Autonomous Military Transportation: Fort Benning

1. Project Narrative and Technical Approach

1a. Introduction

Cover Letter

COLUMBUS STATE UNIVERSITY

Office of the Provost and Executive Vice President

March 17, 2019

To Whom It May Concern:

I am very pleased to submit the Automated Driving Systems grant application from Columbus State University. This proposed collaborative project with Fort Benning and Voyage Auto is an outstanding example of the kind of collaborative, community-focused, innovative demonstration project envisioned in CSU's mission and values of innovation and creativity. Our university brings many assets to this collaboration and can provide the expertise and research analysis component to complement the technology and strategic implementation of all of the partners. Efforts aimed at improving the accessibility and safety of transportation to the Fort Benning military personnel and their families and ultimately our surrounding communities are a logical next step given the history and goals of Columbus State University, Fort Benning, and Voyage Auto.

CSU is committed to designing, implementing, analyzing and assessing effective demonstrations of ADV routes in conjunction with Voyage Auto and Fort Benning. The goal of this demonstration project will enhance access to efficient transportation options for active military, veterans, and their families. This grant proposal and the data generated from the demonstration trials will greatly improve the ability of the residents of Fort Benning to access medical facilities, grocery shopping, educational opportunities, and other needed facilities on base. In addition, Fort Benning residents will be able to work and to live more successfully without worrying about having to use limited personal resources for the purchase of vehicles or other transportation sources.

The data collected and analyzed through this demonstration project will also inform the greater Columbus region as we look for additional ways to provide access to families with limited resources, senior citizens and individuals with disabilities. We will also have an opportunity to prepare researchers of the future through the extensive involvement of graduate assistants in the project.

Our strong and extensive experiences in partnering with Fort Benning and serving the needs of the city of Columbus and surrounding region can support these demonstrations and subsequent implementation of ADV systems at Fort Benning and beyond in the Columbus region. We recognize the importance and need for affordable and safe transportation for all community members, but in particular those who may be challenged by limited resources, limited mobility, and limited options. This project will not only inform how to address these issues in the community but will also assist us in updating and keeping relevant the curriculum and educational preparation of students at Columbus State University.

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University System of Georgia

Office of the Provost and Executive Vice President

As the Principal Investigator and collaborator with Fort Benning and Voyage Auto, the commitment of time, effort, and needed resources proposed for all the parties are reasonable given the planned budget of the grant and existing resources of each of the collaborating entities. The administration of Columbus State University is committed to expanding research and outreach of these ADV transportation options for all of the communities we serve. This proposed Autonomous Driving Vehicle System Project is a worthy effort that has the wholehearted support of CSU's administration.

Respectfully yours,

Deborah E. Bordelon

Deborah E. Bordelon, Ph.D.
Provost and Executive Vice President
Columbus State University

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Summary Table

Project Name/Title	Autonomous Military Transportation: Fort Benning
Eligible Entity Applying to Receive Federal Funding (Prime Applicant's Legal Name and Address)	Columbus State University 4225 University Avenue Columbus, GA 31907-5645
Point of Contact (Name/Title; Email; Phone Number)	Deborah E. Bordelon, Ph.D. Provost and Executive Vice President Columbus State University bordelon_deborah@columbusstate.edu (706) 507-8942
Proposed Location (State(s) and Municipalities) for the Demonstration	Fort Benning, Georgia
Proposed Technologies for the Demonstration (briefly list)	ADS L3/L4 Taxi Service, Smart Camera Systems, HD Mapping
Proposed duration of the Demonstration (period of performance)	3 Years
Federal Funding Amount Requested	$9.91M
Non-Federal Cost Share Amount Proposed, if applicable	$2.21M
Total Project Cost (Federal Share + Non-Federal Cost Share, if applicable)	$12.12M

Table of Contents

Listing of Tables & Figures

1. Executive Summary

1a. Vision, Goals, and Objectives

Vision

In collaboration with US Army Base Fort Benning, Voyage's Open Autonomous Safety (OAS) program, and other partners, Columbus State University (CSU) has a vision to demonstrate and evaluate a safe and effective Automated Driving System (ADS) taxi service, intended to decrease the cost of both personal and fleet vehicle use and increase access to mobility for disadvantaged personnel. In keeping with this vision, CSU will study the effectiveness of reducing the Department of Defense's motorpool vehicle fleet by replacing low-utilization General Services Administration vehicles and reliance on personally-owned vehicles with fewer, highly utilized Voyage ADS taxis.

Goals

CSU and its partners will utilize the expanding robotics expertise at the university and within industry in the Columbus area to further develop and refine the Open Autonomous Safety program (addressing **NOFO Section 2: Goals, Subsection C: Collaboration**), generating a comprehensive set of scenarios, functional safety development paradigms, and assessment metrics that are automatically evaluated using real autonomous vehicles serving passengers at Fort Benning (addressing **NOFO Section 2: Goals, Subsection A: Safety**). While an 'alpha' version of OAS has already been released by Voyage, this grant program will ensure that CSU is able to develop OAS to the point that it can be used as a basis for ADS public policy, in conjunction with the USDOT. Throughout this proposed demonstration program, CSU and its partners will be sharing data and working directly with the U.S. Department of Transportation (USDOT) to ensure that OAS functions as a comprehensive evaluation system of the performance of an ADS vehicle deployment (addressing **NOFO Section 2: Goals, Subsection B: Data for Safety Analysis and Rulemaking**).

Objectives

Within the stated timeline of the proposed program schedule of 36 months, CSU will work with these partners to (1) deploy a safe, effective and accurate Voyage ADS taxi service at Fort Benning, (2) develop a comprehensive evaluation framework that can quantify the performance and public readiness level of an ADS platform, and (3) evaluate how ADS integration can benefit from advanced smart camera systems. The ADS taxi service will be a door-to-door service, enabling soldiers, families, civilian contractors, hospital patients, retirees, and base visitors to travel throughout Fort Benning without use of their personal vehicles.

Objective (1) will utilize the Voyage second-generation ADS, a Plug-In Hybrid Chrysler Pacifica Minivan, and will address USDOT NOFO Work Areas A (**Technologies associated with ADS**), C (**Innovative mobility solutions that involve deployment of automated vehicles**), D (**ADS that**

enhance safety and mobility for older adults and travelers with disabilities), and E (**Demonstration of shared interoperable fleet of automated vehicles**).

Objective (2) will build on top of the open-source Open Autonomous Safety project, and will address Work Area F (**Demonstration and validation of exchanges of data that can support and potentially accelerate the safe, efficient, and secure interoperable integration of ADS**). Objective (3) pairs Voyage vehicles with advanced smart camera hardware and software systems, and will address Work Area B (**Advanced communication systems supporting safety and/or mobility**).

1b. Key Partners, Stakeholders, Team Members, and Others

1. Columbus State University: Deborah Bordelon, Ph.D., Provost and Executive VP
2. Fort Benning: Charles Auer, Plans Analysis and Integration Office
3. Voyage: MacCallister Higgins, Co-Founder and Director of Growth
4. Smart Camera Systems: Francesco Borrelli, Ph.D

1c. Challenges, Technology, and Performance

Issues and Challenges

The first issue being addressed by this proposal is the lack of adequate transportation options currently available within military bases. As Fort Benning acts as a critical training facility for the US Army, it houses large groups of soldiers and international students on temporary duty assignment with no reliable access to personal transportation. Due to the secure nature of a US Army base, there is a unique lack of access to the ridesharing or public transportation options that are present outside the gates. The interior of the base shares many similarities with a city -- servicing offices, restaurants, recreational activities, hotels, schools, and, critically, even a hospital. Of primary concern to CSU is to safely address and study these transportation needs of soldiers, their families, civilian contractors, hospital patients, and retired veterans within Fort Benning with an ADS taxi service, a challenge that will require close collaboration and a tight feedback loop between all involved parties due to the complexity of data and physical security at military facilities.

In order to safely deploy automated driving systems at Fort Benning and other similar geofenced locations, there must be a system for comprehensive testing and approval of the technology, which currently does not exist. CSU intends to address this second issue by adopting and improving the Open Autonomous Safety program published by Voyage (the current version is viewable at http://oas.voyage.auto), creating a public, open evaluation framework that is able to adequately determine if an ADS is able to be safely integrated into the nation's on-road transportation system, a challenge specifically identified within the USDOT ADS NOFO (Work Area F).

The third issue being addressed by this proposal is the number of driver interventions per mile (IPM) that occur in an ADS, which still remains higher than what is required for seamless L4 systems. This is in large part due to lack of prediction and coordination of other road agents in situations with limited sensing capabilities, such as unprotected left turns. The proposal will address this major issue by utilizing advanced smart camera systems, which will allow real-time sharing of status and motion predictions between road users, quantified and shared using real road data.

Secondary to these three issues is the study of the potential to reduce the size and cost of the motor pool fleet of the Department of Defense, as well as understand the alleviation of parking resources that are stretched with the nearly 40,000 vehicles that travel on Fort Benning every day. On a tertiary level, CSU will also explore ways to integrate the data generated every day by these vehicles into the Operational Command Center of Fort Benning.

Technologies to be Demonstrated

- Voyage Autonomous Taxis (Hybrid Chrysler Pacifica Minivans)
  - Perception: LIDAR and Cameras
  - Localization: Real-Time Kinematic GPS, Inertial Measurement Unit, Wheel Odometry, and HD Maps
  - Control: Renovo Drive-by-Wire and Safety-First Architecture
  - Interface: Smartphone App for Dispatch and In-Vehicle Touchscreen
  - Smart Camera Systems: Shared actor models and coordinated maneuvers

Anticipated Quantifiable Performance Improvements

1. Achieve a number of weekly active users that exceeds 10% of the accessible user base.
2. Automated analysis of effectiveness of developed OAS scenarios (100% of all Fort Benning applicable scenarios passing) and assessments.
3. Utilization rate improvement, per vehicle, over existing GSA vehicles (7%) at Fort Benning.
4. Reduce safety driver interventions in covered zones by 50% using smart camera systems.

1d. Geographic Area

This demonstration will occur at the Main Post of the US Army installation Fort Benning, located right outside Columbus, Georgia. Fort Benning is the home of the United States Army Maneuver Center of Excellence, the United States Army Armor School, United States Army Infantry School, the 75th Ranger Regiment of the United States Army Special Operations Command, the Western Hemisphere Institute for Security Cooperation, and many other additional tenant units [1]. Fort Benning is also home to 4,000 family homes, a nearly 900 room hotel facility, a 750,000 SF community hospital, 5 elementary schools, and 1 middle school.

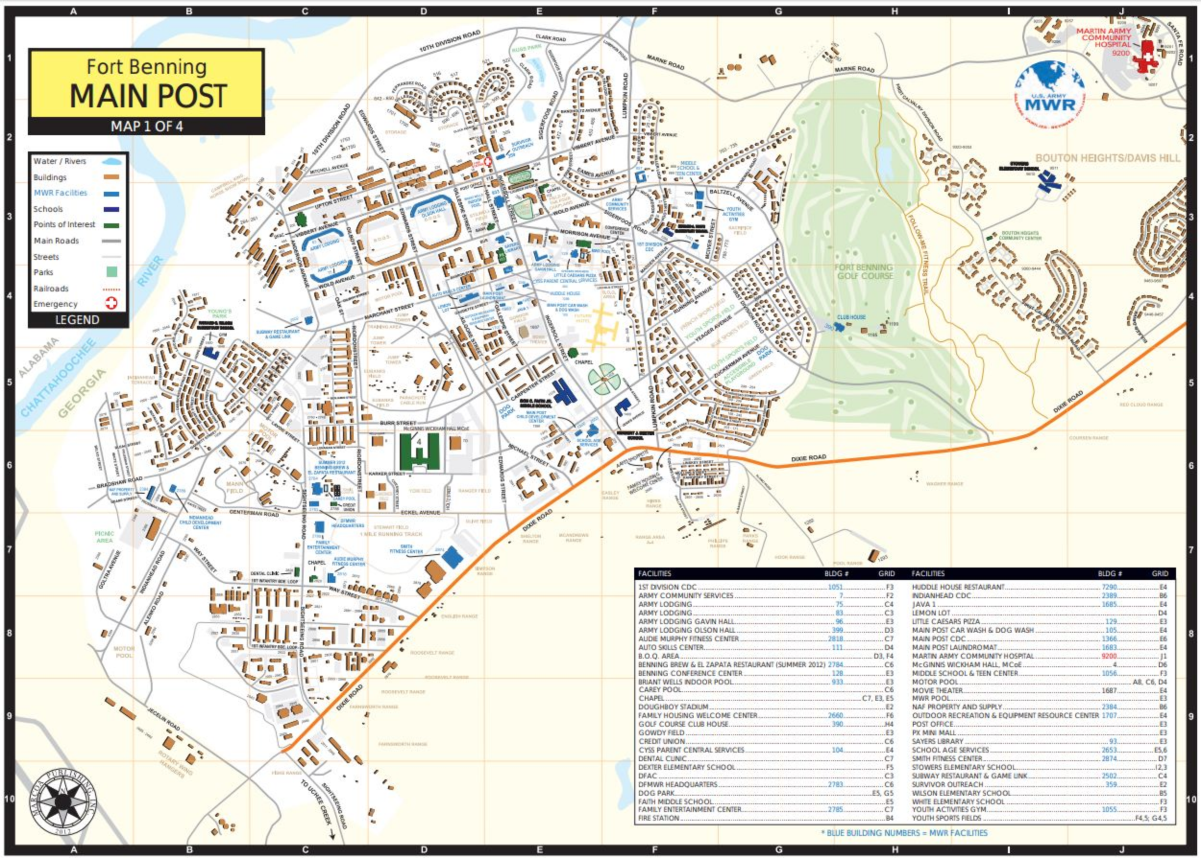


Fig. 1: Map of Fort Benning Main Post [Retrieved from 2]

1e. Proposed Period of Performance

Over a 3 year period and multiple phases, CSU will study (and share) the operational data from an active Voyage autonomous taxi service that addresses transportation challenges felt by active military personnel, their families, and civilian base employees. This will entail the deployment of autonomous vehicles and smart camera systems on a US military base to evaluate their effectiveness at addressing transportation challenges.

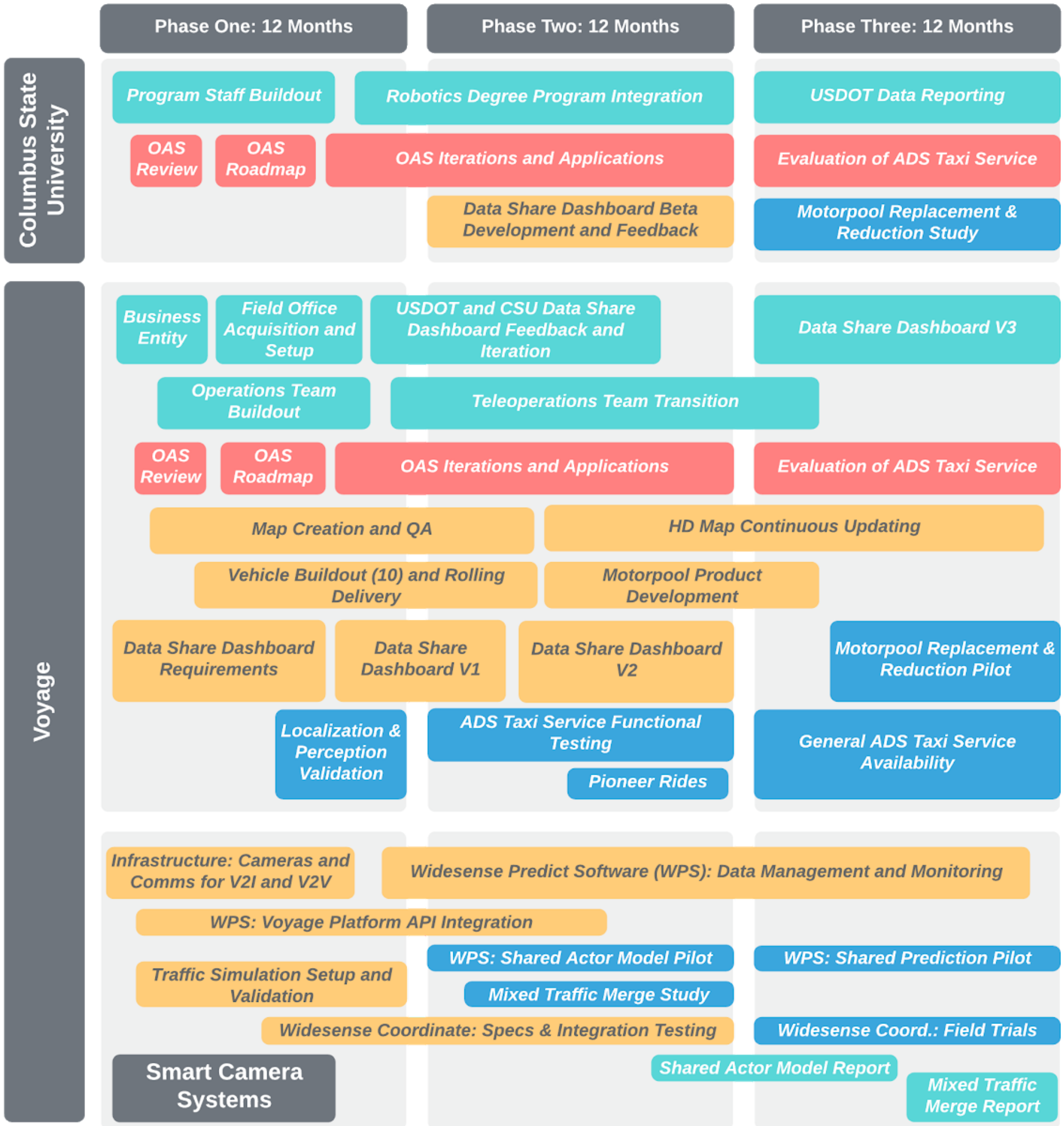
Phase 1: 12 months with a focus on mapping and infrastructure install

Phase 2: 12 months with a focus on OAS development, testing, and validation

Phase 3: 12 months with a focus on general availability & evaluation of the ADS Taxi Service

ADS at Fort Benning Schedule

Columbus State University - USDOT ADS NOFO



2. Goals

The main research outcome posed by this proposal and Columbus State University is the creation of a public, open evaluation framework that can be utilized to prove that an ADS taxi service is operating safely. In order for ADS to be integrated into the on-road transportation system of the US, it is necessary to understand, quantitatively, how well these systems perform in a variety of traffic scenarios. Columbus State University aims to utilize our Robotics Department to build on top of Voyage's existing Open Autonomous Safety program in order to accomplish this goal.

2a. Safety

Voyage has invested significant time and effort in being transparent in their approach to safety, most notably in their release of the Open Autonomous Safety (OAS) program: a fully open-source library of Voyage's internal safety procedures, materials, and test code designed to supplement existing safety programs at autonomous vehicle companies. The following sections will describe the current alpha release of OAS, which is the base program CSU will be using to build the comprehensive performance evaluation framework through this grant.

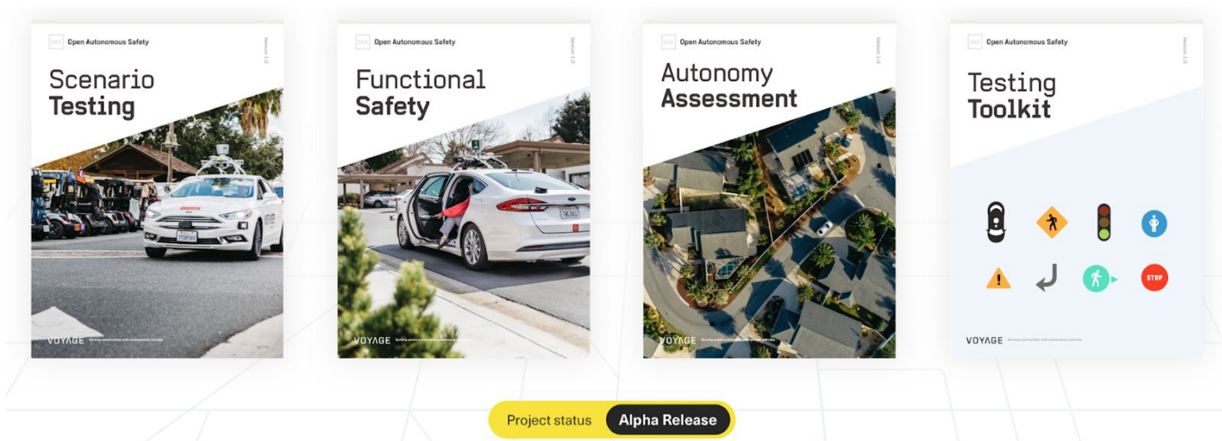


Fig. 2: Voyage's Open Autonomous Safety Program Areas

Voyage designs their technology with the fundamental principle that AVs will soon be operating in a truly driverless world, and that safety is of even greater importance when there is no human behind the wheel. In this scenario, comprehensive safety frameworks like OAS become essential. Currently, OAS focuses on five key areas:

1. **Scenario Testing**
2. **Functional Safety**
3. **Fault Injection Testing**
4. **Autonomy Assessment**
5. **Testing Toolkit**

Scenario Testing

OAS currently contains an extensive list of custom-built scenarios, designed to evaluate the real-world capabilities of autonomous technology. These scenarios are designed for suburban environments, but are flexible and able to integrate high-speed, urban, and other unique surroundings.

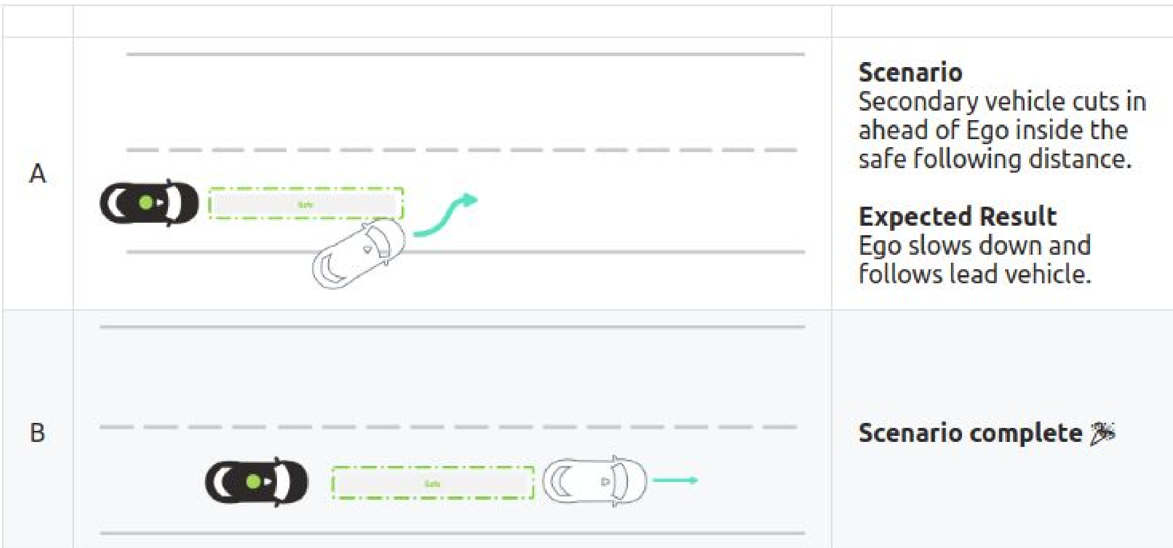


Fig. 3: An Example of One of the Many Scenarios Detailed in OAS

These scenarios represent fundamental questions: How should an autonomous vehicle behave when it reaches a crosswalk and a pedestrian approaches from the right? Or when another car is backing out of a driveway? These scenarios, and many more, provide a rubric for assessing the practical capabilities of an autonomous vehicle while on the road. The scenarios also introduce a qualitative dimension to the safety program, not just asking if an ADS can complete a scenario, but also how well it performs.

Functional Safety

Columbus State University intends to continue to develop the functional safety standards in autonomous vehicles, as well as answering whether or not these standards are being met to ensure the safety of passengers and the general public in this deployment.

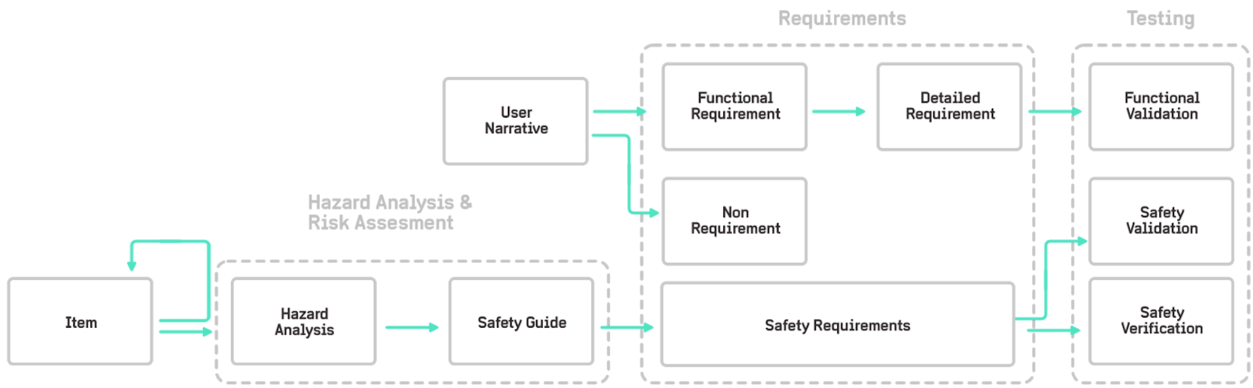


Fig. 4: Flowchart of OAS Requirements Framework

Without a driver to help identify and mitigate failures, ADS need incredibly robust safety requirements and an equally comprehensive and well-defined process for analyzing risks and assessing capabilities. Voyage models its safety approach after the ISO 26262 standard for automotive safety, taking the best practices from the automotive industry and applying them to autonomous technology.

Currently, the Functional Safety section of OAS contains two process definitions: the Safety Requirements and Functional Requirements Flows. Beyond the functional safety standards of traditional production vehicles, the goal of the safety requirements flow is to provide validation coverage and risk mitigation.

The Safety Requirements flow consists of the following steps:

1. Items of the autonomous system are identified and defined. Vehicle functions are broken down and defined as individual items so that they are better understood and isolated.
2. Hazard analysis and risk assessment is performed for each item. Safety ratings are assigned to each hazard and safety goals are determined. The Hazard and Risk Assessment (HARA) considers all potential hazards, and assigns an ASIL rating dependent on Exposure, Severity, and Controllability.
3. To ensure Safety Goals are met, safety requirements are generated that define the Technical Architecture.
4. Verification is performed on safety requirements. Test Cases are created and linked to requirements to validate all design assumptions and implementation tasks.
5. Validation plans are executed and results reported to ensure all Safety Goals and Safety Requirements are passed successfully.

The goal with the Functional Requirements flow is to define what the car should do in various scenarios, and consists of the following:

1. User Narratives are detailed.
2. High level Functional Requirements and Non-Requirements are defined to determine the scope of the functionality of the autonomous vehicle (the Operational Design Domain), and answer the question of “What” the vehicle does. Depending on the environmental needs and determined operational domain, some deployments may require different requirements.
3. Detailed Performance and Quality Requirements are created from the Functional Requirements, which are more granular and testable. These requirements shape the Architecture of the vehicle, at both the system and component level, and answer the questions of “How” the vehicle should perform.

Fault Injection Testing

Evaluating an ADS’ ability to respond to rare system errors is difficult, especially if those errors only happen once every ten thousand miles. Voyage’s fault injection tools enable their developers and Columbus State researchers to programmatically trigger failures in both the hardware and software of critical autonomy components. This allows for the evaluation of an ADS system and its ability to handle a sensor unit that starts malfunctioning after thousands of hours of usage or system damage. Fault Injection Testing enables users to understand the response of a given ADS, design redundancies to handle such cases gracefully, and allow for the validation of:

- Ability to detect a failure
- Proper system and sensor processing and prioritization
- Correct degradation of features or vehicle functions during a fault
- Fail-Safe execution
- End-to-End latency benchmarking and monitoring
- Validation of proper acceptance criteria to pass functional scenarios

Autonomy Assessment

Autonomous technologies often result in incredibly complex systems, involving computers, sensors, custom hardware, and software. One modification can simultaneously impact a host of critical components, which makes it difficult to quantitatively measure the progress of development.

Miles Per System Fault Intervention (MPFI)

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MPFI = (Total Autonomous Miles) / (Total System Fault Interventions)
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Fig. 5: One of the metrics used within the Autonomy Assessment

The Autonomy Assessment section of OAS consists of documentation on how Voyage validates ADS performance. By collecting, processing, and evaluating operational data every single day, these consistent, well-formed metrics can be used to objectively track progress across an ever-evolving system. This program will build on these existing metrics, to study and understand what measurable analysis actually accurately represents ADS performance.

Testing Toolkit

Communicating an idea for a complex test scenario can be difficult. The OAS Testing Toolkit looks to simplify this process with an open-source Sketch library of traffic, roadway and vehicle assets.

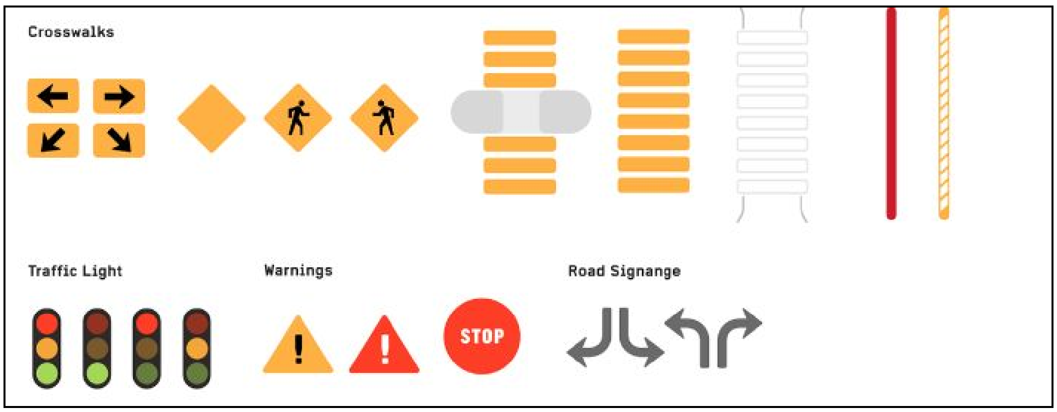

Fig. 6: Subset of OAS Testing Toolkit Assets

Speaking a consistent language across the OAS scenario library has enabled faster iteration, improved test coverage, and higher repeatability in operations testing practices and scenario definition, and Columbus State University intends to utilize these existing assets to continue to move forward in the development of this safety framework.

2b. Data for Safety Analysis and Rulemaking

Voyage will expose a web-based interface to the USDOT that acts as a data sharing portal. In much the same way that simulation testing is used to perform continuous integration testing at the software level, this dashboard will monitor the actual, real-life performance of Voyage vehicles operating within Fort Benning. This system will monitor for the occurrence of OAS functional testing scenarios (developed by Columbus State University in partnership with Voyage and the USDOT), either from natural traffic interactions or contrived testing, and immediately evaluate the performance of the ADS with pass/fail metrics.

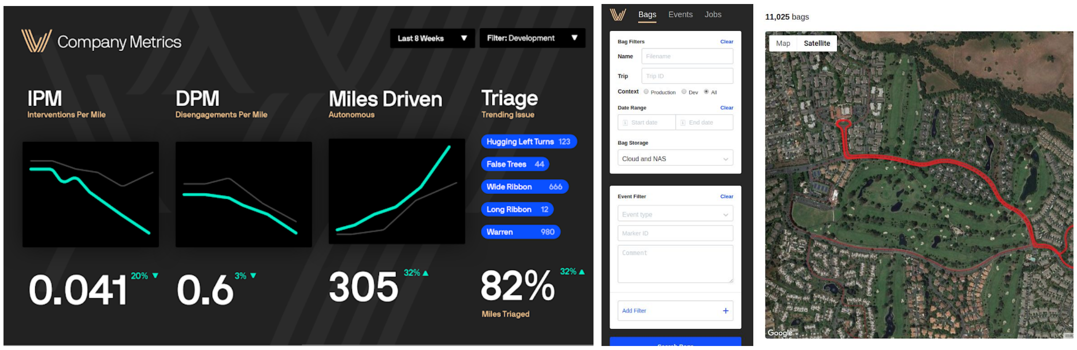

Fig. 7: Existing Internal Voyage Data Dashboards

Additionally, all OAS framework improvements will be made completely public on the OAS website and repository (located at http://oas.voyage.auto) under its current open-source MIT License, allowing all interested parties to review, improve, repurpose, and expand.

2c. Collaboration

Engineering and robotics have been areas of growth for Columbus State University (CSU) over the past several years. In 2011, CSU added both an Associate of Science in Engineering Studies and a 21 credit-hour Robotics Certificate program. Robotics engineering was quickly identified as the discipline in greatest need of rapid workforce development, creating an opportunity for CSU to respond to the needs of our region’s largest employers.

Currently, Columbus State University is in the process of creating new bachelor and masters level Robotics degree programs, which will function in cooperation of this grant to involve students and faculty in the expansion of the OAS ADS evaluation framework. This effort is consistent with the CSU’s new strategic plan, allowing Columbus State to immediately address an area of need of great local importance, while also producing a degree program that will allow students to pursue careers in a field with rapidly growing nationwide demand.

Columbus State University is uniquely poised to provide opportunities for students to prepare for engineering careers, particularly in the specialty area of robotics engineering. CSU faculty, students and staff already are engaged in numerous academic and research efforts in engineering and robotics. The Department of Earth and Space Sciences (ESS) in the College of Letters and Sciences at Columbus State University currently houses faculty with expertise in electrical engineering (Dr. Abiye Seifu) and robotics (Dr. Lavi Zamstein). These faculty serve students in the Associate of Science in Engineering Studies program, Regents Engineering Pathways Program (REPP), and the Robotics Certificate. Additionally, ESS faculty with expertise in astronomy and physics work collaboratively with staff at the Coca-Cola Space Science Center through student-centered research efforts and formal outreach programs focused on robotics.

Recently, Columbus State University has been approached by community partners who have expressed the need to create a more technically trained workforce of home-grown engineers and technicians. Specifically, leadership with the US Army at Fort Benning (the region's greatest economic engine) has made specific requests for CSU to train an engineering workforce capable of sustaining an ecosystem of leadership in the field of robotics [3]. When the Army's Maneuver Center of Excellence relocated to Fort Benning, it brought with it the US military's leading programs in ground-based robotics and unmanned systems. It is the vision of Army leadership that military subcontractors will relocate both research and development and fabrication infrastructure to Fort Benning, where the Army is training and utilizing these technologies in the field, reinforcing the decision to partner with Voyage to bring ADS technology to the Columbus area. This influx of high-tech industry will be a great benefit for the entire state, but it cannot occur without Columbus State playing an active role in the development of the needed technological workforce, which this grant would directly support.

Critical to this proposal, and at the directive of the U.S. Army, Fort Benning – located immediately south of Columbus State University – will significantly expand research and development of military robotics, as well as the next-generation combat vehicle, over the next decade. Supporting more than 120,000 military, civilian, retiree and reserve personnel, Fort Benning has an economic impact of more than $4.75 billion annually on the region. In an October 12th, 2017 speech to the Columbus community, Major General Eric J. Wesley directly tasked Columbus business, civic, political, and academic leaders to take an active, collaborative role in the development of these technologies – both of which rely heavily on the engineering workforce – with a specific challenge to Columbus State University to become an integral part of Ft. Benning's robotics efforts [3].

The introduction of an active ADS program on base, combined with academic support and study from CSU, directly addresses this request. With more than $2.9 million to be invested in the Fort Benning Maneuver Center of Excellence – primarily focused on robotics research and development – Columbus State University has an excellent opportunity to become, in General Wesley's words, part of the "next Silicon Valley of robotics". In addition, as Fort Benning operates its own utilities, road networks, and emergency personnel services, the ability for all parties to interface directly and quickly in the deployment of ADS technology significantly decreases the complexity and logistics of this effort.

In private industry, CSU has found several partners that are willing to work towards this goal of reinforcing robotics excellence in the Columbus area. Voyage, the autonomous taxi company originally responsible for launching the Open Autonomous Systems program, is extremely motivated to collaborate on the study of ADS safety. Voyage has experience in introducing the concept of self-driving vehicles to communities across the country, as they regularly host public engagement events, and work directly with the appropriate community boards, agencies, and law enforcement bodies to ensure a smooth integration of their vehicles. As part of the public outreach efforts of this grant, Voyage will also be sharing OAS improvements with the municipalities of their existing deployments, and using the results of their collaboration with CSU as the basis for working with local and federal lawmakers and regulatory bodies to ensure the safe integration of ADS in the nation's transportation system. With their participation in this grant proposal, Voyage has also brought on several technical partners to ensure project success, and all are aligned and ready to bring their respective technology to the Columbus area.

By partnering with the aforementioned industries and community entities in consultation on the development of this new degree program and integration of the USDOT grant, we assure that graduates from the program will be well prepared to handle the rigors of this emerging area of technology, while helping define safety and performance metrics for ADS for the entire country. These partnerships will facilitate co-op and internship opportunities for our students, allowing them to receive vital hands-on experience in these industries.

3. Focus Areas

3a. Significant Public Benefits

Open Autonomous Safety

One of the main outcomes of the USDOT ADS grant is to “Test the safe integration of ADS into the Nation’s on-road transportation system.” In order to complete this goal, it becomes necessary to define success metrics, and what exactly defines “safe integration.” As previously stated, the purpose of the Open Autonomous Safety initiative from Voyage is to answer that question in a completely transparent and reproducible manner, exposing internal safety validation processes to the general public. In direct collaboration with CSU, USDOT, and the ADS deployment at Fort Benning, Voyage intends to continue to expand on this initiative to develop a comprehensive evaluation framework for these systems. ADS technology (and disparate services) should not compete on safety, and should all be held to a similar standard. With a unified and tested approach to ADS evaluation, the public will benefit significantly once these learnings are integrated into national and public policy.

Taxpayers, the Federal Government, and the Department of Defense

The biggest beneficiaries of ADS technology will be those with the largest vehicle fleets, especially those with fleets that have low daily utilization rates. At the top of this list is the US federal government, which owns and operates more than 600,000 vehicles [4], according to extensive research completed by Marine Corps Lieutenant Colonel Brandon Newell [5]. The Department of Defense is responsible for 175,000 of those, with an annual operating cost of $435 million [4]. These vehicles are not tanks or armored personnel carriers, they are cars, trucks and other vehicles designated as NTVs (non-tactical vehicles), and are utilized less than 7% of the time (less than 100 minutes a day, according to a study conducted by the Army at Fort Hood), spending the majority of their service life in a parking spot [6].

Fort Benning is no exception to these challenges, as they operate 1,425 NTVs at a staggering cost of $10,800,000 a year. As part of this grant, Fort Benning is looking to understand how many of their motor pool vehicles could be removed from their fleet, as the downtime of a vehicle sitting in a parking lot waiting for a user can be drastically cut. This leads to more efficient and resilient bases, a reduced environmental footprint, and an overall better deal for the US taxpayer.

3b. Addressing Market Failure and Other Compelling Public Needs

End-Users of the ADS Taxi Service

In order to fully understand requirements and expand on OAS, the system itself must be applied to an operational ADS deployment with real users. As mentioned previously, Fort Benning supports more than 120,000 military, civilian, retiree and reserve personnel. Without traditional ridesharing options and an expensive, restricted standard taxi service, individuals living and working on the base have extremely reduced options for travel, especially when considering families living on base that only own or lease a single vehicle.

Fort Benning itself also supports a large transient population across several demographics, most without access to temporary personal transportation. Every year, nearly 15,000 soldiers travel to the base from across the country to attend United States Army Airborne School for several consecutive weeks without authorization to bring a vehicle, and over 3,400 soldiers each year attend the Henry Caro Noncommissioned Officer Academy. On top of the initial student population, graduations occur every few weeks that regularly bring in friends and family members of the participating soldiers.

Aside from US Military personnel, Fort Benning hosts several international programs (Western Hemisphere Institute for Security Cooperation and the International Military Student program) that house around 2,000 foreign nationals on base a year, with their only transportation option being a bicycle on loan from the base. As they are unable to drive or procure a vehicle, this population is particularly suited to benefit from an ADS taxi system. Focusing on these transient populations alone would allow CSU and Voyage to reasonably support all of the grant's service adoption goal of 10% of Fort Benning's population, demonstrating compelling need for such a service.

More broadly, vehicle ownership itself is a burden on young enlisted soldiers, as costs average nearly $9k a year [7]. This cost becomes untenable with active duty enlisted soldiers in the Army making between $20k - $40k, especially combined with the inefficiencies of personal vehicle ownership [8]. However, since military personnel are not required to pay for housing, and since existing transportation options on base are inconvenient, young enlisted soldiers are regularly incentivized to make such purchases (sometimes with the use of predatory loans aimed specifically at service members). Direct, door-to-door ADS taxi services can directly address and reduce this incentive to purchase a vehicle by providing a convenient option for on-base transportation.

In addition, the Department of Defense is exploring ways to mitigate the safety risks associated with traditional vehicle ownership. Pulling again from research completed by Marine Corps Lieutenant Colonel Brandon Newell, the US military suffered 1,923 automobile fatalities and

806 motorcycle fatalities between 2000 and 2009 [9]. Of these fatalities, many involved alcohol, lack of seat belt usage, speeding, and other identified high-risk behaviors more prevalent in this demographic.

3c. Economic Vitality

Columbus State University is committed to reinforcing the development of the local engineering and robotics economy, as discussed in Section 2c (Collaboration) of this proposal. More broadly, proposal partners Voyage, Carmera, Renovo, Velodyne, and AV Connect are all US corporations, looking to solve transportation challenges at Fort Benning, a US military base that supports more than 120,000 active-duty military, family members, reserve component soldiers, retirees, and civilian employees on a daily basis.

3d. Complexity of Technology

Voyage currently operates an autonomous taxi service in two US locations (San Jose, CA and The Villages, FL), with the intention of transitioning to SAE L4 within the timeline of this grant. Voyage will be replicating these existing service platforms at Fort Benning in support of the grant objectives.

3e. Diversity of Projects

Through this proposal, we are looking to gather data on personal mobility, and public transportation. Fort Benning is unique in its composition, as it covers suburban housing communities, pseudo-urban office complexes, and remote, rural duty stations. Fort Benning has many restaurants, commercial stores, schools, recreation centers, and even a campground for families living on base.

3f. Transportation-Challenged Populations and Accessibility

The nature of the demographic of retirement communities (Voyage's current operating domain) has necessitated a focus on developing accessible technology. Their second generation vehicle was chosen largely for ease of access for those with mobility challenges or physical disabilities, with their very first passenger being a blind individual who was able to summon a Voyage ADS on her smartphone using vision-impairment features. Fort Benning is home to Martin Army Community Hospital, a 250 bed facility dedicated to serving both the base and local area, and is utilized by the same transportation-challenged demographics as Voyage's existing deployments.

Military bases have hospitals with disabled service members, as well as families with restricted transportation options. To address this population directly, CSU and Voyage will be including retired veterans as our first target demographic for our Pioneer pilot program, as the taxis themselves begin servicing passengers within the Main Post. Taxis, Uber, and Lyft are generally not allowed on base with current security protocols (unknown drivers going on and off base), so individuals needing to get to the base exchange (retail shopping) or the commissary (grocery store) are left with few options.

The complexity of serving military personnel and their families within a base comes from both the difficulty of a commercial service getting access to the base itself, along with the increased costs and complexity associated with data locality and security. Military bases remain underserved in the general transportation economy as it stands now, even before the added difficulty of AV technology is included. Additionally, military funding is generally tied to existing, traditionally under-utilized options such as circulator buses, creating a barrier to entry for new technology.

3g. Prototypes

Voyage as a company has built and deployed several driverless vehicles, and is currently working to enable L4 capability on their second-generation Chrysler Pacifica platform. These vehicles are already moving passengers autonomously in retirement communities, utilizing tools and services from our partners listed in this grant proposal.

4. Requirements

4a. ADS Technology Level

Voyage currently operates an autonomous taxi service in two US locations (San Jose, CA and The Villages, FL), with the intention of transitioning to SAE L4 within the timeline of this grant. Voyage will be replicating these existing service platforms at Fort Benning in support of the grant objectives.

4b. Physical Demonstration

As described in 4a, this demonstration will include an operating door-to-door taxi service within the geofenced bounds of Fort Benning.

4c. Data Sharing

Specific Data Shares:

- Incremental and final versions of OAS scenarios, assessments, functional safety analysis frameworks, testing toolkit assets, and all other resources developed from CSU in conjunction with Voyage and the USDOT
- Phase 3 results of the prior developed OAS resources applied to the Fort Benning ADS taxi service deployment. This includes performance of the Voyage vehicles in all listed scenarios relevant to the Fort Benning environment, a functional safety analysis breakdown of the operational service including Safety Verification, Safety Validation, and Functional Validation, as well as the application of other tests and assessments as applicable and developed by CSU and Voyage. This data will be made available through the web-based dashboard described in section 2b of this proposal.
- CSU and Voyage also intend to study the effectiveness of smart camera systems, sharing the following data:

- Unified total merged actor (road user) models (prediction of actor behavior) for the duration of the evaluation.
- Data and Analysis and on the effectiveness of shared models, including differential analysis of the ego-only view actor model to the merged model.
- Data and Analysis evaluating coordinated maneuver efficiency, including plan graphs for each coordinated maneuver.
- Data and Analysis of mixed traffic interaction effectiveness, including usage statistics on the number of emergency yield requests from mixed traffic.
- Data and Analysis on the percentage of time each vehicle is in reliable communication with both other vehicle actors, and with intersection prediction devices.

- All reported data will be made available for a minimum of 5 years after the award period of performance expires through the analysis dashboard.

4d. Accessibility: User Interfaces

In addition to the discussed general accessibility features of the ADS smartphone application, Voyage has spent considerable time and product iterations improving their in-car interface, allowing for a simplified selection of destinations to popular locations with the option of manual address input. The smartphone application itself has also been simplified, having evolved from the more traditional ridesharing style to the current “press and go” flow.

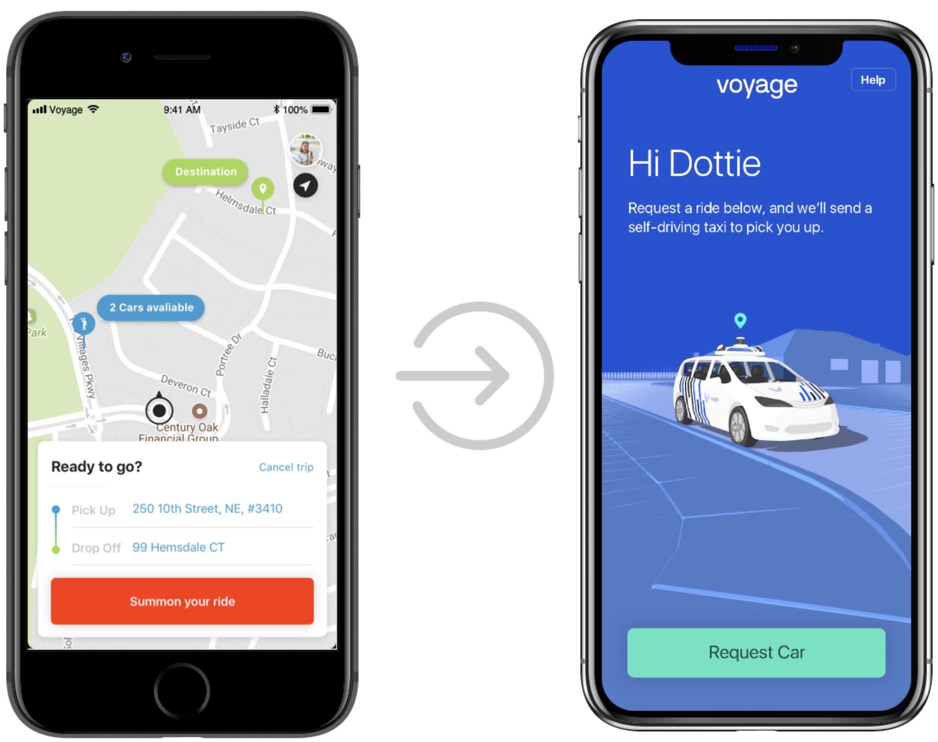

Fig. 8: Simplified user flow of the new Voyage ride hailing application

4e. Scalability

Voyage has approached the vehicle scaling problem by establishing a first-of-its-kind partnership with the leader in commercial fleet leasing and maintenance: Enterprise. This leverages decades of fleet management experience to procure, lease, and service the Voyage fleets, while allowing for retrofitting vehicles with self-driving hardware. When the lease term is up, Voyage is able to return the vehicle to Enterprise, and recycle any vehicle equity back into expanding the fleet.

In addition, all data from this demonstration project is intended to be shared with the Department of Defense, military bases, and federal installations across the country that share similar transportation and security challenges, through the same interface that will be provided to the USDOT (which also will be generally available to the public, advertised through the existing OAS website and code repository).

5. Approach

5a. Technical Approach

Operational Domain

Columbus State University and Voyage both feel strongly that the best first application of ADS is in communities that consist of simpler, slower environments. The operational environment is the single biggest factor in determining the development timeline of a self-driving car, and its corresponding evaluation framework. The environment dictates every key technical challenge, most importantly in terms of speed and complexity.

Within Fort Benning (as well as retirement communities, the current operational domain of Voyage ADS), traffic is often speed-limited to 25 MPH, and although there exists a variety of cars and pedestrians, it’s infinitely less chaotic than a typical city or suburb. The roadway itself is easier to navigate, thanks to simpler traffic patterns and incredible maintenance. Vehicles are able to operate for miles while avoiding complex lane merges, or even traffic lights.

Environmental Mapping

Currently, Carmera provides all mapping services for Voyage ADS systems. Their biggest deployment (The Villages in Florida) consists of 750 linear miles of highway, major arterial and residential roads, and is home to over 125,000 residents, three fully developed downtowns, and thirty-eight golf courses. Carmera also provides continuous updates of localization and navigation data for Voyage self-driving cars, which is critical when covering more road-miles than almost any urban center in the US. Carmera will be responsible for collecting and annotating the HD mapping data at Fort Benning during Phase 1 of this ADS project, and will continue to monitor and upgrade maps as required.

Vehicle Platform and Sensors

The Voyage G2 vehicle is based on the widely acclaimed Chrysler Pacifica Hybrid minivan, and features next-generation sensor technology from Velodyne, best-in-class safety systems, and Voyage's ADS software and technology.

Fig. 9: The Voyage G2 ADS Vehicle and a Resident Customer

LIDAR: Multi-Channel Velodyne Sensors

With 128 channels (or lines) of resolution and 300m of range, the Velodyne 128 is an exceptional sensor that enables the Voyage ADS algorithms to process a dense, 3D view of the world in 360 degrees at all times. The Velodyne VLS-128 produces more than 3x the number of points of any commercially-available ultra long-range LIDAR sensor, and is paired with 4 other lower-resolution lidars to cover blind spots around the perimeter of the vehicle.

Safety Systems

Voyage will continue to invest an immense amount of energy into safety systems. Some examples of the results of their safety first development platform include:

- Hardware-enforced limitations on speed and steering. The Voyage ADS stack is limited, via firmware, to a maximum speed.
- Extensive fault injection testing to test real edge cases.
- A deeply integrated diagnostics module that monitors our systems and vehicle for abnormalities and degradations, with the ability to trigger a safe stop on an independent system if necessary.
- Monitoring of computers and sensors for abnormalities in temperature and output.
- Heartbeat monitoring to ensure all systems are communicating properly.
- Redundancy in key hardware, software and algorithms.
- Redundant, server-grade computer, complete with air cooling and state-of-the-art processing power.

- Hardware-level vehicle state machines
- Real-time execution of safety-critical procedures
- System diagnostics and configurable fault handling
- Automatic, configurable telemetry, logging, and local storage
- A flexible, time-series query language for on-vehicle data (e.g. camera frames or telemetry events)

This platform also enables Voyage to intelligently off-load and store data when the vehicles return to base each night, ensuring that Columbus State University is able to capture and transmit the most important data from the day, without unnecessarily waiting to off-load terabytes of redundant data from each vehicle.

5b. Legal, Regulatory, and Environmental Approach

5bi. FMVSS and FMCSR

As we are not selling a vehicle to a consumer, we are not subject to the Federal Motor Vehicle Safety Standards. Additionally, we do not trigger any of the applicable criteria for being subject to the Federal Motor Carrier Safety Regulations, as our vehicles will only carry a maximum of four passengers.

5bii. Buy American

This grant proposal will not require an exception. The second-generation Voyage vehicle is a leased (not purchased) Chrysler Pacifica, as explained in section 4e.

5c. Data Commitment

Columbus State University is committed to work with all partners and the USDOT to share operational and safety data generated from and specified in this project proposal. In addition to just providing data, CSU is committed to participate in the evaluation of developed safety outcomes with the USDOT, and study particular measures of effectiveness in other arenas, such as mobility, as arises naturally throughout the course of this proposal.

5d. Risks

Many aspects of ADS technology are currently in heavy development across several industries, creating technical milestones that will be reached during the performance period of this grant proposal. Our goal is to fully understand and estimate the work needed to reach these technical challenges, in close collaboration with our partners, to present a clear understanding of inherent risk in any ADS deployment. The major technical challenges that we anticipate are listed below, together with the proposed approaches to mitigate the connected risks.

Military Data Security

Operating ADS on a military base comes with a complex set of data challenges. A significant aspect of this USDOT NOFO is the sharing of relevant data to inform the creation of standards and regulations, but there is a significant segment of sensor data that will be generated from Voyage vehicles and smart cameras that will not be able to leave the confines of the military installation due to security concerns. While the analytical value of raw LIDAR and camera imagery is minimal for the purposes of understanding and studying an ADS deployment, where operational and safety data is far more useful to all parties, a unique challenge is presented when training data cannot be removed from the facility for perception purposes. To mitigate this risk, Voyage is working directly with their partners to enable onsite data storage and processing for annotation and algorithm training, as well as exploring the use of federated learning techniques that maintain data privacy.

Military Base Deployment

Deploying Voyage vehicles and smart camera systems is critical to ensure program success. While these types of sensors and networks are currently providing similar functionality in use cases around the world, a military deployment presents unique challenges in interfacing with the Risk Management authoritative bodies. Voyage vehicles will need to be evaluated under the Department of Defense's (DoD) Risk Management Framework (RMF), and Voyage will need to secure an Authority to Operate (ATO) on the base. For this, we have identified an advisor regularly referred by the DoD to help setup contractors and move them through this process, as well as met several times with base stakeholders to preliminarily understand any potential blockers. As such, we are confident that this ADS technology aligns with the desires of Fort Benning to modernize transportation, connected vehicles, and wireless technology, paving the way for the base of the future.

Speed Increase to Handle 35 MPH Roadways

Currently, Voyage vehicles are restricted via software to 25 MPH. The Main Post at Fort Benning includes a few connector roads that have a speed limit that exceeds this restriction, potentially creating paths that their vehicles are initially unable to utilize. To mitigate the risk of not reaching certain users, Voyage has identified alternative routes that enable connecting these areas initially without traversing the high speed roadways, even if the route itself becomes slightly longer. Voyage's internal technical roadmap indicates that these speeds will be reached during the performance period of this proposal, and they will work with CSU and the OAS program to build upon existing functional testing for verifying vehicle performance at higher speeds. Additionally, other deployments have had their vehicles operate at lower speeds on these routes, which also remains an option while working closely with Fort Benning.

5e. Cost Share

Voyage and the proposal partners are committed to cost sharing, with specific values and percentages indicated in the Budget Detail section. Voyage will be contributing staffing costs for engineering and operations, the incurred cost for the middleware platform for their vehicles, and the annotation of the captured sensor data used to train their perception systems.

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