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Network Development and Autonomous Vehicles: A Smart Transportation Testbed at Fort Carson

Project Report Summary and Recommendations

Lance L. Larkin, Thomas A. Carlson, William R. D'Andrea,
Andrew L. Johnson, and Natalie R. Myers

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Abstract

In this work, a smart transportation testbed was utilized at Fort Carson to demonstrate three use cases for the primary purpose to plan, develop, demonstrate, and employ autonomous vehicle technologies at military installations and within the surrounding communities to evaluate commercially available Connected and Automated Vehicles and the potential to reduce base operating costs, improve safety and quality of life for military service members and their families, and deliver services more efficiently and effectively. To meet this purpose, an automated vehicle shuttle, an unmanned aerial system, and a wireless network were used and tested during the project. Results for the automated shuttle indicated that despite the quantity of data generated by operations, the contractors may not be ready to share information in a readily usable format. Additionally, successful use by the public is predicated on both knowing their mobility patterns and staff members promoting trust in the technology to prospective riders. Results for the unmanned aerial system showed successful identification of foreign object debris and runway cracks at the airfield. The wireless network is now operational and is used for additional work which utilizes the installed traffic cameras.

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Preface

This study was conducted as part of a Congressional Program Increase included in the 2019 National Defense Authorization Act under Program Element 0603728A, Project 03F, “Network Development and Autonomous Vehicles: A Smart Transportation Testbed at Fort Carson” and is sponsored by the Assistant Secretary of the Army for Installations, Energy, and Environment Strategic Integration.

The work was performed by the Engineering Processes Branch of the Facilities Division, US Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL). At the time of publication, the division chief was Mr. Tim Shelton, the branch chief was Mr. Chuck Schroeder, the deputy director of ERDC-CERL was Ms. Michelle Hansen, and the director was Dr. Andy Nelson.

COL Christian Patterson was the commander of ERDC, and Dr. David W. Pittman was the director.

Executive Summary

This report describes the work completed under the FY19 Congressional Program Increase in National Defense Authorization Act for Program Element 0603728A for \$5 million for *Network Development and Autonomous Vehicles: A Smart Transportation Testbed at Fort Carson*. The objective of this work was to explore the use of Connected and Autonomous Vehicles (CAV) at military installations integrated with regional communities to lower costs, improve soldier and family quality of life, and enhance mission readiness.

Three use cases were explored by the contractor US Ignite, under the umbrella of a smart transportation testbed at Fort Carson.

An automated vehicle shuttle using the Polaris GEM platform (Figure ES-1) conducted shuttle operations from 16 September 2020 until 15 March 2021, transporting a total of 204 passengers over that period. After several unfavorable incidents, the provider of the autonomy kit explained that the vehicle was used beyond its operational design domain. As a result, they were required to prematurely remove the shuttle from service.

Figure ES-1. Polaris GEM automated vehicle shuttle.



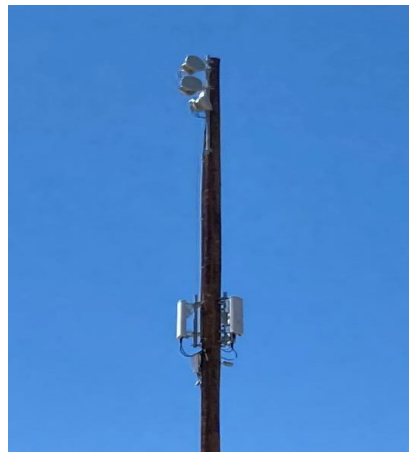
An unmanned aerial system (UAS), or drone (Figure ES-2), provided by GreenSight, demonstrated its ability to detect foreign object debris at the airfield, as well as its capability to image cracks in asphalt and concrete, and the potential for monitoring runway health over time.

Figure ES-2. GreenSight Dreamer unmanned aerial system (drone).



A wireless citizen's band radio system (CBRS) network was designed and installed at Fort Carson (Figure ES-3) to support the automated shuttle along its route, upload vehicle sensor data, and transmit traffic camera images. The system was designed with robust security, proper coverage in the area in which the shuttle operated, and with sufficient data speeds. The network was the last element of the smart transportation testbed to be completed and will be utilized by subsequent projects requiring a sensor network. The traffic cameras are already being used by a current follow-on project requiring traffic and weather input data from Fort Carson.

Figure ES-3. CBRS network components installed on a utility pole at Fort Carson.



1 Introduction

1.1 Background

The Army is reconsidering how it views its installations as part of the battlespace under multi-domain operations (MDO). That review includes technology modernization efforts such as CAV technology,¹ which is expanding rapidly. The DoD community and military installations have an interest in understanding autonomous transportation systems to plan for a broad range of areas that include infrastructure, security, economic impacts, cyber and communications. CAV demonstrations have been conducted on Army installations through the US Army Research Lab, sponsored by the US Army Tank Automotive Research Development and Engineering Center. The Ground Vehicle Robotics program titled *Applied Robotics for Installations and Base Operations* (ARIBO), demonstrated CAV use on installations and matured the technology through increasing stages of chauffeured, safety operator, and fully autonomous vehicle (AV) operations within limited internal installation routes. The ARIBO projects occurred from 2016 to 2018 at locations including Fort Bragg, North Carolina, and West Point US Military Academy, New York (Schaefer et al. 2018). The ARIBO program is no longer active, and with the establishment of Army Futures Command, the reorganization has resulted in institutional expertise at Army Research Laboratory and the newly formed US Army Combat Capabilities Development Command Ground Vehicle.

In February 2019, a collaborative submission for a CAV demonstration project was proposed to Local Motors (LM) by Joint Base Myer-Henderson Hall (JBMHH), Marine Corps Installations Command, and Engineering Research and Development Center (ERDC) with the support of the Office of the Assistant Secretary of the Army (Installations Energy and Environment), Deputy Assistant Secretary of the Army Strategic Integration as part of the Greater Washington Fleet Challenge. On 15 March 2019, an official notice by LM of the selection of JBMHH as the regional selectee for the demonstration was received. A sole source contract from the ERDC contracting office was awarded to LM to allow integration of CAV data into the Virtual Testbed for Installation Mission Effectiveness (VTIME) and for

¹ Connected and autonomous vehicles use network connectivity to communicate with each other, traffic signals, or to obtain data from a cloud server. This connectivity with automated technologies assists or replaces a human in the task of operating the vehicle.

ERDC researchers to observe and document deployment procedures and impacts. The cost for this service acquisition was \$130,000. The results and recommendations from this work have been documented in the ERDC Construction Engineering Research Laboratory (ERDC-CERL) Technical Report TR-20-9, *Autonomous Vehicle Pilot at Joint Base Myer-Henderson Hall* (Allen et al. 2020).

At the same time, and in response to the ERDC 2018 Broad Agency Announcement, Topic CERL-18, *Modeling and Simulation/Analysis tools for Infrastructure Applications*, US Ignite submitted a preproposal to the ERDC-CERL, with the proposed effort focused on piloting a CAV within the Fort Carson and Colorado Springs, Colorado, region. With the selection of this preproposal, US Ignite was asked to submit a full proposal, which they did, titled, *Evaluating On Base Deployment of Smart Transportation Technologies: Planning Report* (Maynard n.d.).

Later in FY19, a \$5 million Congressional Program Increase was received by ERDC-CERL to fund the above projects at JBMHH and Fort Carson.

The desired outcome of these projects was to explore the use of CAVs at military installations integrated with regional communities to lower costs, improve soldier and family quality of life, and enhance mission readiness.

1.2 Objectives

This project planned to develop, demonstrate, and employ AV technologies at military installations and within the surrounding communities to evaluate commercially available CAVs and the potential to reduce base operating costs, improve safety and quality of life for military service members and their families, and deliver services more efficiently and effectively. The project used a multiple-case study embedded design to answer exploratory and explanatory questions with both qualitative and quantitative methods. The goal was to identify gaps in infrastructure, policy, human factors, data analytics and decision making at military bases as they relate to CAV technology and determine ways to improve future planning for CAVs and effectively manage commuter CAV options that can expand transportation choices and reduce service operated vehicles on installations.

This report contains a summary of the testbeds done by ERDC and US Ignite at Fort Carson from August 2019 to August 2021. Fort Carson, located in Colorado Springs, Colorado, is an Army installation with over 65,000

active duty, family members, reserve military civilians, and contractors living or working on base. This creates multiple transportation challenges because of the high volume of off base commuters, limited on base parking, and soldiers moving between barracks, training, dining facilities and work. The smart transportation testbed at Fort Carson consisted of three separate use cases. They included an AV shuttle, AV service vehicle, and wireless CBRS network. The objective of each element is included below.

1.2.1 AV shuttle

The primary objective of this use case was to demonstrate the function of an AV shuttle to provide transportation services to soldiers along a fixed route to selected facilities at Fort Carson. During the project, the following specific objectives were identified:

- Deploy two shuttles on standard roads with mixed vehicle traffic.
- Circulate on a fixed route with stops during standard service hours.
- Collect data from AVs.
- Upload all raw and processed data to the ERDC Azure Govcloud.
- Perform data analytics on collected vehicle data.

1.2.2 AV service vehicle

The purpose of the AV service vehicle use-case was to explore advancements in mobility and automation with the Fort Carson Smart Transportation Testbed, while optimizing operational efficiencies and improving the lives of soldiers and their families. The overall objectives of the AV Service Vehicle project were to do the following:

- use research with AVs and sensor-based technologies to help the DoD reduce transportation costs, improve public safety, and deliver faster services on military installation sites;
- serve as a case study for other smart installations to use AVs;
- and develop a methodology for evaluating the operational safety of the system in various deployment settings.

Ultimately, a UAS operated by GreenSight Inc. was demonstrated to successfully meet the objectives.

1.2.3 CBRS network

The final element of the Fort Carson Smart Transportation Testbed was a dedicated wireless CBRS network with roadside cameras. The purpose of the CBRS network and camera system was to upload AV shuttle data and evaluate AV shuttle effects on traffic. The network was required because there was no public internet access available for use by the AV shuttle. The installation of the network was not completed in time to be used by the AV shuttle. However, the network and cameras will be utilized in additional research focused on traffic and weather.

1.3 Approach

Taking the approach in US Ignite's proposal to create a smart transportation testbed at Fort Carson with three use cases provided the structure for this work. US Ignite competitively sought a subcontractor to deliver each use case. US Ignite accomplished this by soliciting requests for proposals from private companies to meet the objectives. Proposals were received and evaluated according to their ability to meet the overall objectives of the project. The subcontractors chosen included First Transit for the AV Shuttle, GreenSight for the AV service vehicle, and Tilson for the CBRS network. The ERDC was the overall program manager for this work. Final reports given by the contractor and subcontractors contain greater detailed information and can be found in the ERDC library.

1.3.1 Technology approach

1.3.1.1 AV shuttle

First Transit was selected by US Ignite as the provider of the AV shuttle use case. First Transit proposed the Perrone Robotics Incorporated (PRI) TONY ("TO Navigate You") autonomous kit applied to a Polaris GEM e6 electric vehicle. TONY is the combination of Perrone's patented full-stack AV software engine MAX with PRI designed controls to actuate a vehicle's steering, throttle, brake, and shift. MAX was designed from the outset for full autonomy with little-to-no driver intervention and was tested in Level 4 and Level 5 autonomous operation. The technology enables a vehicle to easily maneuver the full course, including traffic, intersections with yield turns, stoplights, pedestrians, etc. The system easily maps the route by driving it once and all intersections and yield points are marked. A short period of testing and tuning follows. Once a course has been established in the system, a completely different vehicle can use the same course and execute the

same mission without repeating the process; this greatly reduces implementation and testing time. Appendixes B, C, and D include listings of the final reports provided by the contractors.

1.3.1.2 Service vehicle

US Ignite selected GreenSight as the provider of the AV Service vehicle use case. The GreenSight proposal stated they would deploy its Aerial Automated Runway Inspection and Safety Scanner (AARISS) technology to Fort Carson to evaluate its effectiveness, safety, and utility. This technology is a fully autonomous unmanned aerial system able to safely, quickly, and efficiently perform both automated inspection of paved surfaces and regularly scan for foreign object debris (FOD) in defined areas. GreenSight combined its mature, US-manufactured, Dreamer unmanned aerial vehicle, remote operations experience, and prior experience with automated inspection of asphalt to deliver an automated capability to meet the requirements of the requests for proposals and deliver a valuable capability for Fort Carson and the surrounding community. Appendix E includes a list of reports provided by the contractor.

1.3.1.3 CBRS network

US Ignite selected Tilson as the CBRS network provider. Tilson's proposal included a wireless communication technology solution that addressed five design philosophies: coverage, capacity, reliability, scalability, and longevity. Another critical aspect included in the proposal was security. Physical security, transmission security, and logical security were each addressed within the proposal as well as during the project effort.

1.3.2 Research approach

Each technology was approached from one of six Lines Of Effort (LOEs):

- Planning and Policy
- Infrastructure and Operations
- Energy and Economy
- Human Factors
- Data Architecture and Cybersecurity
- Data Analytics and Artificial Intelligence (AI)

However, not all LOEs applied to each use case. Therefore, within this report, when an LOE did not apply, it was omitted from that use case and the lens of Program Integration was applied to the project as a whole.

2 AV Shuttle

2.1 Planning and policy

2.1.1 Research focus and methods

This LOE reviews the implementation of two automated shuttles from a wider viewpoint of planning and policy. Planning ensures that AV operations are safe, that they meet the needs of the users, and that they are not a burden to the mission. Policy makers may consider regulating procurement processes, vehicle activities and capabilities, as well as other issues including privacy, security, traffic law and environmental regulations. This section presents the Fort Carson deployment activities and their implications for planning and policy. Of particular importance was the project's Operational Design Domain (ODD). The ODD describes the conditions under which an AV is designed to function. The ODD could include, but is not limited to, aspects of the environment, geography, time of day, and the presence or absence of certain traffic or roadway characteristics.

Review of the project implementation was done from the perspective of making observations of the steps involved in the operation and subsequent recommendations for consideration for future implementation efforts. To help facilitate the successful implementation of future AV operations from a planning perspective, the following was the basic framework from which observations were made:

- What are the steps, things, or operations that may need to be in place to facilitate a successful implementation?
- What were unexpected hindrances to implementation and what could be done in the future to plan for them; were there practices or considerations learned from past implementation efforts incorporated into this effort?
- What would have been helpful to have in place before implementation?
- What can we learn from each of the stakeholder's experience in their efforts to fulfill their role in the process?
- What can be done from a planning point of view to lay a groundwork for a more successful implementation in the future?

The user, operational, policy, and planning considerations are explored further in the sections below.

2.1.2 User considerations

While operational safety and functionality is critical for AV implementation, without ridership many of the goals of the project and technology will not be met. Consideration could be given to increase ridership and awareness of pilot projects. User surveys or events could help guide project planners in choosing preferred destinations and vehicle stops. Promotional material for both advertisement and addressing safety concerns could increase potential ridership during the pilot project. Postrider surveys of riders could give helpful feedback from a user's perspective.

2.1.3 Operational considerations

Risk identification, mitigation, and route mapping before shuttle launch all contribute to a successful pilot project, and these should not be overlooked.

Vehicle ridership design should be considered. In the case of the Polaris GEM e6 vehicle, which contains six separate passenger entrances, several concepts should be considered:

1. Safety: Since the vehicle may be entered from both sides—how does this work with traffic; does it create pedestrian and vehicular conflicts; does it require special infrastructure to allow a loading area for riders?
2. Functionality: Since project objectives noted that operations were for staff and soldiers—what kind of storage does it provide; is adequate space and storage available for staff and soldier equipment?
3. Infrastructure: Do loading requirements necessitate a separate loading area; do physical accommodations need to be made to provide a safe loading environment; route mapping would need to include loading areas; operate in autonomous or manual mode for entering or exiting loading areas?

Matching AV technology to the ODD is important. Observed issues included complexity of traffic management (e.g., eight signal-controlled intersections, five unprotected left turns, one lane change, multiple pedestrian crosswalks, heavy traffic, and traffic speeds), speed, battery life, antilock brakes, traction control, and weak heaters (cold weather environment).

The AV solution was descoped with some features being removed, including traffic light handling, long range intersection merge and cross-path handling, which may have resulted in the significantly higher level of operator intervention than originally planned.

During this pilot, the lack of available storage and maintenance facilities had a big impact on project deployment. Also, the battery life restricted both the route distance and the number of trips that could be offered. Cold weather greatly impacted the battery pull as well as the data log download requirements in the evenings, requiring the vehicle to be plugged in until the large files were transferred.

2.1.4 Policy considerations

The following considerations to policy were dealt with during this pilot:

- Ridership: Who is allowed to ride on the AV (e.g., minors)?
- Safety: Establishing safety standards and regulations for the AV.
- Ownership: Who owns the AV vehicles and supporting equipment?
- Liability: Who assumes liability for property damage or injury?

2.1.5 Planning considerations

The list below contains important considerations when planning a shuttle pilot. Safety, data, route selection, and infrastructure should be anticipated before the launch and monitored during operations.

- Safety:
 - Involve the on base safety team specialist (Base Safety Validation Team) to clarify project goals, selected route, technology, and ODD
 - Before operation, hold an emergency responder training session for safety teams and law enforcement
 - Before operation, install appropriate signage to ensure drivers and pedestrians are aware of AV operations, routes, and station stops
 - Recognize the importance of aligning the ODD with the AV technology
 - Confirm the AV will not perform erratically if accidentally switched to autonomous mode during manual operations
- Data:
 - Include a clear set of deliverables and sufficient high-speed internet availability would ease delivery of data to project partners.
 - Identify how data collected will be used for analytics, geospatial applications, autonomous software modeling, traffic analysis, and other applications for both current project applications, deliverables, and future areas of study.

- Include a review of AV hardware for data collection management and downloading.
- Route Selection:
 - Create autonomous operation protocols for intersections and traffic signals. The project did not include traffic signal recognition and response time after a green light. If the AV response to a light is slow, that may affect overall flow of traffic behind the vehicle.
 - Identify alternative routes and route mapping to allow quicker implementation if decisions are made to include alternative routes in the project as a response to operational issues (e.g., route or ridership).
 - Include a Risk Assessment of route by vehicle manufacturer or third-party as part of the route choosing process.
- Infrastructure:
 - Identify vehicle stopping location improvements such as, physical infrastructure to accommodate safe loading and unloading of riders, lighting, adequate signage identifying shuttle stopping location, and other informational and promotional material related to the project
 - Identify infrastructure deficiencies and improvements that may be necessary to conduct the project efficiently and safely.
 - Before operation, identify staging and storage area requirements and location. Specific items to consider include the following: enclosed secure, and temperature-controlled storage area; electric service for vehicle charging; internet connection, fully functioning office facilities, service areas including availability of tools, power, air, etc. with proximity to shuttle route.

2.1.6 Results and recommendations

A dedicated facility for maintenance, charging, cleaning, office, and restrooms should be provided along with a high-speed Wi-Fi network before project start and verify the vehicle specifications meet the operational needs (a.k.a. matching technology to the ODD).

2.2 Infrastructure and operations

2.2.1 Research focus and methods

The focus of this section is to outline the key infrastructure and operational elements of the AV pilot at Fort Carson. The AV pilot was facilitated by First

Transit, who provided the AV as well as the personnel and necessary equipment. First Transit was also responsible for all aspects of the AV operation.

2.2.2 Infrastructure data and findings

Infrastructure is the collection of physical and organization structures that support the AV shuttle at Fort Carson. In this section, we investigate many of the infrastructural facets that influenced the outcomes of the AV shuttle.

2.2.2.1 Geography

Fort Carson is located south of Colorado Springs, Colorado. Immediately to the west is the Rocky Mountains, which can produce a wide variety of weather, as well as rapidly changing weather. The installation is situated on gently rolling topography with clear lines of sight along the roadways.

2.2.2.2 Roadways

The roads at Fort Carson are generally in good condition. The roads appeared to be well maintained, and many of them even recently paved. Blacktop was the most common roadway material, with concrete curbs and sidewalks.

2.2.2.3 Traffic control signals

Common traffic control devices included stop signs and stop lights. The AV route did include both types, and thus vehicle takeovers were necessary to navigate some of these. In particular, the AV could not navigate the stop light on its own, unless the light was green and there was no oncoming traffic when it needed to make a turn.

2.2.2.4 Pedestrians

Army personnel frequently travel by foot on base. Therefore, pedestrian traffic was common during the AV pilot. The AV slowed and stopped for pedestrian traffic when necessary.

2.2.2.5 Connectivity

The connectivity of the AV was limited during this pilot. The data from the vehicle was manually uploaded to the government cloud, a process which took up to 8 hours. The lack of access to high-speed Wi-Fi by the operators at the vehicle charging station had the biggest impact on project efficiency.

One of the first project discussions and objectives was to test Wi-Fi connectivity along the route. This was one of the main drivers for the installation of a separate wireless CBRS network on Fort Carson, which is covered in Section 4, *CBRS Network*.

2.2.2.6 Vehicle charging and storage

The AVs were charged using standard charging stations and receptacles for the Polaris GEM vehicle. The weather at Fort Carson required sheltered vehicle storage, which consisted of two modified Mobile Mini storage units (Figure 1). These units contained heated office areas, as well as charging hookups. Both the vehicle battery, and the sensor suite battery required charging, so accommodations for both were provided.

Figure 1. Mobile Mini storage unit used to park and charge AV shuttle, with the front half used as office space.



A separate temporary tent (Figure 2) was also erected adjacent to the Mobile Mini storage units to facilitate vehicle cleaning and maintenance. There was no water, restroom facilities, or high-speed Wi-Fi network located at the storage site, so these represented deficiencies from a programmatic stance.

Figure 2. Larger tent setup for cleaning and preparing the AV shuttle.



2.2.3 Operations data and findings

2.2.3.1 Deployment and setup

Significant effort was spent on the deployment and setup of the AVs at Fort Carson. First Transit provided a comprehensive summary of these efforts in their final report, *Autonomous Vehicle Research Testbed: On Base Shuttle Pilot*, section titled, “Vehicle Delivery and Deployment.”² Two vehicles were delivered to Fort Carson for the shuttle operations.

A point of frustration that presented itself over the course of the project was the clear need for on-site support from the AV technology provider, Perrone Robotics. The operators at First Transit lacked training and knowledge of the autonomy portion of the vehicle operation, and this caused delays and difficulty when troubleshooting the incidents that were experienced on-site.

2.2.3.2 Specifications

The vehicle selected for the project was the Polaris GEM e6, fitted with Perrone Robotics’ TONY® Retrofit Kit to enable autonomous operation. This vehicle was selected owing to its versatility, pricing, and ability to

² First Transit, *Final Report, Autonomous Vehicle Research Testbed: On Base Shuttle Pilot* (Fort Carson, CO: First Transit, Unpublished 2021).

work in an urban environment with speeds exceeding the typical autonomous shuttle parameters.

The vehicle specifications include the following:

- Top speed of 25 mi/h³
- Federal Motor Vehicle Safety Standards (FMVSS) approved for street use on roads with a speed limit of 35 mi/h or less
- Six separate entrances
- Weight: Vehicle about 1,600 lb (can carry 1,300 lb)
- Dimensions: length: 13.9 ft, width: 4.6 ft, height: 6.1 ft

The vehicle's autonomy kit and sensor suite consisted of the following:

- Drive-by-wire kit
- Safety interlocking and monitoring
- Digital infrastructure
- 2x lidar and 1x radar for forward obstacle detection and intersection handling
- Interior and exterior facing cameras for visual recording

First Transit reported that Perrone Robotics initially provided a quote for an AV solution tailor-made for the ODD of the project. But because of budgetary constraints, the AV solution was descoped thereby removing some functionality, which included traffic light handling, long range intersection merge, and cross-path handling. As a result of these omissions, the shuttle required significantly more operator interventions than would have otherwise been required.⁴

2.2.3.3 Mapping

First Transit briefly outlined the mapping process in their final report.⁴

First Transit lists four major steps to the mapping process:

1. Map Creation
2. Checkpoint Creation

³ For a full list of the spelled-out forms of the units of measure used in this document, please refer to US Government Publishing Office Style Manual, 31st ed. (Washington, DC: US Government Publishing Office, 2016), 248–252, <https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf>.

⁴ First Transit, *Final Report, Autonomous Vehicle Research Testbed: On Base Shuttle Pilot* (Fort Carson, CO: First Transit, Unpublished 2021).

3. Speed Limit Creation
4. Mission Creation

The first route for the shuttle was able to be setup in seven days, followed by further refinements. The output of the mapping process was the Route Network Definition File, also referred to as the *overall map*.

2.2.3.4 Existing shuttle

One of the challenges during this project was that the installation had an existing minivan shuttle that serviced the base. Therefore, it was necessary to choose an AV route that complemented, rather than competed with the current shuttle routes. The operating routes for the existing shuttle were the North Shuttle Route (Figure 3), the South Shuttle Route (Figure 4), and the Upper War Fighter Route (Figure 5).

Figure 3. Map of North Shuttle Route including stops.

NORTH SHUTTLE ROUTE

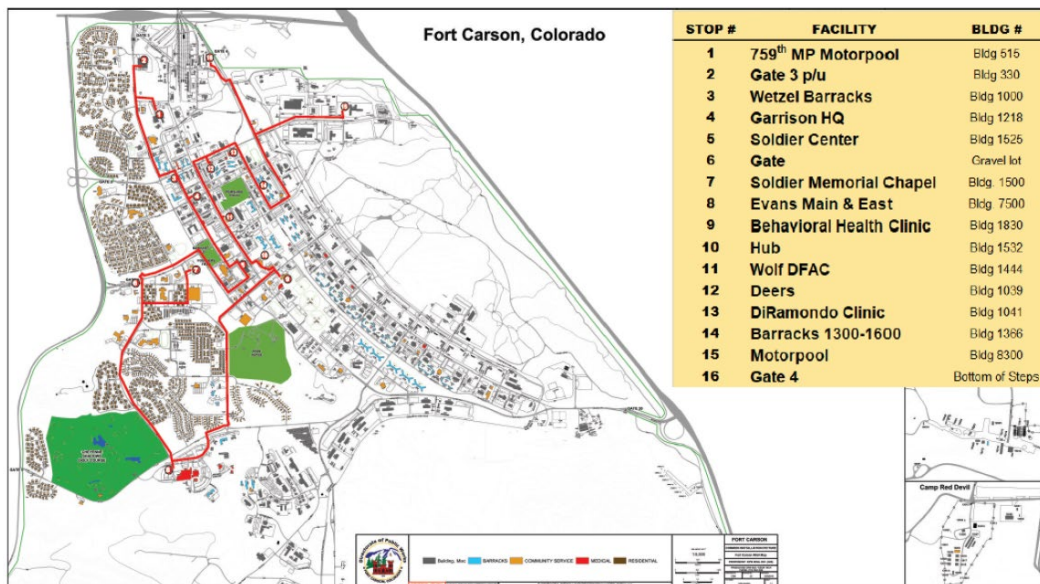


Figure 4. Map of South Shuttle Route including stops.

SOUTH SHUTTLE ROUTE

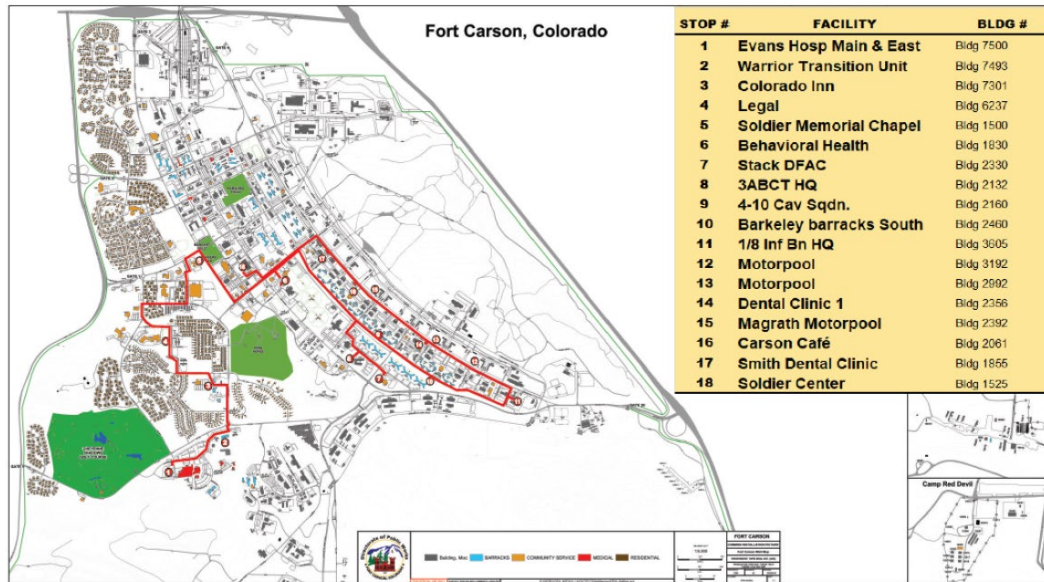
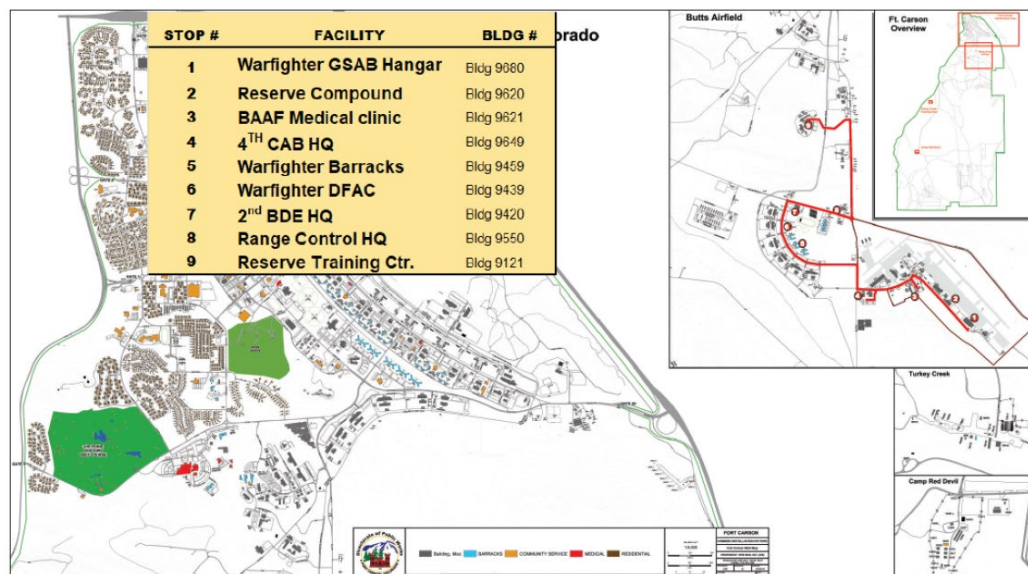


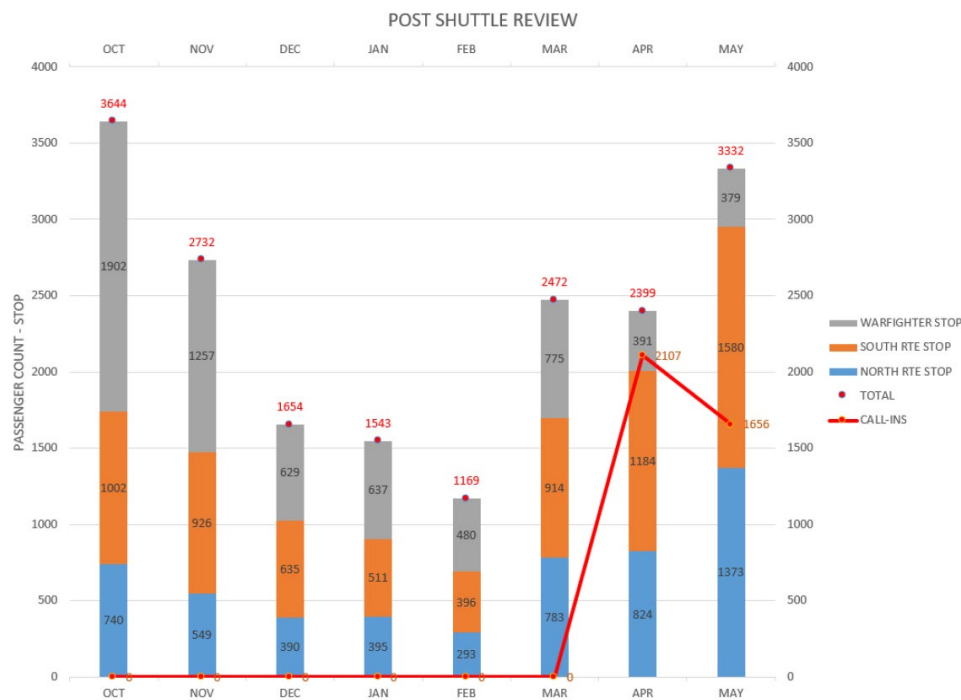
Figure 5. Map of Upper War Fighter Shuttle Route including stops.

UPPER WAR FIGHTER SHUTTLE ROUTE



Ridership for the three existing minivan shuttle routes were tracked, and the passenger count each month were recorded (Figure 6). Somewhere between 1,000 and 4,000 passengers were served each month.

Figure 6. Count of existing shuttle passengers each month.



2.2.3.5 AV shuttle route

The COVID-19 pandemic impacted ridership; and therefore, route modifications were made, including an extension of the route to an alternate barracks to collect soldiers who had been stationed at Fort Carson for a longer time. However, for the extended route, it was necessary for the AV to be driven in manual mode.

During the pilot, several routes were recommended. The original route was the only fully deployed route. Changes to the route were made as mentioned above to reach more passengers. However, because these changes were not fully mapped, and required manual operation of the shuttle, this created mismatches in the operational design domain, and resulted in unplanned incidents.

Initial proposals had plans for two routes, including one in the main cantonment area, and one in the Butts Army Airfield area (BAAF). Ultimately, the route serving the main cantonment area was selected and mapped. This

route was to be serviced in the evenings, and have stops at multiple facilities including barracks, the post exchange, commissary, and fitness center.

As the pilot progressed, there was discussion about modifying the route to meet the ridership needs on base (Figure 7). During operations, the operators provided feedback that some station stops were effective, namely the exchange, commissary, and barracks. Conversely, the fitness center was rarely used by soldiers.

Owing to limited battery life of the Polaris GEM vehicles, operational duration was limited. At the project start operating hours were set from 17:30–21:30 and then modified to 16:00–20:00 as these hours provided the highest riders and enabled sufficient charging time.

The two vehicles staggered their start times to keep shuttles on opposite ends of the route. One would begin operations, and the other would wait 10 min to start at the same origin. This minimized wait times at each stop.

Figure 7. Progression of route options.



A route for the AV was chosen that targeted new troops arriving at the Ivy Replacement Barracks to assist with transit around the installation as they learned the layout of Fort Carson. The two AV shuttles circulated in a counterclockwise movement starting at the Ivy Replacement Barracks, stopping at the exchange, the commissary, and the fitness center (Figure 8).

Figure 8. Final AV shuttle route.

Route / Hours / Station Stops

Hours of Operation:

5:30-9:30 PM Mountain Time.

Station stops:

(See yellow stars)

- Replacement Barracks
 - Start/stop route
- Exchange
- Commissary
- Gym



Storage and charging location (by EV chargers)

8 Emergency Response Training

First Transit

2.2.3.6 AV shuttle ridership

Operation of the AV shuttle was heavily affected by COVID-19 measures put in place across Fort Carson. Also, changes to the installation's opening hours, as well as a reduction in use of public transportation, limited ridership during the project period resulting in 204 total passengers or an average of 5 to 8 riders per day. That is significantly less than the 8-month tracking of the existing minivan shuttle mentioned above of 18,945 total passengers. AV shuttle ridership was tabulated each week during the AV operations (Table 1).

Table 1. Count of AV shuttle passengers each week.

Ridership Log		
Weekly Date	Weekly Rider Totals	Accumulative Ridership
Preservice Total	29	29
Week of 9/16/2020	4	33
Week of 9/21/2020	4	37
Week of 9/28/2020	2	39
Week of 10/5/2020	2	41
Week of 10/12/2020	3	44
Week of 10/19/2020	4	48
Week of 10/26/2020	5	53
Week of 11/2/2020	21	74
Week of 11/9/2020	17	91
Week of 11/16/2020	22	113
Week of 11/23/2020	3	116
Week of 11/30/2020	2	118
Week of 12/7/2020	2	120
Week of 12/14/2020	4	124
Week of 1/4/2021	10	134
Week of 1/11/2021	3	137
Week of 1/18/2021	14	151
Week of 1/25/2021	4	155
Week of 2/1/2021	5	160
Week of 2/8/2021	6	166
Week of 2/15/2021	4	170
Week of 2/22/2021	6	176
Week of 3/1/2021	8	184
Week of 3/8/2021	20	204
Week of 3/15/2021	Service Suspended	

The Mountain Express AV shuttle needed to supplement the already operating service. Although the hours of operation were originally set from 17:30 to 21:30, low ridership led to a reanalysis of the mission. At the beginning of November 2020, the AV shuttle operation hours were changed to 16:00 to 20:00, and there was discussion of testing a new route by driving in manual mode past a more permanent barrack, the Second Brigade Soldiers along Iron Fighter Road. The theory was that a more established group of soldiers would spread the word about this new shuttle. The ridership did go up during this testing period. Unfortunately, the shuttle operations started running into problems (see the 2.4 *Human Factors* section below).

2.2.3.7 Safety

First Transit wrote a Safety Management Plan before deployment, which contained a contact list, accident prevention measures, cleaning protocol, and incident procedures.⁵ In addition, First Transit wrote the Standard Operating

⁵ First Transit, *Safety Management Plan, Autonomous Vehicle Research Testbed: On Base Shuttle Pilot* (Fort Carson, CO: First Transit, Unpublished, 2020).

Procedures for the shuttle including an Operator Training Plan which was provided before deployment.⁶

At project close, First Transit included a section devoted to safety in their final report, which gave a detailed look at the risks encountered while piloting an AV on a military installation.⁷

One of the important recommendations by First Transit was early and continuous involvement by the base safety validation team. Another important element was emergency responder training for local first responders including law enforcement and safety teams. Their report noted that safety procedures and emergency reporting processes should be developed and reviewed by all parties before and during any pilot.

In March of 2020, and because of the COVID-19 pandemic, additional safety measures were instituted in response to health concerns and hazards. The measures taken to mitigate the spread of COVID included masks, hand sanitizer, disinfection, and a clear flexible barrier between the rows of seats to compartmentalize the shuttle.

Safety stewards on board the AV were a critical component of shuttle safety. The First Transit report includes a summary of two incidents that required quick responses of the safety stewards. The incidents highlight the importance of having an alert safety steward who is making the correct decisions for the vehicle and is well trained in the operation and conduct of the vehicle. It is extremely important for operators to know what they are instructing the shuttle to do at all times, the consequences of any improper input, and to be aware of unanticipated autonomous operations.

2.2.3.8 Takeovers

AV operator takeovers were common owing to a reduction in scope of the AV use-case and changes to the route during the project. US Ignite describes this in more detail in their final unpublished report.⁸ The increased number of takeovers by the operator did not cause any major disruptions to the service provided by the AV and contributed to the

⁶ First Transit, *Standard Operating Procedures—Including Operator Training Plan* (Fort Carson, CO: First Transit, Unpublished, 2020).

⁷ First Transit, *Final Report, Autonomous Vehicle Research Testbed: On Base Shuttle Pilot* (Fort Carson, CO: First Transit, Unpublished, 2021).

⁸ Eric Werner, *Fort Carson Smart Transportation Testbed: AV Shuttle Project Report* (Washington, DC: US Ignite, Unpublished, 2021).

research reported by the ERDC's academic partner, the University of Colorado at Boulder (Sankaranarayanan et al. 2021). The takeovers were a significant part of the AV operations and are discussed in more detail in Section 2.4 *Human Factors* below.

2.2.3.9 Advertising

Promotion of the AV shuttle was an important element of raising awareness and increasing ridership. Methods for communicating the schedule included handout cards of the route at the launch event and to riders. An example of such advertising is shown in Figure 9. Also, several articles were published in the installation newspaper, the *Fort Carson Mountaineer* (Appendix H). Later during the pilot, station signs and route maps were implemented. The vehicle was also wrapped with vinyl signs indicating the name of the shuttle *Mountain Express* and the appropriate affiliations.

Figure 9. Advertising for the shuttle service included handout cards with a route map.



Word of mouth by the safety stewards was used to encourage ridership amongst the soldiers. Safety stewards were then able to solicit feedback from the soldiers on what locations were desirable for riding the shuttle. The First Transit report (2021) recommended a short promotional video to increase awareness with the soldiers.

At the start of the operating process, station signage and maps highlighting stations were not readily available or in place. The project team found these beneficial following their implementation. In particular, the handout cards which were provided at the launch event and handed out to riders were useful in communicating the service options.

2.2.3.10 Weather

As expected, the deployment at Fort Carson included some severe weather that interrupted the shuttle service. Weather impacting the shuttle operation included cold weather and snowy conditions. The First Transit report (2021) specifically mentions that the AV heater struggled to keep the shuttle warm during times of cold, and the lack of antilock brakes affected drivability in the snow. Furthermore, snow accumulation in the staging and storage area limited mobility of the vehicle.

2.2.3.11 Data collection

The data generated onboard the AV shuttle included that of the vehicle's speed, direction, braking, accelerating, and from the autonomy kit. Data was offloaded from the vehicle daily and uploaded to the Azure Govcloud.

2.2.3.12 Permitting

The AV shuttle platform (Polaris GEM) is a National Highway Traffic Safety Administration approved vehicle and is therefore legal for use on public roads. The AV shuttle required approval of the Fort Carson leadership, and since the garrison roads are under the jurisdiction of the Army, the military police (MP) had the ability to enforce any laws pertaining to the AV. In addition, before deployment, signoff was required by the on-base safety team specialist.

2.2.4 Results and recommendations

- AV technology still has bugs to work out—and therefore safety stewards are a necessary component of vehicle operation. Furthermore, these

safety stewards should always exercise complete attention to the vehicle. Thoughtful processes of standard operating procedures can help eliminate errors.

- Proper facilities with adequate utilities and network access are necessary for storage, cleaning, charging, and prepping the vehicle.
- Route selection should consider base personnel needs and desired destinations, as well as traffic patterns, traffic control devices, and vehicle capabilities—in particular battery life and autonomy.
- Plan for weather events and the potential impacts on service.
- For pilot projects, ensure adequate support from technology providers to troubleshoot problems or incidents.

2.3 Energy and economy

2.3.1 Research focus and methods

This section focuses on the cost of propulsion for the shuttle, as well as the costs of operating the shuttle. The primary objective is to accurately reflect the costs to allow comparison to other shuttles of its kind, particularly the existing on base shuttle, as well as other AV shuttles.

2.3.2 Data findings

2.3.2.1 Battery range

Battery life was an important consideration in the vendor selection for the AV shuttle. Ultimately, negotiations with First Transit resulted in two Polaris GEM e6 vehicles being delivered to Fort Carson for this pilot.

2.3.2.2 Batteries

The Polaris GEM contained three battery systems: 12 V, 24 V, and 48 V. The 12 V battery powered the cooling units, roof flasher, and some electronics. The 24 V system powered the control motors for steering, braking, and most of the electronics. The 48 V system powered the drive motor, lights, and turn signals. The 12 and 24 V batteries were gel type and required special chargers. The 48 V battery consisted of eight lead acid sealed batteries, each containing 6 V.

One of the restrictions experienced in using the Polaris GEM vehicle was the battery longevity. The battery life restricted both the route distance and the number of trips that could be offered. The operational duration

was limited. At the project start, operating hours were set from 17:30–21:30 and then modified to 16:00–20:00 as these hours provided the highest riders and enabled sufficient charging time.

Cold weather also greatly affected the battery pull as well as the data log download requirements. The main battery life was reduced to 70% of normal capacity at 32°F. Also, the 24 V gel battery was often be drained during data log extraction.

2.3.3 Costs

2.3.3.1 Vehicle and operations costs

First Transit delivered and operated two Polaris GEM e6 vehicles for this project. Each was equipped with standard autonomy kits, installed by Perrone Robotics. The proposed cost for delivery of these vehicles for a 13-month operations period was \$717,500. This consisted of approximately \$318,000 for vehicle preparation and delivery, and \$400,000 for operations. Operational costs included staffing of 8 hour days, 5 days a week, and included 120 hours of operator training. Because of a shortening of the operational period for this project, actual costs were lower than those proposed.

2.3.3.2 Energy costs

The average electricity rate in the United States is roughly 12.55 ¢/kWh (varies by location).

The Polaris GEM website states that on average, it takes approximately 6 to 8 hours to recharge a GEM car from a completely discharged state. And, to fully charge a GEM car from a completely discharged state, it takes 5 to 8.9 kWh of power. Multiplying by the cost per kWh yields the cost for charging a GEM car as shown in Equation (1).

$$8.9 \text{ kWh} \times \$0.1255 \text{ per kWh} = \$1.12 \text{ per charge} \quad (1)$$

The estimated cost to charge the GEM is \$1.12. Further, estimating that the vehicle is charged twice daily, two vehicles operating for an entire year would consume roughly \$1,630 per year.

2.3.3.3 Infrastructure costs

The total cost to install and maintain the infrastructure required for a one-year operational pilot would be approximately \$46,000 given the costs shown in Table 2. Actual project costs were slightly less than this given the duration of operations. Costs were provided by US Ignite.

Table 2. AV shuttle infrastructure costs.

Item	One Time Cost	Lease Per Month	Total for 12 Months
Mobile Mini Storage Units (2)	\$360	\$484 each	\$11,976
Portable Hand Wash Station	\$80	\$300	\$3,680
Electrical Contractor Disconnect Fee (1)	\$11,760+\$630	n/a	\$12,390
Weather Port Purchase and Install	\$16,029	n/a	\$16,029
Miscellaneous Equipment	\$2,215	n/a	\$2,215
Total	–	–	\$46,290

2.3.4 Results and recommendations

On future deployments, we recommend the following considerations:

- Verify that the vehicle specifications meet the operational needs.
- Develop a schedule to charge the vehicle midshift during peak traffic periods.
- Ensure that the vehicle is plugged in during data download.

2.4 Human factors

Studies regarding the adoption of AVs by road users have primarily focused on personal use (Becker and Axhausen 2017; Cho et al. 2017), rather than the use of automation in public transit (Haboucha et al. 2017). However, the acceptance of AV often resolves around the issue of trust in the technology. Accordingly, the human factors portion of this study examined trust from the perspectives of riders, nonriders, and the operators of the AV.

An important note on language is that the subcontractors for this deployment referred to the people manning the AV as *operators*. The previous AV shuttle operated at JBMHH had referred to the official representatives onboard as *safety stewards*. This might have implications for how often

the company's representatives take over the vehicle. In this report, the two terms are used interchangeably.⁹

2.4.1 Research focus and methods

The human factors LOE followed the methodologies used in the Smart Base Autonomous Vehicle deployment at JBMHH to both replicate the successes and provide a direct comparison between the installations (Allen et al. 2020). The research questions from that previous technical report, which this deployment at Fort Carson intended to answer, were:

1. Does AV provide intent and enough information to riders, drivers, and pedestrians at all stops, including stop signs? Does this affect trustworthiness?
2. Does any lack of automated intent, or understanding by humans interacting with the AV, create a hazard?
3. What is ridership compared to other options? Would AV riders be willing to change their transportation patterns based on their experience with the AV?

Our research focused on the social domain using methodologies that gathered both quantitative and qualitative data to answer the above questions. Through the gathering of surveys from both riders and nonriders, plus the use of participant observation, the team planned on examining the Fort Carson AV deployment to empirically document AV interactions with other public road users, highlighting driving as a social endeavor (Vinkhuyzen and Cefkin 2016). Intending to extend our findings from JBMHH and a previous deployment of a self-driving vehicle by the Army at Fort Bragg (Schaefer et al. 2018), unfortunately, the study was severely affected by the Covid-19 pandemic, hindering researchers' efforts to collect data.

2.4.1.1 Surveys

Both a prelaunch questionnaire (Appendix G) and an operations survey (Appendix F) were built on data gathered from previous AV studies. The researchers from the ARIBO's self-driving vehicle deployment at Fort Bragg used surveys to examine riders' perceptions of trustworthiness,

⁹ In addition to the language used possibly affecting the incidence of takeovers, a previous study demonstrated that the number of interventions was affected by whether a vehicle was retrofitted with autonomy and therefore had a steering wheel. A dedicated AV with non-stereotypical controls resulted in fewer interventions (Schaefer and Straub 2016). An operator in a retrofitted AV may see their role as more controlling, whereas a safety steward—as at JBMHH—might allow the autonomy to carry out its orders more often. This is an area that could benefit from future research.

intelligence, level of automation, safety, and comfort. They found that general trust in the AV increased as people observed or interacted with the vehicle, but the researchers were not sure if that was because of the military riders having more trust in the DoD which vetted any technology that would be used on base (Schaefer et al. 2018).

Our previous study at JBMHH also discovered that people were more likely to recommend the AV after riding it, regardless of factoring in age or their working for the DoD (Allen et al. 2020). Therefore, we wanted to determine if people were more hesitant before riding the vehicle and if that hesitance was caused by a previous lack of experience with technology. Before the launch of the shuttle service, a short survey of 7 questions was sent installation-wide via email to see if people were interested in riding the shuttle. This prelaunch questionnaire asked for basic demographics, the participants' technological background, and elicited their interest in the project. After the shuttle service began, another survey provided data on participants' basic demographics, their trust in the autonomy, and their perceptions of safe operations. To collect the operations data, we created an 18-question survey. Both the prelaunch questionnaire and the operations survey were approved through the Army Human Research Protections Office.

The operations survey covered a range of data mostly applicable to both riders and nonriders. The first 11 questions elicited general demographic information and the participants' experience with AV and other technology. Questions 12–15 asked about the participants' perceptions regarding the shuttle using a 5-point Likert scale, including the machine's intelligence, safety, trustworthiness, comfort, and its use on base. These questions follow earlier studies that discovered when participants were given the option to take control of an AV, they did so more often than necessary, indicating a lack of trust in autonomy (Schaefer and Straub 2016). We wanted to see what level of trust passengers or observers of the vehicle had when a safety steward was present on the vehicle. This operator allowed the vehicle to function in autonomous mode unless there was a problem. Questions 16 and 17 asked about the acceptability of the AV in avoiding other objects and obeying traffic rules without human intervention, also using a 5-point Likert scale. The final question allowed for open-ended feedback.

Following the previous success of physically handing out surveys and collecting them in person at JBMHH, we planned on sending researchers

regularly to Fort Carson. Additionally, half page information sheets with facts about the study also included a quick response (QR) code that led to an online version of the operations survey.

2.4.1.2 Participant observation

Through the surveys, we quantitatively measured riders' and nonriders' perspectives. Qualitative data was gathered through participant observation when researchers rode the Polaris GEM, informally talked with passengers, observers, operators, and documented participants' contact with the AV. Although past studies on AV rely on modeling (Wang et al. 2018; Wang et al. 2019) and simulations (DeKort 2019; Schaefer and Straub 2016; Stayton et al. 2017), our observation of the social interactions between the shuttle and all actors in the traffic system allowed greater insight than just quantitative data would suggest.

Surveys are limited in the type of information gathered. Participant observation allows researchers and other study contributors the space for exploratory questions and answers. This method is particularly relevant in real-world settings where we do not know much about a situation, when there are important differences between the views of insiders versus outsiders (DoD versus non-DoD), and the research phenomenon is hidden from public view because AV are not allowed on most public streets (Jorgensen 1989, 12–13). The investigators' rides on the machine provided unmediated views of AV interaction between riders and nonriders alike. Metrics that were recorded during participant observation included body language reactions to the vehicle and the actions of other drivers to the AV on the road.

2.4.1.3 Methods of analysis

The pilot ended earlier than expected owing to several incidents and the shuttle provider recalling the AV for reprogramming and testing. Additionally, the coronavirus pandemic, which led to the DoD limiting all travel, began before the launch of the pilot. Consequently, researchers' data gathering in the field was severely curtailed and led to fewer gathered surveys than expected. With only 66 prelaunch questionnaires and 72 operation surveys gathered, we were unable to quantitatively analyze the results with a high level of statistical significance. Despite this limitation, the quantitative results were useful in comparison with the field notes, trip reports, meeting summaries, and contractor documentation we had gathered and collated. All data was then sorted through componential

analysis, a method that has served many types of qualitative and mixed methods research (e.g., Phillips 2014).

As riders and nonriders were sorted into specific demographics from our survey results—those who work for the DoD, live off base, etc.—a taxonomic analysis further refined categorical domains, leading to multiple componential analyses. The components of cultural patterns as sorted through domains and taxonomy allowed us to integrate the findings across our varied sources and between quantitative and qualitative approaches (Spradley 1980).

2.4.2 Data and findings

Despite the pandemic creating problems by not allowing similar amounts of participant observation and physical gathering of surveys that occurred at JBMHH, we were able to glean enough data to extend the findings from that previous deployment. At Fort Carson, the prelaunch questionnaire provided data on peoples' perceptions before having ridden the AV shuttle and the operations survey allowed us to examine operators' views of safety and trust in the autonomy.

2.4.2.1 Using the AV: A matter of trust or convenience?

Although ERDC's in-person data gathering was limited, the contractor provided weekly rider reports. Correlated with our survey information, it was clear that riders were taking the shuttle for convenience. Nearly half the respondents to the prelaunch questionnaire said they would ride the shuttle as part of their daily routine if it was convenient (48%). While only 9% said they would never ride a self-driving vehicle, some of their comments alluded to the project being a waste of money rather than the participant not trusting the vehicle. Only one of the six negative respondents highlighted safety being a concern, saying

might be nice in the 3 months of summer. We will see if (sic) how much you guys will have to pay in damage when this thing crashes into everything during the winter. I think you guys should be prioritizing your soldiers' living conditions. Instead, you guys are wasting time and money on something that is going to put people's lives in danger. (19 Sept. 2020).

This respondent mentioned a theme that was prevalent in the comments by the other survey takers who had a negative response—that the project was a waste of money ($N = 4$). These cynical responses underscored that 23% of the respondents indicated they would ride the vehicle only if there was a safety steward onboard monitoring operations of the AV. The matter of safety was a concern, but most respondents seemed to trust the machine and were more interested in convenience, which was demonstrated as we examined ridership numbers.

2.4.2.2 Low ridership

Fort Carson leadership used our previous study at JBMHH for planning their deployment (Allen et al. 2020), including many discussions about which routes would best serve the soldiers and result in highest ridership. Once the commander's team had decided on a route that catered to the new troops who had just arrived on the installation and would most likely not own a vehicle, the leadership printed route pamphlets and posted signs at the stops as shown in Figure 10 and the US Ignite unpublished report.¹⁰

Figure 10. Shuttle sign indicating location of stop.



The original planning had the route starting at the Ivy Replacement Center; the barracks where all new soldiers on the installation could take advantage of the shuttle. A rider could travel in a loop from the barracks to

¹⁰ Eric Werner, *Fort Carson Smart Transportation Testbed: AV Shuttle Project Report* (Washington, DC: US Ignite, Unpublished, 2021).

the exchange, commissary, and fitness center. However, after the launch in September 2020, weekly ridership numbers averaged three passengers per week. Therefore, there was discussion about how to raise user numbers and the route was altered so the shuttle operators would put the machine in manual mode to drive to a new stop, testing to see if more riders would take advantage of the service.

The troops staying at the Iron Fighter Barracks were based at this location for a longer period unlike the Ivy Replacement Center where soldiers were just passing through as they got their assignments. Therefore, Fort Carson leadership believed the less transitory troops at the Iron Fighter Barracks would promote the shuttle through word of mouth, and this was confirmed as ridership jumped to 21 people the first week of November, dipped slightly to 17 riders, and then 22 soldiers rode the week before Thanksgiving. Table 3 and the US Ignite unpublished report¹¹ tabulate the weekly ridership data. Unfortunately, an incident the week of Thanksgiving occurred when the shuttle operator inadvertently pushed the automatic/manual (a/m) button causing the vehicle to enter autonomous mode (see 2.6 *Data analytics and AI*). The AV immediately steered to the left across the oncoming lane, which was absent of traffic, and up onto the curb where the operator was able to regain control. This incident would severely affect all the operators' trust in the AV.

¹¹ Eric Werner, *Fort Carson Smart Transportation Testbed: AV Shuttle Project Report* (Washington, DC: US Ignite, Unpublished, 2021).

Table 3. AV shuttle ridership data with the weeks of expanded service highlighted.

Start of Week	Weekly Total	Cumulative Total
Preservice	29	29
16 September 2020	4	33
21 September 2020	4	37
28 September 2020	2	39
5 October 2020	2	41
12 October 2020	3	44
19 October 2020	4	48
26 October 2020	5	53
2 November 2020	21	74
9 November 2020	17	91
16 November 2020	22	113
23 November 2020	3	116
30 November 2020	2	118
7 December 2020	2	120
14 December 2020	4	124
4 January 2021	10	134
11 January 2021	3	137
18 January 2021	14	151
25 January 2021	4	155
1 February 2021	5	160
8 February 2021	6	166
15 February 2021	4	170
22 February 2021	6	176
1 March 2021	8	184
8 March 2021	20	204
15 March 2021	Service Suspended	

2.4.2.3 Trust and safety perceptions

The lack of data gathering by ERDC led to a dearth of quantitative data, as we were unable to broadly survey riders in person. Once the DoD opened travel again during the spring of 2021, the deployment was ended early by Perrone Robotics because of software inconsistencies.¹² Therefore, we were only able to gather 35 surveys from riders, which was not enough for

¹² Eric Werner, *Fort Carson Smart Transportation Testbed: AV Shuttle Project Report* (Washington, DC: US Ignite, Unpublished, 2021).

statistical significance regarding trust in the AV. However, participant observation allowed close analysis of the incidents and their effect on the operators.

Trust was clearly influenced after the incidents on the people to whom it would have the most affect—the operators. First Transit underscored at the beginning of the project that operators were the public face for the deployment and would be promoting the AV to prospective riders in person. Additionally, the company emphasized the operators' role as ambassador for the autonomous technology (from First Transit presentation on 8 June 2021). In the unpublished final report they said, “[the Operators] are also the voice of the project to all passengers and need to be willing to educate and answer questions.”¹³

However, the operator's trust in the autonomy was clearly shaken after the incidents. As other studies have shown (Dikmen and Burns 2017), including our previous deployment at JBMHH (Allen et al. 2020), trust in AV goes up as people get more exposure to it or ride it. Contrary to this, the shuttle operators, who were given multiple surveys over time, indicated a drop in trust following the incident on 27 November 2020.

One operator's survey on 15 September 2020 strongly agreed that the vehicle was safe and trustworthy. The comment in the open-ended section stated, “I drive this car, and I always feel safe.” On a new survey 1 December, the same person's responses to the vehicle's safety and trustworthiness had changed to “somewhat agree.” Another operator's inclination toward the autonomy mirrored this drop in trust after the incident.

First Transit noted a higher prevalence of takeovers by the operators following the November incident¹⁴, indicating they were not as comfortable with the machine operating in autonomous mode. It is also likely the operators were not promoting the vehicle to passengers as much. As discussed in the JBMHH report (Allen et al. 2020), operator takeovers—regardless of the reason—lessen riders' trust in the vehicle. In this deployment the lessening of trust started with the operators and probably resulted in a cascading effect to riders.

¹³ First Transit, *Final Report, Autonomous Vehicle Research Testbed: On Base Shuttle Pilot* (Fort Carson, CO: First Transit, Unpublished, 2021).

¹⁴ Eric Werner, *Fort Carson Smart Transportation Testbed: AV Shuttle Project Report* (Washington, DC: US Ignite, Unpublished, 2021).

2.4.2.4 *Postincident response and implications*

Immediately following the incident, the operator notified his supervisor and the MP. When the safety steward described to the MP that he was not driving the vehicle when it lost control—because it was in autonomous mode—the officer was not sure how to proceed. Consequently, the MP issued a citation to the operator for careless driving, which included a fine that would be noted on the safety steward’s driving record. Fort Carson could not support the operator in clearing the citation, nor attend the court date to speak on his behalf since an MP had issued the citation. Because of the unique nature of the circumstances surrounding the citation, and that conflict of interest, First Transit spent numerous hours trying to contact opposing Council before the operator’s court date in March 2021.

The extensive measures to clear the operator’s citation were to ensure the violation would not apply to his personal driving record and insurance. The operator’s concerns were clear when I asked him about the upcoming court date and he said, “I’m not worried, or at least I’m less worried because there will be someone from Perrone, the base, and maybe First Transit there, and they’re going to explain how it is an experimental vehicle” (Anonymous, pers. comm. 9 Feb. 2021).¹⁵ Although his—and other operators’—trust in the vehicle was shaken by the incident, institutional support was given to the degree possible which ultimately resulted in his record being cleared.

Following protocol by long established transit companies, the incident should not have ended up in court before an internal investigation was completed. Preempting any citations for perceived wrongdoing by MP can only be done before an incident occurs. Briefing all emergency personnel and having a strong incident response order of operations in place for contacting appropriate stakeholders will save time and money in case of something going awry.

2.4.3 Results and recommendations

It is recommended that future AV pilots determine transportation goals, user origin and destination plus mobility patterns before implementation—which is exactly what Fort Carson did. However, they discovered that adjustments to the route were needed. Problems with the programming led to the provider having someone come out, reprogram, and then stay

¹⁵ All interviews were conducted in confidentiality, and the names of the interviewees are withheld by mutual agreement.

for the results which created a financial cost that may have prematurely closed the pilot. Future deployments should insist that at least one such change is included so the installation can fulfil the goal of moving as many soldiers and their families as possible.

Deployments that are interested in surveying riders should not solely rely on physical surveys, despite that being the most guaranteed method of getting results. The pandemic and limitations on researcher travel highlighted that there should also be an integral online method of gathering survey results from participants. For example, at JBMHH, LM worked as a collaborator by sending requests for survey participation via email after riders had signed their digital waivers for riding the AV. Having the option to gather surveys through digital means, although less reliable, provides alternative means to get data if researchers do not have access to the field site.

The lessening of operator AV trust is a critical issue from the perspective of both promotion of the technology and engendering trust for riders. Programming so that the AV can operate in manual mode and not attempt to jump back to missed parts of the route should be integral to any deployment. At JBMHH the safety stewards would often travel in manual mode and then return to autonomous mode later in the route. This issue needs to be fixed via both programming and positioning the a/m button in an area of the vehicle less likely to be accidentally engaged. Finally, the training of operators should cover all eventualities, so they know what to expect during the likely scenario of driving in manual mode and then needing to return to automatic operations.

Furthermore, all stakeholders should plan and brief for worst-case scenarios, such as the vehicle losing control in automatic mode. Internal investigations by all involved in an experimental pilot must be conducted before fault and citations are given. Stakeholders include, but are not limited to, the contractors, installation leadership, and emergency personnel who will be responding to any incidents.

2.5 Data architecture and cybersecurity

2.5.1 Research focus and methods

The data architecture and cybersecurity LOE focused primarily on the capture, storage, and transmission of data during the project, and the associated risk of security compromise of the data in this process. This LOE used

evidence from field observations, data collection, and data management documentation. Units of analysis included the number of TB, time, and hours of effort. The goal of this exploratory research was to characterize the data and cybersecurity impacts of an AV transportation service on Fort Carson.

2.5.2 Data and findings

2.5.2.1 Data organization

The raw data collected by the autonomous vehicle, through its suite of sensors, was a critical deliverable for the project. The goal was to collect the vehicle data from both shuttles over the one-year operational period to show trends in several key performance indicators. US Ignite worked closely with First Transit and Perrone Robotics during the contract negotiations phase to ensure the vehicle raw sensor data was collected and stored on the ERDC Azure Govcloud. The intent was to provide a source of information for analysis well beyond the term of the project.

2.5.2.2 Calibration data information

The AV vendor, Perrone Robotics, was unable to provide the calibration data. The calibration information needed in this case was,

- intrinsic parameters which are camera specific;
- extrinsic parameters, which define the relationship between the camera and lidar sensor with respect to the GPS sensor

2.5.2.3 Data file format and data types

It is very important for collected vehicle data to be accessible and easy to use by various stakeholders, both inside and outside the organization. Use of proprietary methods limits the data exchange, so it is important that an open-source framework be used.

For this project, Robot Operating System (ROS) was selected as an open-source robotics middleware suite. ROS is not an operating system but a collection of software frameworks for robot software development. It provides services designed for a heterogeneous computer cluster such as hardware abstraction, low-level device control, implementation of commonly used functionality, message passing between processes, and package management. Being open source, it provides a wide community of support for helping on various issues along with extensive documentation and tutorials.

A major advantage of using ROS is the ability to collect data with timestamps, making it easy to track data from different sources at the same instant. The ROS data transfer architecture can also work in tandem with existing systems and make use of a data transfer pipeline from sensors called *topics*, enabling all the data to be stored in files called ROSBAGS. A ROSBAG or bag is a file format in ROS for storing ROS message data.

The ROS topics for the AV Shuttle Project consisted of the following topics, although there were some inconsistencies in the data capture:

- a. /GPS
- b. /RadarFrontCenter
- c. /RadarFrontCenter_points
- d. /VelodyneFrontLeft
- e. /VelodyneFrontRight
- f. /tf
- g. /frontCamera
- h. /RunSummary
- i. /ChargeInfo
- j. /VehicleState

The data was transferred from the vendor to ERDC in the form of ROSBAGS. These bags are often created by subscribing to one or more ROS topics and storing the received message data in an efficient file structure.

2.5.3 Data visualization methods

Tools provided by the ROS were helpful to visualize the data provided by the vendor. Other tools such as Web Wiz, were also used to visualize the data provided by the autonomous shuttle vendor. The data collection period was approximately 8 months from August 2020 to March 2021. The initial preliminary test data, which was collected in August 2020 included sample test bags to check the data format followed by regular operational data collected from October 2020. The original dataset was in a nonstandardized Perrone Robotics proprietary format called MAX logs (entailing the run summary and the vehicle logs output). The raw PCAP (packet capture) data was later collected in the ROSBAG format by making use of the ROS. The total number of ROSBAGS received was 261 ROSBAG files (120 files with complete sensor data), and the total size of data received was 1,010.452 GB (about 1 TB).

While the final executed contracts with First Transit included terms defining the shuttle data as a deliverable, it was a much more complicated task obtaining high quality ROSBAG files from the First Transit operations team. Several factors contributed to these data challenges throughout the project. A few of the key issues encountered are described below.

2.5.4 Vendor proprietary data formats and software tools

Autonomy stack providers typically use proprietary data formats and software tools specific to their system, which complicates research efforts conducted by outside parties. Even the raw data files provide limited value if they are not able to be processed into a useful format.

Recognizing this, the project team worked with Perrone Robotics to script the raw PCAP files into ROS format. Unfortunately, this conversion was not straightforward and resulted in low quality, corrupt, or incomplete ROSBAG files. The level of effort to complete this file scripting was underestimated by the project team and a source of great frustration throughout the project. The project team also learned the raw data files used to create the ROSBAG files were not retained by the vendor, eliminating the possibility of revising the script to recreate the files.

2.5.5 Vehicle software and hardware configurations

The software and hardware configurations installed on AVs were also proprietary. The number, position, and type of sensors used, as well as how they are connected to the compute devices are also unique. The Perrone Robotics TONY autonomy kit is adaptable to many different vehicle platforms, so the level of vehicle integration varies by application. Two cameras, one facing forward and one facing rearward into the passenger compartment were included in the TONY sensor suite per the project requirements. While these cameras are not used for navigational purposes, the large data files from the devices increased the burden on the overall data management.

Perrone Robotics does not have a standard policy to collect and store all the types of data required by the ERDC from their autonomous vehicles while in operation. As a result, they do not maintain an archive of extensive run data for their own records. Robotic Research, another autonomy stack provider (used at the JBMHH deployment), requires the collection

and transmission of more robust run data from every one of their AV vehicles that is operating.

Perrone Robotics selected a Polaris GEM vehicle they had been using as a development and demonstration prototype for use in this project. The vehicle did not appear to have undergone any significant upgrades or downgrades in preparation for delivery to Fort Carson. The staff from Perrone Robotics and First Transit struggled to effectively manage the large data files once operations began. Much of this difficulty appeared to stem from the limited capability of the hardware installed on the vehicle, which required end of day downloads taking up to 8 hours to complete. At times, the download and ROSBAG scripting process would encounter an error, either corrupting the file or requiring the process to be restarted. The onboard computing devices relied on a dedicated battery that would be depleted during the long downloads, necessitating additional attention through charging or replacement of the battery.

2.5.6 Cybersecurity

Fort Carson, as an Army post, did not have public internet access available for use by the operator. To address this, a dedicated private wireless CBRS network was planned to be installed as part of the Smart Transportation Testbed Program to support data uploads through a Unite Private Network (UPN) fiber connection. The design and deployment of the network was not able to be completed in time to support the operational needs of the AV shuttle project. As a workaround, a few portable hard drives were used to download the data from the vehicle. The hard drives were then mailed to Colorado University Boulder and uploaded to the Azure Govcloud storage location.

Given this reality, there were no cybersecurity issues encountered with this basic data transfer method. Looking toward the future, if the AVs are to send and receive active data, then the communication links would need to be encrypted with zero trust authentication. If the AV is to be actively connected to a DoD system, the time and cost associated with obtaining an Authorization to Operate would have to be considered in planning.

All AVs rely on a dependable GPS signal for geolocation data to drive their programmed route. GPS signals are vulnerable to jamming using readily available devices and such devices could potentially confuse the AV and lead to an accident. GPS jammers were not tested but future AV

experiments should explore this possibility. Another risk are GPS spoofers which could lead the AV vehicle on an undesired course.

2.5.7 Results and recommendations

For new testbed innovation projects, data extraction is key to learning how vehicles function in the test environment. During the contractual period of the project, different data discussions were held but a clear and agreed on set of deliverables between all project partners were not established early enough, resulting in delay of data transfer and usability of the data.

At the start, a recommendation was made by a project partner to introduce a ROSBAG data format which would sync key files, MAX logs, camera logs, and sensor data. This proved successful but did not always provide sufficient reference information for project partners evaluating the data. The specification of this requirement was also not clear and should be defined from the project start.

Extraction of large data files, sometimes 40 GB or greater, were delayed as systems in place were insufficient to expedite this process. As a high-speed network was unavailable, a temporary solution was implemented to download data onto portable hard drives which were then mailed and loaded to a cloud storage device by a project partner. We identified early on that downloading the files took considerable time owing to file size preventing other tasks to be carried out during this time. Downloading the files also affected the battery life of the AVs.

Over the course of this project, the importance of having open standards for data representation as well as vehicle information became apparent. Part of our research team's initial data request included raw sensor measurements as well as calibration data regarding both internal sensor models and external mounting locations. Other supporting information to be captured at a regular rate included elements of vehicle state (such as battery state and a/a/m mode markers) to accompany sensor measurements at a regular rate. Additionally, we sought to address limitations of previous project deployment datasets by specifying the method by which data were to be stored as an open standard useful for robotics (e.g., ROSBAG). While the choice of a storage system is arbitrary, any future project should clearly specify the data storage method to avoid vendor proprietary formats.

One problem with previous datasets collected at JBMHH was a lack of timestamp synchronization between sensors. While the sensor systems on the current project were soft synchronized to one another, our team was unable to verify through architecture design or clapboard techniques the accuracy of the vehicle's time synchronization infrastructure.

Without accurate timing data, correlating measurements between sensors is difficult and unreliable. Any future project specification should include a clear time domain map that indicates how various sensor measurements are correlated to a common time base that includes the data capture mechanism.

On the basis of our current datasets, we have several promising areas of future research. In the project vehicle architecture, GPS signals augmented by local real-time kinematic corrections sourced via cell phone signal were used to guide the vehicle along its course. One limitation of such a technique is the dependence on the local cell network for connectivity, as well as dependence on GPS signals themselves; with these dependencies, the project vehicle may have poor positioning in urban canyons or other locations with poor sky visibility as well as areas with poor cell phone coverage. One idea for future work using our existing data is to verify GPS positioning using successive lidar scans, camera images, and radar returns. Such a system could serve as a go/no-go verification system to detect possible system interference (whether intentional or otherwise).

An additional research direction relates to object classification in mixed military-civilian environments. Using the vehicle and track camera data, we can test object classification systems trained on civilian-only data to determine shortcomings and failure modes in a military environment. After augmenting civilian datasets with military-specific labelled data including elements such as tactical vehicles and service members in unit physical training, we can then develop classifiers suitable for mixed environments to meet stakeholder needs. One example includes access control gate vehicle classification, where vehicles are to be classified as civilian automobile, commercial truck, or tactical vehicle.

2.6 Data analytics and AI

2.6.1 Research focus and methods

This section will focus on the AV shuttle's autonomy and its performance at Fort Carson.

2.6.2 Data and findings

2.6.2.1 Autonomy kit

The Polaris GEM was modified by Perrone Robotics to enable autonomous operation using a FMVSS approved vehicle. This concept is traditionally known as stack technology because of having safety and mobility systems stacked on an existing vehicle platform.

Perrone Robotics' technology is known as TONY, which is a modular full-stack solution for AV and Robotics. Both GEM vehicles were equipped with this technology for the Fort Carson project. Characteristics of the vehicle technology are outlined in the 2.2 *Infrastructure and operations* section above.

2.6.2.2 Autonomous/manual (a/m) mode

The AV shuttle had the ability to be operated in either manual or autonomous mode. Switching between the modes was accomplished via an a/m button on the driver's side door (Figure 11).

Figure 11. Location of a/m button for switching between manual and autonomous mode.*

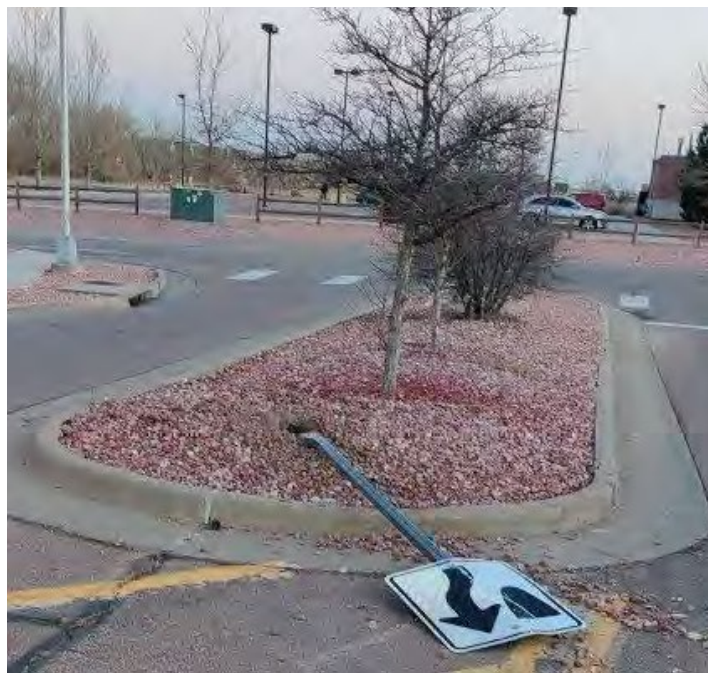


* Eric Werner, *Fort Carson Smart Transportation Testbed: AV Shuttle Project Report* (Washington, DC: *US Ignite*, Unpublished, 2021).

Disengagement of autonomous mode using the button was necessary if the safety steward believed the vehicle could not safely navigate the route or an obstacle was encountered. This was a relatively routine procedure, usually happening at all stop lights.

Engagement of the autonomous mode was carried out in much the same way, however, accidentally pressing the button while off course from the mapped route did cause errant vehicle behavior. An incident occurred when the button was pressed while the shuttle was outside the programmed route, resulting in the vehicle trying to return to the mapped course. At the intersection, the shuttle immediately jerked to the left resulting in it departing the road hitting a median curb and knocking down a traffic sign on a metal post that was inserted in gravel (Figure 12).

Figure 12. Damaged street sign by the shuttle after engaging autonomous mode while off the programmed route.*



* Eric Werner, *Fort Carson Smart Transportation Testbed: AV Shuttle Project Report* (Washington, DC: *US Ignite*, Unpublished, 2021).

It was not an expected result that the vehicle would react in the way it did when its operating mode was changed on an unmapped section. As shown in the event logs, the operator reselected the a/m button within approximately 1.5 s when he realized the errant vehicle's behavior. The vehicle came to a stop on the other side of the road after crossing the median 4.4 s following the original automatic mode switch.¹⁶

¹⁶ First Transit and Perrone Robotics, *Autonomous Vehicle Research Testbed: On Base Shuttle Pilot, Incident Report 11/27/2020*, V. 0.7 (Fort Carson, CO: *First Transit*, Unpublished, 2020).

Further anomalies with the AV shuttle occurred when the AV Operations team identified the vehicle stopping and surge behavior while moving between manual and autonomous operation. While this did not occur consistently, a determination was made to remove the vehicle from autonomous service, investigate the logs, recreate the event in a test environment to identify the root cause and implement modifications to reduce the risk.

After investigation, PRI concluded that no fault had occurred with the AV system. The observed behavior is rooted in a mismatch between the scoped vehicle capability and its scoped ODD. Because of this mismatch the operators engaged the a/m button beyond the system design's original intention. It was through this investigation that PRI and First Transit became aware that the increased use of the a/m button was being done in a manner not originally designed for by PRI engineers. PRI took these new operational design requirements and created both a software update and speed changes to the route to better suit the ODD. The software update enables the operator to engage the a/m button anytime during a mission and the speed adjustments will prevent the vehicle from surging in speed when entering a stop point.

A final incident occurred during which the AV suddenly deviated off course in manual mode. Unfortunately, the root cause was inconclusive, and the AV shuttle service was halted.

2.6.2.3 *Data analytics*

The work accomplished by the University of Colorado included several instances of feature extraction from the AV shuttle's data. These features included the following:

- Extracting useful vehicle states
- Object detection from camera data
- Camera/lidar calibration
- Analyzing driver's manual braking behavior

Furthermore, the team sought to create an integrated system for converting traffic camera streams to ROS messages then record the ROS messages for future analysis. The goal was to use traffic data to construct a probabilistic model for prediction of human-driven car trajectories at runtime within the framework of runtime verification. The team successfully developed an online maneuver classification and multimodal trajectory

prediction framework. However, this work is not complete, and the team plans to apply this framework to the Fort Carson traffic camera data. The details and results of these efforts are provided in greater detail in their report titled, *Final Project Report: Evaluating On-Base Deployments of Autonomous Vehicles* (Sankaranarayanan et al 2021).

2.6.3 Results and recommendations

Multiple incidents stemming from the vehicle's autonomy ultimately led to the premature ceasing of the AV shuttle service. The conclusion in this matter was that the vehicle was being operated in a manner inconsistent with its intended ODD. For this reason, future deployments should be certain that the ODD, route, and vehicle systems are aligned to ensure operational success. Efforts were successful to utilize AV sensor and camera data for data analytics including object detection. Progress was also made on efforts to utilize traffic camera data for predicting human driver trajectories. The data from this pilot was stored on the Govcloud and is available for future use and research.

A worthwhile area of future work mentioned by the University of Colorado researchers is that of object classification in mixed military-civilian environments. Using the vehicle and traffic camera data, they could test object classification systems trained on civilian-only data to determine shortcomings and failure modes in a military environment.

3 AV Service Vehicle

The DoD has a desire to advance military installations through the integration of smart technologies into their infrastructure. This is to plot a path for development and modernization that is in line with that of smart cities around the world (DoD 2022). ERDC has expanded research and development into these technologies as part of the Smart Base and Automated Technologies Program. Here, efforts that involve data processing, AI, and automation have been put in motion to modernize installations and ensure that they persevere in the technological future. One such effort of the program looks to coordinate Small Unmanned Aircraft System (SUAS) flights on the BAAF at Fort Carson, Colorado, as a means for FOD detection at the installation using red-green-blue and infrared imagery.

FOD is any kind of material or object that has been displaced on an airfield—either living or inanimate. Some examples of FOD would be tools, trash, loose pavement, and wildlife. This debris poses a severe potential risk to both airfield personnel and the aircraft itself, as it may damage vital aircraft equipment on contact. The potential for FOD ingestion into aircraft engines, landing gear destruction, the creation of dangerous projectiles from the foreign objects, and other detrimental applications are all examples of the destruction that FOD may cause. Current operations require airfield inspectors to manually evaluate the pavement and remove any debris to continue flight operations.

FOD removal requires prolonged examinations of the pavement, which constrains activity on the airfield runways, disrupts the flight schedule, and exposes inspectors to hazardous environments. The incorporation of automated drones in the inspection process seeks to decrease the amount of time required per inspection to lessen the duration of airfield flight restrictions, decrease the number of inspectors required per inspection, provide a safer work environment for the inspectors and the aircraft, and ultimately guide the way for the future of asset management sustainment.

3.1 Planning and policy

3.1.1 Research focus and methods

This LOE reviews the deployment of an AV service vehicle to demonstrate the capability of human-machine teamed FOD and automated runway infrastructure inspection.

Review of the project implementation was done from the perspective of making observations of the steps involved in the execution and subsequent recommendations for consideration for future implementation efforts. To help facilitate the successful implementation of future AV operations from a planning perspective, the basic framework from which observations were made include the following:

- What are the steps, technology, or operations that may need to be in place to facilitate a successful implementation?
- What were unexpected hindrances to implementation and what could be done in the future to plan for them?
- Were there practices or considerations learned from past performances incorporated into this effort?
- What would have been helpful to have in place before implementation?
- What can we learn from each of the stakeholders' experience in their efforts to fulfill their role in the process?
- What can be done from a planning point of view to lay a groundwork for a more successful implementation in the future?

3.1.2 Policy considerations

The operation of SUAS within Active Restricted Airspace (ARA) requires specific documentation for approval before flights may be conducted. An airworthiness release (AWR) form and an aviation waiver package for the aircraft in question must be obtained and approved before any flight plans on an installation. Also, the third-party is required to submit the DD2400, DD2401, DD2402, and ACORD25 forms (WHS 2021a; WHS 2021b; WHS 2021c; ACORD 2016) to the installation in which test flights are conducted before approval to operate within ARA is granted.

The completion of these required documents necessitates detailed specifications that pertain to the configuration and operation of the drone in discussion. A bill of materials (BOM) that identifies the individual components'

manufacturers must be generated to ensure the onboard firmware, logic boards, and software of the SUAS are not products of the People's Republic of China, as the FY2020 National Defense Authorization Act (NDAA) public law 116—92 prohibits the use of Chinese-manufactured components in SUAS test flights with the exception of use in counter-SUAS flight demonstrations (US Congress 2019). Once the components have been identified and presented in the BOM, approval for the AWR, Aviation Waiver Package, DD2400, DD2401, DD2402, and ACORD25 (WHS 2021a; WHS 2021b; WHS 2021c; ACORD 2016) may be submitted to their respective authorities for authorization. If the components that comprise the SUAS are replaced after the submission of said documents, the documentation process must be resubmitted for the new SUAS configuration.

The AWR is a document that details the specifications about the SUAS in question after an inspection is conducted on the aircraft. This form defines the operational environment restrictions and information, which is based off the airworthiness qualification level (AQL) at which the SUAS was classified. The AWR is the chief authority, and any conflict in operational procedures found in other documentation are superseded. Each AWR is sent to the Aviation Engineering Directorate (AED) for approval. GreenSight's AWR for the Dreamer drone was designated AQL 3 (Department of the Army 2020 [Appendix I]), which states that the designation is,

issued for expendable UAS that are intended to regularly operate in Restricted Airspace and small UAS that intend to operate in combat zones. These UAS are not designed to accepted engineering standards and/or do not possess adequate engineering data to determine their compliance with acceptance standards. The data requirements for AQL 3 directly correlate to the proposed operational restrictions, area of operation, and allowed usage of the UAS. These systems have undergone a system level safety assessment that identifies the hazards for the intended operations. The AQL 3 AWR applies restrictions to mitigate the hazards identified in the system safety documentation. If the hazards cannot be mitigated through restrictions, the associated risk must be accepted at the appropriate level before the AWR is issued.

Like the AWR, the Aviation Waiver Package is another mandatory document that pertains to any commercial SUAS that is to fly in ARA. This document discloses the proper procedures to mitigate cyber and information security vulnerabilities through detailed data storage and data transfer practices. All approved SUAS within the Aviation Waiver Package are limited to a six-month period of operability. If any modifications are made to the SUAS's hardware or software, a resubmittal or exemption request must be conducted before flights may be resumed. A proposed Aviation Waiver is addressed at the Pentagon and approved by the Department of the Army.

Flights conducted with a third-party operator may require proper insurance documentation from said third-party as they may be deemed liable for any incidents that occur while they operate the SUAS as per the Ground and Flight Risk Clause (DoD 2010) depending on the specifications of their established contract and the classification of the flight activity. Public aircraft operations conducted by contractors on ARA may be deemed covered by the Ground and Flight Risk Clause depending on the terms of the contract between the third-party and the government, while civil aircraft operations conducted by contractors are excluded from the clause without exception.

The DD2400, DD2401, and DD2402 (WHS 2021a; WHS 2021b; WHS 2021c) provide information that pertains to the third-party's insurance certification for the SUAS; their purpose for request to land the aircraft on ARA; and their acceptance of liability for any harm or damage that may occur throughout operation. As well, the ACORD25 (ACORD 2016) is a document that details the specifics of the contractor's insurance providers and the extent of the coverage that they provide. These documents must be submitted directly to the airfield in which the SUAS flights are to be conducted in ARA for authorization and approval.

Once the proper documentation has been submitted and the respective SUAS has been approved to conduct flights within ARA, the SUAS operator must follow a series of operational conditions and regulations that are determined by the SUAS's AWR designation. Because the Dreamer's AQL 3 designation, the SUAS is subjected to detailed conditions in which the drone must abide while flights are conducted in ARA.

- The SUAS is restricted to flights conducted only in visual meteorological conditions where operations within 25 nmi of lightening activity, any form of precipitation, extreme temperatures, exposure to flammable vapors, and low-pressure environments should be avoided.
- The SUAS is not equipped with any form of a sense and avoid system. As such, the SUAS shall always have the operator within visual line of sight. This is to prevent collisions with other aircraft, to ensure the SUAS does not traverse over nonflight crew personnel, or that the aircraft does not fly across or adjacent to roadways open to traffic.
- If communications are lost between the SUAS and the operator, it is to return to a designated point to land for return to base (RTB) operations, so it does not enter unauthorized airspace. If the operator receives any indication through the control station that the SUAS is exerting unintended behavior or is transmitting erroneous data, the SUAS must immediately RTB. A confirmed loss of the critical subsystem of the drone or control station shall result in RTB. As well, any unexplained anomaly shall result in RTB.

The operator who conducts the SUAS flight must also comply to a standard of rules and regulations for authorization to fly in ARA.

- The SUAS is never allowed to be connected to the internet or any other type of network.
- All collected data must be treated as sensitive materials.
- The SUAS is never allowed to operate over people or sensitive facilities, equipment, or activities. A lateral clear zone from the SUAS's flight path equal or greater to the aircraft's altitude must be maintained.
- Crew members must be thoroughly briefed before each mission day.
- Command and Control (C2) data links must be encrypted to Advanced Encryption Standard (AES) 128.
- Cameras must be covered when not in use to prevent unencrypted camera feeds.
- Flights are restricted to conduct operations in approved or sanitized locations only to not expose tactics, techniques, and procedures.
- The operator may only operate SUAS that have software and hardware configurations that correspond with the specific configuration defined and approved in the Aviation Waiver Package and AWR for flights to commence.

3.1.3 Results and recommendations

- Create parameters of use for SUASs considering operations related to ongoing base operations, operational altitude, weather conditions, wind, approved locations, and frequency of use.
- Develop frequency or schedule of postprocessing analysis for asphalt health detection and changes over time, including matrix for monitoring changes and recommended maintenance scheduling using that matrix.
- Consider geolocating fixed fixtures, such as tie-down and drains, before UAV operations to address false positive matches for FOD identification. Complete reliance on such preflight geolocations could result in missed positive FOD identifications at those locations.
- Acquire exceptions and waivers related to the use of commercial-off-the-shelf (COTS) UAS and AWR, if applicable.
- Develop standard operating procedures for preflight validation and other compliance issues with waiver compliance, if applicable.
- Review and validate the UAV's ground control's (GCS) digital terrain model and reality to prevent altitude issues from flight plan because of any mismatches in data.

3.2 Infrastructure and operations

3.2.1 Research focus and methods

This section will focus on the infrastructure necessary for the AV service vehicle and the operations surrounding it. The information below has been provided from US Ignite and GreenSight reports.

3.2.2 Infrastructure data and findings

3.2.2.1 Aircraft

A GreenSight Dreamer UAS was used for this work. The Dreamer is a 30 in propeller span, 2 kg quadcopter originally developed by GreenSight in 2018. It is all electric and can uniquely fly for 60 min on a single charge while carrying a 250 g payload. Onboard, a Sony RX0 miniature high-definition camera was utilized for image capture. Other components of the UAS included the following:

- RFD900+ Telemetry/C2 radio
- Graupner remote controller
- GreenSight custom avionics, sensors, electronics

It was necessary to ensure the UAS was compliant with NDAA rules and regulations, which specifically prohibited items manufactured in China.

The Dreamer carried a 16-cell lithium-ion pack with a maximum capacity of 180 Wh. This allowed the drone to produce an hour's worth of flight time per charge. An electric cost of \$0.06/kWh on the Fort Carson installation, resulted in a \$0.01 expenditure per full charge of the Dreamer drone.

3.2.2.2 *User interface*

Outputs from FOD detection model were designed to be passed to a tablet containing the Android Team Awareness Kit (ATAK), an android-based geospatial situational awareness application developed and widely used by the military. It is open source and available in a variety of licensing contexts, and *ATAK-CIV* was the version used for this project. The ATAK was used by audience members during demonstrations and was used without issues.

3.2.2.3 *Location*

Several remote locations were utilized by GreenSight to gather data from the drone and test the software. Some locations were used before the work commenced, and others during the course of this work. These are described in the following:

1. **McMillan Airfield:** This runway is located at Camp Roberts, California, and used for Naval Postgraduate School Joint Interagency Field Experimentation events and other UAS test operations. It is used exclusively for small UAS now and is in some disrepair, although in its prime it was used for full size manned aircraft. Flights listed here at McMillan airfield were conducted before the start of the US Ignite/AARISS project but are included for reference as they are good imagery datasets and excellent source material. This location was also used during the project.
2. **Lolans Farm:** This rural and operating farm located in southern Massachusetts was used by GreenSight as a flight test operations location. It is a low-risk area which GreenSight used for preoperations flight testing for all its UAS. Note that Lolans Farm data has no paved areas so was not useful for FOD detection but was useful for assessing image quality and testing.
3. **Gardner Municipal Airport (KGDM):** A low traffic airport in western Massachusetts. The asphalt at this airport is older but consistent. It has numerous cracks and surface defects, despite being in active use. It has a

- single runway which is in worse shape than the taxiways and storage areas. GreenSight used this location for crack detection tests.
4. Fitchburg Municipal Airport (KFIT): Slightly more trafficked GA airport northwest of Boston, Massachusetts. It is larger than Gardner and better maintained, although runways are also quite old. It has some taxiways that have been recently repaved and are very uniform. This location was also used for crack detection tests.

3.2.2.4 *Weather*

Weather during the UAS flights was recorded and reported during all UAS flights. Wind had the ability to interfere with image capture, and winds were usually encountered during flights. Winds up to 15 kn were experienced during the in-progress review (IPR) demonstration on 13 July 2021.

3.2.3 **Operations data and findings**

3.2.3.1 *Clearances*

For GreenSight to operate its Dreamer UAS on behalf of ERDC, it was required to obtain an exception to the policy for the use of COTS UAS as well as an AWR (Appendix J), both from the US Army Corps of Engineers (USACE) Headquarters Aviation Program Office.

3.2.3.2 *Locations*

BAAF and McMillan Airfield were both used to demonstrate the FOD detection algorithm and crack detection by the drone during this project. BAAF was used exclusively during the demonstrations for US Ignite and ERDC personnel.

3.2.3.3 *Foreign object debris*

The goal of the FOD detection system was to inform the user where the FOD is located on the airfield so it can get removed. A series of images were taken and processed to identify FOD. Color differences in the images are used in conjunction with several processing steps to find potential FOD. Ultimately, if FOD was identified, the GPS coordinates were sent via Curser on Target to the ATAK application to inform the user of the location of FOD for its removal. Figure 13 shows an example of FOD detected.

Figure 13. Example FOD detected with Broad Pass.



3.2.3.4 Runway crack detection

To identify cracks on runways, GreenSight developed a deep learning model. The crack detection deep learning model was accurate in identifying cracks on several airfields. The drawback of the algorithm is that it is computationally heavy, preventing it from being run in real time. However, the crack inspection use case is not expected to be performed in real time (as FOD detection is), so this is not a significant limitation. The crack detection model would be useful to run in a postprocessing context to analyze asphalt health and crack changes over time. Figure 14 shows an example of the model result.

Figure 14. Example of full image crack detection.



3.2.3.5 *Demonstration results*

After meeting the proper regulations, GreenSight was able to conduct FOD detection flights at Fort Carson's BAAF on 3 November 2020, and 8 June 2021. Operations were limited to FOD detection on the airfield.

The initial 3 November 2020, operation at BAAF was conducted by operator Dan Gerke from GreenSight with an approved, NDAA-compliant Dreamer drone. ERDC members Tina Hurt, Ryan Strange, James Stinson, and Ben Eubanks reported to Fort Carson, Colorado, to participate and oversee the initial flight demonstration at the airfield. Before the demonstration, an in-brief was given to ERDC members and airfield personnel to discuss the objective of the unmanned flight, as well as any concerns and recommendations for the utilization of the drone technology. The test flight demonstration began at 12:30 and ended as the drone collided with the airfield tower shortly after takeoff owing to identified malfunctions that resulted in erroneous magnetometer and motor compensation as well as malfunctions with the onboard GPS system. Test flights at BAAF were then delayed until further notice. GreenSight made modifications to its Dreamer drone's hardware and software, conducted test flights in controlled environments, and resubmitted an application for an AWR as well as an application to be included in the May 2021 Aviation Waiver Package. BAAF did not require resubmittals for the DD2400, DD2401, and DD2402, or ACORD25 documents for future flight demonstrations (WHS 2021a; WHS 2021b; WHS 2021c; ACORD 2016).

GreenSight was approved for a follow-up demonstration at BAAF 8 June 2021, during the Transportation Testbed IPR after a second approval for the AWR and inclusion in the May 2021 Aviation Waiver Package. Key researchers from ERDC, Fort Carson officials, US Ignite partners, the GreenSight flight crew, and other essential subcontractors gathered to discuss the current state and milestones of the Smart Base and Automated Technologies program and the LOEs that are being conducted at the Fort Carson installation. GreenSight's CEO, James Peverill, presented on the milestones that their company had achieved for FOD detection using the Dreamer SUAS. A successful test flight was conducted 7 June 2021, to demonstrate that the Dreamer would operate effectively and respond accordingly to the operator's commands, which then was followed by the FOD demonstration the next day. The 8 June 2021 demonstration was conducted by Ian Burwell of GreenSight. During this demonstration, various pieces of FOD were distributed across Echo ramp at BAAF. A geofence

was constructed for the location, then the drone was set to autonomously scan the pavement within the parameters. The drone effectively detected all pieces of FOD on Echo ramp; however, it was noted that the Dreamer incorrectly determined its own shadow to be FOD.

3.2.3.6 *In-progress review*

During the IPR, the contractor identified several areas of improvement. Areas considered for improvement included: operational, algorithmic, use of ground vehicles, docking station, and partnerships.

Operation improvements identified included tighter cybersecurity, connectivity using 5G, and use of camera covers. The algorithmic improvements included reducing false negatives and positives by using facility specific algorithm training. The contractor described quantifying the system's speed and accuracy and using those results to determine benefits derived when scaling the number of UAS and automating operations. The use of ground vehicles for FOD and crack detection was mentioned, to avoid the logistics and operational challenges of using UAS. GreenSight has designed a docking station that can house and deploy 4 Dreamers for simultaneously launching the aircraft. Such a unit could potentially cover 200 acres in 15 min. GreenSight also identified several potential partnerships they feel would be valuable and which could benefit from this technology.

3.2.4 Results and recommendations

- An unmanned aerial system was granted an exception to the policy for the use of a COTS item, as well as an AWR, both from the USACE HQ Aviation Program Office.
- GreenSight successfully demonstrated both foreign object debris detection and crack detection using the drone.
- Several ideas and recommendations for improvement were identified during the in-progress review, including operational, algorithmic, the use of ground vehicles as docking stations, and expanded partnerships.

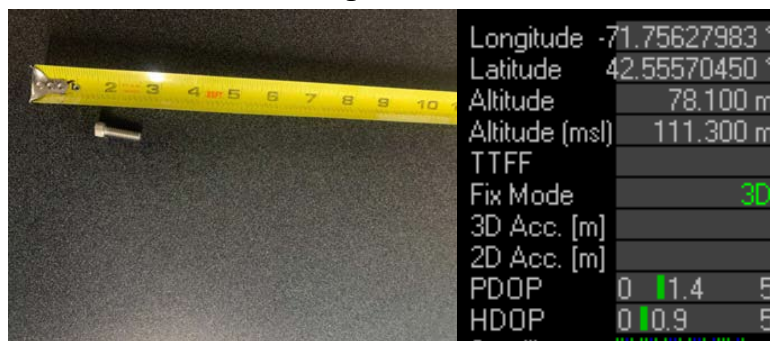
3.3 Data architecture and cybersecurity

3.3.1 Research focus and methods

This section will include a discussion of the data types and cybersecurity concerns involved with the GreenSight Dreamer drone. The following three different procedures were utilized for data gathering:

1. Artificial FOD Placement with Ground Truth. The location was flown with FOD placed in the area before flying. Location of each FOD was noted, photographed, and geotagged. After the flight, the FOD was collected. This was the procedure followed for flights with FOD in the figure below. Example spreadsheet entry below for each FOD item that is placed in the dataset. Notes the FOD description, a picture of the item with a size reference, object number, and a snapshot of the geocoordinate with latitude and longitude coordinates (Figure 15). These missions were marked *FOD with ground truth* in the mission list. Two flights were conducted following this method.

Figure 15. One-in stainless bolt used for artificial FOD placement with ground truth.



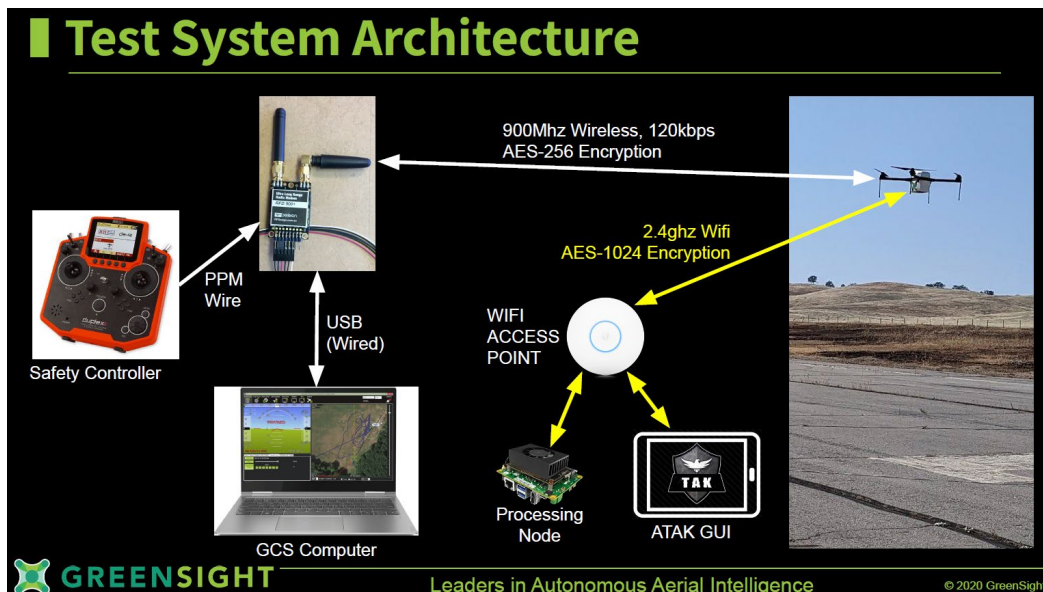
2. Artificial FOD placement without ground truth: Similar to the previous method, in these flights artificial FOD was placed in the flight area. The FOD was not inventoried in detail during placement. After initial algorithmic tests with the ground truth, it was found that the automatic labeling was working well enough to find the FOD without inventory. Also, detailed inventorying of the FOD was taking long enough that it was affecting the flight test schedule, particularly given that the flights were taking place on actively used airfield areas which had to be shut down while the FOD was placed, and SUAS flights were taking place.
3. Clean dataset gathering: For these datasets, no additional FOD was placed. They were clean—clear of FOD—although in theory there could have unknown FOD present (active airfield areas). None was noted during post processing, but it was conceivable that there was random FOD present in the dataset. After initial tests inserting synthetic FOD using image processing software, it was determined to be acceptable to build more training data using this method. Pictures of FOD were inserted by the test system into the clean datasets which could then be found and verified with the FOD classification algorithms. Collecting data this way was significantly more efficient.

3.3.1.1 Data transfer

The model of GreenSight's Dreamer drone used at Fort Carson does not possess the hardware required to process FOD data onboard in real time. All imagery collected by the Dreamer must be processed externally by a processing node for FOD detection. GreenSight used compliant infrastructure to safely transfer the data between the Dreamer and the processing node.

The AARISS system architecture contained computing devices both attached to the Dreamer drone and located off-board the UAS. The software was designed to meet two objectives: (1) the AARISS system controlled the drone's flight, and (2) it automatically detected FOD in real time using imagery collected by the drone. The safety controller, radio, and GCS computer monitored and directed the drone. These components were networked through a 900 MHz wireless 120 kbps AES-256 encryption connection. The drone, processing node, and ATAK graphical user interface were all connected by a Wi-Fi access point which enabled quick transfer of data. During flight, the drone captured images and sent them to a processing node which used a trained computer vision model to identify and localize FOD in the imagery. Figure 16 graphically depicts the test system architecture.

Figure 16. Drone test system architecture.



3.3.2 Data and findings

3.3.2.1 Data file formats

The data types captured by the drone included the following:

- *.mov*: a .mov file showing a movie of the flight from the camera. It is saved in the QuickTime File Format, a multimedia container format developed by Apple.
- *.jpg*: for still pictures
- *.mp4*: digital multimedia
- *.pdf*: reports provided by GreenSight, revealing debris found on runway, cracks, etc.

3.3.2.2 File storage

All files were submitted to the ERDC Microsoft Azure Cloud storage drive. Researchers from ERDC gave GreenSight access to this secure storage drive. All program data is present under a directory called *Green-Sight_AARISS_USIgite* in the Azure storage. Under the top-level directory are three subdirectories as well as a *README.TXT* file. Subdirectories are organized as follows:

- *Imaging Flight Data*: Under this directory are all the image files, flight logs, mission plans. A spreadsheet file *FOD Detection Sites Descriptions and FOD Surveys.xlsx* contains details of all the flight locations that were considered (some not flown yet) with contact information. Also in this spreadsheet are the FOD placement data described above for the *Artificial FOD* data gathering profiles.
 - There is a directory for each flight location. Under each of these directories is a mission directory in the format of *DMxxx_Location_Altitude_Date*. Such as *DM106_Lolans_25m_011421*, indicating DM106 (the aircraft), Lolans (Location), 25 m altitude, and mission on 14 January 2021. Telemetry logs are in each of these directories in *Mavlink tlog* format (which can be opened with Mission Planner or QGround-control as well as many other tools). Also, in these directories there is a *Flight Plan* directory with the mission data (waypoints, etc.) in *Mission Planner* waypoint format (also compatible with QGroundcontrol GCS). Raw image data (in *JPG* format) is in an *Images* directory. New revisions are added rather than replaced.

- *Software*: Snapshots of software archives are in this directory. They are archived as *zip* files and dated. Each one contains additional information on how to use it. A *README.TXT* file will be present here if needed to further explain.
- *Media*: Miscellaneous videos and other media are in this directory. Including an example test flight video. Photos from the IPR are also included.
- *Reports*: Contains all milestone reports for the project, including this one. Presentation slides in *PDF* format from the project are also contained here.

3.3.3 Cybersecurity

3.3.3.1 NDAA compliance

UltraBlue, GreenSight's avionics is specifically designed to be NDAA compliant and is made in the USA. It is designed to work with GreenSight's family of NDAA compliant payloads and components. The multispectral camera utilized in this project is just one of those payloads, and the first to be completed.

The system's NDAA compliance was evaluated against the specific requirements on a one-by-one basis, as shown in Table 4, which was submitted along with the waiver request. From these responses, it was determined to be NDAA compliant. A full bill of materials was also provided along with the waiver, demonstrating that all components meet the sourcing requirements of the NDAA.

Table 4. NDAA Compliance evaluation.

		Is System NDAA 848 Compliant?	
		Is System Made in China?	
(a) PROHIBITION ON AGENCY OPERATION OR PROCUREMENT. —The Secretary of Defense may not operate or enter into or renew a contract for the procurement of system that—	(A) is manufactured in a covered foreign country or by an entity domiciled in a covered foreign country		Drone system is assembled by GreenSight in US from custom-designed and COTS components. The system does have certain Chinese components but these are not-NDAA Pt. 848 relevant, such as motors, propellers, and frame hardware.
	(B) uses flight controllers, radios, data transmission devices, cameras, or gimbals manufactured in a covered foreign country or by an entity domiciled in a covered foreign country	Flight Controller	Flight controller is designed by GreenSight and assembled in the US. GPS/magnetometer module is also designed and assembled by GreenSight in the US.
		Radios	Datalink: Microhard PMDDL300 (Made in Canada) WiFi: Sparkfun WUBT-236ACNBT1 (made in Taiwan) RC Receiver: DMD XLRS RXD1 AES128 Encrypted. (Made in Spain) RC Transmitter: DMD XLRS BTS01 Encrypted transmitter, with input signal from a Jeti Duplex DS12 (Czech Republic)
		Data Transmission Devices	See "radios" above.
		Cameras	Designed and assembled by GreenSight in US. VISINIR Imager modules are the VC MIP110X412 from Vision Components (Germany) and Seek Thermal (USA). These are used in conjunction with a custom PCB designed by GreenSight and made in the USA.
		Gimbals	Controller and mechanical components designed and assembled by GreenSight in US.
	(C) uses a ground control system or operating software developed in a covered foreign country or by an entity domiciled in a covered foreign country	Ground Control System	Two computers on the ground will use the Microhard in mesh network mode to communicate with the drone. The first will be a laptop running Mission Planner for flight planning and control. Mission Planner is open source software and the source code is available at https://github.com/ArduPilot/MissionPlanner . The second will be a tablet PC running ATAK (Android Tactical Assault Kit) to display the images of detected FOD, along with COTI (Cursor on Target) data showing the locations of detected FOD.
		Operating System	GreenSight-designed flight controller runs open-source Ardupilot APMCopter software. Nvidia Jetson Xavier NX companion computer runs open-source Ubuntu Linux.
	(D) uses network connectivity or data storage located in or administered by an entity domiciled in a covered foreign country	Network connectivity	Wifi module will be present for periodic remote diagnostics and updates, but can be disabled or removed entirely if necessary to confirm to facility regulations.
		Data Storage	Onboard data storage: An SD card inside the autopilot subsystem records flight data logs. A second SD card holds the operating system and system logs of the Jetson Nano companion computer. It also holds the imagery captured with the camera. Off-drone data storage: Image files will be uploaded via Microhard to the ATAK tablet, along with COTI (Cursor on Target) data showing the locations of detected FOD.

3.3.4 Results and recommendations

GreenSight was able to accomplish the objective of the service vehicle while demonstrating good data gathering practices. Ultimately, all the data generated was uploaded to a secure Govcloud location and is available for future analysis.

3.4 Data analytics and AI

3.4.1 Research focus and methods

This section focuses on the data analytics and AI elements of GreenSight's Dreamer drone.

The research and development were conducted in collaboration with sub-contractor GreenSight and their Dreamer autonomous drone technology, algorithms, and user interface (UI).

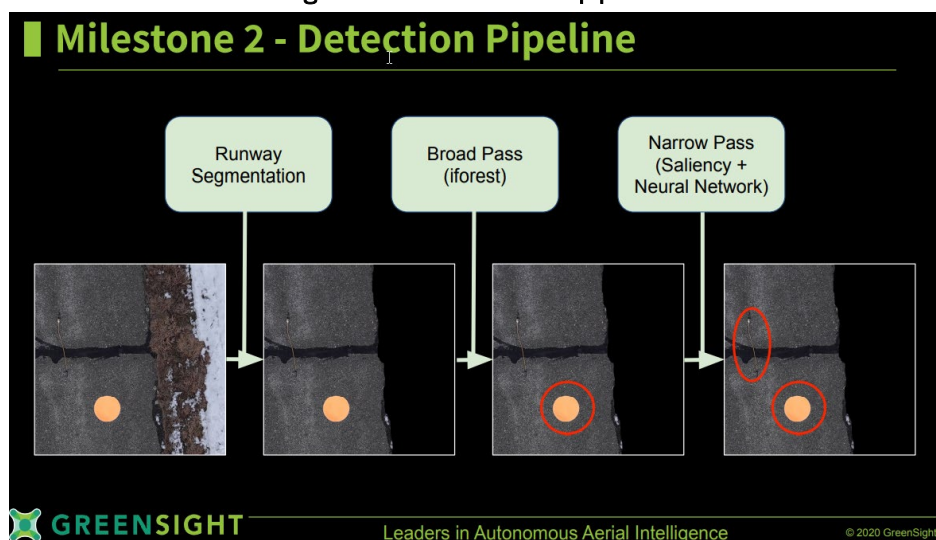
3.4.2 Data and findings

3.4.2.1 Software

GreenSight's FOD detection capabilities rely on their self-developed data pipeline (Figure 17). This data pipeline is composed of a collection of

algorithms that enact various image processing techniques on the raw, geotagged images captured by the Dreamer drone to determine where FOD is located on an airfield.

Figure 17. FOD detection pipeline.



Initially, the Dreamer collects sets of six images per pavement section that are grouped together by the data pipeline. These images are then modified by a preprocessing technique that uses Histogram Deviation Analysis (HDA) and back projection to isolate any foreign objects. Histogram deviation analysis is a preprocessing methodology that is used on imagery to detect color variation within the color histogram. Areas in imagery that display wide color variation act as indicators to potential FOD locations. Runway segmentation then collects imagery data that displayed little to no variation within the color histogram and removes those portions from the overall images (Figure 18). These runway segmentation areas typically include grass next to the pavement, buildings, or painted lines on the pavement.

The preprocessed images are sent along the data pipeline to the broad pass portion of the pipeline. The pipeline leverages the isolation forest anomaly detection algorithm to enact a more in-depth examination of the color variation of the imagery. Like HDA, portions of imagery that have high variability in color act as indicators for where FOD is likely located. The isolation forest model does not require a significant amount of training data for detection; however, what FOD imagery available is scarce. GreenSight created a methodology for adding synthetic FOD to help grow the model's dataset. This synthetic FOD was implemented by artificially adding colored shapes over preprocessed images to add variation of objects. The addition of

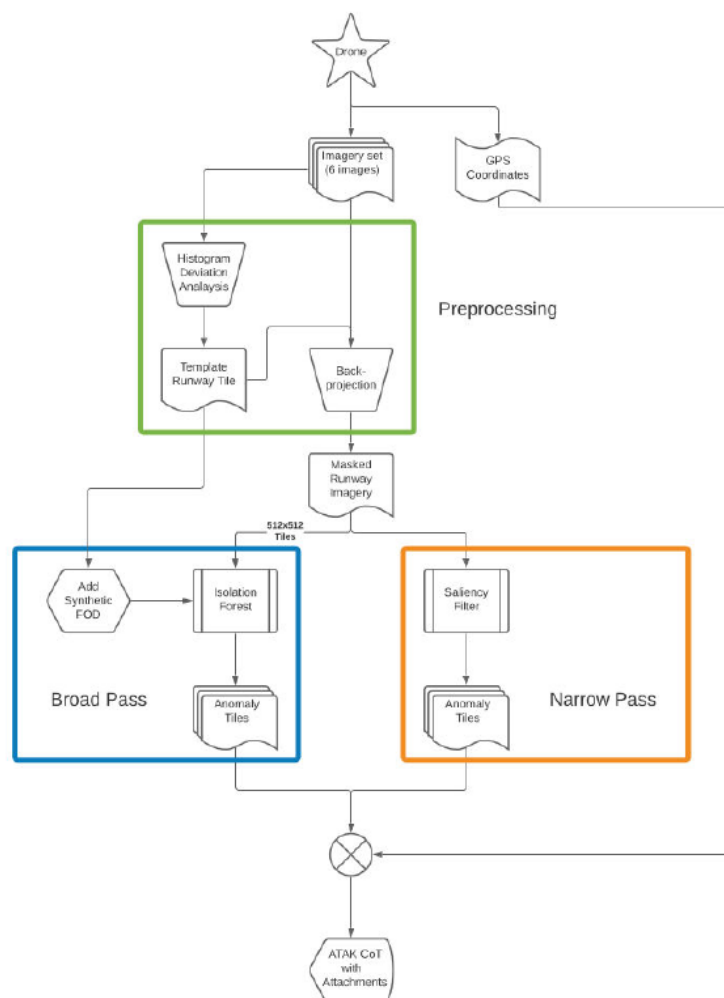
synthetic FOD in the isolation forest model resulted in an increased accuracy rate of 99% on a per-tile basis. GreenSight has noted there are roughly 5 false positives for FOD in every 10 aerial photos given the modified model.

Figure 18. Runway segmentation algorithm.



As more FOD imagery becomes available to create larger datasets, the narrow pass portion of the data pipeline may be better utilized. Using Google's Efficientnet architecture, GreenSight trained a machine learning technique called convolutional neural network (CNN) with imagery of physical and synthetic FOD on airfield pavements. This CNN (Figure 19) acts as a separate approach to FOD detection when compared to the isolation forest methodology used in the broad pass, as the CNN relies more heavily on training data for FOD detection. Before the submittal of potential FOD data collected by the Dreamer to the CNN, GreenSight created a secondary preprocessing step where images are subject to a saliency filter and then blurred to suppress high frequency noise. The regions of interest on the saliency map are then removed and the finished preprocessed data is sent to the CNN for FOD detection. GreenSight has states that the addition of the preprocessing step has increased the accuracy of FOD detection in the narrow pass by 10%, ultimately contributing to a 72% accuracy in detection.

Figure 19. Convolutional neural network.



3.4.3 Results and recommendations

GreenSight successfully combined two different approaches into a hybrid design to detect FOD across a varied dataset. The broad pass uses a suite of conventional computer vision approaches (such as histogram and color-based matching) as well as an unsupervised learning algorithm to detect FOD without a significant amount of training data. This was done because of the limited amount of training data available (which is and will be typical until a much larger database of FOD imagery is collected by the aviation industry). The limited training data that was gathered was then used to create a narrow pass algorithm using a CNN. The sum of these represents a unique approach able to achieve reasonable results despite limited training. As the system evolves and is evaluated against new types of airfields, and more data is gathered, the approach can be refined and improved.

4 CBRS Network

4.1 Planning and policy

4.1.1 Research focus and methods

This section focuses on the planning steps necessary to implement a wireless CBRS network at Fort Carson in support of the traffic cameras and the AV shuttle data. Policy, which affected the design and construction of the network, is also discussed.

Review of the project implementation was done from the perspective of making observations of the steps involved in the execution and subsequent recommendations for consideration for future implementation efforts. To help facilitate the successful implementation of future networks from a planning perspective, the basic framework from which observations were made include the following:

- What are the steps, things, and operations that may need to be in place to facilitate a successful implementation?
- What were unexpected hindrances to implementation and what could be done in the future to plan for them?
- Were there practices or considerations learned from past implementation efforts incorporated into this endeavor?
- What would have been helpful to have in place before implementation?
- What can we learn from each of the stakeholders' experiences in their efforts to fulfill their roles in the process?
- What can be done from a planning point of view to lay a groundwork for a more successful implementation in the future?

4.1.2 Data and findings

4.1.2.1 Installation briefings and requirements

Preparation for the CBRS network installation required Tilson to brief the Fort Carson Network Enterprise Center on 10 December 2020 on the specifics of the network design and field remaining questions about the installation. Tilson followed up with the spectrum manager on additional tasks from the meeting. A list of spectrum and frequencies used in the network design was sent to the Fort Carson spectrum manager for review and comment. Tilson acknowledged receipt of the spectrum manager's comments

and acted on those requests. These were formalized in the Execution Package for Project #CIV21-06. Specific attention was given to pole construction standards and spectrum approval. Tilson was also sent access approval forms for the installation subcontractors in January.

To capitalize on existing fiber optic cables, US Ignite understood the availability of existing civilian fiber would have an impact on the cost of deploying the network. Therefore, US Ignite submitted requests to the graphical interface system (GIS) team for maps of existing fiber. This process required approval from a NetOps security review.

4.1.2.2 Permitting

The installation of a CBRS network on Fort Carson required many approvals and requests to be granted. As mentioned above, US Ignite (or its subcontractor) was required to apply to the DoD's Joint Spectrum Clearance Program to deploy their sensors and private Long-Term Evolution (LTE) network. This process was expected to take 3 to 6 months.

Before any infrastructure was constructed, permits were needed for digging. Digging was required for the installation of wooden poles. As work progressed, additional trench permits were required to trench around discovered decommissioned power junction boxes. These activities delayed installation by a few weeks.

When UPN took over completion of the CBRS network install, no further permitting was required. They were able to successfully connect the installed equipment to their existing fiber network once the Fort Carson installation provided the appropriate conduit.

4.1.2.3 Contractor changes

In October 2021, US Ignite learned that Tilson was undergoing an internal reorganization with employees being laid off, or choosing to resign, from the company. This event greatly affected the Fort Carson CBRS network installation as the Tilson onsite project manager and others dedicated to this project were no longer with the company. US Ignite developed a containment plan to address this issue.

The containment plan utilized the UPN which had a project team dedicated to completing the connection to the UPN fiber network. The UPN

project team provided US Ignite with a plan that included a completion date of 13 December 2021. At the time of publication of this report, the network was being tested by a third party, NeuComm Solutions, for functionality in line with the original metrics of this project.

4.1.3 Results and recommendations

There were significant delays in the installation of the CBRS network. As a result, the network was not completed in time to be used by the AV shuttle. This failure led to disruptions of data collection, data distribution, and data analytics. Future planning considerations may include the following:

- Early evaluation of existing infrastructure related to network development and request for relevant and applicable GIS data, to include allowing for time related for NetOps security review
- Time allowance for network approval and spectrum analysis—it was noted that it might take up to 6 months to get the DoD's Joint Spectrum Clearance Program to deploy sensors and private LTE network
- Consideration and identification of all local permits for work related to network infrastructure (poles and trenches)
- On military installations, underground networks must consider abandoned and decommissioned utility lines during trenching activities

The CBRS network supporting traffic cameras and wireless data transfer for AVs is now installed at Fort Carson. However, the AV shuttle is no longer operating on site. Plans for using the traffic cameras are in play for the ongoing project titled *AI for Traffic and Weather*, which is based at Fort Carson. The network is available for use, and other research projects can make use of it.

There are plans in place for the garrison to take ownership of the CBRS network assets, including the traffic cameras, so that this can continue to be a smart installation testbed.

4.2 Infrastructure and operations

4.2.1 Research focus and methods

This section will focus on the aspects of the CBRS network that supported the AV shuttle and traffic cameras at Fort Carson. The research methods included direct observation as well as testing completed at the time of

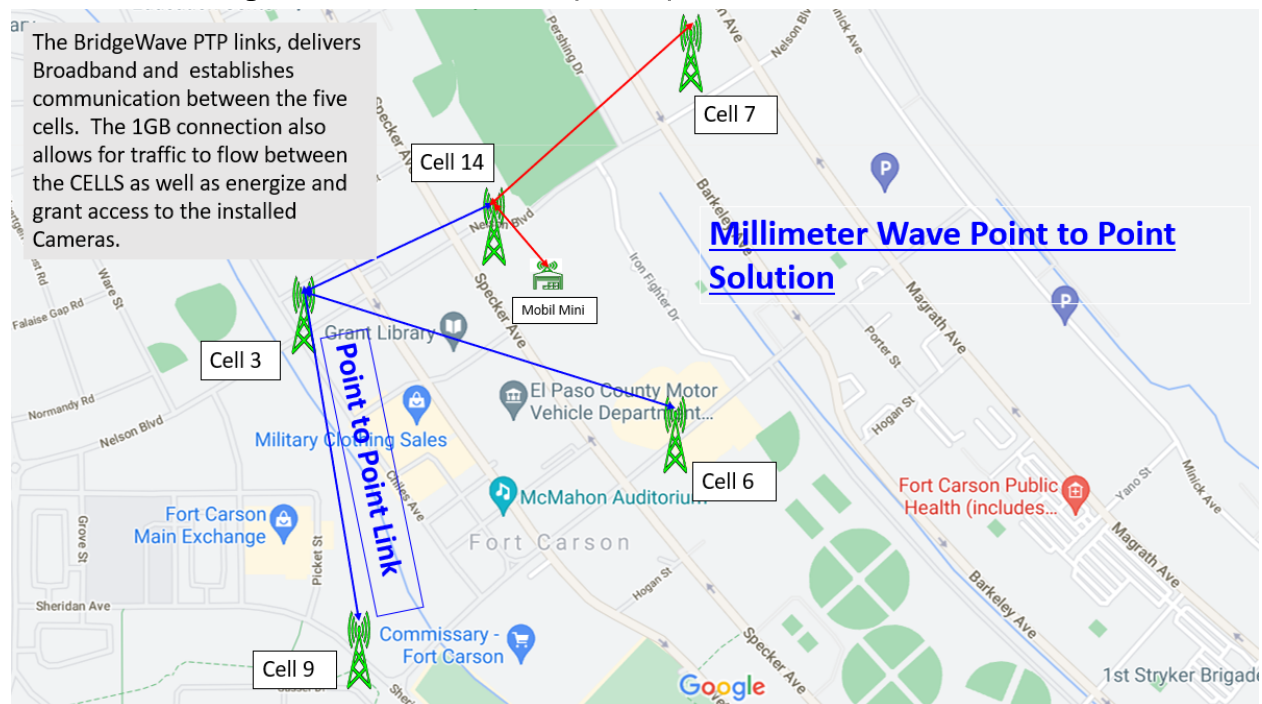
installation. Tilson was the contractor who designed and installed the CBRS network components.

4.2.2 Infrastructure data and findings

4.2.2.1 Location

The CBRS network was established in the area of the AV shuttle, for the purposes of capturing traffic conditions along the AV shuttle route and allowing connection to the vehicle for wireless data transfer, particularly at the storage location. Figure 20 shows the location of the five point-to-point links and installed cameras.

Figure 20. Location of the five point-to-point links and installed cameras.



4.2.2.2 Network design

The CBRS network designed by Tilson met or exceeded the specified minimum throughputs for both the cameras and AV shuttle telemetry, producing a minimum of 6 MB/s upload speeds and 14 MB/s download speeds for the mobile portion. A combination of omnidirectional antennas and carefully aimed sector antennas with specific down tilt were used to ensure complete radio frequency (RF) coverage for the AV shuttle route in its entirety. The RF network was designed specifically to have -102 reference signals received power (RSRP) minimum signal for handoff to the next cell for maximum availability, reliability, connectivity, and throughput at all

times. The designed location and mounting utilized either existing or new utility or light poles installed in the right of way along the routes as needed. Mounting the cells closer to the AV shuttle route provides more consistent coverage of the route and increased accessibility via bucket truck for future maintenance.

4.2.2.3 Equipment

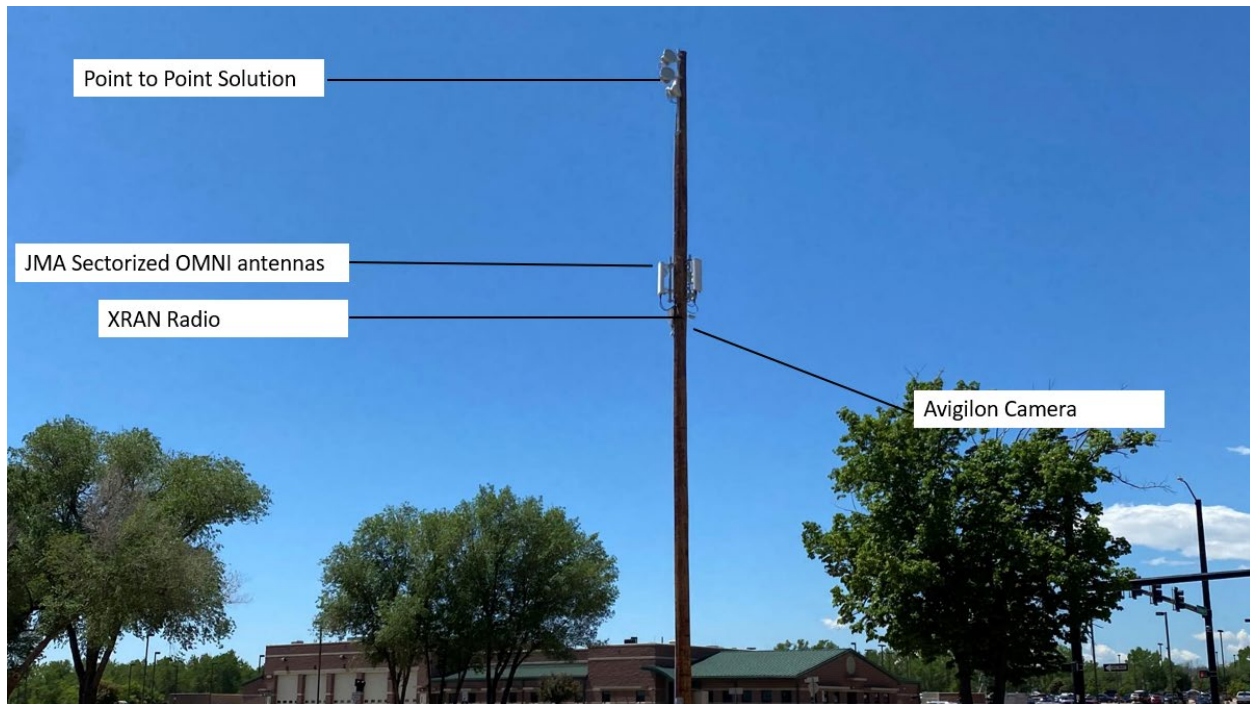
The communication component selected for the point-to-point network was a Bridgewave Flex4G-1000. The BridgeWaveFlex4G-1000 is a 70–80 GHz millimeter wave system delivering 1 GB/s full-duplex data throughput per radio and the highest system gain of any 80 GHz radio on the market. The product is shown in Figure 21. It is an all outdoor, IP radio system operating in the 71 to 86 GHz frequency band with capacities up to 1 GB/s. This component allowed communication between poles.

Figure 21. The BridgeWaveFlex4G-1000 used for point-to-point communications.



Communication to the vehicle was made possible with an Extensible Radio Access Network (X-RAN) radio and antenna also located on the pole. The coverage area of each radio was expected to allow communication with the AV shuttle within that area. Figure 22 shows the typical arrangement of pole mounted hardware.

Figure 22. Typical arrangement of pole mounted hardware.



The camera component selected for imaging was Avigilon Model 6.0C-H5A-BO1-IR. The camera has an infrared beam for illumination in the dark, ports for microphone and speakers, high efficiency video coding, memory card slots, and high-definition streaming management. The camera direction and viewing angles were optimized for the adjacent roadways.

The above equipment was roadside pole mounted and supported with a base station enclosure housing a server, switch, power supply units, and heating, ventilation, and air conditioning unit for cooling. The entire assembly was powered by a 100 A transformer that was tied into the base utility. Figure 23 shows a typical equipment arrangement.

Figure 23. Equipment installed at the base of the utility pole.

100A Transformer, that ties into base utility.

A list of Fort Carson Transformers will be submitted as a part of the information packet.



HVAC unit,
2000 BTU, HVAC unit needed for cooling the radio equipment.

Base station Enclosure. Houses the following equipment.

- X-RAN Server
- MIKROTEK PTP switch
- PSUs for both the xRAN Radio, as well as the PTP radios.

4.2.2.4 Internet provider

UPN delivered internet traffic through a dense wavelength-division multiplexing connection through the UPN network. Internet traffic was routed from Fort Carson to 102 S Tejon Street in Colorado Springs. It was then routed over the UPN network to the internet point-of-presence (POP) at 910 15th Street in Denver. UPN played an important role in the completion of the network when the original contractor was not able to do so.

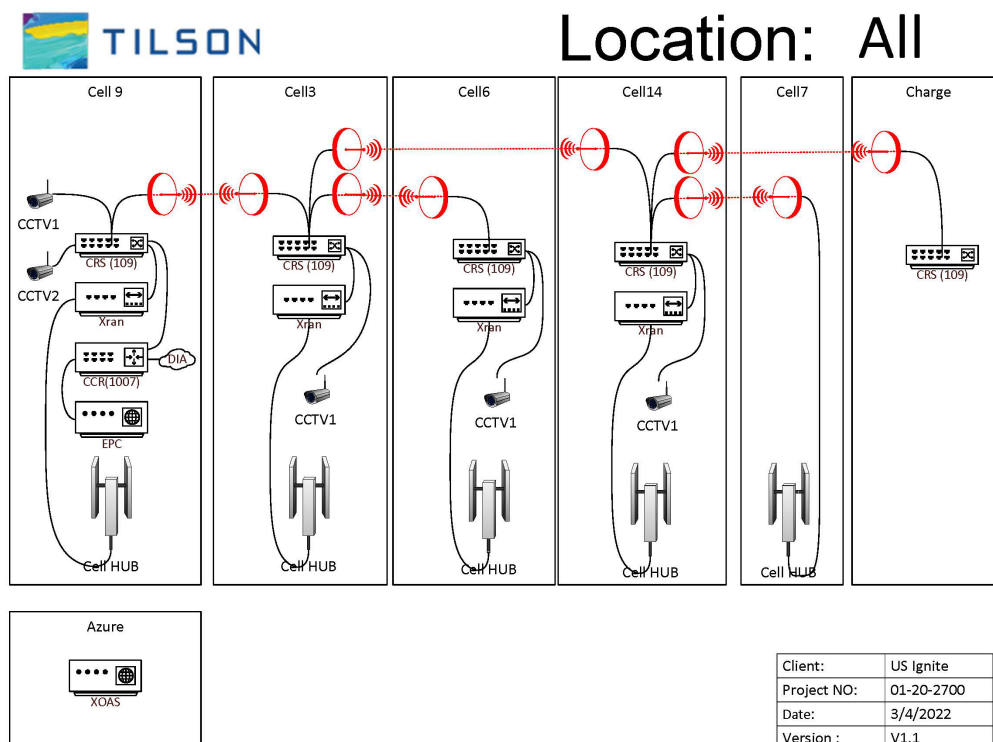
4.2.2.5 Network layout

The network consisted of 5-node X-RAN private LTE CBRS network. The X-RAN nodes and antennas were optimized to provide optimal coverage along the AV shuttle route. One of the poles contained two cameras, three of the poles contained one camera each, and the final pole contained only the cell antenna. The full diagram showing all components at all locations is shown in Figure 24. The location labelled *Charge* is the AV shuttle charging location.

Internet access for the network was achieved through UPN's fiber vault located 15 ft away from Cell 9. This connection provided 3 G/s throughput capability.

The point-to-point solution will carry the internet access to the rest of the cells and distribute to the vehicle through the XTRAN radio solution.

Figure 24. Tilson network diagram with all locations included.



4.2.2.6 Network installation timeline

Design of the CBRS network began in January 2021, including dig permits and mounting locations. In February, physical construction commenced, and equipment was delivered and tested. Installation continued in March, with delays because of weather and permitting. In April 2021, power was applied to the network for testing purposes. Final commissioning was planned for May. Internal issues with Tilson after May caused delays with the completion of the network, and ultimately, the UPN project team was able to complete connection to their fiber network. UPN provided a plan to connect the installed network to their fiber network during the month of December 2021. Their plan included the following steps: site walk, engineering plan, construction, fiber splicing, and electronics installation.

4.2.2.7 Weather

Weather impacted the construction of the CBRS network, particularly the installation of poles and other outdoor equipment. Naturally, the cameras that were installed are meant to always capture traffic events, but data has not yet been reviewed to determine if inclement weather has negative consequences on the quality of video feeds.

4.2.3 Operations data and findings

4.2.3.1 Deployment and setup

Tilson's proposal stated the installation would require a total of three separate crews—pole set crews, topsides install crews, and electrical and fiber cable crews. Equipment required would include a bucket truck, man-lift, or crane to support the topside installation on the poles, plus trenching and boring equipment. The proposal stated DigSafe would be contacted before any underground work. Flaggers were provided when necessary along the route. The estimated time to install, configure, test, and turn up 12 cell locations was approximately 62 days.

4.2.3.2 Safety

Safety during installation of the CBRS network needed to be factored in. Traffic near the installation site had to be considered to furnish the required flaggers. Electrical connections had to be made in a safe manner, which was provided by the subcontractor Tilson. Equipment had to be attached to the poles safely when at elevated heights, using bucket trucks.

4.2.4 Results and recommendations

The CBRS network and camera system took much longer than planned to install and was therefore not available to the AV shuttle. The final testing of the CBRS network indicated adequate coverage on all parts of the AV shuttle route, as well as adequate data transmission speeds. The CBRS network will be useful for current and future research projects including the AI For Traffic and Weather Project currently ongoing at Fort Carson.

4.3 Data architecture and cybersecurity

4.3.1 Research focus and methods

This section focuses on the data and cybersecurity elements of the CBRS network installed at Fort Carson. The information provided below was adopted from several unpublished monthly reports provided by US Ignite.¹⁷

4.3.2 Data and findings

In Tilson's proposal, they outlined a three-pronged approach to security. Physical security, transmission security, and logical security were identified as the three main attributes to be incorporated into the network security practices.

4.3.2.1 Physical security

Physical security is sometimes referred to as the first line of defense because it is often the easiest way for someone to gain access. Physical security is defined as that part of security concerned with physical measures designed to safeguard and to prevent unauthorized access to equipment and material against sabotage, damage, and theft. The following list of physical security measures were included in the network design:

- Barriers, locks, and keys
- Maintenance
- Intrusion detection and monitoring
- Disaster prevention

4.3.2.2 Transmission security

The transmission portion of the network offers an attacker a likely way to gain access to the network. For this reason, each component of the transmission network has been evaluated for security.

The fiber segments of the CBRS network represent the most secure forms of communications used. Fiber cable is run exclusively below ground and the nature of fiber cable makes it very difficult to eavesdrop on. Because of

¹⁷ US Ignite, ERDC: Evaluation On Base Deployment of Smart Transportation Technologies Fort Carson Smart Installation Project (Washington, DC: US Ignite Monthly Status Update, Unpublished, 2020–2021).

these factors, fiber can be considered inherently secure and thus does not require additional security measures.

4.3.2.3 Logical security

Logical security consists of measures that can be put in place and safeguards that can be enabled on systems themselves to offer protection.

Tilson proposed that all systems and equipment that are deployed as part of this communications network along the AV shuttle route should have the following security measures put in place:

- All default passwords will be changed. This ensures that should physical access to a device be gained by a potential attacker they would not be able to gain control of the device using known, default passwords.
- Devices that offer remote access will be secured against access.
- Additional and unused ports on equipment will be disabled and put into a null virtual local area network where possible. This will ensure that should physical access be gained to a cabinet a potential attacker cannot simply plug-in and gain access to the network.
- Where possible, separate user accounts will be created and used. This allows for more accurate logging and tracking of user access into devices.

4.3.3 Results and recommendations

The subcontractor, Tilson, identified and ensured the proper security measures were implemented into the CBRS network, considering the type and quantity of data which was to be transmitted over the CBRS network.

4.4 Data analytics and AI

4.4.1 Results and recommendations

The CBRS network that is described in this report did not come to completion until after the AV shuttle use case was completed at Fort Carson, and therefore was not utilized in the manner for which it was designed. However, subsequent projects at Fort Carson, such as the AI For Traffic and Weather, will make significant use of the network and the attending traffic cameras. The network will play an instrumental role in future data analytics and AI efforts at Fort Carson. Weather data from the cameras will be used to inform installation personnel, and aid in relevant decisions.

In particular, the pole-mounted cameras have the potential for capturing data that could be useful for the following:

- Traffic engineers
- Installation planners
- Garrison leadership
- Department of Public Works (DPW)

5 Program Integration and Mission Assurance

5.1 Research focus and methods

Program integration refers to the synchronization and arrangement of plans and actions to engage. Program integration serves as the resource and knowledge integrator to contextualize, refine, generalize, and expand on the results of this research project to take the greater DoD perspective and to apply those results to achieve broader national security objectives and to serve the needs of related missions.

This section examines outcomes and implications of the project through the lens of the Army Installation Strategy, (HQDA 2020). The Army now views its installations as part of the battlespace under MDO. Installations as Strategic Support Areas (SSA) emphasize the necessity of maintaining competitive advantage at the point of initiating combat power by leveraging the latest automation technologies to expedite Army modernization, improve readiness, and enhance quality of life on installations. This effort deployed an updated and commercially available CAV and UAV to further demonstrate their use and conduct research and development to optimize and inform the integration of these emerging technologies at installations that serve as SSA under the new MDO doctrine. CAVs and UAVs capture, store, and analyze tremendous amounts of data. The stakeholders at the Department of the Army and Army installations need to understand the data systems and processes involved in these deployments to leverage it for internal optimization and protect it from external exploitation.

5.2 Data to decision

Applying smart data nodes and sensors is the process of using data for decision making, in which operators collect data, detect patterns from the data, put together an analysis, and make these analyses available for users to take actions. Key components of data to decisions include the following:

- Data collection and access
- Data repositories
- Data analytics
- Data visualizations

The Army Installations Strategy nests these under the critical enabler—data analytics, to achieve the strategic outcomes (Figure 25). The capability for the Army to see itself through data analysis will allow prioritized resource investment over the long term. Success requires increased use of data science techniques, to include AI and machine learning, as well as the creation of data-informed common operating pictures (COP) across the Army’s installation enterprise. The ideas of visualization, notification, and automation define the COP.

Efforts like the Fort Carson Testbed demonstrate the characteristics of modernization with the support of a secure, latest-generation broadband network, sensors, and a robust information technology infrastructure. The accomplishments of this effort with Fort Carson are a greater understanding of available and future data sources as various smart areas and engagement of stakeholders regarding analysis processes.

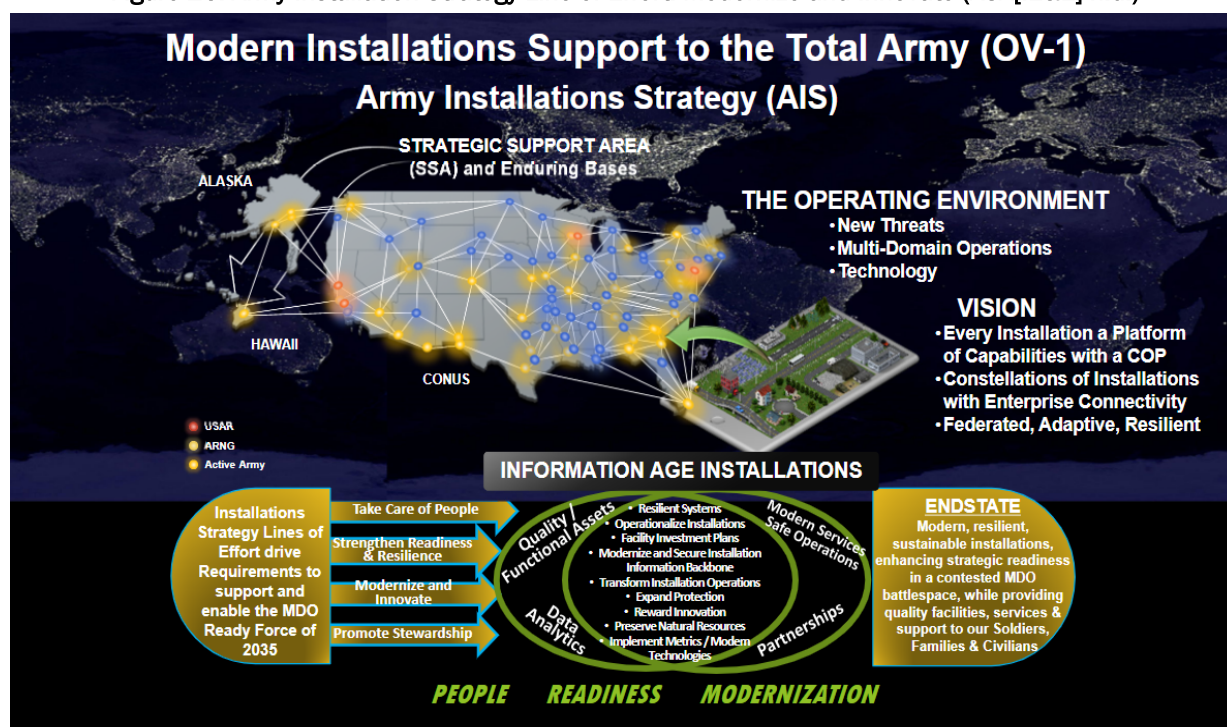
Figure 25. Army Installation Strategy (HQDA 2020).

ARMY INSTALLATIONS STRATEGY FRAMEWORK					
LINES OF EFFORT		ENABLERS		STRATEGIC OUTCOMES	END STATE
1	TAKE CARE OF PEOPLE • Adapt Quality / Functional Facilities • Deliver Modern Services • Conduct Safe Operations	D A T A A N A L Y T I C S	P A R T E N S I V E	Attract, Retain, and Enable People	Modern, resilient, sustainable installations, enhancing strategic readiness in a contested MDO battlespace, while providing quality facilities, services, and support to our Soldiers, Families, and Civilians.
2	STRENGTHEN READINESS and RESILIENCE • Operationalize Installations • Expand Protection • Adopt Resilient Systems • Educate / Train the Team			Project Combat Power and Sustain Operations from a Contested Environment	
3	MODERNIZE and INNOVATE • Modernize and Secure the Information Backbone • Support Army Modernization Initiatives in the AMS • Transform Installation Operations • Reward Innovation			Modernized Installations Supporting the Modernized Army	
4	PROMOTE STEWARDSHIP • Preserve Natural Resources / Sustain the Mission • Remediate Contaminants • Implement Risk-Informed Metrics and Modern Technologies			Healthy, Sustainable Training, Working, Living Environment	

5.3 Solution gap

Recent information systems enhance select data analytics, but largely remain disjointed, and personnel lack a coherent, real-time, COP from which to conduct analysis, plan, and select optimized solutions. The Army recognizes that a capability is needed to integrate data from diverse existing systems and sources as well as emerging technologies, enhance the data, enable standardization, improve processes, and provide holistic dashboards with historical, real-time, and predictive information to optimize operations and investment decisions, improve efficiency and resilience. VTIME is an Assistant Secretary of the Army Installation, Energy, and Environment (ASA [IE&E]) funded initiative to showcase and fast track the infusion of new technologies and data analytics within a COP. Figure 26 illustrates the ASA (IE&E) vision for VTIME to support the Army Installation Strategy with data collection and analysis, data repository, data analytics, and data visualization. Installations are data rich but information poor, encumbering the ability to comprehensively recognize, prepare, absorb, and respond to threats. VTIME strives for rapid installation modernization and innovation through ready access to relevant data.

Figure 26. Army Installation Strategy Line of Effort: Modernize and Innovate (ASA[IE&E] n.d.)



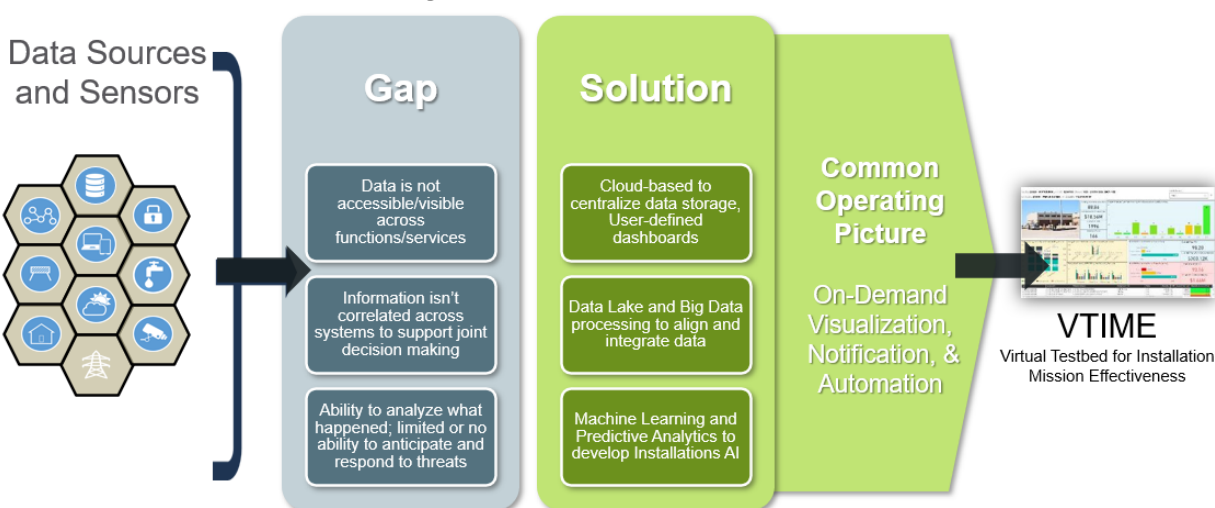
As described in the MDO concept, installations are initial maneuver platforms and critical Army enablers, and no longer seen as sanctuaries.

Installations must be able to monitor, recognize, notify, and respond to these threats to assure accomplishment of their mission as battle platforms. Installations lack reliable, integrated data analytics, smart tools, technologies, and automation controls necessary to respond to threats, efficiently and effectively respond to changing conditions that affect installation missions, reducing readiness, impacting stewardship and sustainability, increasing costs, and ultimately degrading assured accomplishment of installation missions as battle platforms.

5.4 Recommendations

The program integration LOE is an ongoing effort that explores how the application of smart and connected technologies, such as CAVs and UAVs, support installations as SSAs under the new MDO doctrine. CAV and UAV technologies present opportunities to improve data collection and analysis and inform decision makers at installations through COPs. Figure 27 captures the Army's transformation to an information-age organization, leveraging new technologies to support relevant information shared across the enterprise. The recommendation is to continue demonstrations across the Army enterprise that address the gaps, refine the solution, and establish requirements for the COPs.

Figure 27. Modernization framework.



5.5 Way ahead

As follow-on to this effort, the Installations of the Future Program within the office of the ASA (IE&E) will leverage the existing testbed at Fort Carson and expand into the Colorado Springs local community to include

sensor deployment, data integration, AI model, and decision dashboards development that integrate traffic and weather-related information. The continued effort will support design and implementation of a new predictive model analyzing traffic and weather data to optimize traffic management and responses to inclement weather. The model will provide information learned from the data set through a Smart Installation and Community Dashboard that will use a dedicated CBRS wireless network, open-source data, and smart sensors to provide leadership at both the city and the installation with real-time analysis of traffic and weather conditions. Specific capabilities and outcomes will include the following:

- Capabilities:
 - Includes remote monitoring of traffic and weather conditions affecting installation entry and exit.
 - Has data fusion with AV testbed and AI model development to inform smart base operational decisions.
 - Includes integration with Colorado Springs current smart city innovations.
- Outcomes:
 - Analyze operations, maintenance, and data costs of system.
 - Improve safety, security, and traffic flow at congested gates.
 - Evaluate commercial weather and traffic AI solutions.

Data integration will include cloud hosted data that feeds into the ERDC Azure GovCloud that hosts other installation CAV data and the VTIME.

5.6 Achieving modernization

In pursuit of the Army Installation Strategy, this effort integrates within ongoing ERDC-CERL research efforts supporting modernization and readiness with automated systems, data fusion, and data analytics at the SSA. The Smart Installation Research Portfolio (Figure 28) identifies strategic future locations with known interest in smart and connected technologies, along with their unique geography and climates, academic partners, and joint force mission sets for a proposed structured research and development framework that builds on this foundational project. An adequate sample of field sites and CAV and UAV technologies is required before the

lessons learned from this single case study can be integrated into formalized installation policy or regulation.

Figure 28. ERDC's Smart Installations research portfolio.

Location	Geography / Climate	Academic Partner	Mission Set
Joint Base Myer-Henderson Hall & Pentagon, Virginia	Urban environment, Atlantic coast, four seasons	George Mason University and Virginia Tech	Washington DC headquarters support
Ft Carson, Colorado	Mountains and high plains, high altitudes, four seasons	University of Colorado - Boulder	Combat Deployment: 4 th Infantry Division (5 brigades)
Miramar Marine Corps Air Station, Naval Base San Diego	Desert and low mountains, Southwest temperate and Pacific coast	University of California – San Diego	Combat Deployment: Marine Air Wing National Force: Shipyard and Naval Support Group
Ft Leonard Wood, Missouri	Woodland, Midwest four seasons	Missouri University of Science and Technology	Institutional Training: Basic, Driver, Convoy, Engineer
Redstone Arsenal, Alabama	South-east region, low altitude, high heat and humidity	University of Alabama	Sustainment: Army Materiel Command
Ft Benning, Georgia	South-east region, varied terrain, high heat and humidity	Georgia Tech University	Combat Deployment and Institutional Training
Rantoul and Champaign, IL	Midwest plains, four seasons, intermodal transportation	University of Illinois	Smart Installation and Autonomy Research

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Appendix A: Comprehensive Table of Stakeholders

Table A-1. List of stakeholders and their roles or activities.

Stakeholder	Roles/Activities
Engineer Research and Development Center	Manage research activities
Fort Carson	Host Installation
US Ignite	Primary Contractor
First Transit	AV Shuttle Operator
Tilson	Network Designer
Unite Private Network	Internet Provider
University of Colorado Boulder	Academic Partner
GreenSight	Drone Operator

Appendix B: Final Reports Provided by US Ignite

US Ignite provided a final report for the AV shuttle titled *Fort Carson Smart Transportation Testbed: AV Shuttle Project Report*. Eric Werner is the author, and the report was delivered in 2021. The contents of the report are shown below, while the report itself is published as a contractor report.

US Ignite AV Shuttle Report Outline:

1. Executive Summary
2. Introduction
3. Project Objectives
4. Project Approach
5. Project Scope
6. Milestones and Schedule
7. Vendor Selection Process
8. AV Vendor Selection
9. AV Vendor Approaches
10. Contract Award and Kickoff
11. Service Area and Shuttle Route Development
12. Operational Planning
13. Shuttle Service Description
14. Staging and Storage Area
15. Project Branding
16. Operational Launch
17. Autonomous Vehicle Data Collection, Storage and Analysis
18. University of Colorado at Boulder Research
19. Third Party Safety Assessment
20. On-Route Vehicle Observations
21. Ridership Improvement Revisions
22. Total Ridership Transported
23. Impacts of COVID-19
24. Shuttle Operations
25. Shuttle Performance Issues
26. Containment Planning
27. June IPR
28. Conclusion
29. Lessons Learn and Recommendations
30. Project Vendors

US Ignite also provided a final report for the Service Vehicle titled *Fort Carson Smart Transportation Testbed: AV Service Vehicle Report: Automated Aerial Runway Inspection and Safety Scan (AARISS)*. The contents of the report are shown below, while the report itself is published as a contractor report.

US Ignite Service Vehicle Report Outline:

1. Background
2. Introduction
3. Milestones and Schedule
4. Project Stage 1 Scope
5. Project Kickoff and pre-flight clearances
6. November Test Flight Incident
7. Project Stage 2 Scope
8. Milestone 1: Off-site testing
9. Milestone 2: Algorithm and UI Development
10. Milestone 3: Off-site testing using COTS compliant aircraft
11. Milestone 4: On-site testing at BAAF
12. Project Impact
13. Concluding Remarks
14. Project Team

Appendix C: Final Report Provided by First Transit

First Transit provided a final report titled, *Autonomous Vehicle Research Testbed: On Base Shuttle Pilot*. The contents of the report are shown below, while the report itself is published as a contractor report.

Report Outline:

1. Introduction
2. Project overview
3. Deliverables completed and results
4. Lessons learned
5. Event management
6. Containment plan
7. Recommendations for future projects

Appendix D: Final Report Provided by University of Colorado Boulder

The University of Colorado at Boulder provided a final report titled *Final Project Report: Evaluating On-Base Deployments of Autonomous Vehicles* (2021). The authors were Sriram Sankaranarayanan, Steve McGuire, Morteza Lahijanian, Nisar Ahmed, and Christoffer Heckman. The contents of the report are shown below, while the report itself is published as a contractor report.

Report Outline:

1. Introduction
2. Data Analysis Pipeline
3. Feature Extraction
4. Traffic Camera System
5. Human Factors Study: Examining Changing Operator and Rider
6. Attitudes During an Autonomous Vehicle Test Deployment
7. Lessons Learned
8. Future Directions
9. Conclusions

Appendix E: Reports Provided by GreenSight

GreenSight provided the following list of reports summarizing the milestones achieved during the project:

- 3 November 2020 Visit Fort Carson After Action Report
- AARISS TO2 Milestone 1 Deliverable: Test Flight Operations Report, Interim Report, 29 July 2021 Revision 2.0
- AARISS TO2 Milestone 2 Deliverable: Algorithm and UI Development Report, 30 March 2021 Rev 1.0
- AARISS TO2 Milestone 3 Deliverable: Test Flight Operations Report
- 30 July 2021, Rev 1.1

Appendix F: Engineer Research Development Center Survey Questions

Survey Questions

*Questions in this survey are intended to be answered by **both riders and non-riders** of the Automated Vehicle (AV). Please answer all questions to the best of your ability stemming from your observation of the self-driving shuttle. This feedback will be considered by AV companies for future improvements, so be honest and thorough. This is an anonymous survey, do not record your name* Questions in this survey are intended to be answered by both riders and non-riders of the Automated Vehicle (AV). Please answer all questions to the best of your ability stemming from your observation of the self-driving shuttle. This feedback will be considered by AV companies for future improvements, so be honest and thorough. This is an anonymous survey, do not record your name or any other identifying information on this form.

Activity: Human Factors Fort Carson Survey for Autonomous Vehicles (AV)

Project Identification Number: 2020-06-NR

Investigator: Lance L. Larkin, PhD, CEERD-CERL Investigator: Lance L. Larkin, PhD, CEERD-CERL

1. *Is this your first time filling out this survey?*

Yes No

2. *Will you ride, or have you ridden an Autonomous Vehicle (including the Fort Carson shuttle)?*

Yes, I have ridden before. Yes I've ridden, but not again.

No I haven't, but I would try it. No I haven't, and never will.

3. *What is your age? (Only adults of 18 years and older.)* _____

4. *How do you normally get around Fort Carson? (Choose all that apply.)*

Walking Biking Installation transportation Personal vehicle

5. Which is the most appropriate description of where you work and/or live?

Live or work in Fort Carson

Work for the Dept. of Defense off-post

Do NOT work for the Dept. of Defense

6. *Select the most appropriate description of your interaction with the vehicle:*

Safety Operator Passenger Observer (not riding on vehicle)

Other (please explain below)

7. How many times have you been a passenger on this vehicle?

Zero	1	2	3-4	5-9	10 or more
------	---	---	-----	-----	------------

8. Choose if, and how, you were provided enough information by people or other means to feel safe riding the vehicle. If you did not ride the vehicle, answer using any information you might have already heard/seen about the vehicle. Select all applicable answers.

Word of mouth Steward/Safety Operator Video media

Written publications	None
----------------------	------

9. *I have a strong understanding of computers.*

Agree Somewhat agree Neither agree nor disagree Somewhat disagree

Disagree

10. *I have programming experience.*

Yes No

11. On a scale from 0-10, how likely are you to recommend the Autonomous Vehicle to a friend or colleague (circle answer)?

0	1	2	3	4	5	6	7	8	9	10
Not at all likely								Extremely likely		

Not at all likely

Extremely likely

Directions: Please rate your agreement with each item based on your past or current experiences with the vehicle. If you have not ridden the shuttle, answer according to your perception of either having watched it operate, or what you generally know about Automated Vehicles.

12. The vehicle is intelligent. (Select one)

Strongly agree	Somewhat agree	Neither agree nor disagree
Somewhat disagree	Strongly disagree	

13. The vehicle is safe. (Select one)

Strongly agree	Somewhat agree	Neither agree nor disagree
Somewhat disagree	Strongly disagree	

14. The vehicle is trustworthy. (Select one)

Strongly agree	Somewhat agree	Neither agree nor disagree
Somewhat disagree	Strongly disagree	

15. If you were a rider: the vehicle gave a comfortable ride. If you were NOT a rider: the vehicle appeared to give a comfortable ride.

Strongly agree	Somewhat agree	Neither agree nor disagree
Somewhat disagree	Strongly disagree	

Directions: Please rate the acceptability of each item based on your past or current experiences with the vehicle. If you have not ridden the shuttle, answer according to your perception of either having watched it operate, or what you generally know about Automated Vehicles.

16. The vehicle avoided other vehicles, obstacles, and pedestrians without human intervention.

Perfectly acceptable	Slightly acceptable	Neutral
Slightly unacceptable	Totally unacceptable	

17. The vehicle responded to traffic rules (e.g., road signs, road rules) without human intervention.

Perfectly acceptable	Slightly acceptable	Neutral
Slightly unacceptable	Totally unacceptable	

18. Please leave any open-ended feedback prompted by the survey. Write the number of the question if you are referring to your answers above.

Appendix G: Prelaunch Questionnaire

Prelaunch Questionnaire

These questions are intended to gauge interest in a self-driving shuttle at Fort Carson. This is an anonymous survey, do not record your name or any other identifying information on this form.

Activity: Human Factors Fort Carson Pre-launch Questionnaire for Autonomous Vehicles (AV)

Project Identification Number: 2020-05-NR

Investigator: Lance L. Larkin, PhD, CEERD-CERL

1. What is your age? (Only adults of 18 years and older.) _____

2. How do you normally get around Fort Carson? (Choose all that apply.)

Walking Biking Installation transportation Personal vehicle

3. Which is the most appropriate description of where you work and/or live?

Live or work in Fort Carson

Work for the Dept. of Defense off-post

Do NOT work for the Dept. of Defense

4. I have a strong understanding of computers.

Agree Somewhat agree Neither agree nor disagree Somewhat disagree

Disagree

5. I have programming experience.

Yes No

6. If an autonomous (self-driving) vehicle was to offer free shuttle service at Fort Carson, which of the following describes your attitude to this technology (choose all that apply):

I will ride a self-driving shuttle for the experience.

If it is convenient, I will ride a self-driving shuttle as a regular part of my daily routine.

I will ride a self-driving shuttle if there is a safety steward on board monitoring operations. (A safety steward allows the vehicle to operate autonomously, but immediately takes over if there is a problem.)

I will never ride a self-driving vehicle.

Other (leave a comment in the section below) ...

7. Please leave any open-ended feedback prompted by the survey. Write the number of the question if you are referring to your answers above.

Appendix H: News Articles

Carson Becomes a test bed for latest AV (Prater 2020b)



Carson becomes a test bed for latest AV

Public Affairs Office Aug 17, 2020 0

"We've created a shuttle route for the evening that will take Soldiers from barracks to the Exchange, the Commissary and the Ivy gym, in a nice loop."

— Tami Gale

By Scott Prater

Mountaineer staff

FORT CARSON, Colo. — This September 2020, Soldiers looking for a ride from their barracks to the commissary, exchange or the gym will be in luck. The Mountain Post is getting a new type of shuttle that is sure to turn heads, since it drives itself and runs on electricity.

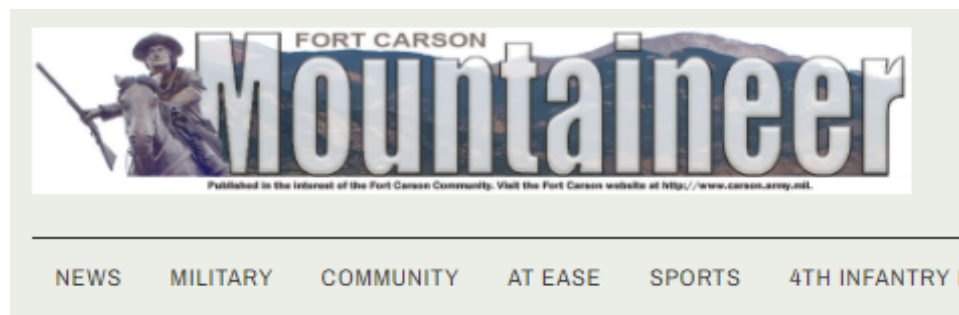
The Army has partnered with several companies, including U.S. Ignite, First Transit and Perrone Robotics to operate a pair of automated vehicles (AV) as post shuttles during a yearlong pilot program.

"Fort Carson is the host site to test this technology," said Tami Gale, community liaison, U.S. Army Garrison Fort Carson. "The U.S. Army Engineer Research and Development Center (ERDC) is funding the project, and it's intent is to determine the benefits, costs and feasibility of autonomous technology on a military installation."



FORT CARSON, Colo. — Two Polaris GEM automated shuttles, custom-configured by Perrone Robotics using their TONY (TO Navigate You) autonomy kit, will operate as Fort Carson post shuttles beginning in mid-September. (Courtesy photo)

AV Shuttle Program Kicks Off (Prater 2020a)



AV shuttle program kicks off

Public Affairs Office Sep 14, 2020 0

“A specially trained First Transit safety operator is always on board the shuttle and has the ability to take over manual control at any time.”

– Chris Degaray

By Scott Prater

Mountaineer staff



FORT CARSON, Colo. – Fort Carson will take a leap into the future Sept. 14, 2020, as leaders will kick off a new program that transports people around post in a vehicle that drives itself.

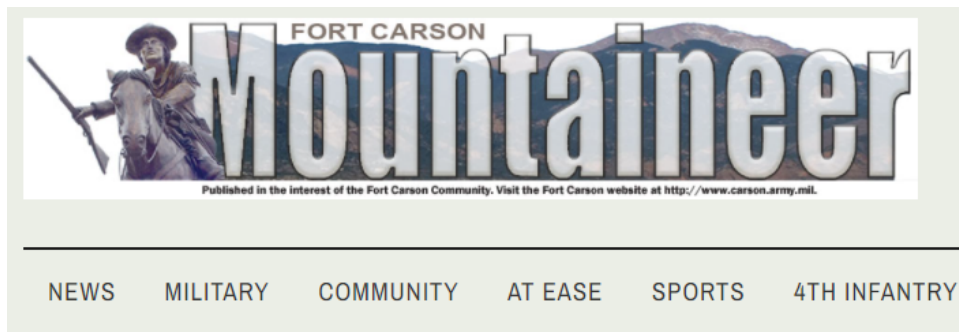
The Automated Vehicle (AV) pilot program was announced last month. But, in the last few weeks, the AV team has arrived on post and started testing.

U.S. Army Garrison Fort Carson Commander Col. Nate Springer will join AV pilot program leaders at Pershing Field to officially launch the yearlong program Sept. 15, 2020, at 9:30 a.m.

Springer and pilot program leaders will educate and inform attendees and introduce the vehicle, which will be augment the Fort Carson shuttle service, during the ceremony. Attendees will then get a chance to take a test ride in the shuttle.

The AV is on track to begin operating as an evening post shuttle starting Sept. 16, 2020, and will then run routinely Monday through Friday from 5:30-9:30 p.m.

High tech shuttle rolls at Carson (2020c)



High tech shuttle rolls at Carson

Public Affairs Office Oct 2, 2020

By Scott Prater

Mountaineer staff

FORT CARSON, Colo. – Fort Carson leapt into the future Sept. 15, 2020. Following a brief kick-off ceremony, a small group of Soldiers climbed into a new type of vehicle, never seen before on post, and took a short ride along the streets surrounding Pershing Field.

Known as the Mountain Express, the new vehicle resembles something between a shuttle van and an oversized golf cart, with large windows and small wheels. But that's where most of the similarities with normal cars end.

This one actually drives itself.



FORT CARSON, Colo. – The Mountain Express automated vehicle (AV) departs Pershing Field on its maiden voyage with five passengers following a kick-off ceremony for a yearlong AV pilot project at Fort Carson Sept. 15, 2020. (Photo by Scott Prater)

Appendix I: Dreamer Air Worthiness Release



DEPARTMENT OF THE ARMY
U.S. ARMY COMBAT CAPABILITIES DEVELOPMENT COMMAND
AVIATION AND MISSILE CENTER
5400 FOWLER ROAD
REDSTONE ARSENAL, ALABAMA 35898

FCDD-AMR

20 October 2020

MEMORANDUM FOR U.S. Army Corps of Engineers, Aviation Program Office,
441 G Street NW, Washington, DC 20315-1000

SUBJECT: AWR for Operation of the Greensight Dreamer UAS (AWR 220881)

1. Scope: This memorandum constitutes an Airworthiness Qualification Level 3 Airworthiness Release (AWR) authorizing operation of the Dreamer Unmanned Aircraft Systems (UAS).
2. Validity: This AWR is new and terminates **20 Oct 22** or upon change in configuration of the subject equipment, or upon issuance of a later AWR whichever occurs first. This AWR only applies to Dreamer systems that are owned and/or operated by/for the U.S. Army Corps of Engineers (USACE). This AWR authorizes flight operations within Active Restricted Airspace (ARA) and within the National Airspace in accordance with the DoD/FAA Memorandum of Understanding.
3. Appendices: This memorandum and its appendices shall be briefed to flight crew prior to flight operations, carried in the log books and available to the Operator.
 - Appendix A: Restrictions and Operating Information
 - Appendix B: Configuration and Installation Detail
 - Appendix C: Inspections, Maintenance, and Logbook Instructions
 - Appendix D: Reference List
4. The points of contact (POC) are Mr. Bob Helton, commercial, (256) 955-2210, robert.s.helton4.civ@mail.mil and Mr. Jeremy Rimmer, commercial, (256) 955-9040, jeremy.a.rimmer.civ@mail.mil.

BANKS.FRED.D
JR.1231275785

Digitally signed by
BANKS.FRED.D.JR.1231275785
Date: 2020.10.20 12:29:26 -0500

for KEITH R. DARROW
Director for Airworthiness
Systems Readiness Directorate

FCDD-AMR

20 Oct 20

SUBJECT: AWR for Operation of the Greensight Dreamer UAS (AWR 220881)

Appendix A. Restrictions and Operating Information:

1. The aircraft operating instructions, procedures, and limitations shall be in accordance with the System Safety Management Plan (SSMP) (see D.1), User Manual (see D.2), DoD FAA Memorandum of Understanding for UAS operations in the national airspace (see D.3), U.S. Army Corps of Engineers Small Unmanned Aerial Systems (SUAS) Policies and Procedures memo (see D.4), and this AWR. In the event of conflict between these documents, the information in this AWR shall prevail.

CAUTION

The UAS has not been tested for the effects of lightning. A lightning strike could result in damage to or loss of the aircraft. Flight operations less than 25 nautical miles from lightning activity should be avoided.

The UAS has not been qualified for the effects of precipitation. Flight operations shall be restricted from flight into or during measureable precipitation activity within the operational area. In the event of inadvertent flight into precipitation activity the aircraft shall make every attempt to exit the activity or land in a suitable location.

The UAS has not been qualified to MIL-STD-810G environmental temperature extremes to demonstrate the equipment function satisfactorily/safely. Therefore, the system may not operate or may cease operation when exposed to extreme temperatures, low pressure environments, and other non-standard climatic conditions. If conditions are entered that are outside of past experience, proceed with caution.

2. Flight of the UAS is restricted to Visual Meteorological Conditions (VMC).

3. The lost link waypoint, return to launch point or alternate rally point shall be over a suitable point such that the aircraft will not exit the appropriate airspace during lost link flight.

CAUTION

The UAS has not been qualified to MIL-STD-810G environmental temperature extremes. The aircraft shall not operate at altitudes or temperature conditions beyond which the batteries can safely provide power to the aircraft. The battery system shall be capable of providing adequate power to descend and land at an alternate ditching location.

FCDD-AMR

20 Oct 20

SUBJECT: AWR for Operation of the Greensight Dreamer UAS (AWR 220881)

4. Batteries self-discharge over time. Prior to every flight all batteries (e.g. aircraft battery, Control Station (CS) battery etc.) shall be verified to contain adequate charge to ensure that aircraft can be operated safely in the event of an emergency.
5. Rotors/Propellers/Turbines could cause injury to the human eye or skin. Use eye protection and keep face, fingers and clothing clear from rotors/propellers/turbines.

WARNING

The UAS does not have a sense and avoid system. Mid-air collision is a risk. All flight operations shall be conducted to ensure that minimum separation standards are maintained from any other aircraft.

6. Ground observers shall maintain positive contact with the aircraft at all times outside of ARA.
7. In the event of loss of communications between the aircraft operator and ground observers, operations shall cease immediately and not resume until communications anomalies are corrected.

WARNING

The UAS has not completed full airworthiness qualification. Operation in and around flight crew personnel has potential to cause injury, however, the potential to cause serious injury is low. Operations should maintain the Safety Standoff Distance (SSD) from flight crew personnel where practicable.

8. A flight crew SSD exclusion zone should be maintained during flights. This distance shall be determined by a preflight survey of the operational area used for the risk determination developed from the SSMP.
9. The aircraft shall not be flown across or adjacent to any operational roadways open to non-participating personnel at a horizontal distance less than the predetermined SSD.

WARNING

The UAS shall not be flown over non-flight crew personnel. An SSD shall be maintained at all times from non-flight crew personnel.

10. Flight over non-participating personnel is prohibited.

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WARNING

The UAS Control Station (CS) has not undergone a formal Human-Machine Interface (HMI) evaluation. The CS has a demonstrated reliability but the performance, accuracy and efficiency have not undergone a formal analysis. The system should be used with caution.

11. Datalink frequencies shall be de-conflicted through local frequency manager or coordinator prior to any operations.
12. The operator in command must monitor the Control Station at all times during all flight modes. In the event that the operator receives an indication of erroneous information or unintended behavior, the operator shall abort the mission and Return to Base (RTB).
13. Verified loss of any aircraft flight critical subsystem or control station flight critical sub-system shall require RTB.
14. Any unexplained anomaly shall initiate a RTB and operations shall not resume until the anomaly is resolved and reported to the POCs listed in paragraph 4 of this AWR.
15. Any procedural deficiencies or flight anomalies detected during operations shall be corrected, annotated, and reported to the POCs listed in paragraph 4 of this AWR.

WARNING

The UAS has not undergone Explosive Atmosphere testing. A serious fire or explosion may result if the aircraft is powered while flammable vapors are present during ground or flight operations. Do not operate the system in the presence of flammable vapors.

WARNING

Low altitude missions introduce land-based flight obstacles not encountered during typical UAS and manned aircraft flights. These obstacles include buildings, power lines, balloon tethers, and trees. Failure to identify and avoid land-based obstacles could result in aircraft damage or personnel injury.

16. Flight planning shall identify and avoid land-based obstacles.

FCDD-AMR 20 Oct 20
SUBJECT: AWR for Operation of the Greensight Dreamer UAS (AWR 220881)

17. Commander's Corner:

The UAS has been issued an Airworthiness Qualification Level (AQL) 3 AWR IAW AR 70-62 and has not met full airworthiness qualification or reliability demonstration requirements. AQL 3 is not based on traditional airworthiness substantiation from test data or analyses, and is issued for expendable UAS that are intended to regularly operate in Restricted Airspace and small UAS that intend to operate in combat zones. These UAS are not designed to accepted engineering standards and/or do not possess adequate engineering data to determine their compliance with acceptance standards. The data requirements for AQL 3 directly correlate to the proposed operational restrictions, area of operation, and allowed usage of the UAS. These systems have undergone a system level safety assessment that identifies the hazards for the intended operations. The AQL 3 AWR applies restrictions to mitigate the hazards identified in the system safety documentation. If the hazards cannot be mitigated through restrictions, the associated risk must be accepted at the appropriate level before the AWR is issued.

The content of this AWR is based on information provided to the Systems Readiness Directorate, site visit, and technical interchange with the aircraft operator and physical inspection of the UAS.

The potential for the UAS to create a fatality does exist, but is extremely remote due to size, weight, speed and operational constraints. There is also the possibility to cause a serious injury. A serious injury or fatality may result from a series of events such as but not limited to an event where the aircraft departs flight path and strikes car causing driver to swerve off the road or strikes the window of a building showering 3rd parties with broken glass. An operational assessment should be conducted in conjunction with application of the System Safety Management Plan for Unmanned Aircraft Systems process. A risk assessment shall be completed, risks identified, addressed, accepted and adequate mitigations in place prior to commencement of any flight operations. A horizontal SSD shall be maintained at all times from non-flight crew personnel. This distance must be maintained to minimize the possibility of mishaps occurring that jeopardize 3rd parties not associated with the flight crew.

Electromagnetic Interference/Electromagnetic Compatibility (EMI/EMC) testing has not been performed on this aircraft. Flights in areas where EMI density is high pose a significant threat to safe operations. EMI interference may affect the behavior of the entire system and the operator is advised to be vigilant to recognize anomalies that were not present in prior operational areas of low density EMI. Operators should make every effort to identify and mitigate sources of potential EMI prior to operations and plan flight paths accordingly.

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Appendix B. Configuration and Installation Detail:

Approved configurations for the UAS are identified in the manual (see D.2).

FCDD-AMR 20 Oct 20
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Appendix C. Inspections, Maintenance, and Logbook Instructions:

1. In the event any operating limit or limits established by this release are exceeded, it is recommended that in addition to the normal entry in flight log all limits that were exceeded shall be entered/noted and appropriate inspections shall be performed prior to next flight.
2. A copy of this AWR shall be inserted in the logbook and the following entry shall be noted: "Operate within limitations and restrictions specified in the enclosed Airworthiness Release dated 20 Oct 20."

FCDD-AMR 20 Oct 20
SUBJECT: AWR for Operation of the Greensight Dreamer UAS (AWR 220881)

Appendix D. Reference List:

1. System Safety Management Plan for U.S. Army Corps of Engineers, Aviation and Remote Systems Program, Jul 19.
2. Greensight Dreamer User Manual, Version 7-2020.
3. Memorandum, 9 May 19, subject: Memorandum of Understanding between the Department of Defense and Federal Aviation Administration for Unmanned Aircraft System Operations in the National Airspace System.
4. U.S. Army Corps of Engineers Small Unmanned Aerial Systems (SUAS) Policies and Procedures, Aviation Policy Memo 19-08, Aug 19.

Abbreviations

a/m	Autonomous/manual
AARISS	Aerial Automated Runway Inspection and Safety Scanner
AES	Advanced encryption standard
AI	Artificial intelligence
AQL	Airworthiness Qualification Level
ARA	Active restricted airspace
ARIBO	Applied robotics for installations and base operations
ASA (IE&E)	Assistant Secretary of the Army for Installations Energy and Environment
ATAK	Android Team Awareness Kit
ATO	Authority to operate
AV	Autonomous vehicle (or Automated Vehicle as defined by USDOT AV 4.0 guidance)
AWR	Airworthiness release
BAAF	Butts Army Airfield
BOM	Bill of materials
C2	Command and Control
CAV	Connected and autonomous vehicle (or Connected and automated vehicle)
CBRS	Citizen's Band Radio System
CERL	Construction Engineering Research Laboratory
CNN	Convolutional Neural Network
COP	Common operating picture
COTS	Commercial-off-the-shelf
DPW	Department of Public Works
ERDC	Engineer Research and Development Center
EV	Electric vehicle
FOD	Foreign object debris
GCS	Ground control

GEM	Global Electric Motorcars
GIS	Graphical interface system
HDA	Histogram deviation analysis
HQ	Headquarters
IPR	In-progress review
JBMHH	Joint Base Myer-Henderson Hall
KFIT	Fitchburg Municipal Airport
KGDM	Gardner Municipal Airport
LM	Local Motors
LOE	Line of effort
LTE	Long-term evolution
MDO	Multi domain operations
MP	Military police
NDAA	National Defense Authorization Act
ODD	Operational design domain
PCAP	Packet capture
RF	Radio frequency
ROS	Robot operating system
RTB	Return to base
SSA	Strategic support areas
SUAS	Small unmanned aircraft system
TONY	To Navigate You
UAS	Unmanned aerial system
UAV	Unmanned aerial vehicle
UI	User interface
UPN	Unite Private Network
USACE	United States Army Corps of Engineers
USDOT	United States Department of Transportation
VTIME	Virtual testbed for installation mission effectiveness
XRAN	Extensible Radio Access Network

REPORT DOCUMENTATION PAGE				<i>Form Approved</i> OMB No. 0704-0188	
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13. SUPPLEMENTARY NOTES					
14. ABSTRACT In this work, a smart transportation testbed was utilized at Fort Carson to demonstrate three use cases for the primary purpose to plan, develop, demonstrate, and employ autonomous vehicle technologies at military installations and within the surrounding communities to evaluate commercially available Connected and Automated Vehicles and the potential to reduce base operating costs, improve safety and quality of life for military service members and their families, and deliver services more efficiently and effectively. To meet this purpose, an automated vehicle shuttle, an unmanned aerial system, and a wireless network were used and tested during the project. Results for the automated shuttle indicated that despite the quantity of data generated by operations, the contractors may not be ready to share information in a readily usable format. Additionally, successful use by the public is predicated on both knowing their mobility patterns and staff members promoting trust in the technology to prospective riders. Results for the unmanned aerial system showed successful identification of foreign object debris and runway cracks at the airfield. The wireless network is now operational and is used for additional work which utilizes the installed traffic cameras.					
15. SUBJECT TERMS Automated shuttle, Service vehicle, Drone, Wireless network, Testbed					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT SAR	18. NUMBER OF PAGES 123	19a. NAME OF RESPONSIBLE PERSON Lance Larkin
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