IDEA

Innovations Deserving
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Transit IDEA Program

sUAS-based GeoINTEL1 for Commuter Rail Parking in Rural and Suburban Areas

Final Report for
Transit IDEA Project 90

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sUAS-based GeoINTEL[1] for Commuter Rail Parking in Rural and Suburban Areas

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[1] Small Unmanned Aircraft Systems (sUAS) based geo-spatial intelligence (GeoINTEL)

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IDEA T-90 EXECUTIVE SUMMARY

Concept and Innovation

Commuter rail services bring travelers from the rural and suburban fringes to the inner neighborhoods and central business districts of many large metropolitan areas in the U.S. The isolated nature of these rural and suburban commuter rail parking lots makes it difficult and expensive to secure and safely operate these transit assets. Further, as the more than two dozen commuter rail systems in the U.S. try to avoid cash payments for fares and parking fees, they must embrace consumer friendly options and mobile phone-based payment systems. These fare systems are not standardized and are not easily integrated into large databases for "big data" analysis. This situation makes the validation of commuter rail parking payments difficult and increases the potential for systemic fraud and abuse.

FIGURE 1. DJI Inspire 2 with Remote Pilot. Photo by Bridgewater State University Public Affairs Office

Using automated flight modes, the sUAS can provide high resolution imagery that can document *each individual vehicle parked in a specific parking space at a specific date and time*. The speed at which this data can be collected is at least four times faster than manual methods, thereby providing four times the efficiency of data collection using the same human resources (the remote pilot)[2]. In addition to revenue validation, sUAS capabilities can be used to detect *breaking and entering* (B&E) into parked vehicles and *physical assault* of commuters through an efficient and effective reconnaissance operation. *The purpose of this research project is to develop, and field test a <u>prototype</u> of small unmanned aircraft systems (sUAS) and geospatial intelligence (GeoINTEL) technology in a "LivingLab[3]" to enhance the safety, security, and validation of parking revenue at small urban and rural commuter rail parking areas.*

The primary objectives of the prototype

- To develop and publish a *systems engineering approach* for the project that can be readily used by local FAA-certified remote pilots and public transit personnel to procure and update sUAS geospatial intelligence hardware and software.
- To develop a prototype *sUAS technology* application that can be applied in a cost-effective manner by regional transit agencies managing commuter rail parking facilities in small urban and rural commuter rail systems with existing staff and within the rules and regulations of the Federal Aviation Administration (FAA).
- To develop a prototype <u>*geospatial analysis*</u> application that uses commercially available off the shelf (COTS) software and hardware that can enhance the safety and security of commuter rail parking lots <u>*and*</u> provide parking revenue validation.

Conclusions

Objective #1. *Systems Engineering for Transit-90.* The U.S. DOT approach to systems engineering for intelligent transportation systems was very helpful in organizing this prototype project. While sUAS are much less complex than city-wide multi-modal ITS systems, the ITS process was particularly adaptable for designing and delivering

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[2]These efficiencies may be understated. The Department of Interior's annual report (April 2019) on its "Drones for Good" program noted efficiencies of data collection seven times faster at 1/10th the cost. See https://www.doi.gov/sites/doi.gov/files/uploads/doi_fy_2018_uas_use_report.pdf accessed by L. Harman on 23 April 2019.
[3]See the Wikipedia description of the LivingLab research concept at https://en.wikipedia.org/wiki/Living_lab accessed by L. Harman on 23 April 2019.

sUAS/GeoINTEL applications for small urban and rural systems. The systems engineering approach was used to update sUAS/GeoINTEL products and services over the course of the project.

Objective #2. *sUAS Technology Applications.* Drone manufacturers came out with improvements to sUAS that raised the potential for application in small urban and rural transit settings including the following features.

- *Geofencing technology is now standard* that prevents drones from taking off in and around airports or over large crowds and festivals and sporting events without FAA authorization.
- *Computer Vision for 360° obstacle avoidance and using visual positioning systems*. Advanced sUAS have 3-D visioning systems for avoiding obstacles in flight and maintaining its vertical position without global positioning systems (GPS) when flying indoors. A few manufacturers have added advanced pilot assistance systems (APAS). When reaching an obstacle, the sUAS with APAS will attempt to fly around it.
- *Automatic Dependent Surveillance-Broadcast (ADS-B) system to detect aircraft for drone pilots.* Commercial drone manufacturers can provide ADS-B systems to detect manned aircraft within 3 statute miles of their drones and notify the remote pilot of the potential for collision with the drone through their radio controller.
- *Increasing availability of inexpensive remote pilot training programs for FAA sUAS certification, flying skills, and geospatial analysis of sUAS-based imagery*. Currently, there are approximately 116,000 commercial remote pilots that have been certified by FAA since December 2018. The FAA forecasts a that 350,000 remote pilots will be needed in 5 years. The most recent FAA re-authorization law (2018) has encouraged higher education, particularly public community colleges, to get involved in workforce development for UAS pilots.

Objective #3. *Geospatial Analysis Application.* Matching the rapid technology innovations in aircraft systems are the improvements in geospatial analytical software and Cloud-based services over the past year.

- *Software-as-a-service (SaaS) geospatial tools that provide production of 2D high-resolution "stitched" orthophoto mosaics and 3D models for aerial photography and thermal imagery*. Geospatial intelligence analytical tools are becoming more powerful, easier to use, more Cloud-based and somewhat less expensive over the past year. Corporate partnerships between drone manufacturers and global computer hardware and software firms are being announced with much promise for *faster, better, and cheaper* sUAS geospatial intelligence analysis.

- *Cyber-security capabilities for secure operations and secure imagery data storage.* During 2018, the U.S. Armed Forces indicated its concern for 1) the security of data collected by sUAS, 2) susceptibility of Chinese drones to unauthorized operation or 3) the hacking of drone controllers by nefarious actors. Recently, the Department of Homeland Security has expressed its cyber-security concerns with drones made in China. At least one Chinese drone manufacturer has designed new features to protect the integrity of photos, videos, flight logs and other data generated during sensitive flights with their commercial aircraft. In addition, the T-90 project worked with the Bridgewater State University Information Technology and Police Departments to create secure streaming video communications using the University's outdoor Cisco Wi-FI mesh network capabilities and a custom Real Time Messaging Protocol (RTMP) service from a commercial sUAS. This prototype will permit streaming video in real-time from the drone's radio controller to secure displays at BSU PD.

- *SaaS geospatial tools that will count cars from 2D and 3D imagery without identifying the` licensed owner of the individual vehicle.* During the review of the T-90 Stage 1 Report, one member of the Expert Review Panel noted the emerging negative view by the general public of government agencies collecting and storing personally identifiable information (PII). T-90 found a US-based Cloud service to beta test algorithms to "count cars." This would provide a way to verify the exact count of vehicles parked in a commuter rail parking lot against the transit agencies parking payment database(s) in precise space and time without machine learning algorithms to read license plates and identify the owner of the vehicle from public agency databases.

1.0 INTRODUCTION

FIGURE 2. BSU Scout 2 sUAS used in RSPA/NASA RS&T Project c. 2000. Photo by L. Harman

In 1998, a national program on commercial remote sensing and geospatial technology (RS&T) applications was created under the authority of the national surface transportation authorization legislation.[4] The program, administered by the U.S. Department of Transportation's (US DOT) Research and Special Programs Administration (RSPA) and the National Aeronautics and Space Administration (NASA) focused on applying remote sensing technology for achieving smarter and more efficient transportation services, safety and security. One project demonstrated flying a small unmanned aerial vehicle (sUAS) to acquire imagery of transit infrastructure and transit operations in Boston (UMASS/JFK Station) and Bridgewater (Commuter Rail Station on the University campus) in the Commonwealth of Massachusetts, USA. US DOT and NASA claim that this was the first autonomous small unmanned aircraft system flight in an urban area in the United States[5]. This Transit-90 IDEA project is a direct descendant of the US DOT/NASA RS&T innovation effort at the turn of the 21st Century. (See Figure 2.)

Twenty years after the U.S DOT/NASA initiative, everything about small unmanned aircraft systems (sUAS) is "faster, better and cheaper." After addressing concerns about the safety of operating sUAS aircraft in U.S. National Air Space (NAS), the Congress of the United States and the Federal Aviation Administration (FAA) have created a legal and administrative framework to accelerate these pioneering efforts in the United States[6,7]. In June of 2018, the National Academy of Sciences (NAS) awarded a Transit Innovations Deserving Exploratory Analysis (Transit-IDEA) project to Harman Consulting LLC in a private-public partnership with the GeoGraphics Laboratory at Bridgewater State University[8]. The title of this prototype research is "sUAS-based GeoINTEL for Commuter Rail Parking in Rural and Suburban areas". This Final Report describes the Transit IDEA (T-90) prototype product/service as proposed, elaborates on the concepts and innovations that are included in the project, summarizes the investigation process, and presents plans and activities underway to implement the T-90 project. In separate sections, the report presents the conclusions drawn by the researchers, provides a profile of the principal investigator, and presents a glossary and references. The systems engineering approach document is incorporated by reference as a Web document hosted by the GeoGraphics Laboratory.

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[4] Section 5113 of the Transportation Equity Act for the 21st Century (TEA-21) of 1998.

[5] *Remote Sensing and Spatial Information Technologies Application to Multimodal Transportation – Program Accomplishments.* (Washington, D.C.: U.S. DOT, RSPA), May 2003, p. 31.

[6] FAA Small UAS Rule (14 CFR part 107) and the FAA Re-authorization Act of 2018 (H.R. 302)

[7] See "Opportunities Exist for FAA to Strengthen Its Review and Oversight Processes for Unmanned Aircraft System Waivers," US DOT, Office of Inspector General, FAA Report AV2019005, 7 November 2018, www.oig.dot.gov.

[8] NAS Transit-IDEA Program, Subaward No. Transit-90, Purchase Order No.: SUB0001172

2.0 THE IDEA TRANSIT-90 PROTOTYPE

Merriam Webster defines a prototype as "an original model upon which something is patterned.[9]" The goal of this research is to create a prototype product or service which can be adopted by small transit agencies that provide commuter rail transit systems with parking management services using sUAS technology. In some cases, these transit agencies connect the intercity commuter rail services with their own local transit services. This section will provide the objectives of this model, the innovative concepts in the application to commuter rail parking, the investigative steps, and the approach to outreach and implementation.

2.1 IDEA TRANSIT-90 PRODUCT/SERVICE

The primary objectives of this prototype are:

- To develop and publish a *systems engineering approach* for the project that can be readily used by certified remote pilots and public transit personnel to procure and update sUAS geospatial intelligence hardware and software.

- To develop a prototype *sUAS technology* application that can be applied in a cost-effective manner by regional transit agencies managing commuter rail parking facilities in small urban and rural commuter rail systems with existing staff and within the rules and regulations of the FAA.

- To develop a prototype *geospatial analysis* application that uses commercially-available off the shelf (COTS) software and hardware that can enhance the safety and security of commuter rail parking lots *and* provide parking revenue validation.

2.2 CONCEPT AND INNOVATION

Commuter rail services bring travelers from the rural and suburban fringes to the inner neighborhoods and central business districts of many large metropolitan areas in the U.S. The isolated nature of these rural and suburban commuter rail parking lots makes it difficult and expensive to secure and safely operate these transit assets. Further, as the more than two dozen commuter rail systems in the U.S. try to avoid cash payments for fares and parking fees, they must embrace consumer friendly options and mobile phone-based payment systems. These fare systems are not standardized and are not easily integrated into large databases for "big data" analysis. This situation makes the validation of commuter rail parking payments labor-intensive and difficult, increasing the potential for systemic fraud and abuse.

Using automated flight modes, the sUAS can provide high resolution imagery that can document *each individual vehicle parked in a specific parking space at a specific date and time*. The speed at which this data can be collected is at least four times faster than manual methods, thereby providing four times the efficiency of data collection using the same human resources (the remote pilot)[10]. In addition to revenue validation, sUAS capabilities can be used to detect *breaking and entering* (B&E) into parked vehicles and *physical assault* of commuters through an efficient and effective reconnaissance operation. *The purpose of this research project is to develop, and field test a prototype of small unmanned aircraft systems (sUAS) and geospatial intelligence (GeoINTEL) technology in a "LivingLab[11]" to*

[9] "Definition of prototype," Merriam Webster on-line dictionary, accessed by L. Harman on 24 April 2019 at https://www.merriam-webster.com/dictionary/prototype

[10] These efficiencies may be understated. The Department of Interior's annual report (April 2019) on its "Drones for Good" program noted efficiencies of data collection seven times faster at 1/10th the cost. See https://www.doi.gov/sites/doi.gov/files/uploads/doi_fy_2018_uas_use_report.pdf accessed by L. Harman on 23 April 2019.

[11] See the Wikipedia description the research concept of LivingLab at https://en.wikipedia.org/wiki/Living_lab accessed by L. Harman on 23 April 2019.

enhance the safety, security, and validation of parking revenue at small urban and rural commuter rail parking areas.

2.3 INVESTIGATION

The development of a systems engineering document[12] for the T-90 project provided an opportunity to demonstrate the usefulness of a systems engineering process where the commercially available sUAS hardware and software technology is changing rapidly. Systems engineering keeps the researchers and potential users focused on the general problem to be solved while the detailed specifications of available products and services in the marketplace are continuously evolving. Systems engineering also allows the researcher to document decisions at a given point in time that can be used as a point-of-departure for future research projects as these new technologies become available. For this T-90 prototype project, the research team adopted the U.S. Department of Transportation's approach to systems engineering for intelligent transportation systems (ITS)[13].

Systems engineering is often explained through a set of steps undertaken in order in the shape of the letter "V." (See Figure 3.) The left side of the "V" are tasks that are characterized as "decomposition and definition." These tasks include: 1) Concept of Operations, 2) System Requirements, 3) High-Level Design, and Detailed Design. The base of the "V" includes software/hardware development and field installation. The right side of the "V" are the tasks of

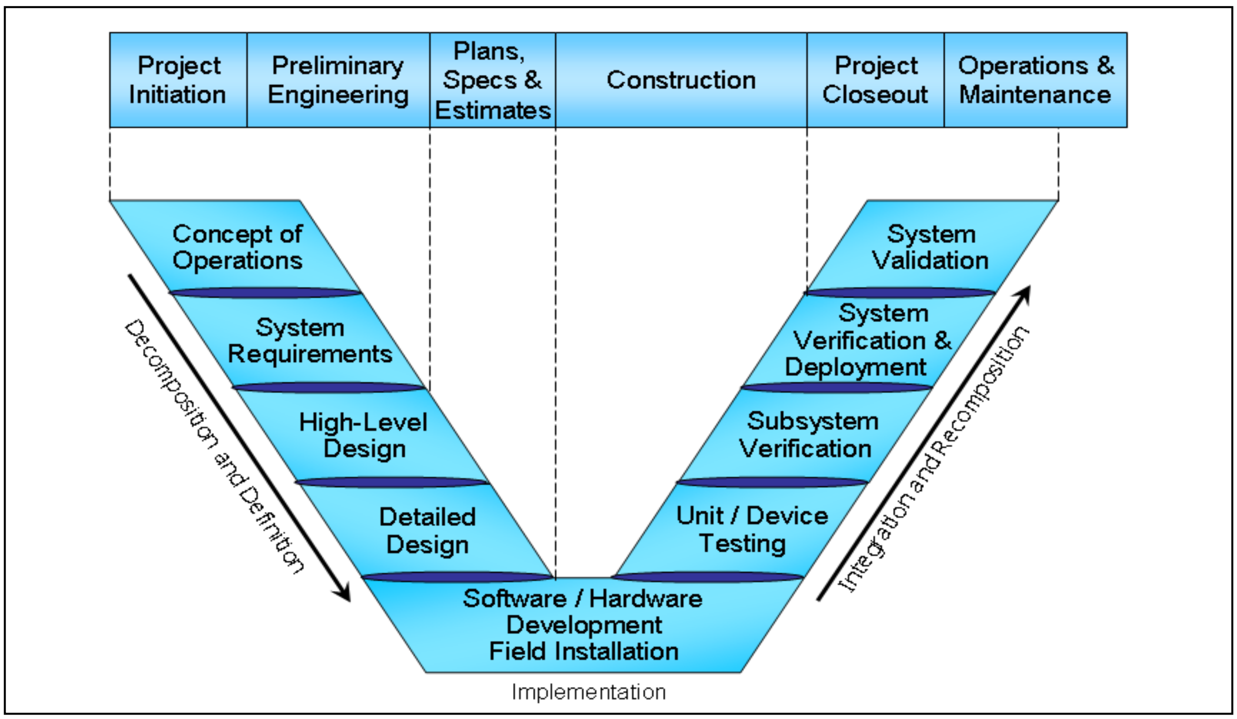

FIGURE 3. The ITS Systems Engineering "V" Diagram in relation to the Transit Capital Planning Process. Source unknown.

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[12] L. Harman and U. Shama. "Small Unmanned Aircraft Systems(sUAS)-based Geo-spatial Intelligence (GeoINTEL) for Commuter Rail Parking in Rural and Suburban Areas -- A Systems Engineering Approach," A paper by the GeoGraphics Laboratory, Bridgewater State University, Bridgewater, MA, dated December 2018. http://www.geographicslab.org/T-90%20IDEA/T-90%20Sys%20Eng%20Sec%201-5_v1.pdf

[13] *Systems Engineering for Intelligent Transportation Systems,* U.S. Dept. of Transportation, January 2007, accessed by L. Harman on 19 October 2018 at https://ops.fhwa.dot.gov/publications/seitsguide/seguide.pdf

integration and recomposition. These tasks are 1) Unit/Device Testing, 2) Subsystem Verification, 3) System Verification and Deployment, and System Validation.

Field Tests. Field tests of sUAS-based aerial photography and videography for geospatial intelligence required creating flow charts for mission planning, sUAS operations, and managing databases of archived imagery. The T-90 project created a flowchart organizing the mission planning and operations. (See Figure 4.) At the outset, the T-90 project designed a relational database to manage these imagery archives and collect important mission planning and operations data. (See Figure 5.) Cybersecurity is particularly important for public transit agencies at the local and national level. Significant privacy issues were raised during system design as efforts to avoid fraud and theft conflict with the law-abiding citizen's expectation of personal privacy in public spaces. These issues were addressed in the software/hardware development stage of the systems engineering process. Also, the Bridgewater LivingLab uses state-of-the-art, publicly owned (BSU) closed point-to-point outdoor wireless 4G Wi-Fi network and fiber optic broadband backbone from the "Edge of the Cloud" to the New England regional internet hub (BOSIX) in downtown Boston (MA).

A variety of sUAS systems were used during the field operational tests, from very small to full-sized commercial sUAS drones as follows:

- The Ryze Tello: a quadcopter weighing 80 grams (.17 pounds) with a 5-megapixel un-gimbaled camera, and ten-minute flight time.
- The Da-Jiang Innovations Science and Technology Co., Ltd. (DJI) Phantom 4: a quadcopter weighing 1380 grams (3 pounds) with a 12-megapixel 3-axis gimbaled camera, fixed landing gear and forward obstacle avoidance systems, and 28-minute flight time.
- The DJI Inspire 2: a quadcopter weighing 3440 grams (7.5 pounds) with a 20 megapixel 3-axis gimbaled camera with a 360° lateral range of motion, interchangeable lenses, independent forward point of view 2-axis pilot camera, forward and vertical obstacle avoidance systems, retractable landing gear, dual self-warming batteries, dual controller support, speeds up to 60 mph, and up to 27 minute flight time.
- The DJI Mavic Air: a quadcopter weighing 430 grams (1 pound) with a 12-megapixel 3-axis gimbaled camera, folding props, records UHD video at 100 Megabits per second (Mb/s), has 8 Gb solid state storage, forward and backward obstacle avoidance systems, speeds up to 42 mph, and 21 minutes flight time.
- The DJI Mavic 2 Enterprise: a quadcopter weighting 905 grams (2 pounds) with a 12-megapixel 3-axis gimbaled zoom (6x) lensed camera, records UHD video at 100 Mb/s, has 360° obstacle avoidance systems, and external lighting systems (spotlights and aircraft lighting), significant cyber security capabilities, provides GPS and timestamped meta-data for imagery, has 24 Gb solid state storage, features self-warming batteries, detects nearby aircraft and informs remote pilot, supports dual controllers, has a top speed of 45 mph, and 31 minutes flight time.

The principal investigator (PI) flew approximately 50 sUAS missions for training, collection of digital photography and video, and demonstrating sUAS-based GeoINTEL at cooperating entities as a part of the T-90 project development. More than 1 terabyte of imagery was collected and is stored at the GeoGraphics Lab behind the BSU firewall. The BSU GeoGraphics Lab network is maintained by the BSU Information Technology staff and monitored by the U.S. Department of Homeland Security (US DHS).

Transit applications of sUAS technology is a key focus of the Bridgewater State University's GeoGraphics Laboratory[14]. (See Figure 6.) They include the following:

1. Real-time monitoring of traffic operations associated with bus transit services **(**See Figures 7 and 8.);
2. Real-time monitoring of the operation of transit park and ride lots for safety and security;
3. High-resolution aerial survey of transit parking illumination (low-light imagery);

[14] L. Harman and U. Shama, PhD, "Drones Part 2 – Data, Asset Management and the LivingLab," MassDOT Innovation Conference, Worcester, MA, April 2018.

4. High-resolution aerial survey of transit maintenance and operation facilities – including perimeter security and operational safety;
5. Periodic monitoring of "traffic calming" and optimization of traffic schemes (See Figure 9.);

For T-90, *aerial survey imagery* of selected BSU parking lots was converted into high-resolution digital 2D orthomosiacs and 3D models using the DroneDeploy™ professional cloud-based service. sUAS-based video of

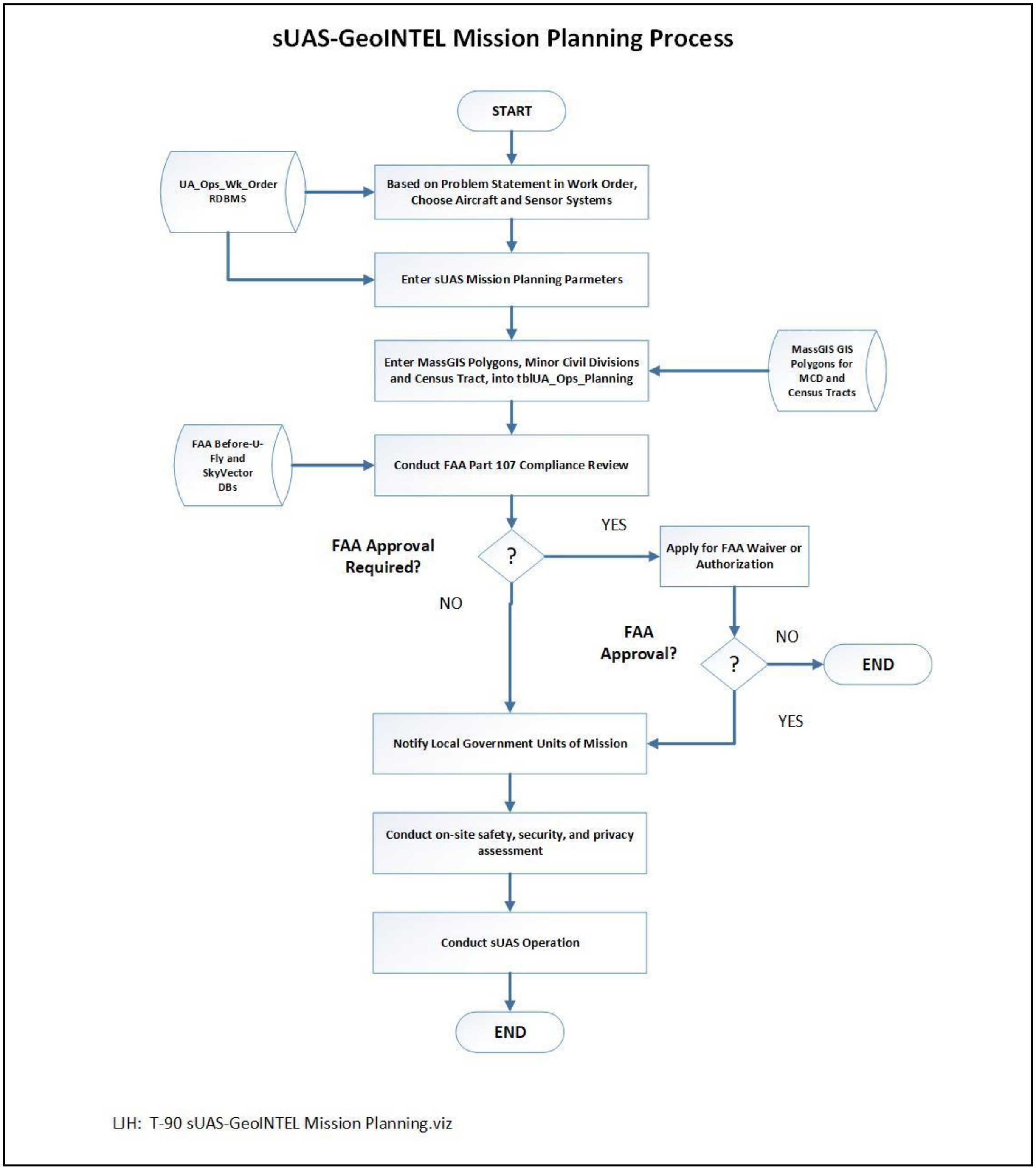

FIGURE 4. sUAS GeoINTEL Mission Planning Process from "Systems Engineering Approach" (Harman and Shama,2019).

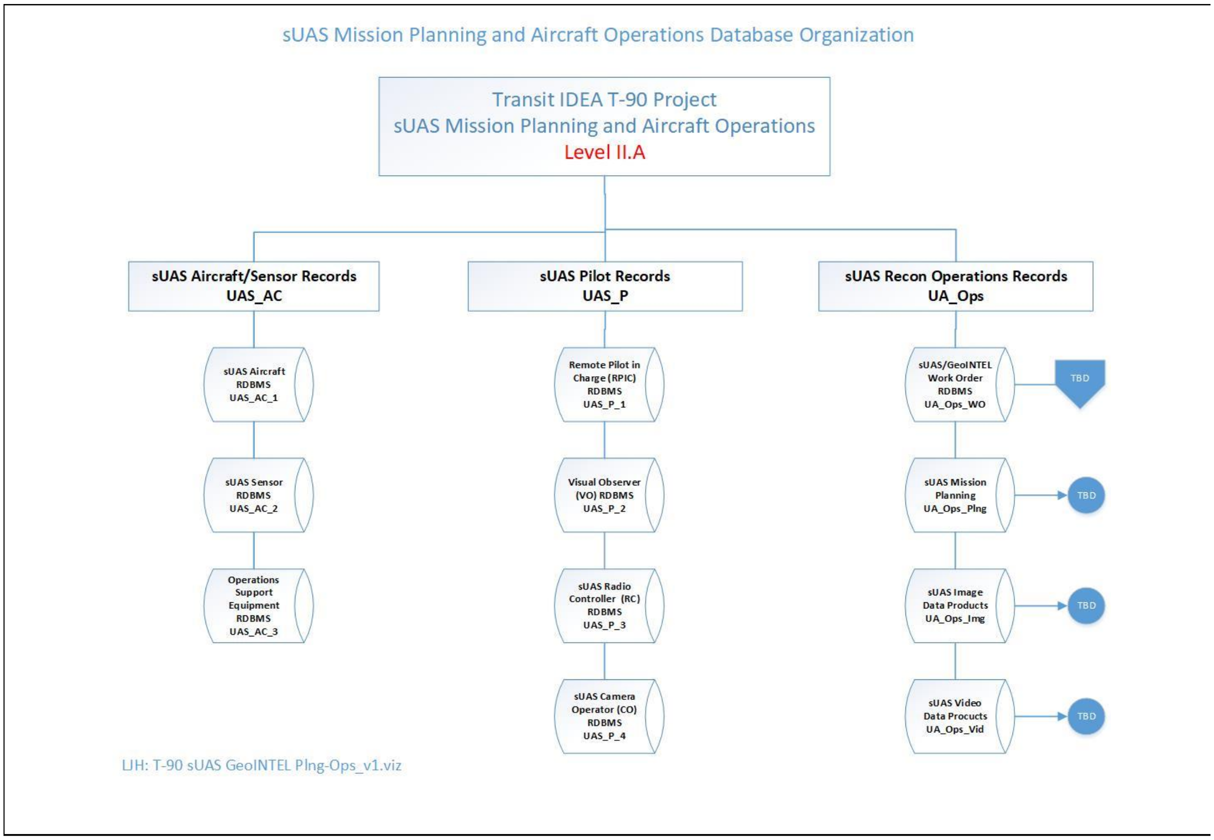

FIGURE 5. sUAS Mission Planning and Operations Database Organization from "Systems Engineering Approach" (Harman and Shama, 2018)

FIGURE 6. BSU Transit bus crossing MBTA Commuter Rail tracks in Bridgewater, MA at critical multimodal intersection for sUAS research. Cisco outdoor Wi-Fi access point on pole in left of photo. Photo by L. Harman.

FIGURE 7. Oblique photo of MBTA commuter rail parking, BSU surface parking, and BSU parking garage from DJI Phantom 4 sUAS. Photo by L. Harman.

FIGURE 8. Oblique photo of BSU transit bus serving MBTA rail station (background) and BSU East Campus (foreground). Photos by L. Harman.

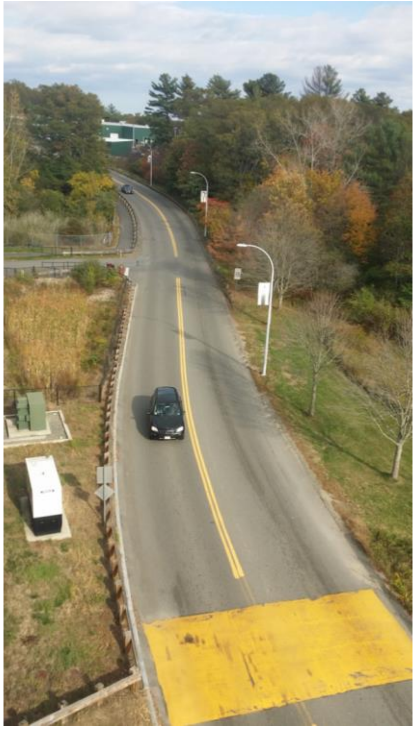

FIGURE 9. Oblique Photo of MBTA-provided access road with "calming" speed bumps. Photo by L. Harman.

traffic flows accessing and egressing key parking facilities were created using off-the-shelf Microsoft Windows 10 Moviemaker software at normal speed and with time-lapse techniques.

A range *of automated flight modes* were tested. The autonomy taxonomy, adopted from the Drone Industry Insights' infographic "The 5 Levels of Drone Autonomy"[15], is summarized in Table 1 below.

TABLE 1. The 5 Levels of Drone Autonomy

Autonomy Level	Level 0	Level 1	Level 2	Level 3	Level 4	Level 5
Degree of Automation	No Automation	Low Automation	Partial Automation	Conditional Automation	High Automation	Full Automation
Description	Drone control is 100% manual	Pilot remains in control. Drone has control of at least one vital function.	Pilot remains responsible for safe operation. Drone can take over heading, attitude under certain conditions	Pilot acts as a fall back system. Drone can perform all functions given certain conditions.	Pilot is out of the loop. Drone has backup systems so that if one fails, the platform will still be operational.	Drones will be able to use AI tools to plan their flights as autonomous learning systems.
Obstacle Avoidance	NONE	SENSE & ALERT		SENSE & AVOID	SENSE & NAVIGATE	
Source of Information: Drone Industry Insights at www.droneii.com						

The Drone Industry Insights taxonomy is useful to sort out the varying degrees of autonomy presented by various sUAS manufacturers. The T-90 project presented several automated functions in the systems engineering specifications document. The table below presents the sUAS T-90 automated items by name, the description of these items, the application for transit safety and security, and an assessment of the level of autonomy by the Transit-90 principal investigator. During the term of the Transit-90 research the sUAS industry has moved rapidly from a Level 1 – "Low Automation" to a Level 3 – "Conditional Automation" and beyond. Given that in the United States, the FAA does not permit beyond visual line of sight (BVLOS) except in a few FAA test sites, Level 4 – "High Automation" is constrained in practice. The T-90 project has indicated that Level 5 – "Full Automation" may be possible, when the regulatory framework has been put in place.

[15] "Tech Talk: The 5 Levels of Drone Autonomy," published March 12, 2019, Accessed by L. Harman on 5 April 2019 at https://www.droneii.com/category/market

TABLE 2. Application of Levels of Autonomy to sUAS for Transit IDEA T-90 Prototype

	T-90 Item	*Specifications*	*T-90 application*	*Level of Autonomy*
1	***Tripod Mode***			*1*
		This mode provides for a stable platform for conducting "perch and stare" video collection by slowing sUAS speed and manual input on controls.	*Safety and security situational awareness observation post (SA/OP). Recon high-crime parking lots and monitoring traffic flows in real-time to Police (PD) and Facilities Management (FM).*	
2	***Course Lock***			*2*
		In this mode, the controls will be relative to the sUAS's current path – like a movie camera dolly shot. This low-level navigation tool allows the pilot to fly alongside moving objects or across scenes.	*Allows pilot to collect imagery of automobile license plates from low oblique camera angles along a rectangular parking lot.*	
3	***Waypoints 2.0***			*3*
		The pilot sets multiple GPS points, or way points, and the aircraft will automatically fly to them while the pilot focuses on controlling the cameral.	*Provides perimeter and area surveillance (i.e. "night watchman checkpoints") that can be exactly replicated for comparative coverage for manual and automated imagery interpretation.*	
4	***Point-of-Interest***			*3*
		The pilot picks a specific building, object or location as the point-of-interest (POI) and the aircraft will continuously circle around the point while the pilot records photos or video.	*Provides 360° monitoring of complex multi-modal traffic accessing or egressing commuter rail parking or station area.*	
5	***Active Tracker 2.0***			*3*
		Using machine learning visual sensing systems can identify up to 16 selectable subjects simultaneously, allowing the pilot to select one subject to be tracked. The sUAS-based algorithm can create a 3D map using front cameras. If the subject runs behind a tree, the Tracker can predict where it will come out and continue the chase.	*Collects actionable intelligence on breaking and entering (B&E) on parked cars in commuter parking lots, assaults on patrons at rural and suburban stations, and hit-and-run fender benders with simultaneous video streaming to transit PD tactical units.*	
6	***Motion Time Lapse***			*3*
		With motion time lapse video, the pilot can follow a pre-programmed flight path (see above) or create one on the fly. These complex options are done automatically or with a few taps on the mobile phone or tablet.[16]	*Documentation of multi-path intersections of cars, trains, buses, bicyclists, and pedestrians to document best and worst practices around commuter rail rural and suburban parking facilities.*	
7	***Advanced Pilot Assistance System***			*3+*
		More powerful computing capabilities and optimized algorithms help sUAS fly smarter and safer through obstacles and terrain. Data gathered from multiple onboard cameras and infrared sensors are used to construct a 3D map of its environment for more precise hovering and better flight performance. To help navigate through more complex outdoor environments, Advance Pilot Assistance Systems (APAS) helps pilots avoid and bypass obstacles (up and around) automatically.[17]	*(See also "Active Tracker 2.0 above.) Assists in pursuit of fleeing suspects of B&E on parked cars and assaults on CR patrons. Can stream high-definition video to transit police department while storing ultra-high definition video on mSD cards for criminal investigation and prosecution purposes*	

[16] See Joshua Goldman, "DJI Mavic 2 Pro, Mavic 2 Zoom add Hasselblad quality and optical zoom to folding drones," CNET.com, published August 23, 2018, accessed by L. Harman on 28 August 2018 at https://www.cnet.com/reviews/dji-mavic-2-pro-preview/

[17] See Joshua Goldman, "DJI Mavic Air Review: A folding 4K mini drone that's close to perfect," CNET.com, published February 12, 2018, accessed by L. Harman on 28 August 2018 at https://www.cnet.com/reviews/dji-mavic-air-review/

3.0 PLANS FOR IMPLEMENTATION

The Transit-90 researchers actively reached out to transit operators, state departments of transportation, Federal UAS Test Sites, private corporations, and academia to develop implementation opportunities.

Outreach to transit operators and state DOT. Several Massachusetts Regional Transit Authorities (RTAs) have assisted the researchers in exploring the concepts of applying sUAS-based GeoINTEL for commuter rail parking safety and security. They are the MetroWest RTA, the Montachusett RTA, and the Cape Cod RTA. The T-90 PI has made presentations at Massachusetts Association of Regional Transit Authorities (MARTA) and the Massachusetts Department of Transportation (MassDOT) annual conferences. The T-90 project will also participate at the biennial Northeast Passenger Transportation Association meeting in July of 2019.

Outreach to FAA/NASA unmanned aircraft systems Test Sites. The Co-PIs have participated in the annual conferences of the Northeast UAS Airspace Integration Research (NUAIR) Alliance – one of six test sites in the U.S. established by the U.S. Congress and the only test site in the Northeastern U.S.[18]

Outreach to private corporations. The TCRP Transit-90 Project was selected by Cisco™ for possible participation in the Cisco Digital Acceleration (CDA) Program for the Commonwealth of Massachusetts. The specifics of the partnership are under development. Only Michigan and Massachusetts have been designated as state partners in this world-wide Cisco *Internet-of-Things* initiative[19].[20] *DJI™ and Microsoft™ have announced a partnership to extend DJI software to 700,000,000 Windows 10 users*.[21] The University is an enterprise partner with Microsoft and the GeoGraphics Laboratory has partnered with Microsoft Research projects in real-time remote sensing and spatial information systems as a part of the Microsoft Developers Network (MSDN). Microsoft's Azure Cloud™ and hybrid cloud applications have relevance to the T-90 project.

Outreach to national research organizations, technical schools, higher education and community colleges.

- Mr. Harman and Dr. Shama presented a TCRP-IDEA poster session on the T-90 project at the 2019 Annual Meeting of the Transportation Research Board (TRB) in Washington, DC, on January 14, 2019
- Mr. Harman and Dr. Shama reported on the Transit-90 Project at the TRB UAS Subcommittee at the 2019 annual meeting.
- Mr. Harman and Dr. Shama participated in the pre-TRB Conference one-day workshop on UAS on Sunday in Washington, DC.
- Mr. Harman and Dr. Shama reported on the Transit-90 at the APTA/ITS America PTSS committee meeting held during the TRB 2019 week.
- Mr. Harman made a presentation at the TCRP IDEA Oversight Committee meeting on the Transit-T90 project on January 29, 2019 in Washington, DC.
- Mr. Harman created the curriculum and conducted an experimental upper-level undergraduate course on sUAS and GeoINTEL as a part-time professor of the BSU Aviation Science Department
- As a part of a higher education collaborative, the BSU GeoGraphics Laboratory and the T-90 project have created an sUAS training program with the Holyoke Community College's (HCC) Community Services Division on the Western Massachusetts campus of HCC. Mr. Harman has taught the course on Saturdays during the Fall and Spring semesters during the T-90 project period, drawing a diverse group of professionals. (See Appendix: Flying Drones Course Syllabus.)

[18] https://www.nuairalliance.org/
[19] https://newsroom.cisco.com/cda
[20] https://blogs.cisco.com/government/kicking-off-ciscos-first-state-digital-acceleration-sda-program-in-michigan
[21] https://news.microsoft.com/2018/05/07/dji-and-microsoft-partner-to-bring-advanced-drone-technology-to-the-enterprise/

- Mr. Harman participated in the FAA UAS Symposium in Baltimore, MD, from June 3 – 5, 2019.

4.0 CONCLUSIONS

The results from the Investigations Phase of T-90 project are presented in three categories: 1) research findings related to the initial three objectives of the product/service, 2) additional unanticipated findings, and 3) suggestions for future research.

4.1 Research Findings by Objective

Objective #1. *Systems Engineering for Transit-90.* The U.S. DOT approach to systems engineering for intelligent transportation systems was very helpful in organizing this prototype project. While sUAS are much less complex than city-wide multi-modal ITS systems, the ITS process was particularly adaptable for designing and delivering sUAS/GeoINTEL applications for small urban and rural systems. Currently, there are a few dominant prosumer drone makers in the world, but as that changes and new hardware and software manufacturers enter the sUAS civilian commercial arena, system engineering documentation allows for product comparisons and easily updated specifications. During the T-90 period of performance, DJI, the dominant manufacturer of sUAS products in the world, brought out *a **variety of sUAS aircraft with autonomous flight capabilities*** that provide a range of applications for the transit industry. Using systems engineering approaches from the intelligent transportation systems (ITS) field is proving useful in sorting out these rapidly developing capabilities for transit agencies. (See consumer, commercial, and enterprise products by DJI below).[22,23,24] The systems engineering approach was used to continuously update sUAS/GeoINTEL products and services.

Objective #2. *sUAS Technology Applications.* DJI and affiliated 3rd party vendors came out with improvements to sUAS that raised the potential for application in small urban and rural transit settings including the following features.

- *Geofencing technology is now standard on new DJI drones.* This technology is downloaded on their drones as firmware updates that prevent drones from taking off in and around airports or over large crowds and festivals and sporting events.[25], [26]
- *Computer Vision for 360° obstacle avoidance and (non-GPS) visual positioning systems*. Since the launch of the Phantom 4 quad copter, DJI has provided 3-D visioning systems for avoiding obstacles in flight[27] and maintaining its vertical position without GPS (e.g. when flying indoors). With the introduction of the Mavic Air, DJI has added Advanced Pilot Assistance Systems (APAS). When reaching an obstacle, the sUAS with APAS will attempt to fly around it[28]. The recent release of the Mavic 2 Enterprise, promises obstacle avoidance in all directions with a combination of eight 3-D visioning sensors and two infrared sensors.[29]

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[22] DJI Consumer drones accessed by L. Harman on 13 February 2019 at: https://www.dji.com/products/consumer?site=brandsite&from=nav
[23] DJI Professional drones accessed by L. Harman on 13 February 2019 at: https://pro.dji.com/?site=brandsite&from=nav
[24] DJI Enterprise drones accessed by L. Harman on 13 February 2019 at: https://enterprise.dji.com/?site=brandsite&from=nav

[25] https://www.dji.com/newsroom/news/dji-refines-geofencing-to-enhance-airport-safety-clarify-restrictions accessed by L. Harman on 13 February 2019.
[26] https://www.theverge.com/2019/2/13/18223184/dji-geofencing-airport-gatwick-disruption accessed by L. Harman on 13 February 2019.
[27] https://www.dji.com/newsroom/news/inside-a-drone-computer-vision accessed by L. Harman on 13 February 2019.
[28] https://www.dji.com/newsroom/news/dji-introduces-mavic-air-for-limitless-exploration-wherever-adventure-takes-you accessed by L. Harman on 13 February 2019.

[29] Paul Ridden, "DJI gets down to business with Mavic 2 Enterprise editions," *New Atlas,* DRONES, published 29 October 2018, accessed by L. Harman on 13 February 2019 at https://newatlas.com/dji-mavic-2-enterprise/56999/

- *Aircraft lighting systems for night operations – for visual positioning, spotlights and aircraft (A/C) beacons*[30]. With the new the DJI Mavic 2 Enterprise, several new lighting options became available for the first time. On the top of the aircraft is a mini-USB port that allow two lighting options – a 2400 lumen LED spotlight and an LED flashing beacon that can warn manned aircraft at 3 statute miles. On the bottom of the aircraft, there are two LED lights that assist the vertical 3-D visual positioning system in low-light. After 25 meters above ground, the bottom light becomes a flashing beacon that assists the remote pilot in locating the aircraft in twilight or night-time operations. It also would allow the M2E to fly indoors in a dark room without GPS positioning systems.
- *Automatic Dependent Surveillance-Broadcast (ADS-B) system to detect aircraft for drone pilots.* DJI has led the commercial drone manufacturers in providing ADS-B systems to detect manned aircraft within 3 statute miles of their drones and notifying the remote pilot of the potential for collision with the drone through their radio controller.[31]
- *Military-style tethering systems for prosumer drones that the FAA allows to operate at 150' without FAA approval and without an FAA licensed remote pilot.* With approval from the FAA, the national agencies providing security at the 2019 NFL Super Bowl used a tethered drone to provide state-of-the-art surveillance below 200' (including multi-sensor imagery streaming video to Federal, state and local law enforcement) while sharing the airspace with Blackhawk helicopters.[32]
- *Increasing availability of inexpensive remote pilot training programs for FAA Part 107 certification, flying skills, and geospatial analysis of sUAS-based imagery*. Currently, there are approximately 116,000 commercial remote pilots that have been certified by FAA since December 2018.[33] The FAA forecasts that 350,000 remote pilots will be needed in 5 years[34]. The most recent FAA re-authorization law (2018) has encouraged higher education, particularly public community colleges, to get involved in workforce *development for UAS pilots*[35]*. The T-90 project has been focused on contributing to commercial remote* pilot workforce development through the BSU Aviation Science Department and Holyoke Community College's Community Services Division by developing curriculum and teaching classes on sUAS for professional and continuing education.
- For FAA certified sUAS remote pilots, FAA has deployed a Low Altitude Authorization and Notification Capability (LAANC) *to provide **near-real-time approval in US National Airspace (NAS**) with Air Traffic Control zones below 400' in controlled airspace near airports.* A variety of private providers, such as AirMap™, provide smartphone apps to access LAANC[36].

Objective #3. *Geospatial Analysis Application.* Matching the rapid technology innovations in aircraft systems are the improvements in geospatial analytical software and Cloud-based services over the past year.

- *Software-as-a-service (SaaS)* ***geospatial tools*** *that provide production of 2D high-resolution "stitched" orthophoto mosaics and 3D models for aerial photography and thermal imagery*. Geospatial analytical tools are becoming more powerful, easier to use, more Cloud-based and somewhat less expensive over the past year. Corporate partnerships between drone manufacturers and global computer hardware and

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30 Fintan Corrigan, "Top Mavic 2 Enterprise Review And **FAQs** – Thermal, Dual Spotlight, Loudspeaker And Beacons Mounts, " posted on 26 January 2019. Accessed by L. Harman on 14 February 2019 at: https://www.dronezon.com/drone-reviews/mavic-2-enterprise-review-with-spotlights-loudspeaker-beacon-faqs/

31 DJI Press Release, "Mavic 2 Enterprise Brings Aerial Capabilities To Every Professional, With Zoom Imaging, Modular Accessories, Heightened Security Features And Airspace Protection," published on 29 October 2018. Accessed by L. Harman on 14 February 2019 at https://www.dji.com/newsroom/news/dji-mavic-2-enterprise. [Emphasis added.]

32 Dronebelow Press Release, "Skyfire Drones Secure Super Bowl," published 6 February 2019, accessed by L. Harman on 14 February 2019 at https://dronebelow.com/2019/02/06/skyfire-drones-secure-super-bowl/

33 "Unmanned Aircraft Systems, FAA Aerospace Forecast 2019 – 2039," accessed by L. Harman on 23 May 2019 at https://www.faa.gov/data_research/aviation/aerospace_forecasts/media/FY2019-39_FAA_Aerospace_Forecast.pdf, p. 50.

34 *Ibid. p. 50.*

35 FAA Reauthorization Act of 2018, accessed by L. Harman on 15 February 2019 at https://www.congress.gov/bill/115th-congress/house-bill/302/text?q=%7B%22search%22%3A%5B%22disaster+aid%22%5D%7D&r=7

36 See https://support.airmap.com/hc/en-us/articles/360006908551-What-is-LAANC- accessed by L. Harman on 13 February 2019.

software firms (*e.g*. DJI, Intel, and Microsoft) are being announced with much promise for faster, better, and cheaper sUAS geospatial intelligence analysis. Currently, there are at least two[37],[38] Cloud-based services that provide the T-90 project with options in producing the products that are useful in manually counting parked vehicles in a transit commuter lot**:** orthomosaics and three dimensional (3D) digital models. The digital aerial images collected from drones can be rectified to correct for the curvature of the camera lens and, using the using the spatial information from the on-board global positioning systems (GPS) can be geographically referenced. These corrected and geo-referenced images can be "stitched" together using computer algorithms to create a orthomosaic map. In Figure 10 below, the digital image of the BSU Spring Street parking lot collected during the summer (leaves on trees) has been integrated into Google Maps aerial imagery collected during the winter (leaves off trees).

FIGURE 10. A 2D stitched "orthomosaic" of a portion of BSU Spring St. Commuter Lot from DJI Inspire 2 sUAS processed by DroneDeploy SaaS. The orthomosaic is superimposed on Google Maps. Note cars in shadow of trees to right of image. MBTA Commuter Rail Line in left of image. Imagery by L. Harman.

Using the 3D data from each digital image that comprised the 2-dimensions (2D) orthophoto map in Figure 10, third-party vendors (e.g. DroneDeploy) can create a 3D model of the parking lot that is free floating on the computer screen. Using the 3D model, vehiclse are easily identified and counted, even when partly obsucured by the trees bordering the commuter parking lot. Interestingly, the image processing algorithm truncates the light poles at the base.

FIGURE 11. A screenshot of a 3D image from 2D orthomosaic of BSU Spring St. commuter lot (above). Source of imagery: L. Harman. SaaS by DroneDeploy.

[37] DroneDeploy accessed by L. Harman on 14 February 2019 at https://www.dronedeploy.com/
[38] SimActive Correlator 3D, accessed by L. Harman on 14 February 2019 at https://www.simactive.com/

Similarly, Figure 12 integrates an orthomosaic of the BSU Facilities Management Department's facilities, including the BSU Transit vehicles, into Google Maps. Figure 13 and 14, are screenshots of a 3D model of a portion of this parking facility on Tower Hill.

FIGURE 12. Mission planning of reconnaissance of BSU Tower Hill Lot (in yellow) integrated into Google Map screen shot of BSU Facilities Management and BSU Police Deparment Operations Center. Imagery from DJI Mavic Air mUAS. SaaS from DroneDeploy. Source of Imagery: L. Harman.

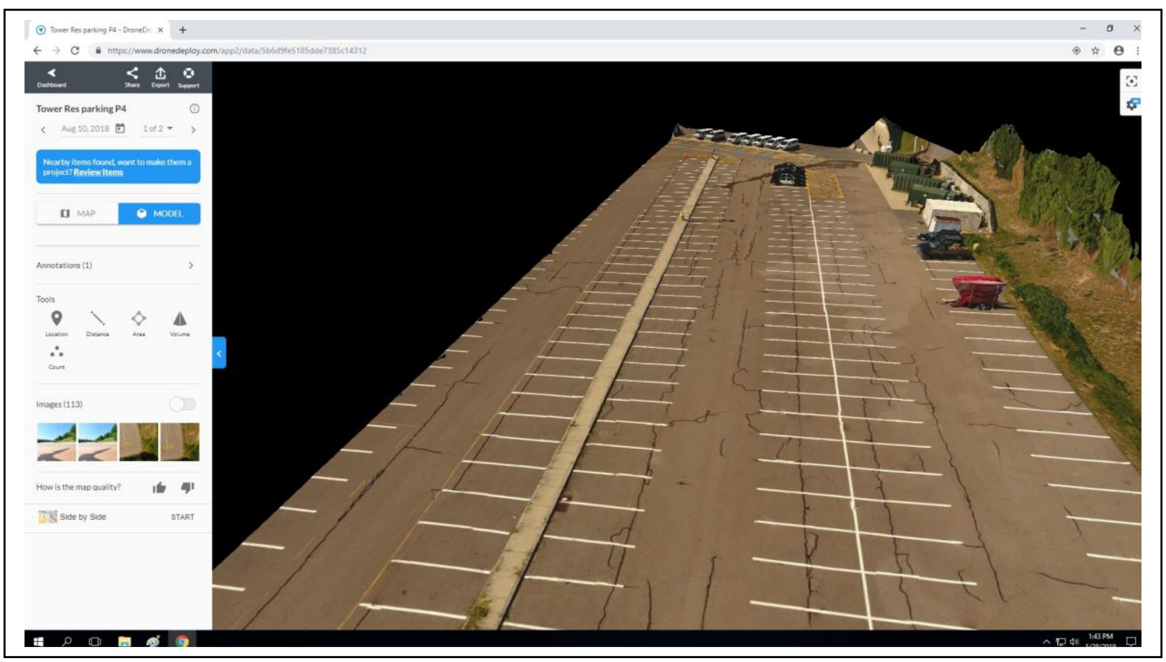

FIGURE 13. A screenshot of 3D model from DroneDeploy's orthomosaic of BSU Tower Hill Lot from mUAS mission planned in previous image. Orientation South to North. Note the "count" feature in the Tools menu. Source of image: L. Harman.

FIGURE 14. Screenshot of 3D model of Tower Hill Lot from 2D orthomosaic (Fig. 12) looking East to West. Note Tools in Dashboard including area, distance, and count. Imagery by L. Harman using DJI Phantom 4.

- *Cyber-security capabilities for secure operations and secure data storage of imagery.* During 2018, the U.S. Armed Forces indicated its concern for 1) the security of data collected by sUAS, 2) susceptibility of DJI drones to unauthorized operation or 3) the hacking of drone controllers by nefarious actors. Recently, the Department of Homeland Security has expressed concerns about cyber-security with drones manufactured in China.[39] With the introduction of the DJI Mavic 2 Enterprise, the manufacturer provided a Local Mode in its controller software and password protections as follows.
  - [The DJI] *Mavic 2 Enterprise is designed with new features to protect the integrity of photos, videos, flight logs and other data generated during sensitive flights. An industry first, Mavic 2 Enterprise incorporates 24 GB of onboard data storage and password protection, creating accountability for all access to the drone's functions and stored data. When Password Protection is enabled, users are required to enter their password each time they activate the drone, link the remote controller with the drone, and access the drone's onboard storage, giving them full, exclusive use and enhanced security. This provides secure access to the drone and its onboard data storage, while protecting that data even if the drone is physically compromised*
  - *A new GPS timestamping feature encodes the time, date, and location of every recorded image, aiding in pilot accountability and ensuring that data captured by the drone can be trusted and used in situations from reviewing critical infrastructure inspections to potential legal proceedings.*
  - *In addition, Mavic 2 Enterprise users with heightened data security concerns can use DJI's Local Data Mode feature which, when activated, will stop the user's connected mobile device from sending or receiving any data over the internet. This provides added security assurances for operators of flights involving critical infrastructure, governmental projects or other sensitive missions.*[40]

  In addition, the T-90 project is working with the BSU Information Technology and Police Departments (BSU PD) to create a prototype secure streaming video communications capability that will use the

[39] David Shortwell, "DHS warns of 'strong concern that Chinese-made drones are stealing data'", published on 20 May 2019, accessed by L. Harman on 23 May 2019 at https://www.cnn.com/2019/05/20/politics/dhs-chinese-drone-warning/index.html
[40] DJI Press Release, "… *__Heightened Security Features__," op.cit.* [Emphasis added.]

University's secure Cisco outdoor Wi-FI capabilities using Adobe's Real Time Messaging Protocol (RTMP) from the DJI's Mavic 2 Enterprise communicating with a secure BSU GeoGraphics Lab RTMP server. This will permit streaming video in real-time from the drone's radio controller and mini iPAD or smartphone to secure displays at BSU PD and Facilities Maintenance Department.

4.2. Additional Research Findings. During the investigation phase, several developments that were unanticipated were software solutions to validating parking revenue, development of drone parachutes for additional operational safety, a major revision to the FAA's sUAS Rules and Regulations, and a cost-estimate for T-90 deployment by transit agencies, as discussed below.

- *SaaS geospatial tools that will count cars from 2D and 3D imagery without identifying the licensed owner of the individual vehicle.* The use of artificial intelligence (AI or machine learning) to read license plates and identify the owners of the vehicles from digital imagery, is state-of-the-practice for parking management, and one way to verify/validate revenue generated by commuter rail parking facilities. During the review of the T-90 Stage 1 Report, one member of the Expert Review Panel noted the emerging negative view by the general public of government agencies collecting and storing **personally identifiable information** (PII). A new service by DroneDeploy noted that it is beta testing AI algorithms to "count cars." This would provide a way to verify the exact count of vehicles parked in a commuter rail parking lot against the transit agencies parking payment database(s) in precise space and time.[41] As DJI pointed out in a recent White Paper, leading technology companies (*e.g.* Facebook, Google, Microsoft, Twitter and Verizon) have raised these issues with the Supreme Court of the United States.[42]

  > "***No constitutional doctrine should presume that consumers assume the risk of warrantless government surveillance simply by using technologies that are beneficial and increasingly integrated into modern life***. [Brief for Technology Companies in Amici Curiae in Support of Neither Party, *Carpenter v. United States,* No. 16-402 (U.S. Sup.Ct.) August 2017, at p.11.]"

- *Automatic Drone Parachutes*. Third-party manufacturers are producing ***affordable drone parachutes*** that are meeting international standards for emergency use by consumer drones. This will provide risk management capabilities that will increase approval of FAA waiver requests and lower insurance costs for sUAS operations. In at least one case, ParaZero™ is marketing **a p*arachute system for the Phantom 4 and Mavic 2 that can be repacked in the field.*[43]** Automated parachutes will significantly reduce the risk of sUAS operations over people in commuter rail parking lots. While pricing of these parachutes is high at this time (1/5th of the cost of the drone), it should be offset by lowering the cost of insurance as a significant risk management enhancement.

- *FAA Notice of Proposed Rule Making regarding the Operation of Small Unmanned Aircraft Systems.* During the 2019 Annual meeting of the Transportation Research Board, US DOT Secretary Elaine Chou announced that the FAA intended to publish a proposed rule that would allow the operation of sUAS over people and at night without a specific waiver under 14 CFR Part 107.[44] The NPRM was published in the

[41] DroneDeploy Blog, " Product Release Wrap-up – January 2019 – Kick off the New Year with improved accuracy and AI tools from DroneDeploy", published January 30, 2019, accessed by L. Harman on 14 February 2019 at https://blog.dronedeploy.com/product-release-wrap-up-january-2019-3e4f11fd3736?elqTrackId=24dc67493c1647ab9713a5709a55a806&elq=b6e59c847ba54a0f8ebbebc2b7cab391&elqaid=619&elqat=1&elqCampaignId=463

[42] "Understanding the U.S. Federal Aviation Administration UAS Identification & Tracking ARC Report," A DJI Technology Discussion Paper, dated December 19, 2017.

[43] ParaZero™ drone parachutes accessed by L. Harman on 13 February 2019 at: https://www.parazero.com/lp/safeair-cs-1-goo-2/?gclid=Cj0KCQiAnY_jBRDdARIsAIEqpJ1mDIqluzMVcWav19voW0uZhDT-IWosaiQgiw1vEkKnOpg9HrjjLlwaAj8kEALw_wcB

[44] "Remarks Prepared for Delivery by U.S. Secretary of Transportation Elaine L. Chao, Transportation Research Board Annual Meeting, Washington, DC, Monday, January 14, 2019, accessed by L. Harman on 14 February 2019 at https://blog.dronedeploy.com/product-release-wrap-up-january-2019-3e4f11fd3736?elqTrackId=24dc67493c1647ab9713a5709a55a806&elq=b6e59c847ba54a0f8ebbebc2b7cab391&elqaid=619&elqat=1&elqCampaignId=463

Federal Register [Docket No.: FAA-2018-1087; Notice No. 18-07] RIN 2120-AK85, "Operation of Small Unmanned Aircraft Systems over People," published on 13 February 2019[45] This proposed rule is most supportive of the T-90 project in three categories of risk for micro-UAS operations: –*waiver of prohibition of* ***night flight operations, 2) operations over people*** (See Figure 15.) *and 3) c**ompliance and enforcement tools*** *– education and consequences.*[46] The comment period for this NPRM expired on 15 April 2019, the final rules should be available about the time of this publication.

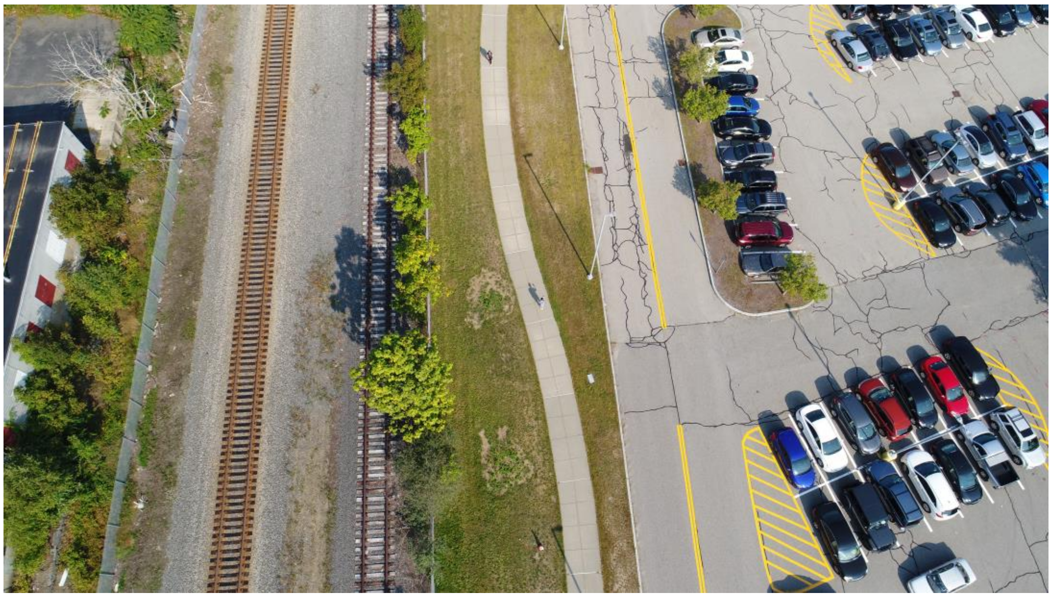

FIGURE 15. An oblique image of the BSU Spring St commuter parking lot adjacent to the MBTA commuter rail line. Imagery from the DJI Inspire 2 using "perch and stare" reconnaissance from a secure location in Tripod Mode from about 100' AGL. Note that flying over the pedestrians on walkway will be addressed by new FAA regulations permitting operations over people. Also note the parking lot lighting masts that were truncated in creation of orthomosaic and 3D models in previous figures (Figure 10 - 14). Imagery by L. Harman.

- *Estimated Cost of Deploying sUAS/GeoINTEL for CR Parking Safety and Security at a small urban RTA – Option 1 (Prosumer mUAS) and Option 2 (Professional mUAS).*

TABLE 3. Micro-Unmanned Aircraft System – Prosumer Option

Item	Brand Name	Description	Estimated Cost
sUAS	DJI Mavic Air™	Foldable quad-copter, 1 lbs., 3-axis gimbal, 4K 30 fps camera, 100 mb/s download	$800
Training	ASA Remote Pilot Test Prep	Includes Remote Test Book, FAA Airman Knowledge Testing Supplement, and 5 on-line study tests	$20
FAA Remote Pilot in Command Certification	At FAA certified Testing Centers	60 questions, 2 hours, at FAA certified test centers.	$150
Liability insurance	Specialty general liability carriers	Requires a description of pilot training and experience, specific drones used, description of sUAS application and risk management	c. $1000 est
Image processing	MS Windows 10	Provides photo and video processing with operating system (Microsoft or Apple).	0

[45] https://federalregister.gov/d/2019-00732
[46] L. Harman, "Recent FAA NPRM 'Operation of Small Unmanned Aircraft Systems over People' Provides Significant Support for TCRP Transit IDEA T-90 Project", A Memorandum to Transit-90 Research Team, 19 Feb 2019.

COST			$1970

TABLE 4. Small Unmanned Aircraft System – Professional Option			
Item	Brand Name	Description	Estimated Cost
sUAS cost	Mavic 2 Enterprise™	Foldable quad-copter, 2 lbs., 3-axis gimbal, 6X zoom camera, 4K 30 fps, spotlight/loudspeaker accessories, 360-degree obstacle avoidance, Local Data Mode, 100 mb/s download communications, aircraft sensing, dual radio controllers, 24GB on-board storage.	$2,000
Training	community college certified drone flying course	Four-part course – FAA RPIC test prep., flying skills, mission planning/automated operation, geospatial analysis.	$300 (est.) per module.
FAA Remote Pilot in Command Certification	At FAA certified Testing Centers	60 questions, 2 hours, at FAA certified test centers.	$150
Liability Insurance	Specialty general liability carriers	Requires a description of pilot training and experience, specific drones used, description of sUAS application and risk management	$2000 (with multiple drones)
Image processing	DroneDeploy™	Cloud-based 2D "stitched" orthomosaics, 3D models, thematic maps, point cloud maps, "counting" algorithms	$1000 per year (many options)
COST			$5450

4.3 Proposed Future Research and Demonstrations

Several research topics have emerged from the T-90 prototype development that may be addressed through TCRP Synthesis studies or TCRP Research projects

- *Impact Analysis of FAA sUAS NPRM on sUAS/GeoINTEL applications in transit applications.* The recent Notice of Proposed Rule Making is the most significant change in the regulations on sUAS since the promulgation of Part 107 in 2016. FAA proposes a new sub-category of sUAS, *the micro-Unmanned Aircraft System (mUAS)* that will make it easier and safer to deploy sUAS/GeoINTEL systems in small urban and rural areas safely, quickly and less expensively.

- *Impact of US DHS alert on Chinese-based manufacturers of sUAS on Geospatial Intelligence applications in the transit industry.* Recently national news organizations[47] and drone industry commentators[48] have noted the implications of the U.S. Department of Defense and U.S. Department of Homeland Security national security concerns over potential access to infrastructure and operational security data by foreign intelligence agencies. The transit industry needs to determine ways to lower the potential risk of strategic and tactical intelligence operations by these entities while gaining the improvement to safety and security of U.S. transit assets and services that these high-quality sUAS bring to the transit industry.

- *Impact of machine learning (ML) and deep learning (DL) on automated object identification from sUAS imagery.* Algorithms that process remotely sensed imagery on the Cloud can provide real-time imagery interpretation through the automatic identification of objects (e.g. cars, trucks, pedestrians, bikes and scooters). Commercial off the shelf video cameras on mUAS can communicate high-resolution imagery to the Cloud for significant improvements in safety and security of small urban and rural commuter rail parking lots. Trained algorithms will also help with automated imagery interpretation of archival still imagery to provide valid and reliable revenue validation. More importantly, applying machine learning to high-resolution video can identify unsafe and insecure situations in pedestrian and vehicular movement in real-time. For example, using space and time data analysis, automated imagery interpretation could identify the pedestrian characteristics of B&E's or lurking predators and alarm transit security. Using the

[47] Shortwell, *op. cit.*

[48] Mariam McNabon, "The Latest DHS Alert About Chinese Manufactured Drones: Prudence or Politics?", DronLife.com, 21 May 2019, Accessed on 22 May 2019 at https://dronelife.com/2019/05/21/the-latest-dhs-alert-about-chinese-manufactured-drones-prudence-or-politics/

same space and time analysis, traffic flows that indicate illegal turning movements, failure of certain vehicle type to "Stop, Look, and Listen," and pedestrians consistently jaywalking in a dangerous intersection could be automatically identified for safety personnel in real-time.

- *Impact of low-cost dual sensor sUAS for mUAS application in transit and rail systems.* The most recent addition to the DJI Mavic 2 Enterprise mUAS integrates a visible spectrum camera with a thermal sensor. While the resolution of the thermal camera is lower than those on the high-end larger sUAS, there appears to be enough resolution to provide a very mobile, inexpensive, mUAS-based GeoINTEL tool that increases the safety and security of isolated transit parking. It would identify suspicious pedestrian movements in low-light situations through body-heat signatures in combination with visible imagery.

5.0 INVESTIGATOR PROFILE

The principal investigator for T-90 is Lawrence J. Harman. Larry Harman is the co-founder and co-Director of the GeoGraphics Laboratory at Bridgewater State University in Bridgewater, Massachusetts. He is a part-time professor in the Department of Aviation Sciences at the University. He is also the managing partner of Harman Consulting LLC in Boston, MA. Mr. Harman holds a bachelor's degree in Education and Earth Science from Bridgewater State and a master's in urban planning from the University of Washington in Seattle, Washington. He was a Fellow for Advanced Technology (Geographic Information Systems and Intelligent Transportation Systems) at the National Transit Institute at Rutgers University- New Brunswick, NJ. He competed the Massachusetts Senior Executive Program at Harvard's Kennedy School of Government, in Cambridge, MA. His employment experience includes Assistant Secretary for Public Transportation for the Massachusetts Department of Transportation, Special Assistant to the Chairman of the Massachusetts Bay Transportation Authority, Special Assistant to the President of the University of Massachusetts, Assistant Director for Regional Planning for the South Florida Regional Planning Council, and Intelligence Officer/Photo Analyst for the Central Intelligence Agency. A Vietnam-era veteran, he completed the U.S. Army Intelligence School's imagery interpretation course and the National Geospatial-Intelligence Agency's (NGA) intelligence officer/photo interpretation course. He has fifty years of experience in transportation planning, policy, and operations.

GLOSSARY

Glossary of Acronyms and Terms Used in this Report	
14 CFR part 107	Operation of small UAS (sUAS) weighing less than 55 pounds, for other than recreation or hobby purposes, is governed by chapter 14 Code of Federal Regulations (CFR) part 107 (Federal Aviation Administration)
2D	Refers to computer imagery that is "flat" with horizontal and vertical (x and y) dimensions in the workspace.
3D models	Refers to computer imagery that has height (z) added to the horizontal and vertical dimensions in the workspace.
APAS	Advanced Pilot Assistance System
ADS-B	Automatic Dependent Surveillance – Broadcast system
big data analytics	Big data analytics is the use of advanced analytic techniques against very large, diverse data sets that include structured, semi-structured and unstructured data, from different sources, and in different sizes from terabytes to zettabytes. (IBM)
cloud-based	(of digital) Data stored, managed, and processed on a network of remote servers on the Internet (Google)
cyber security	Refers to the body of technologies, processes, and practices designed to protect networks, devices, programs, and data from attack, damage, or unauthorized access. (Google)

geo-fencing	The use of global positioning systems (GPS) or radio frequency identification (RFID) technology to create a virtual geographic boundary, enabling software to trigger a response when a mobile device enters or leaves an area. (Google)
geo-spatial analysis	The gathering, display, and manipulation of imagery, GPS, satellite photography and historical data, described explicitly in terms of geographic coordinates or implicitly, in terms of a street address, postal code, or forest stand identifier as they are applied to geographic models. (Whatis.com)
GPS	Global position system is a system of satellites, computers, and receivers that can determine the latitude and longitude of a receiver on Earth by calculating the time difference for signals from different satellites to reach the receiver. (yourdictionary.com)
mUAS	Micro-Unmanned Aircraft Systems is a classification of small unmanned aircraft system (sUAS) that is currently being defined by the Federal Aviation Administration to facilitate rules that apply to flying over people in the national airspace (NAS).
NAS	The National Airspace System is made up of a network of air navigation facilities, air traffic control (ATC) facilities, airports, technology, and appropriate rules and regulations that are needed to operate the system. (FAA)
oblique imagery	Oblique imagery is aerial imagery captured at an angle of 40 to 45 degrees, designed to provide a more natural perspective and make objects easier to recognize and interpret. (eagleview.com)
Orthomosaic map	A digital orthomosaic map is "a detailed, accurate photo representation of an area, created out of many photos that have been stitched together and geometrically corrected ("orthorectified") so that it is as accurate as a map. (https://uavcoach.com/drones-orthomosaic-map/
PII	Personally identifiable information (PII) is any data that could potentially identify a specific individual. Any **i**nformation that can be used to distinguish one person from another and can be used for de-anonymizing anonymous data can be considered PII. (techtarget.com)
RPIC	Remote Pilot in Command (Remote PIC or Remote Pilot). A person who holds a remote pilot certificate with an sUAS rating and has the final authority and responsibility for the operation and safety of an sUAS operation conducted under part 107. (FAA)
RTMP	Real-Time Messaging Protocol (RTMP) was designed for high-performance transmission of audio, video, and data between Adobe Flash Platform technologies, including Adobe Flash Player and Adobe AIR. RTMP is now available as an open specification to create products and technology that enable delivery of video, audio, and data in open formats compatible with Adobe Flash Player. (Adobe.com)
SaaS	Software as a Service, a method of software delivery and licensing in which software is accessed online via a subscription, rather than bought and installed on individual computers. (Google)

REFERENCES.

Federal Aviation Administration Resources.

- "Micro Unmanned Aircraft Systems - Final Report," Aviation Rulemaking Committee, Federal Aviation Administration. April 1, 2018, Accessed by L. Harman 25 April 2019 at https://www.faa.gov/uas/resources/policy_library/media/Micro-UAS-ARC-FINAL-Report.pdf

- "Remote Pilot – Small Unmanned Aircraft Systems – Study Guide." (Washington, D.C.: U.S. Department of Transportation, Federal Aviation Administration, Flight Standards Service, FAA-G-8082-22, August 2016. https://*www*.faa.gov/regulations_policies/handbooks_manuals/aviation/media/remote_pilot_study_guide.pdf

- "Safe and Secure Operation of Small Unmanned Aircraft Systems – A Proposed Rule by the Federal Aviation Administration" on 02/13/2019 at https://www.govinfo.gov/content/pkg/FR-2019-02-13/pdf/2019-00758.pdf

- "Small Unmanned Aircraft Systems," *Advisory Circular*, (Washington, D.C.: U.S. DOT, Federal Aviation Administration), AC No. 107-2, 21 June 2016. https://www.faa.gov/uas/media/AC_107-2_AFS-1_Signed.pdf

TCRP T-90 Project Documents:

- L. Harman and U. Shama, "Small Unmanned Aircraft Systems (sUAS)-based Geo-spatial Intelligence (GeoINTEL) for Commuter Rail Parking in Rural and Suburban Areas – A Systems Engineering Approach," GeoGraphics Laboratory, Bridgewater State University, Bridgewater, MA, USA, December 2018 (a pdf document). http://www.geographicslab.org/T-90%20IDEA/T-90%20Sys%20Eng%20Sec%201-5_v1.pdf

APPENDIX: Flying Drones Course Syllabus

***Flying Drones for Profit, Public Safety, and Commercial Applications, SFTY 003,* Community Services, Holyoke Community College, Fall Semester, 2018**

Instructor Information:

- Lawrence J. Harman
- Co-Director, GeoGraphics Laboratory
- Dana Mohler-Faria Science and Mathematics Center, Room 460
- Phone: 508-531-6144
- E-Mail: lharman@bridgew.edu, larry@geographicslab.org
- Office Hours: 10:00 m to 2:00 pm, Monday through Friday, with prior appointment.

Class Times and Locations:

- Fall Semester 2018, Saturdays, 9 am – 1 pm, September 29 – October 20, 2018
- The Kittredge Center, Room 203

Anticipated Learning Outcomes

- A basic understanding of Commercial-Off-The-Shelf (COTS) sUAS available on-line for small budget operations (including a demonstration of a several sUAS).
- A basic understanding of local, regional and national airspace regulations evolving to promote the safe operation of sUAS for public and commercial purposes that respects individual privacy.
- A basic understanding of the skills necessary to safely operate sUAS manually and autonomously.
- A basic understanding of the skills necessary for the analysis of sUAS imagery for infrastructure planning, operation, and evaluation.
- A policy level understanding of public and private approaches to applying sUAS capabilities for safety, security, and emergency response.

Approach to Learning:

- The class will be organized into small work groups in Week One to address the following areas, depending on the prior experience and training of the participants:
  - ***FAA Airman's Knowledge Requirements*** – What do you need to know to pass the FAA Remote Pilot In Charge test?
  - ***sUAS Flying Skills*** – What skills do you need to know to pilot a state-of-the-art sUAS proficiently (*e.g.* DJI Spark, DJI Phantom 4 Pro and the DJI Inspire 2)?
  - ***sUAS Mission Planning*** –How do you use the skills learned in 1 and 2 above to identify your *problem and solve it with the remote sensing capabilities of an sUAS*?
  - ***Geospatial Intelligence*** – *How do you analyze imagery* using open source and/or reasonably priced commercial programs that results in geospatial intelligence?

Approach to Assessment:

1. **Weekly quizzes:** There will be a brief weekly quiz based on the FAA Part 107 Study Guide and the Bard College Center for the Study of the Drone's Weekly Roundup. All students must complete the quizzes in a timely fashion on-line.
2. **sUAS Flying Skills**:
    - takeoff and landing,
    - low-level flight side to side,
    - low-level flight around a box course – clockwise and counter clockwise,

    Additional Skills Development, if time and weather conditions permit

    - fly an X pattern from the corners of the box,
    - fly an X pattern overhead from inside the box where controls reverse themselves
    - fly in Positioning mode (with GPS),
    - fly without GPS
    - Fly using "Tripod" and" Course Lock" intelligent modes
3. **Final Exam for HCC Continuing Education Credit (Optional)** As with the FAA Official Exam, the student must complete 70% of the final exam questions correctly to pass the AVSC 399 final exam.
4. **Final Grade (CEU Option).** The final grade will be derived from the FAA Mock Exam, class attendance and participation.

Resources – suggested readings:

- Gettinger, Dan, "Drones at Home -- Public Safety Drones," (NY: Bard College for the Study of Drones), April 2017, accessed by L. Harman on 11 November 2017 at http://dronecenter.bard.edu/public-safety-drones/
- Michel, Arthur Holland, "Drones at Home --Local and State Drone Laws,"(NY: Bard College Center for the Study of Drones), March 2017, accessed by L. Harman on 11 November 2017 at http://dronecenter.bard.edu/state-and-local-drone-laws/
- Michel, Arthur Holland and Dan Gettinger, "Drones at Home – Drone Incidents: A Survey of Legal Cases," (NY: Bard College for the Study of Drones), April 2017, accessed by L. Harman on 11 November 2017. http://dronecenter.bard.edu/drone-incidents/
- **"**Presidential Documents -- Unmanned Aircraft Systems Integration Pilot Program – Memorandum for the Secretary of Transportation,**"** *Federal Register*, Vol. 82, No. 208, (Washington, D.C.: The White House), October 25, 2017. https://www.federalregister.gov/documents/2017/10/30/2017-23746/unmanned-aircraft-systems-integration-pilot-program
- "Procedure for Unmanned Aircraft Systems Operations at the Northeast UAS Airspace Integration Research Alliance (NUAIR) Massachusetts Unmanned Aircraft Systems Test Center ((MA UASTC)," Vol.10.0 29 April 2015.
- "Remote Pilot Knowledge Test Guide," (Washington, D.C.: U.S. Department of Transportation, Federal Aviation Administration), FAA-G-8082-20, September 2016. https://www.faa.gov/training_testing/testing/test_guides/media/remote_pilot_ktg.pdf

- “Remote Pilot – Small Unmanned Aircraft Systems – Study Guide.” (Washington, D.C.: U.S. Department of Transportation, Federal Aviation Administration, Flight Standards Service, FAA-G-8082-22, August 2016. https://*www*.faa.gov/regulations_policies/handbooks_manuals/aviation/media/remote_pilot_study_guide.pdf
- “Small Unmanned Aircraft Systems,” *Advisory Circular*, (Washington, D.C.: U.S. DOT, Federal Aviation Administration), AC No. 107-2, 21 June 2016. https://www.faa.gov/uas/media/AC_107-2_AFS-1_Signed.pdf
- *Users Manual for Phantom 4*, [accessed at https://dl.djicdn.com/downloads/phantom_4/20170706/Phantom+4+User+Manual+v1.6.pdf]
- *Weekly Round-up*, (NY: Bard College Center for the Study of Drones) accessed by L. Harman on 11 November 2017 at http://dronecenter.bard.edu/category/roundup/

Resources – suggested YouTube videos:

- “DJI Training Tutorials – Phantom 4” accessed by L. Harman on 11 November 2017 at https://www.youtube.com/playlist?list=PL65kukZorPdMjwzR5PmzAnMdR6RYwS1mB
- Maptitude Training Tutorials, accessed by L. Harman on 11 November 2017 at http://www.caliper.com/training/MaptitudeTutorials.htm
- “Adobe Premier Pro for Absolute Beginners,” access by L. Harman on 11 November 2017 at https://www.youtube.com/watch?v=aMeHRRWNGgA
- “UAV/Drone Survey with Agisoft Photoscan (Part 1),” published by Sketchfab on 29 March 2017, Accessed by L. Harman on 11 November 2017 at https://blog.sketchfab.com/uavdrone-survey-with-agisoft-photoscan-part-1/
- “UAV/Drone Survey with Agisoft Photoscan (Part 2),” published by Sketchfab on 4 April 2017, accessed by L. Harman on 11 November 2017 at https://blog.sketchfab.com/uavdrone-survey-agisoft-photoscan-part-2/

Resources – suggested On-Line:

- 3D Robotics FAA Study Guides accessed by L. Harman on 12 November 2017 at https://3dr.com/faa/study-guides/
- “How to Fly a Drone (& NOT Crash) - in 4K!,”Chelsea and Tony Northrup, accessed by L. Harman on 12 November 2017 at https://www.youtube.com/watch?v=OcxUCepBHkM&list=PLwIVS3_dKVptduSLoE4Qb_vC_tdpSo053
- Tom’s Tech Time Tutorials, accessed by L. Harman on 11 November 2017 at https://www.youtube.com/user/goblinpicturesger