data collected with the Total Station?

- What, if any, data/images will you use or create that depend uniquely on data collected with the UAS?

5.1.5 UAS Operational Impact

Questions in this section are common for both the reconstructionist responders and UAS pilot/observer responders. This section asks about the estimated impacts of UAS on data collection speed, officer safety, and road closure. It also asks the reason for these impacts. The questions in this section are listed below.

- Did using the UAS impact reconstruction data collection?
  - ❍ Made it faster.
  - ❍ No change.
  - ❍ Made it slower.

- (C) How did the UAS make data collection faster?

- (C) How did the UAS make data collection slower?

- Did the using the UAS affect safety for the officers and first responders?
  - ❍ Made it safer.
  - ❍ No change.
  - ❍ Made it less safe.

- (C) How did the UAS make data collection safer?

- (C) How did the UAS make data collection less safe?

- Did using the UAS on scene affect the road closure time?
  - ❍ Made it shorter.
  - ❍ No change.
  - ❍ Made it longer.

- (C) How did the UAS decrease road closure time?

- (C) How did the UAS increase the road closure time?

5.1.6 Predictions on Potential UAS Benefits

This section is for reconstructionist responders only. It asks the reconstructionist's opinion about several benefits UAS would bring if all logistical, administrative and technology challenges associated with UAS use were resolved. The questions in this section are listed below.

- Think about a world in which the logistical, administrative and technology challenges associated with UAS are resolved (e.g., enough pilots/observers/UAS, appropriately powerful software and hardware; no citizen concerns.) How, if at all, would having ready access to a UAS change your reconstruction strategy and workload?

	Less time required	About the same	More time required
Collecting data on the scene	❍	❍	❍
Post-processing / analyzing data in the office	❍	❍	❍
Creating the reconstruction report	❍	❍	❍
Creating exhibits to support deposition or testimony	❍	❍	❍

- Again consider a world in which the logistical, administrative and technology challenges associated with UAS are resolved. Which data collection tool or tools would you use to collect reconstruction data for this crash?
  - ❍ Total Station
  - ❍ UAS
  - ❍ Sled
  - ❍ Cameras
  - ❍ Measuring Tape
  - ❍ Other ____________________

5.1.7 Closing

The final section has a single question that asks whether there are any additional details about this investigation that should be mentioned.

- Are there any details about this scene or reconstruction analysis that we should know about? (e.g., Road closure time was lengthened by hazardous material spill or other extraneous events.)

5.2 MCAT Data

MCAT provided data for 16 crash investigations. One investigation was conducted in November 2015 and the rest were conducted from May through August 2016. Data provided by MCAT did not contain all types of information detailed in the previous section. For all sixteen cases MCAT provided the following information:

- List of the tools that were used in the investigation
- MCAT dispatch time and the arrival times of the officers to the scene
- Data collection times by both the UAS and the TS
- The number of tripod locations and the number of data points that were collected by the TS
- Road closure time
- Whether TS operators were exposed to traffic
- Environmental conditions (temperature, wind speed, visibility, precipitation, and light conditions)

5.3 Post-Crash Data and Analysis

Post-crash data was gathered from July through October, 2016. This data was supplemented by UAS flight log book data as well as MCAT RFI response data. No other data was collected or analyzed. An online tool called Qualtrics was utilized for data collection. Analysis was performed using Qualtrics along with Excel spreadsheets.

There were 43 incidents reported using the online tool. ISP reported 42 of the 43 incidents. MSP started participating in the data gathering but shortly after reporting one incident the MSP team became inactive in UAS usage for crash reconstruction over most of the period of performance. The inactivity was due to a combination of events but was primarily because MSP had competing priorities. MSP was also evaluating the repeatability of their measurement accuracy in preparation for usage of photogrammetry data in court.

Most of the responses came from reconstructionists. Nine different ISP reconstructionists participated in the study by providing post-crash data. One ISP UAS pilot and one MSP UAS pilot also provided post-crash data. Another method preferred by the ISP for sending UAS data was by sending a copy of the flight log entries each month. The flight log did not provide as complete a data set as the data collection tool, but it was useful and could be correlated with reconstructionist data.

Figure 11 illustrates the investigation tool usage reported in the study. The ISP reconstructionists predominantly utilized robotic total stations and hand-held cameras for data collection. A TS was used in 39 of the 43 investigations. UAS were utilized in 14 investigations either during the first response or subsequent site visits. A TS was used in 11 of these 14 investigations and a TS was not used in the remaining 3. Interestingly, the most common tool identified for use at second and subsequent site visits was the UAS. Half the time, tape measures were also used in the investigations. Other tools occasionally used included measuring wheels and levels.

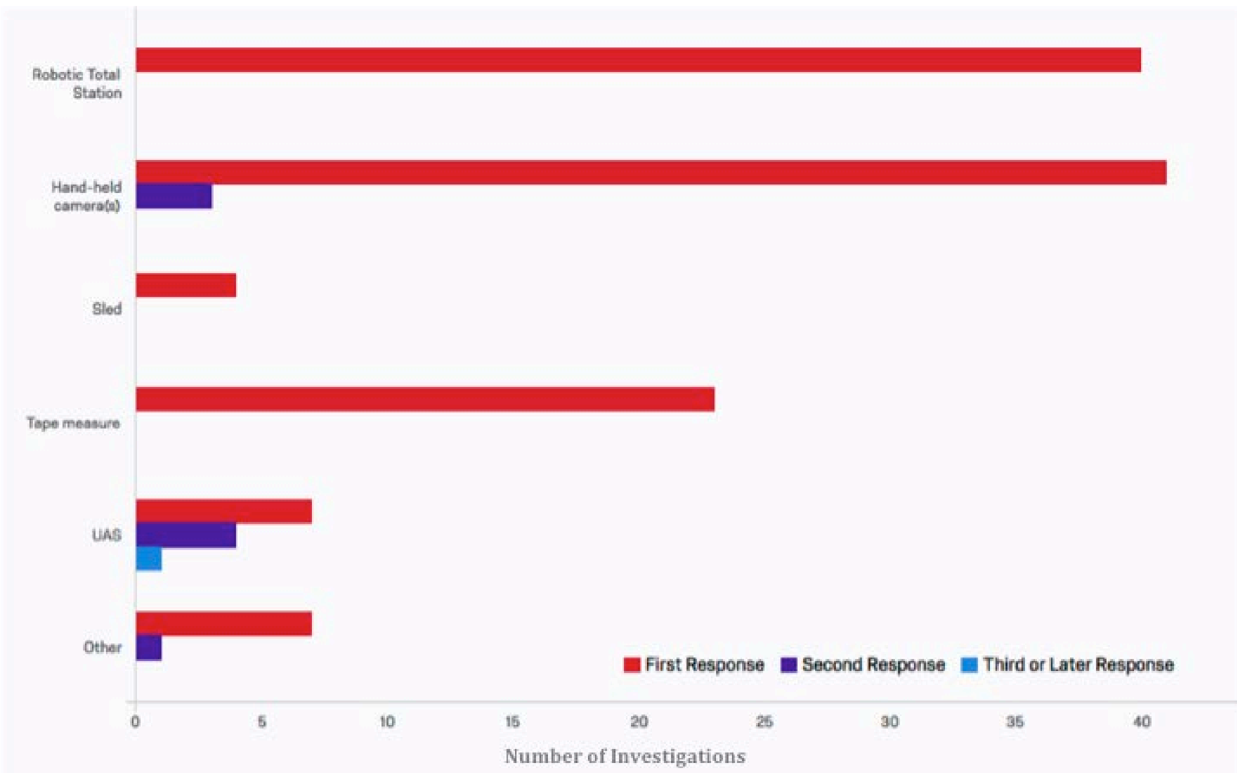

Figure 11: Investigation tool usage

When broken down to individual investigation tasks, the tool usage reflected a similar distribution as above with the exception of driver's perspective data. There was no clear bias of tool usage when focusing on aspects such as scene overview, skid marks, roadway objects, stationary objects, permanent pavement markings, and road surface and grade. Driver's perspective data, however, was exclusively gathered using the hand-held camera.

Several reasons were given for the decision to request UAS support for an incident, as shown by Figure 12. The most common reason was because an aerial view of the scene was preferred, followed by UAS ability to provide faster documentation, and by policy requirements. To quote from one response: "The additional photographs from an aerial view will be beneficial for my report." It was also mentioned that the UAS was useful for a large scene, was useful to capture roadside evidence, and can open the road faster.

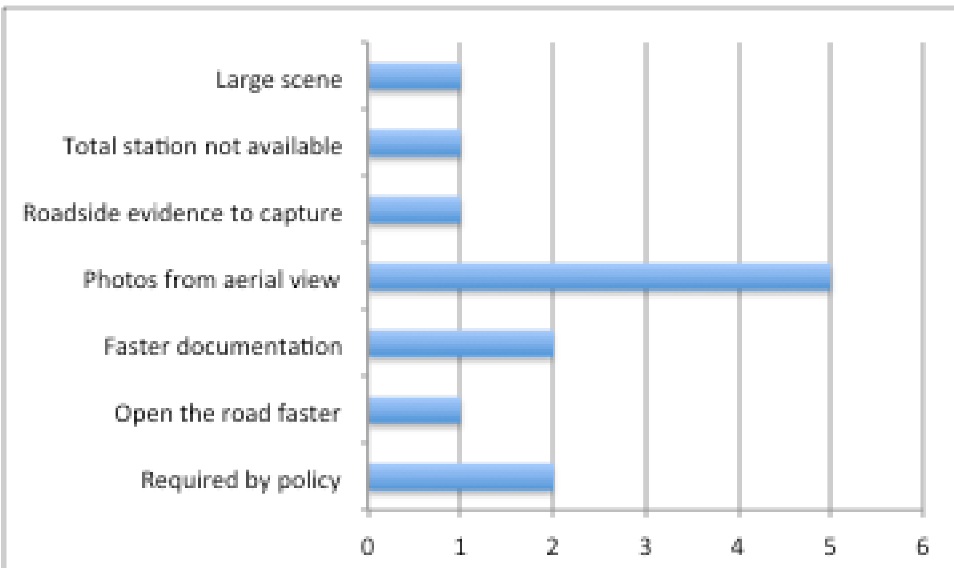

Figure 12: Reasons to request UAS support

Figure 13 shows the breakdown of the reasons given for not requesting UAS support. The most common reason given for not deploying a UAS was the time to deploy. The UAS assets/operators were far from the crash scene, so waiting for them would delay the investigation. Note that ISP only had one active pilot during the period of performance.

Another common reason for not deploying a UAS was darkness. In some of these cases UAS was requested during a subsequent site visit. Typically, the second and subsequent site visits were during the day, which allowed for UAS usage.

Other reasons for not deploying a UAS (in declining order) included expired medical certificates by the UAS operator, incident location near an airport, bad weather, lack of evidence to capture and tree cover.

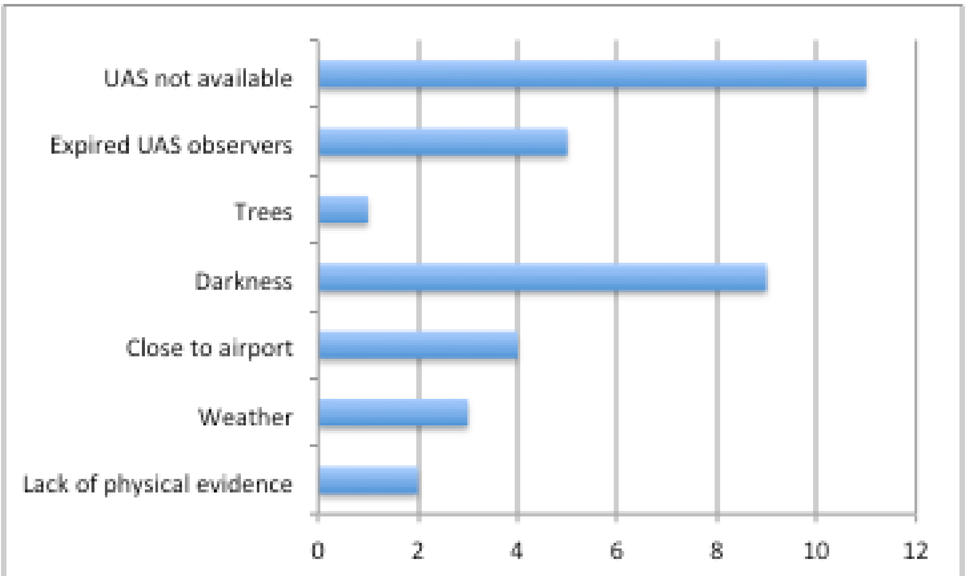

Figure 13: Reasons for not requesting UAS support

5.3.1 UAS and Total Station Timeline Data

UAS flight time was captured for 10 ISP investigations, using either the online tool or the flight log entries. Additionally, MCAT provided UAS flight times for 16 investigations they had conducted.

Timelines for the ISP UAS team showed that all UAS activities took place during daylight. Earliest time arriving on scene was 10:20am. Latest time leaving the scene was 8pm. Since this data was captured in the summer, all times at scene were in daylight.

Times for the UAS team to get to the crash scene, to start UAS setup, to start UAS flight, and to tear down after the flight were collected using only the online data collection tool, since this information is not captured in the UAS flight logs. There were 5 crash scenes for which this information was reported. The average time for the UAS team to get to a crash scene from the time they learned about incident to the time they arrived on scene was 1 hour 32 minutes. Note that, as mentioned previously, the UAS team was not requested for several scenes since they were too far away from the scene; therefore this average reflects the cases for which they were reasonably close to the scene.

Once at the scene, the time between arrival and starting UAS setup averaged 30 minutes. UAS set up time averaged 18 minutes, including one outlier scene for which the UAS set up time took 47 minutes. If the outlier is not counted, the average set up time for the remaining 4 scenes is only 11 minutes. UAS tear down time averaged 7 minutes with the UAS team remaining at the scene for an additional 22 minutes after tear down.

The average time for the ISP reconstructionist team to get to a crash scene from the time they learned about incident to the time they arrived on scene was 1 hour 19 minutes. Once at the scene, the time between arrival and starting total station setup averaged 1 hour 49 minutes. This time is significantly greater than the corresponding time for the UAS team, because there are typically additional tasks that are handled by the reconstructionists before setting up the total station. Total station set up time averaged 9 minutes, which is slightly shorter than the average UAS set up time. Total station tear down time averaged 8 minutes, which is slightly longer than the average UAS tear down time. The reconstructionist team remained at the scene for an additional 1 hour 26 minutes on average.

UAS flight time data was collected from three resources: the online tool, UAS flight log entries that were matched to reported crash incidents, and MCAT RFI response data. Figure 14 shows the distribution of UAS flight times along with TS measurement times. ISP UAS flight time averaged 24 minutes per incident with the number of flights at a scene ranging from 1 to 3. UAS flight log data showed overall UAS operation times ranging from 6 minutes to 3 hours 32 minutes. Note that the longer operation times included multi-flight scenes with the accumulation of individual flights as well as the turn-around times between flights. The 3 hours 32 minutes operation time included two flights separated by 3 hours 9 minutes; the actual combined flight time for the two flights was only 23 minutes. The next longest operation time was 1 hour 19 minutes consisting of three flights. Turn-around time between flights ranged from 16 minutes to 3 hours 22 minutes with an average of 1 hour. Individual flight times ranged from 6 to 16 minutes with an average of 12 minutes. For MCAT scenes, the average flight time was 24 minutes, consistent with the ISP data.

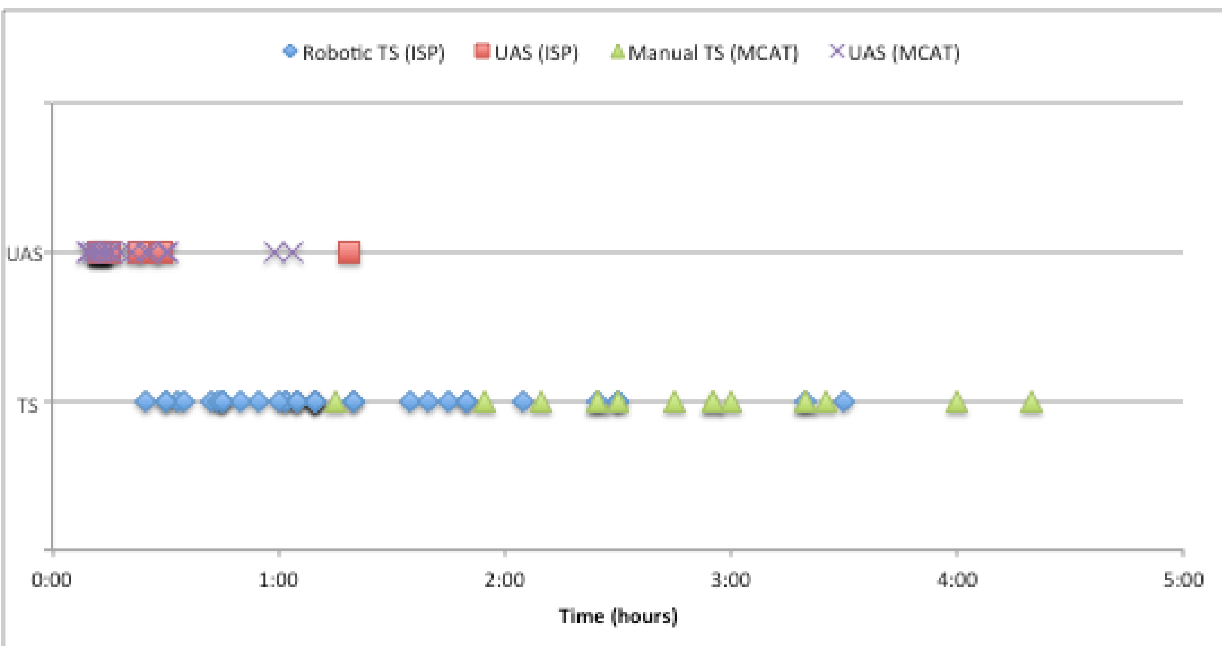

Figure 14: UAS flight time and TS data gathering time distribution

ISP total station data gathering time averaged 1 hour 19 minutes. The total station was always set up in a single tripod location. The average time per total station data point was 35 seconds. The number of data points collected ranged from 52 to 565.

Additional total station data was provided in the MCAT RFI response. For this organization, the total station data gathering time averaged 2 hours 50 minutes, and the average time per total station data point was 53 seconds. The number of data points collected ranged from 70 to 313. The increased time per data point for MCAT is likely accounted for by their usage of manual total stations. ISP utilized robotic total stations, which should typically result in faster data collection and that appears to be corroborated by this data.

Figure 15 shows a comparison of the UAS flight times and TS data gathering times. The crash investigations represented by the horizontal axis are divided into five groups. The first group consists of ISP crash investigations for which only a TS was utilized. The average TS data gathering time in this group was 1 hour 16 minutes. The second group consists of three investigations for which only UAS was utilized. The third group consists of ISP investigations for which both a UAS and a TS were utilized. The average TS data gathering time in this group was 1 hour 32 minutes, which is close to the average of the first group. The average UAS flight time in this group was 24 minutes – substantially less than the TS data gathering time. The fourth "group" is the single MCAT crash investigation for which only UAS was utilized. Finally, the fifth group consists of MCAT investigations for which both a UAS and a TS were utilized. The average TS data gathering time in this group was 2 hours 50 minutes. This time is significantly larger the corresponding time for ISP investigations, but the difference may be attributed to using manual vs robotic TS. The average UAS flight time in the fifth group was 24 minutes, which was identical to the UAS flight time in the third group.

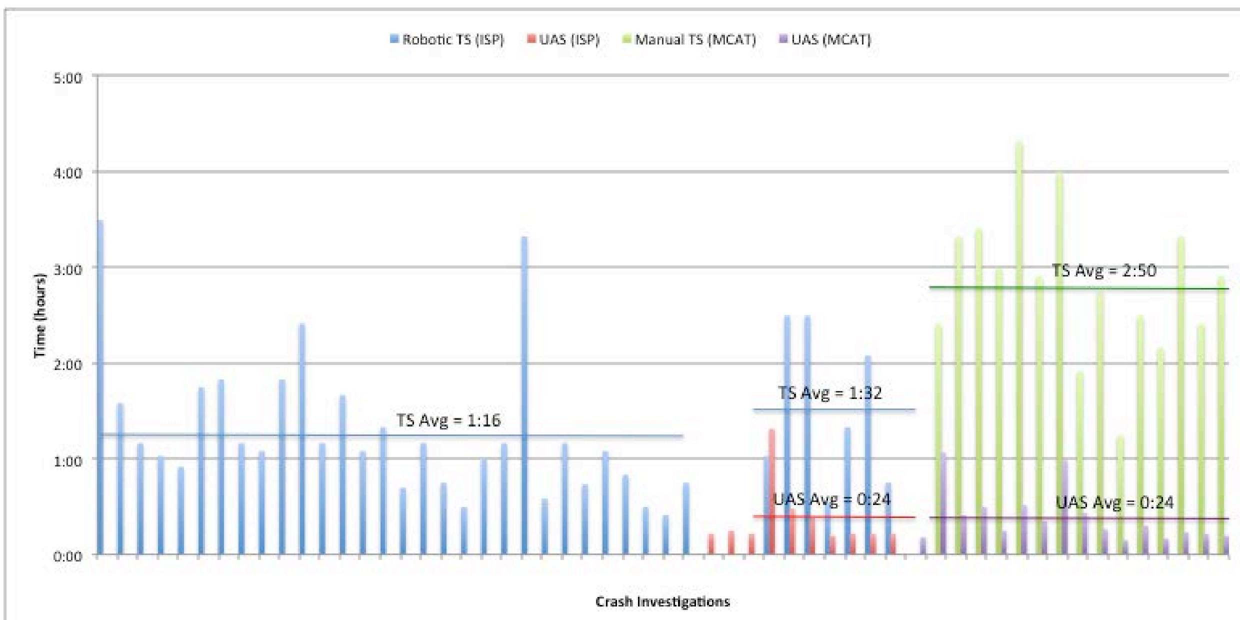

Figure 15: UAS flight time and TS data gathering time comparison

Above analysis shows that UAS flight time can be significantly less than both manual and robotic TS data gathering time. If using UAS can totally negate the need for a TS in an investigation, then the total investigation time will be reduced. The differences between UAS flight time and TS data collection time for each incident are shown in Figure 16 and Figure 17, for ISP and MCAT data, respectively. Except for one ISP investigation in which the UAS flight took longer than the TS usage, UAS flight times were consistently shorter than TS data collection times.

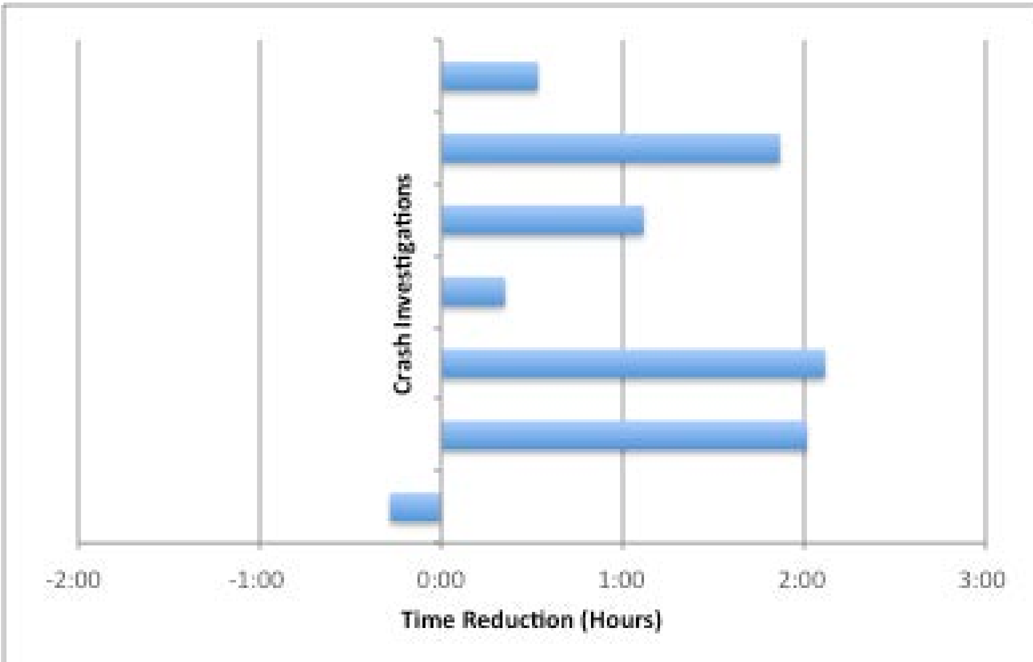

Figure 16: Potential reduction in investigation time based on ISP data

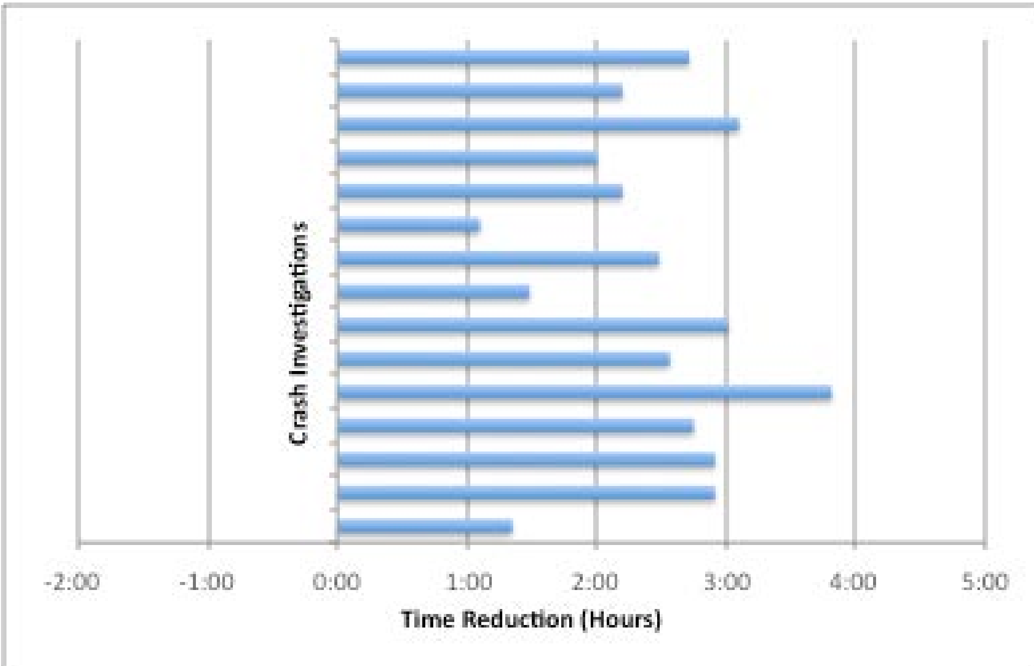

Figure 17: Potential reduction in investigation time based on MCAT data

5.3.2 Road Closure Time

Road closure times and traffic exposure data were captured from the ISP reconstructionists participating in the study. These data were not captured from the UAS team except to indicate that the team was never directly exposed to flowing traffic. Road closure times up to 9 hours 29 minutes were reported with an average time of 2 hours 36 minutes with all lanes closed and 1 hour 10 minutes with some lanes closed. Total station operators indicated that they were directly exposed to flowing traffic at 26% of the scenes. Exposure times up to 1 hour were reported. No secondary accidents were reported for any of the crash scenes.

Figure 18 illustrates the relation between TS data collection time and road closure time based on the ISP data. Although road closure is not a strict function of TS data collection time, the trend line shows increasing road closure time as TS data collection time increases. There is a positive correlation with correlation coefficient of 0.53 between the two quantities. This suggests that shortening the data collection by utilizing UAS instead of TS will result in shorter road closure times in general.

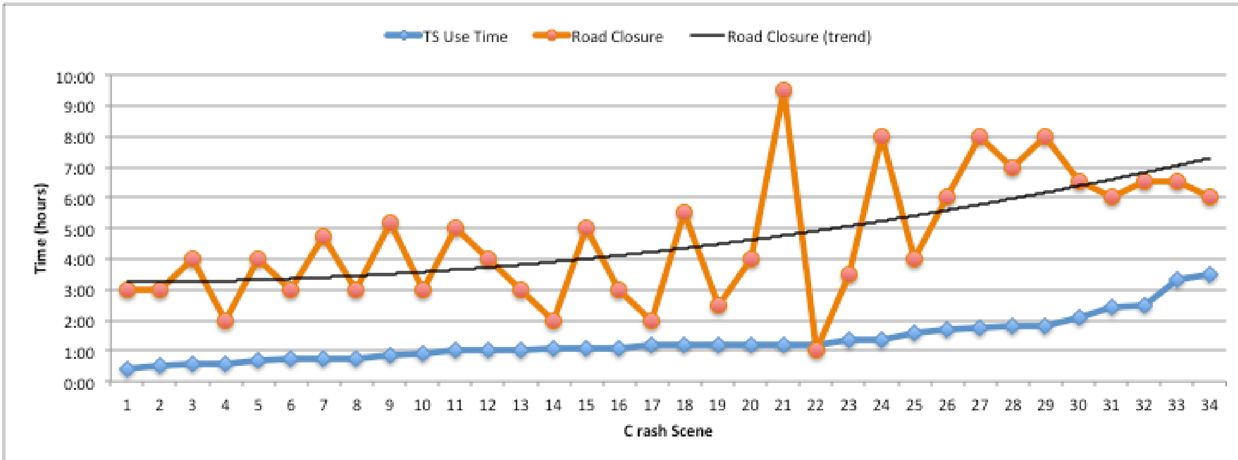

Figure 18: Road closure time and TS data collection time

5.3.3 Officer Time On Scene

Overall time on scene for the reconstructionist team averaged 2 hour 55 minutes, while the corresponding time for the UAS team averaged 1 hour 34 minutes. The reconstructionist "team" was typically one person while the UAS team was two people (pilot and observer). Note that the data on the number of people on the reconstructionist team came from ISP who uses robotic total stations. For users of manual total stations the number of people needed to operate would go up from one to two.

Figure 19 illustrates the relation between TS data collection time and officer time on scene based on the ISP data. Similar to the road closure time discussed above, the trend line for officer time on scene increases as TS data collection time increases. There is a positive correlation with correlation coefficient of 0.64 between the two quantities, suggesting that shortening the data collection by utilizing UAS instead of TS will result in shorter officer times on scene in general.

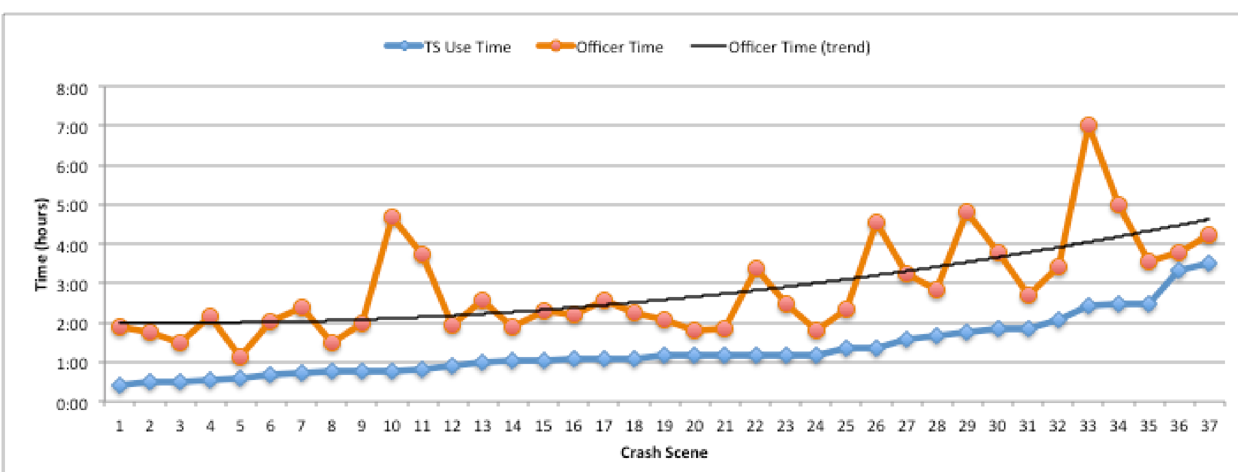

Figure 19: Officer time on scene and TS data collection time

5.3.4 Data Analysis and Accuracy

In general the reconstructionists would use both the total station data and the UAS data in their report. The primary use of the total station data is to create a diagram of the scene. Also mentioned was use of the data in speed calculations. Primary use of the UAS data is for overhead photographs of the scene. Also mentioned was using a photograph as a diagram of the scene.

As mentioned earlier, post-crash data collected was not adequate for a quantitative evaluation of UAS measurement accuracy, since ISP mainly used UAS to obtain aerial images for the investigation. Discussion with MCAT after receiving their RFI response revealed that they had conducted accuracy measurements in some of the 16 scenes they reported. They compared their photogrammetric measurement results to their ground control points measured using tape, and found that for a linear measurement the photogrammetric results matched the tape measurements within +/-0.3%.

5.3.5 UAS Operational Impact

Estimated impacts of UAS on data collection time, officer safety, and road closure time were gathered from six different ISP reconstructionists and a UAS pilot. Table 2 summarizes the responses.

		Role at this scene		
		Reconstructionist	UAS Pilot/Observer	Total
Data collection time	Faster	2	0	2
	Same	8	11	19
	Slower	2	0	2
	Total	12	11	23
First responder safety	Safer	3	0	3
	Same	9	11	20
	More dangerous	0	0	0
	Total	12	11	23
Road closure time	Shorter	2	1	3
	Same	9	10	19
	Longer	1	0	1
	Total	12	11	23

Table 2: UAS operational impact

UAS made no impact on reconstruction data collection time according to the UAS pilot. The reconstructionist responses indicated that UAS made data collection faster in 2 investigations (17%), made no impact in 8 investigations (66%) and made data collection slower in 2 investigations (17%). Reasons for faster data collection included not having to shoot as many points and faster usage than a total station. The reason for slower data collection was waiting for the UAS team to arrive.

UAS made no impact on safety for the officers and first responders according to the UAS pilot. The reconstructionist responses indicated that UAS made the investigation safer in 3 cases (25%) and had no impact on safety in 9 cases (75%). Several reasons were given for the improved safety. Using UAS resulted in less time in traffic. Road was closed for a shorter time, reducing possible secondary crashes and exposure of officers at the scene. There was also less exposure to adverse weather due to reduced road closure time.

UAS made no impact on road closure time according to the UAS pilot except one investigation, where it reduced the closure time. The reconstructionist responses indicated that UAS reduced road closure time in 2 investigations (17%), made no impact on road closure time in 9 investigations (75%), and increased it in one investigation (8%). The reason for shorter time given by several participants was that the UAS was faster to operate than what would have been required to document the scene with a total station. The reason for longer time given was the need for waiting on UAS arrival.

5.3.6 Predictions on Potential UAS Benefits

In this part of data collection, responses were requested with the premise that all logistical, administrative, and technology challenges associated with UAS use were resolved. The potential benefits or drawbacks of UAS usage for collecting data, post processing, creating reports and creating exhibits were gathered. Only reconstructionists responded to this section. The responses are summarized in Table 3, where the table entries represent the number of crash investigations that would benefit from, be unaffected by, or be adversely affected by ideal UAS use.

		Number of Crash Investigations
Collecting Data	Less time required	38
	About the same	2
	More time required	1
Post Processing	Less time required	18
	About the same	17
	More time required	6
Creating Report	Less time required	9
	About the same	26
	More time required	6
Creating Exhibits	Less time required	23
	About the same	13
	More time required	5

Table 3: Potential UAS benefits

Based on the above premise, 93% of responses indicated that less time would be required for collecting data on the scene with 5% believing there would be no change and 2% believing it would require more time. Post-processing and data analysis in the office would require less time according to 44%, about the same time according to 41%, and more time according to 15% of the responses. Creating a reconstruction report would take about the same amount of time according to 63%, require less time according to 22%, and would require more time according to 15% of participants. Creating exhibits to support deposition or testimony would require less time according to 56%, about the same according to 32%, and more time according to 12% of responses.

Also based on the above premise assuming UAS challenges have been resolved, the UAS would be the most preferred tool, identified by 89% of the responses. Also popular was the hand-held camera (80%), followed by the measuring tape (57%), total station (41%), sled (30%), and finally a smart or digital level (11%).

5.3.7 Closing

This part of data collection requested any additional details about each investigation that should be mentioned. Relatively few responses were provided. Peculiar challenges at the crash scene were mentioned such as tow truck difficulties and helicopter coordination for addressing injuries at the scene. Problems with data collection such as tree cover blocking UAS photography and total station failure were also listed.

6. SUMMARY OF FINDINGS

Currently the most common reason for using UAS in crash scene investigations is to obtain aerial photographs of the scene. The UAS provides a Bird's Eye view that may encompass the entire crash scene in one photograph. Both ISP and MSP mentioned the ability to create the entire picture within an hour of the crash, which enables them to see or to overlay crash scene details to better understand the process of the crash, including the movement of the vehicles and the direction of travel. Aerial view photographs benefit traffic incident reports regardless of how other data is gathered. ISP also highlighted the additional potential benefit for presenting crashes in court, where the overhead view from UAS can make it easier to explain the crash to the jury.

In general, use of UAS only for aerial photos to complement total station measurements does not reduce road closure time or officer on scene time significantly. In fact, waiting for a UAS pilot to arrive can increase these times. However there were a few crash scenes for which the reconstructionists believed that UAS use reduced the road closure time and officer on scene time.

Using photogrammetry software with UAS enables making measurements of the crash scene. Although this use was not common in our study sample, and UAS photogrammetry data has had little to no usage in court yet by participants in the operational evaluation, reported accuracy of UAS photogrammetry measurements in earlier studies suggests that this method can replace total station usage at least in some cases. When used in place of a total station, UAS can save, on average, approximately one hour when replacing a robotic total station or two hours when replacing a manual total station for data gathering at the scene, resulting in potentially shorter road closure times and officer on scene times. This potential benefit of UAS is recognized and it was mentioned by all of the interviewed law enforcement agencies. ISP added that this benefit outweighs the cost of operating the UAS.

Replacing total station usage by UAS requires trust in the accuracy of measurements using UAS with photogrammetry and an increased availability of UAS for crash scene investigations. The trust can be improved by further studies in a variety of conditions that compare UAS measurements with total station measurements. It would be important to identify equipment, software, environment, and weather factors that may impact measurement accuracy. A related concern is the lack of assurance in the completeness of the captured UAS data before leaving a scene. Photogrammetry measurements require that the appropriate ground control points are included in the photos, the photos overlap an appropriate amount, and the coverage area is wide enough for adequate overlap at the edges of the area of interest. Validation of the collected data at the crash scene is critical because errors or missing data discovered during post-processing would require additional visits to scene and some evidence may be lost.

The availability of UAS for a crash scene investigation was affected by several factors. Time to deploy was the primary issue that held back UAS usage. FAA rules requiring a pilot's license to operate UAS prevented most reconstructionists from operating UAS themselves. If the UAS assets/operators were far from the crash scene, UAS may not have been deployed since waiting for them would delay the investigation. Expiration of UAS operator's medical certificates also prevented UAS deployment for several investigations throughout the study period. The recent release of FAA Part 107 may help mitigate these issues by reducing the requirements for certification to operate the UAS.

Another common issue holding back UAS usage was scene darkness. FAA rules limit UAS use for law enforcement to daytime operations unless the COA specifically allows nighttime usage; therefore UAS were not deployed for several nighttime crash investigations or UAS operators came to the scene later to take the aerial pictures. Such follow up visits also enable working around the weather limitations of UAS.

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8. APPENDIX A: UAS TECHNICAL SPECIFICATIONS

8.1 Leptron Quad Copter

This section provides detailed technical specifications of the Leptron Quad Copter, shown in Figure 20.

Figure 20: Leptron Quad Copter

Technical specifications (Ref. [18], [19]):

General	
Product Name:	Leptron RDASS Quadcopter
Product Description:	
Year of initial development::	2009
Year of last update:	2016
Typical Applications:	Commercial and Public Safety
Platform	
Platform:	Aircraft
Brand:	Leptron RDASS
Max. payload [kg]:	.8
Max. stay in the air [min]:	15
Max. speed [km/h]:	15
Max. height above ground [m]:	3650
Propulsion:	Electric
Dimensions	
ø / wingspan [cm]:	80.1
Height [cm]:	30
Weight [kg]:	3.5
Weight of battery [kg]:	1.3
Weight of filled fuel tank [kg]:	0

Dimensions	
Number of rotors:	4
Transport on human back:	Y
Environment	
Min. operation temperature [°C]:	-17
Max. operation temperature [°C]:	43
Max. wind speed [m/sec]:	15
Max. humidity [%]:	100
Navigation Sensors	
Onboard navigation sensors:	IMU, Compass
Type of GNSS:	
Type of IMU:	
Type of Barometer:	
Type of Compass:	
Other :	
Imaging/scanning devices	
Onboard imaging/scanning devices:	Camera, Additional sensors
Type of Camera:	Application Specific
Type of Lidar:	Application Specific
Additional Sensors:	Custom
Build-in Stabilization:	Y
Exchangeable :	Y
Sensor tilting to allow oblique views:	Y
Launch and Landing	
Min. ø of launch/landing site [m]:	1
Launching method:	VTOL
Automatic landing:	Y
Fully pre-programmable flight:	Y
Piloting	
Min. size of field crew:	1
Piloting skills required:	N
Training provided:	Y
Amount of training [hrs]:	40
Software Included	
Type of software included:	Flight planning, Photogrammetric software, Point cloud processing software

Software Included	
Block adjustment software:	
Camera self-calibration software:	
Flight planning software:	
Photogrammetric software:	
Point could processing software:	
Automatic Generated Products	
Automatically Generated Products:	
Safety	
Shielded propellers:	No
Collision avoidance systems (CAS):	Y
Autonomous emergency landing :	Y
Base Station	
Ground computer included:	Y
Type of Ground computer:	
Sensor control:	
Real time image and video download link:	Y
Speed downloadlink [Mbytes/sec]:	

8.2 Aeryon Sky Ranger

This section provides detailed technical specifications of the Aeryon SkyRanger shown in Figure 21.

Figure 21: Aeryon SkyRanger

Technical specifications (Ref. [20], [21]):

General	
Product Name:	Aeryon SkyRanger

General	
Product Description:	Suitable for a wide range of mapping and surveying applications, the Aeryon SkyRanger provides; single operator transport and deployment; up to 50 minutes of flight time; reliable flight performance in demanding environments and high winds; integrated payloads and software solutions.
Year of initial development::	2013
Year of last update:	2013
Typical Applications:	Aerial imagery, inspection, surveying, mapping
Platform	
Platform:	Copter
Brand:	Aeryon
Max. payload [kg]:	1.0
Max. stay in the air [min]:	50
Max. speed [km/h]:	65
Max. height above ground [m]:	1500
Propulsion:	Battery
Dimensions	
ø / wingspan [cm]:	102
Height [cm]:	24
Weight [kg]:	2.4
Weight of battery [kg]:	1.2
Weight of filled fuel tank [kg]:	
Number of rotors:	4
Transport on human back:	Y
Environment	
Min. operation temperature [°C]:	-30
Max. operation temperature [°C]:	50
Max. wind speed [m/sec]:	65
Max. humidity [%]:	
Navigation Sensors	
Onboard navigation sensors:	
Type of GNSS:	
Type of IMU:	
Type of Barometer:	

Navigation Sensors	
Type of Compass:	
Other :	
Imaging/scanning devices	
Onboard imaging/scanning devices:	Camera
Type of Camera:	HD, IR
Type of Lidar:	
Additional Sensors:	
Build-in Stabilization:	Y
Exchangeable :	Y
Sensor tilting to allow oblique views:	Y
Launch and Landing	
Min. ø of launch/landing site [m]:	6
Launching method:	Vertical Take-Off and Landing (VTOL)
Automatic landing:	Y
Fully pre-programmable flight :	Y
Piloting	
Min. size of field crew:	1
Piloting skills required:	N
Training provided:	Y
Amount of training [hrs]:	
Software Included	
Type of software included:	Flight planning, Photogrammetric software, Point cloud processing software
Block adjustment software:	
Camera self-calibration software:	
Flight planning software:	Aeryon MCS
Photogrammetric software:	Pix4D
Point could processing software:	Pix4D
Automatic Generated Products	
Automatically Generated Products:	3D City Models, 3D Landscape Models, DEMs, Orthomosaics
Safety	
Shielded propellers:	Not applicable
Collision avoidance systems (CAS):	N
Autonomous emergency landing :	Y
Base Station	

Base Station	
Ground computer included:	Y
Type of Ground computer:	Tablet
Sensor control:	Y
Real time image and video download link:	Y
Speed downloadlink [Mbytes/sec]:	6 Mbit

The SkyRanger has a maximum flight time of 50 minutes with payload. It can tolerate 40 mph sustained wind or 55 mph wind gusts and has a temperature range of -22F to 122F. It supports a secure network connectivity using AES 256 bit encryption.

8.3 DJI Inspire 1

This section provides detailed technical specifications of the DJI Inspire 1 shown in Figure 22.

Figure 22: DJI inspire 1

Technical specifications (Ref. [22], [23]):

General	
Product Name:	DJI Inspire 1
Product Description:	Quad copter capable of capturing 4K video and 12 megapixel photo capture and transmitting HD video to multiple devices. Provides dual controller mode. Equipped with retractable landing gear, it can capture unobstructed 360 degree view from camera. Advanced all in one video in the market. Has approximately 18 minutes maximum flight time
Typical Applications:	Aerial imagery and video popular with film makers on a budget.
Aircraft	

Aircraft	
Model	T600
Max. payload [kg]:	3.4
Max. stay in the air [min]:	18
Max. speed [m/s]	22
Max. height above ground [m]:	4500
Dimensions	
Height [cm]:	43.8
Width [cm]:	45.1
Length [cm]:	30.1
Environment	
Min. operation temperature [°C]:	-10
Max. operation temperature [°C]:	40
Max. wind speed resistance[m/sec]:	10
Max. humidity [%]:	
Gimbal	
Model	ZENMUSE X3
Output Power (with camera)	Static: 9W; In Motion: 11W
Operating Current	Station: 750 mA; Motion: 900 mA
Mounting	Detachable
Camera	
Onboard imaging/scanning devices:	Camera
Name	X3
Model	FC350
Total Pixels:	12.76M
Effective Pixel	12.4M
Image Max Size	4000x3000
ISO Range	100-3200 (video) 100-1600 (photo)
Electronic Shutter Speed	8 s to 1/8000 s
CMOS	Sony EXMOR ½.3”
Video Recording Modes	UHD (4K); FHD; HD
Supported File Formats	FAT32/exFAT Photo: JPEG, DNG Video: MP4?MOV (MPEG-4 AVC/H.264)
Operating Temperature Range [C]	0 to 40
Battery (standard)	
Name	Intelligent Flight Battery
Model	TB47

Battery (standard)	
Capacity	4500 mAh
Net weight	570 g
DJI Pilot App	
Mobile Device System Requirements	iOS version 7.1 or later; Android version 4.1.2 or later
Software	
Flight planning software:	Pix4D; Map Pilot App
Photogrammetric software:	Pix4D

DJI Inspire 1 has a maximum flight time of 18 minutes with an operating temperature range of 14F to 104F. The gimbal and camera settings are integrated into its remote controller. It has smartphone compatibility provided by a DJI GO application. Mobile device operating system requirements are iOS8.0 or later and Android 4.1.2 or later. DJI Inspire 1 is supported by several mobile devices including iPhone 6, iPhone 5S, iPad Air, iPad Air 2, iPad Mini 2, iPad Mini 3, iPad 4; Samsung Note 3, Samsung S5 and Sony Z3 EXPERIA. It is recommended to use a tablet for the best experience.

9. APPENDIX B: MEETING NOTES FROM LEA INTERVIEWS

This appendix provides details of the interviews RT&E Center conducted with participating LEAs. The interviews in Sections 9.1 to 9.4 were conducted by phone and the interviews in Sections 9.5 to 9.7 were conducted face-to-face during study team's Michigan trip.

9.1 Interview with Brook Rollins, Special Operations Division Researcher, APD

Lieutenant Brook Rollins is with the Special Operations Division of the Arlington, TX Police Department. He conducts research for the department. The RT&E Center team interviewed Lt. Rollins on March 25, 2016. Below are the notes from this interview:

- UAS are being used for crash reconstruction (for speed up), crime scene search, missing persons, and for clearing areas difficult to clear by foot.
- For crash reconstruction, UAS are typically only deployed at fatality accidents. UAS are not available for all crash teams.
- The UAS team comprises of three people: a primary pilot, a safety pilot, and a distance scene security.
- Benefits of the UAS include speeding up the investigation, keeping officers away from harm's way, and opening the highways faster after a crash.
- The Arlington, TX Police Department performs six to eight UAS missions per year with a quarter of them traffic related.
- The primary data product from the UAS is a video of the crash scene.

9.2 Interview with Allan Avery, Reconstructionist, MSP

Sergeant Allan Avery is a reconstructionist with the Michigan State Police. He is responsible for all fatal and serious crashes in his region under state police jurisdiction and assists other agencies on serious injuries and fatal crashes. The RT&E Center team interviewed Sgt. Avery on April 26, 2016. Below are the notes from this interview:

- There are nine reconstructionists across the state of Michigan, each with their own region, but they help each other as needed.
- The reconstructionists don't fly the UAS. Instead, they call the aviation unit when UAS support is desired. The aviation unit is briefed by the reconstructionist, performs the flight(s), and gives the captured images to the reconstructionist.
- The reconstructionists have had some issues with the software for handling the images. Large files can sometimes overwhelm the software.
- The overhead shots are valuable for the report. Sometimes when UAS are unavailable, a Google Map image is used in the report but this is not as compelling as an image from the scene showing the evidence.
- It is unlikely that UAS can replace a total station because of the restrictions due to darkness, airport proximity and weather conditions, but they complement each other.

9.3 Interview with Brian Miller, Unmanned Aircraft System Coordinator/Pilot, ISP

Mr. Brian Miller is the Unmanned Aircraft System Coordinator/Pilot as well as the Forensic Diagramming and Animation Section supervisor with the Crime Scene Services Command of the Illinois State Police. His background is in photographic production technology. The RT&E Center team interviewed Mr. Miller on April 26, 2016. Below are the notes from this interview:

- Mr. Miller had suggested the use of UAS to the department as a result of observing officers capturing crash scene photographs via a chest height camera that produced poor quality.
- Mr. Miller believes there are multiple benefits of using UAS. UAS can enable opening of highways in a shorter period of time. When a jury sees a bird's eye view they can better understand the spatial relationships in the scene, which may help the jurors get on the same page with the reconstructionist.
- The primary UAS data product is a picture of the entire scene.
- Accurate measurements of distances and crush would require a photogrammetry software tool like Pix4D.
- It was noted that ISP is one of the few police departments that has a section geared to providing diagraming assistance, animations and photography.
- UAS operations require a pilot and an observer. Crash scene investigation officers have been trained as observers. This allows an officer to talk to the pilot without violating FAA's sterile cockpit rules.

9.4 Interview with Robert Ventura, Traffic Crash Reconstruction Resource Officer, ISP

Sergeant Robert Ventura is a Traffic Crash Reconstruction Resource Officer with the Illinois State Police. He is a front line supervisor, primary responder, and resource officer managing reconstructionists in a region south of Chicago. The RT&E Center team interviewed Sgt. Ventura on April 28, 2016. Below are the notes from this interview:

- ISP captures both pictures and video from the UAS. They typically fly the aircraft to its ceiling (400 feet) first, and then it comes down and takes closer shots to reveal more detail. It takes lookdown shots of individual vehicles from about 10 feet to capture the crush information, which helps determining the direction of force and enables crush measurements from the photos. The aircraft then captures a video from the perspective of each of the vehicles, from each direction.
- Upon completion, the pilot lands the aircraft, immediately downloads the SD memory card to an external drive, and the reconstructionist reviews it. In most cases the pilot hands off the pictures to the reconstructionist and then leaves. The reconstructionist continues working at the scene gathering other necessary data.
- Sgt. Ventura sited two main benefits of using UAS. He indicated that a scene that would have taken 2 hours to clear can be reduced to 30 minutes with a UAS. He also mentioned that the aerial view of a crash scene provides value. Looking at a crash scene from 100

feet up provides insights such as the path of the vehicles, the movement of the vehicles, and how they rotated, as indicated by tire marks or tire scrubs. The reconstructionist may not see the trails from a close range but they can be visible from a bird's eye view.

- Prior to UAS, ISP had an air operations division with manned aircraft. Images obtained from these planes were sometimes blurry because the planes move fast and the camera technology was not as good.
- Measurements with a total station are accurate, but they require assumptions regarding objects such as the lane line width and tire width. Measurement accuracy depends on the accuracy of these assumptions. Measurements using UAS, particularly with Pix4D, don't require similar assumptions.
- Measurements with a total station may take several hours, whereas UAS measurements are much quicker.
- Sgt. Ventura mentioned that the lack of nighttime operations is one of the main barriers to UAS use. The current workaround is marking the location of the cars and highlighting short-lived evidence, so that a good representation of a scene can be captured a day or a week later. A top down view of the scene is still valuable even if it is not captured immediately after the crash.
- Sgt. Ventura discussed public perception of UAS use with the RT&E Center team. He mentioned that people can perceive UAS as offensive systems and can believe UAS will fly around and look into their houses, while this is not even an option.
- In September-October 2015, ISP had a news channel go to the crash scenes with the UAS team. The news channel ran a story, where ISP was able to convey the value of UAS to the public. Sgt. Ventura believes that the public found the story very interesting.

9.5 Interview with Angie Kremer, Traffic Incident Management Engineer, MDOT

Angie Kremer is a Traffic Incident Management Engineer for MDOT who works closely with the MSP. The RT&E Center team met with her at the MSP Aviation Unit on Port Lansing Road in Lansing, MI. Below are the notes from the interview with Ms. Kremer:

- UAS are envisioned to be used by the MDOT for bridge inspection, surveys, asset management, and crash reconstruction.
- Crash reconstruction depends on photogrammetry for measurements. Since photogrammetry has been tried in court, Ms. Kremer expects that the courts would accept UAS usage. She noted that there is a significant learning curve on photogrammetry software.
- MDOT is involved with safety of responders at crash scenes. Anyone at a crash scene can be in danger regardless of where they are at the scene. MDOT emphasizes that responders should use best traffic management practices to minimize danger, including blocking the vehicles, having chevron markings on the backs of the vehicles, and wearing reflective vests.

- Ms. Kremer pointed out that tow truck drivers are at the highest risk at a crash scene. Minimizing the time on scene improves safety; therefore, MDOT provides incentives to tow truck operators for quick turnaround.
- Part of the value of UAS photogrammetry is that it reduces the time on scene and instead moves some of the crash reconstruction work to a post-processing activity back at the station. Paradoxically, there can be disincentives regarding moving this work. Officers potentially get overtime at the scene but are less likely to get it if doing work back at the station.

9.6 Interview with Matt Rogers, Tactical Flight Officer, MSP

Sgt. Matt Rogers is a Tactical Flight Officer (TFO) for the MSP Aviation Unit and also runs the MSP Unmanned Aircraft Systems (UAS) program. Sgt. Rogers has 20 years of experience in law enforcement. His background includes road patrol, undercover investigation, driving instructor, detective, post supervisor, and the Aviation Unit UAS team. He possesses a pilot's license (now inactive) which is a requirement for UAS operation under MSP's FAA COA. Below are the notes from the interview with Sgt. Rogers:

- Sgt. Rogers helped establish the UAS team for MSP. The UAS program was established with funding support from a homeland security grant after policies were put into place with transparency as a focus. Outreach was made to both the ACLU and media outlets prior to initiating the program.
- MSP selected their UAS based primarily on a report from the Department of Homeland Security (DHS), Science &Technology (S&T) Robotic Aircraft for Public Safety (RAPS) program that tested and evaluated Small Unmanned Aircraft Systems for potential use by the first responder community and DHS operational components. Flight demonstrations for MSP were not possible since vendors did not have the FAA Section 333 Exemption authorization granted, so having the evaluations of the various vendors from the RAPS report were critical.
- The UAS team is part of the MSP Aviation Unit and supports other parts of the MSP organization including the reconstructionists. When desired, the reconstructionists contact the UAS team requesting support. There is a plan to include personnel with a reconstruction background on the UAS team.
- Coincidentally, the RT&E Center team was visiting the MSP Aviation Unit on the day they were celebrating the completion of 100 UAS missions. Sgts. Matt Rogers and Jerry King were honored for their involvement with the UAS program. UAS equipment was put on display and cake was served.

Figure 23: Celebrating 100 UAS missions (left – Sgt. Jerry King, right – Sgt. Matt Rogers.)

:

Figure 24: Congratulations MSP March 2015 - March 2016 UAS 100th Mission

- The 100 missions performed by the MSP UAS team break down approximately as follows: 25% fire and arson scenes, 25% crime scenes, 25% traffic crash scenes, 25% training.
- MSP uses the Aeryon SkyRanger UAS. The SkyRanger had the highest ratings in class in the RAPS survey. Of particular interest to MSP was the exceptional flight time of up to 50 minutes on a single battery charge. The SkyRanger includes many safety features including auto return and land if any flight parameter is out of limits. Parameters include battery power, wind speed and communications link status.
- The SkyRanger also integrates seamlessly with the Pix4D photogrammetry software. The SkyRanger control station provides a user interface well-tailored to the needs of Pix4D. Rather than flying the aircraft in the traditional manner using stick controls and manually snapping photos, an area of interest polygon is drawn on a map (Google Maps or similar) of the flight area. The control station then calculates a flight plan that covers the entire polygon and determines the flight path and frequency for taking photos based on the desired overlap between photos. The photogrammetry software ingests the resulting set of photos and produces various work products.
- The primary photogrammetry work product used by MSP is a single large mosaic photo created by "stitching" together the multiple individual photos The photogrammetry

software uses metadata provided with the individual photos along with the redundant information in the overlapping images to ensure that the large mosaic is seamless and geo-referenced. The large mosaic provides a wide-area high-resolution view of the crash scene and may also be used to make distance measurements.

- Currently the UAS data is used to supplement the data traditionally gathered by the reconstructionist. It provides a bird's eye view of the crash scene that helps tell the story of what happened.
- While distance measurements could in concept replace measurements taken from some other source such as a total station, currently the data is not being used in this manner. The UAS distance data is sometimes used as a cross check to make sure the other measurement tools are working properly.
- Because of their proximity, MSP UAS team has experience working with the police in Canada. Toronto, Canada uses UAS more extensively than Michigan. Sgt. Rogers indicated that the reasons for this include the lack of FAA oversight, making it much easier to deploy, and the better weather as compared to Michigan. Transport Canada has different UAS aviation regulations than those established by the FAA in the United States.
- The MSP UAS team is very concerned about public perception and is taking a conservative approach in establishing usage. They are avoiding even the perception of contentious usages. For a recent event they used a helicopter for a surveillance mission instead of the UAS, because the public is accustomed to seeing a helicopter overhead. The UAS could have performed the same mission much cheaper.
- Regarding crash reconstruction, Sgt. Rogers indicated during the interview that UAS data has yet to go to trial. There are not yet judicial precedents to establish what will be accepted. It is believed that because the UAS data is based on photogrammetry, it should be perceived as technically sound in the court. While many areas of the country do use photogrammetry for reconstruction purposes, it is not common in Michigan.
- MSP Aviation Unit Chief Pilot Lt. Patrick Lawrence was also present during part of the interview. He was asked if he thought it was reasonable to operate the UAS with one person. Lt. Lawrence mentioned the concerns that UAS may collide with a manned airplane and felt that two people (one pilot, one spotter) are critical to safety. He believes that UAS should be part of an aviation unit where the culture in place already has an established understanding of the airspace and the sorts of missions performed by UAS since they are similar to the missions already being performed by other aviation assets (manned fixed wing aircraft and helicopters). He also acknowledged that the location of the teams is a consideration. A single unit requires extensive travel in response to requests for service.
- MSP started to use reference marks at every scene to aid the photogrammetry software in performing the geo-referencing. They continually refine the methods by which they establish the reference marks (currently looking at supplemental GPS hardware to independently measure the marks) to improve the accuracy of the system.
- When asked about additional capabilities desired in the UAS, Lt. Lawrence and Sgt. Rogers provided several future improvements they would like to see:

- Recently they have been looking into the addition of an ADS-B[1] receiver to their setup to be able to electronically detect other nearby manned aircraft.
- The real-time video downlink needs to support higher data rates to keep up with the capabilities of the payloads. Currently the best quality video is stored onboard the UAS for retrieval after the air vehicle lands. The video on the downlink is compressed to a lower resolution and lower refresh rate and is noticeably worse than the stored video.
- Finally, the files created by the Pix4D photogrammetry software are extremely large and overwhelm the IT infrastructure. Some of the tools used by the reconstructionists also have trouble ingesting these big files.

9.7 Interview with Steve Cook, Operations Engineer, MDOT

Steve Cook, P.E. is an Operations Engineer for MDOT and Project Manager for the MDOT program called Implementation of Unmanned Aerial Vehicles for Assessment of Transportation Infrastructure. The focus of the interview with Mr. Cook was on UAS usage by MDOT. Below are the notes from this interview:

- MDOT has been sponsoring a multiphase research project evaluating the viability of UAS in support of MDOT needs. Some of these needs have similar issues as crash reconstruction such as minimizing disruptions of traffic and capturing photos of a scene. MDOT is also dealing with FAA constraints as well as concerns with public perception.
- Viability studies investigated possible uses for UAS. Research was performed to see how UAS could provide visual inspections for a variety of structures and locations of interest to MDOT. These included confined spaces such as pumps stations and entrances to sewers and culverts. They investigated the use of infrared imaging to evaluate surface and structural integrity of bridge elements. Traffic monitoring and construction site monitoring demonstrations were performed.
- MDOT is also evaluating the possible use of UAS in support of Property Division Reclamation Project (PDRP). PDRP is responsible for roadway maintenance issues such as fixing damaged guardrails. UAS are envisioned to capture photos of the damage and follow up with photos of the repair to reduce time on scene and streamline record keeping for PDRP events. Another idea mentioned was the possibility of replacing permanent camera towers along the roadways with autonomous UAS monitoring traffic corridors. As UAS become more automated over time, human interaction will be further reduced.
- MDOT currently has several UAS assets, but they will likely subcontract for UAS services in the future. They believe that the growing commercial UAS sector will provide these services in a more efficient manner than MDOT can do directly.

[1] Automatic Dependent Surveillance-Broadcast (ADS-B) is FAA's satellite-based successor to radar. ADS-B makes use of GPS technology to determine and share precise aircraft location information, and streams additional flight information to the cockpits of properly equipped aircraft. (https://www.faa.gov/nextgen/programs/)

10. APPENDIX C: ABBREVIATIONS AND ACRONYMS

APD	Arlington, Texas, Police Department
COA	Certificate of Waiver or Authorization
CRP	Close-Range Photogrammetry
CSR	Crash Scene Reconstruction
DHS	Department of Homeland Security
FAA	Federal Aviation Administration
FDOT	Florida Department of Transportation
GPS	Global Positioning System
HD	High Definition
ISP	Illinois State Police
JHU/APL	Johns Hopkins University Applied Physics Laboratory
LEA	Law Enforcement Agency
MCAT	Major Crash Assistance Team
MDOT	Michigan Department of Transportation
MSP	Michigan State Police
NIJ	National Institute of Justice
PDRP	Property Division Reclamation Project
RAPS	Robotic Aircraft for Public Safety
RFI	Request for Information
RT&E Center	National Criminal Justice Technology Research, Test, and Evaluation Center
SWaP	Size, Weight and Power
TS	Total Station
UAS	Unmanned Aircraft Systems
USDOT	U.S. Department of Transportation
VTOL	Vertical Take-Off and Landing

11. APPENDIX D: GLOSSARY

Contact Damage	A type of damage that can occur on a vehicle caused by direct contact with some object that is not a part of the vehicle itself
Crash Scene Reconstruction	The systematic practice of investigating, analyzing, and drawing conclusions about the origins and sequence of events for a traffic incident
Incident Clearance Time	The time between the first recordable awareness of an incident by a responsible agency (incident reported) and the time at which the last responder has left the scene
Induced Damage	A type of damage that can occur to vehicle parts that did not come in contact with the object struck, but result from the shock of the collision
Lidar	A laser scanning system that uses light waves to perform detection and ranging
Personnel Exposure Time	The cumulative time law enforcement officers remain at risk at the crash site from arrival to departure
Photogrammetry	The science of making measurements from photographs
Roadway Clearance Time	The time between the first recordable awareness of an incident by a responsible agency (incident reported) and the first confirmation that all lanes are available for traffic flow
Total Station	An electro-optical instrument that measures the position of an item relative to the instrument by combining a laser range finder for distance measurement and an electronic theodolite for angle measurement