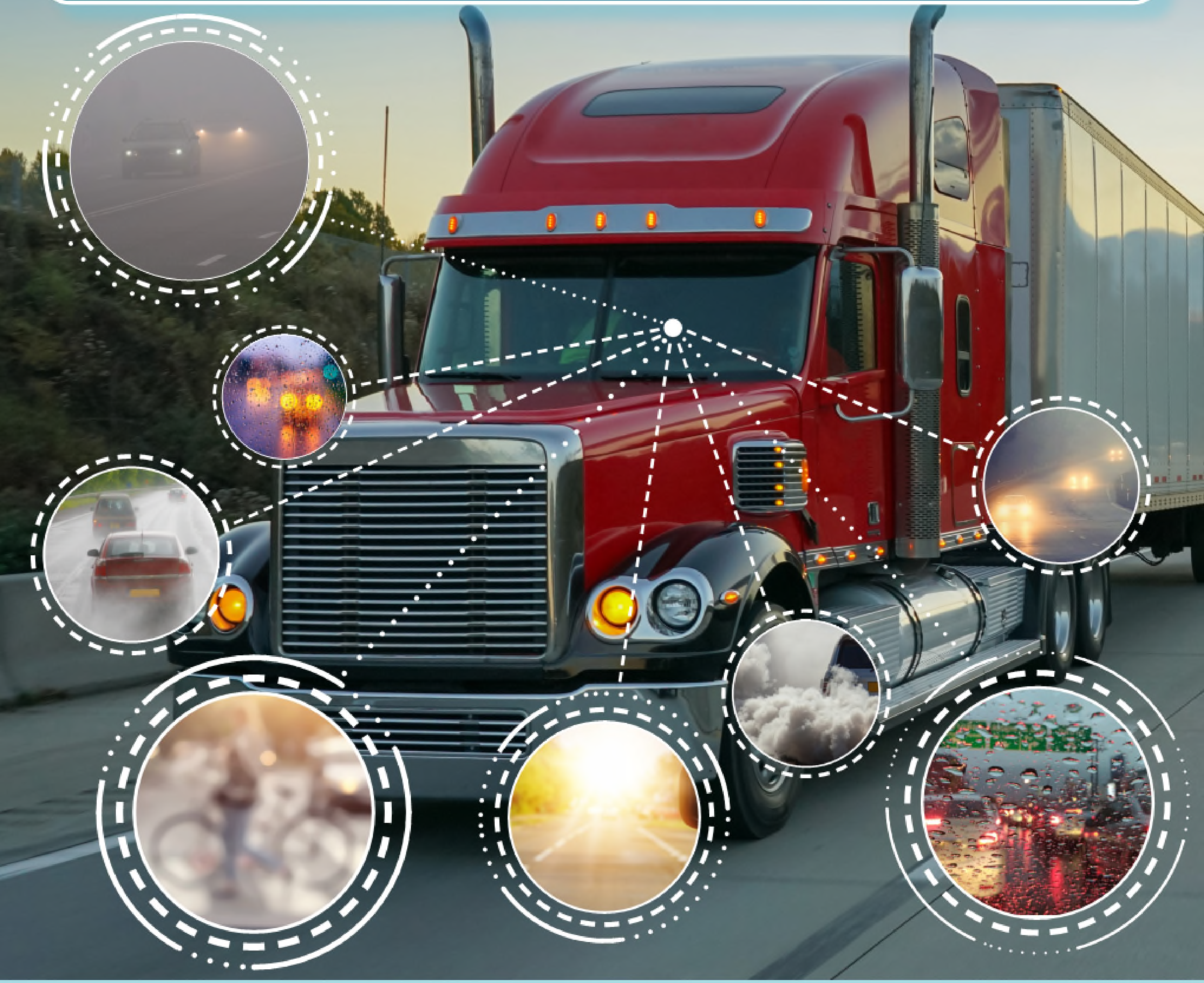
Establishing Pavement Marking Standards and Criteria for Automated Driving Systems

PART 1:
Project Narrative and Technical Approach



2019 FDOT ADS DEMONSTRATION GRANT APPLICATION
United States Department of Transportation
Notice of Funding Opportunity Number 693JJ319NF00001

FDOT

Florida Department of Transportation

RON DESANTIS
GOVERNOR

605 Suwannee Street
Tallahassee, FL 32399-0450

KEVIN J. THIBAULT, P.E.
SECRETARY

March 6, 2019

The Honorable Secretary Elaine L. Chao
U.S. Department of Transportation
Federal Highway Administration
1200 New Jersey Avenue, SE; Mail Drop: E62-204
Washington, DC 20590

Attention: Sarah Tarpgaard, HCFA-32

Re: Automated Driving System (ADS) Demonstration Grants, NOFO No. 693JJ319NF00001

Dear Secretary Chao:

The Florida Department of Transportation (FDOT) is pleased to submit the application for the ADS Demonstration Grant under the Notice of Funding Opportunity to the United States Department of Transportation (USDOT). FDOT shares the USDOT's vision to promote safety, mobility, and efficiency through ADS technologies. We believe that one of the ways to safely integrate Automated Vehicles (AVs) on the nation's roadways is through innovative pavement markings. Consequently, our project approach centers around the testing and development of ADS-ready pavement markings, establishing standards for normal conditions and work zones, and collecting real-world data to identify and advance the ADS-ready pavement marking technologies.

FDOT proposes a 3-stage demonstration initiative. **Stage 1** will use the Society of Automotive Engineers (SAE) Level 3 or higher AVs to test innovative pavement markings under various pavement, weather, and lighting conditions at the FDOT SunTrax testing facility. This will establish thresholds for new pavement marking specifications. **Stage 2** will collect real-world pavement marking data on Interstate 10 (I-10) and Interstate 75 (I-75). This will help refine the standards preliminarily set in Stage 1, and identify a roadmap to implementing AV-ready systems. **Stage 3** will include the testing of AVs in work zones for developing work zone pavement marking criteria. The information from this project will generate a body of work and design standards for pavement markings that will be applicable nationally and can pave the path for ubiquitous and safe AV deployments. With this project, FDOT believes that the following can be accomplished:

- Developing pavement marking standards and specifications for ADS vehicles including a roadmap for AV readiness, implementation, and full-scale deployment.
- Collecting pavement marking data to identify the current state of practice, gap-filling needs for SAE Level 3 or higher ADS-readiness and establishing baselines.
- Advancing public-private partnerships for realizing the full potential of ADS technologies.

FDOT stands ready to work with USDOT on this important initiative for delivering a safe and congestion-free travel experience. Please inform us if we may address any questions.

Sincerely,

Kevin J. Thibault, P.E.
Secretary
Florida Department of Transportation

Summary Table

Table 1: Summary Table

Project Name/Title	Establishing Pavement Markings Standards and Criteria for Automated Driving Systems
Eligible Entity Applying to Receive Federal Funding (Prime Applicant's Legal Name and Address)	Florida Department of Transportation, State Traffic Engineering and Operations Office
Point of Contact (Name/Title; Email; Phone Number)	Raj Ponnaluri, Ph.D., PE, PTOE, PMP Connected Vehicles and Arterial Management Engineer raj.ponnaluri@dot.state.fl.us (850) 410-5616
Proposed Location (State(s) and Municipalities) for the Demonstration	Florida
Proposed Technologies for the Demonstration (briefly list)	• Society of Automotive Engineers (SAE) Level 3 or higher Automated Vehicles • Lane Keeping Assist System (LKAS) • Lane Departure Warning (LDW) • Radar • GPS • Inertial Measurement Unit (IMU) • Retro-reflectometers • Cameras • Others as technologies develop during project duration
Proposed duration of the Demonstration (period of performance)	2.5 years
Federal Funding Amount Requested	$7,314,000
Non-Federal Cost Share Amount Proposed, if applicable	$1,782,000
Total Project Cost (Federal Share + Non-Federal Cost Share, if applicable)	$9,096,000

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List of Acronyms

ADS .... Automated Driving System
ASTM .... American Society for Testing and Materials
AV .... Automated Vehicle
CAV .... Connected and Automated Vehicle
CCTV .... Closed-Circuit Television
CV .... Connected Vehicle
DATP .... Driver Assistive Truck Platooning
DIVAS .... Data Integration and Video Aggregate System
DSRC .... Dedicated Short-Range Communication
FDE .... Fundamental Data Element
FDOT .... Florida Department of Transportation
FHP .... Florida Highway Patrol
FHWA .... Federal Highway Administration
FMCSR .... Federal Motor Carrier Safety Regulations
FMVSS .... Federal Motor Vehicle Safety Standards
FTP .... Florida Transportation Plan
GPS .... Global Positioning System
IMU .... Inertial Measurement Unit
LDW .... Lane Departure Warning
LiDAR .... Light Detection and Ranging
LKAS .... Lane Keeping Assistance System
MIRE .... Model Inventory of Roadway Elements
MOU .... Memorandum of Understanding
MPO .... Metropolitan Planning Organization
MUTCD .... Manual on Uniform Traffic Control Devices
NCUTCD .... National Committee on Uniform Traffic Control Devices
NHTSA .... National Highway Traffic Safety Administration
ODD .... Operational Design Domain
RCI .... Roadway Characteristics Inventory
R&D .... Research and Development
TEOO .... Traffic Engineering and Operations Office
TMC .... Traffic Management Center
TPO .... Transportation Planning Organization
TSM&O .... Transportation Systems Management and Operations
SAE .... Society of Automotive Engineers

SHSP .... Strategic Highway Safety Plan
UFTI .... University of Florida Transportation Institute
USDOT .... United States Department of Transportation

1. Executive Summary

1.1 Background

Florida Department of Transportation (FDOT) is responsible for maintaining approximately 12,106 miles of state roads, 6,858 bridges and culverts, 2,753 miles of rail, 49 transit systems, 780 airports, 15 public seaports, two spaceports, and 10 launch facilities support the nation's 4th largest economy and 3rd largest population with more than 20 million residents and 112 million visitors per year. FDOT also maintains 7,438 bicycle and 3,417 pedestrian facilities. FDOT's annual investment is $10.8 billion in infrastructure spending, which includes $1.0 billion for capacity improvements, $1.0 billion for maintenance and operations, $568 million in public transit development, $530.6 million for airports and spaceports, $186.1 million for safety initiatives. The department also includes the Governor's Highway Safety Program and the Turnpike Authority both of which help expand economic opportunities in the state. FDOT's Strategic Highway Safety Plan (SHSP) is aligned with and builds on the Florida Transportation Plan (FTP), the state's long-range transportation plan. Both the FTP and the SHSP share the vision of a fatality-free roadway systems.

FDOT understands USDOT reporting requirements and maintains the records and accounting systems that will allow it to comply with USDOT's reporting and administration requirements. Included in the FDOT's $10.6 billion dollars program are robust Intelligent Transportation System (ITS) and Research and Development (R&D) entities that can serve as resources to deliver these projects. The FDOT ITS program implements projects that use technology to drive the efficient movement of people, goods, and services throughout the state. The FDOT R&D unit oversees transportation related research that investigates materials, operations, planning, ITS, traffic and safety, structures, human environments, and natural environments challenges that impede the efficient development, construction, operations and maintenance of the statewide transportation network.

1.2 Vision

The vision of the FDOT is to deliver a fatality-free and congestion-free transportation system. To support FDOT's vision, the State Traffic Engineering & Operations Office (TEOO) continues to identify, prioritize, develop, implement, operate, maintain, and update various strategies, and measure their effectiveness for improving the safety and mobility outcomes. This proposed project aligns with FDOT's vision by testing pavement markings for automated vehicles (AVs) and automated driving systems (ADS).

FDOT's demonstration is divided into three stages. **Stage 1** will apply the Society of Automotive Engineers (SAE) Level 3 or higher AVs to test pavement markings under various pavement, weather, and lighting conditions at the SunTrax testing facility in central Florida. This will establish thresholds for new standards and specifications. **Stage 2** will collect real-world AV data on I-10 and I-75 as well as non-freeway roads as a future enhancement. **Stage 3** will involve performing additional testing of AVs in work zones. This stage will refine the framework and criteria for pavement markings standards in work zones.

1.3 Goals

1.2.1 Goal 1: Develop Standards for Pavement Markings for AV Operational Readiness

The first goal of the project is to develop standards and criteria for pavement markings for AV operational readiness under various pavement, lighting, and weather conditions. The ADS grant will provide the opportunity to use AVs with retro-reflectometers, cameras, and other surveying technology to sense pavement markings under different weather and lighting conditions as well as support data analysis and standards development. This testing will occur at SunTrax in central Florida. The outcome will be to initiate new pavement marking standards and specifications.

Our key partners, including SunTrax, 3M, Cisco, and Starsky Robotics will help collect and analyze data at SunTrax. Researchers from the University of Florida Transportation Institute (UFTI), with FDOT and project partners, will help design experiments and create interfaces for data collection and analysis to define thresholds.

The team at the SunTrax facility will assist in setting up pavement types, pavement markings, and work zone scenarios for all AV testing and demonstration. 3M will sell pavement markings and may oversee contractors during installation by the FDOT contractor and assist Starsky Robotics in understanding machine vision and learning. Cisco will lead the data element with cloud hosting and edge computing for data collection and processing and will work with this FDOT ADS Project Team. FDOT will develop the minimum pavement marking requirements and will work toward updating standards and specifications based on the findings of this project. These new standards and specifications will ensure AV preparedness of Florida roads, and for use by other states and the Federal Highway Administration (FHWA).

1.2.2 Goal 2: Refine Standards based on Pavement Marking Conditions on Various Roadways

Data will be collected on I-10, I-75, and possibly lower-speed non-freeway roads. The outcome will help identify gaps and refine the pavement marking standards and specifications, leading to an enhanced process of pavement marking evaluation for nationwide use. The collected data will be stored and analyzed so that deficient pavement markings may be identified and addressed by FDOT and other jurisdictions.

FDOT ADS Project Team will support this goal in the following ways:

- 3M will sell pavement markings and may oversee contractors during installation by the FDOT contractor.
- Starsky Robotics will provide the AVs for the data collection and will work with 3M to perform data analytics. This will lead toward the desirable human-machine interface for ADS-ready AVs and roadway infrastructure.
- UFTI and Cisco will gather, process, store, and make the data available to USDOT and third parties.

Because the AVs will be equipped with technology that will collect more than just pavement markings, the data can be used to enhance the FDOT Roadway Characteristics Inventory (RCI) to fully align with the Model Inventory of Roadway Elements 2.0 (MIRE 2.0) Fundamental Data Elements (FDE) requirements for data collection, USDOT's initiative to facilitate uniformity in roadway data collection that is standardized throughout the nation. RCI is the computerized database of information related to the roadway environment utilized by many FDOT offices including safety, asset management, and maintenance.

1.2.3 Goal 3: Develop Standards for Pavement Markings for AVs in Work Zones

Work zones are challenging for human drivers, and likely for AVs also. There is a need for pavement marking standards and specifications especially for AVs in work zones. AVs have difficulty with re-striping, if it is not done precisely after work zone reconstruction. Painting or taping over existing lane lines can lead the AV perception technology to track more than one lane. Stage 3 will involve performing additional testing of AVs in work zones to refine the framework and criteria for pavement markings standards in work zones. Some initial work zone testing will commence at SunTrax in Stage 1. The AVs will also be tested with pavement markings in work zones immediately before and after the lane shifts as well as traffic pattern changes. The FDOT ADS Project Team members will serve in their respective capacities, as in Stages 1 and 2.

1.4 Key Partners, Stakeholders, and Team Members

The FDOT TEOO will lead the project with the support of its key partners and project team members. Upon award, FDOT will enter into the agreement with USDOT and will establish partnerships, facilitate discussions, and create the Memorandum of Understanding (MOU).

1.3.1 Key Partners

Key partners are entities from industry that will provide products, services, or other resources for the project. Under the overall leadership of FDOT, the following key partners are vital to the success of the project by serving in their capacity described below. More information about the key partners is presented in *Part 2: Management and Staffing Approach* of the grant application.

1. Cisco will provide private cloud hosting, edge computing, and machine learning services. It will work with 3M, Starsky Robotics, and UFTI to make the data available to USDOT analysts and third parties. It will participate in all three stages.
2. 3M will provide pavement marking materials, assist in installation, analyze data from AVs (retro-reflectometers, video, sensors, etc.), and define thresholds for pavement marking standards for AVs. It will assist FDOT and other partners in understanding machine vision and learning and test experimental products and materials. 3M will participate in Stages 1 and 2.
3. Starsky Robotics will provide the AVs for testing at SunTrax in Stage 1, collect pavement marking data in Stage 2, and navigate through real-world work zones in Stage 3. It will work with 3M to analyze the data and understand machine vision and learning, and with Cisco in capturing and packaging the data.

1.3.2 Team Members

Team members also include FDOT offices, Districts, and UFTI. They will support the project by providing guidance, evaluating recommendations, and/or updating the pavement marking standards and specifications. Since most of the project will be collecting data, the team members will ensure that the key partners have the data and resources for the project.

1. SunTrax will provide the initial test-bed, and will assist in setting up pavement types, pavement markings, and preliminary work zone scenarios for all AV testing. SunTrax will play a role in Stage 1.

2. UFTI will collect data, perform analysis, support developing interfaces for data exchange with USDOT, and will conduct the before and after analysis. UFTI, with other partners such as Cisco, will host data and will participate in all three stages.
3. The FDOT State Material Office will evaluate the recommendations from the tests and develop the standards and specifications for new pavement markings. It will collaborate on the testing procedures and test cases.
4. The FDOT Office of Program Management, Specifications Division will develop the requirements for road and bridge construction.
5. The FDOT Office of Program Management, Product Evaluation Division will review test procedures and recommendations for new pavement markings and will work with the State Materials Office to develop standards and specifications. It will also research and test alternate markers and other pavement marking products.
6. The FDOT Transportation Technology Office will provide the data access governance and policy framework, storage requirements, and data management protocols for the project and will work with UFTI, Cisco, and USDOT.
7. The FDOT Transportation and Data Analytics Office, Transportation Data Inventory Division can use the data to enhance the RCI data to align with the MIRE FDE requirements.
8. The FDOT Maintenance Office will coordinate efforts to address any identified pavement marking improvement areas from the Stage 2 real-world data collection effort.
9. FDOT Districts Two, Three, Five, and Seven will also monitor the movement of AVs on the freeways through the Closed-Circuit Television (CCTV) cameras and Traffic Management Centers (TMCs) and will assist in executing the data collection efforts by collecting pavement marking information in both project-specific and MIRE data formats. All the Districts will help the Central Office develop a framework and criteria for the pavement marking standards.
10. Florida Highway Patrol (FHP) and local law enforcement will assist the project as necessary.

1.3.3 Stakeholders

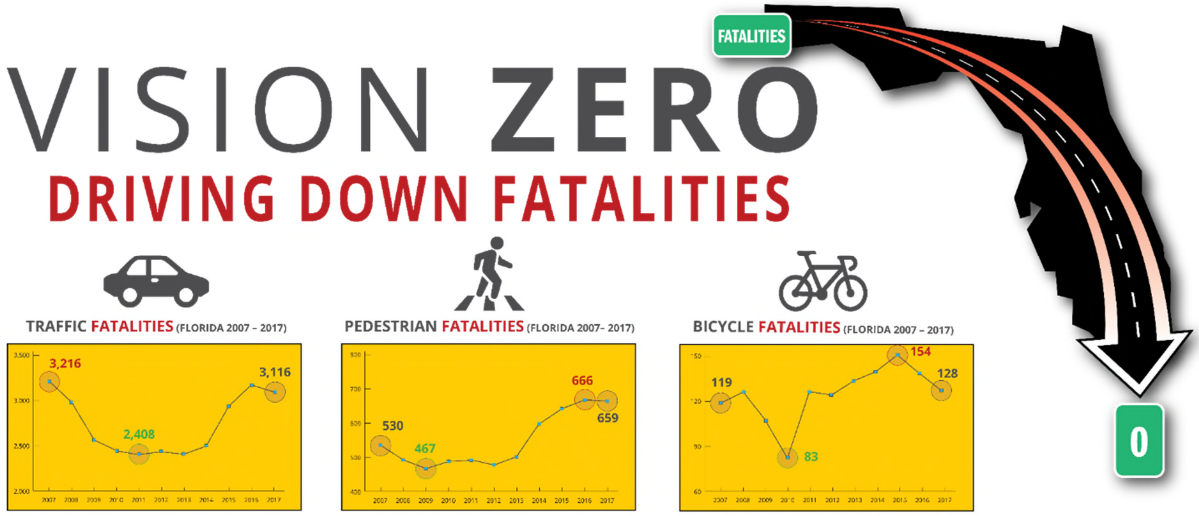
The team members are also stakeholders because the project will directly affect their offices and may require their involvement in Stage 2's data collection effort. Other stakeholders include local city and county agencies and Transportation and Metropolitan Planning Organizations (TPOs and MPOs). TPOs and MPOs will be notified of project activities within in their jurisdictions and can be additional reviewers on the recommended pavement marking standards and specifications.

1.5 Issues and Challenges to be Addressed

1.4.1 The Need for AVs to Reduce Fatalities and Injuries

FDOT recognizes that safety is paramount in every aspect of this and all projects. According to the *Transportation Crash Facts: Annual Report 2017* from the Florida Department of Highway Safety and Motor Vehicles, there were 402,385 crashes in 2017 of which there were 2,924 fatal crashes involving a total of 3,116 fatalities (see Figure 1). As stated in the USDOT's *Automated Vehicle 3.0: Preparing for the Future of Transportation*, *"Unlike human drivers, automation technologies are not prone to distraction, fatigue, or impaired driving, which contribute to a significant portion of surface transportation fatalities."* The crux is how to realize the potential benefits that AVs can provide.

Figure 1: FDOT Vision Zero



1.4.2 The Need for Safe ADS Design

The automobile industry has been at work for over a hundred years to perfect its craft with human drivers. There are no clear standards for states to turn to when it comes to ADS technologies. *AV 3.0* stated that existing standards assume that a vehicle may be driven anywhere, but future standards will need to consider that the Operational Design Domain (ODD) for an ADS within a vehicle is likely to be limited in some ways that may be unique to that system. This project will assess the conditions of pavement and the pavement markings that are conducive to operating ADS-equipped vehicles.

AV 2.0: Automated Driving Systems: A Vision for Safety discusses twelve priority safety design elements for ADS. This project will address six of the twelve priority safety design elements, as follows:

- System Safety—helps to establish pavement marking standards for AVs.
- ODD—tests the specific conditions in which AVs can operate.
- Object and Event Detection and Response—verifies the ADS in AVs.
- Fallback—relies on the human driver to intervene if the AV cannot operate properly.
- Validation Methods—the AVs did or did not detect pavement markings.
- Data Recording—the data captured will be analyzed to develop improved pavement marking standards and specifications and identify pavement marking deficiencies.

1.4.3 The Need for Pavement Marking Standards for AVs

According to the Transportation Research Board's 2019 Annual Meeting paper, *Machine Vision Detection of Pavement Markings*, "The most commonly heard highway infrastructure comment regarding the effectiveness of Lane Departure Warning (LDW) and Lane Keeping Assistance System (LKAS) is that the pavement markings need to be maintained to a good state of repair."[1]

The National Committee on Uniform Traffic Control Devices (NCUTCD), an organization that recommends changes to FHWA for the *Manual on Uniform Traffic Control Devices (MUTCD)*, published a paper with immediate pavement marking needs for SAE Levels 1 through 3

[1] TRB 19-0145 *Machine Vision Detection of Pavement Markings* November 15, 2018

automations. Table 2 compares its recommended standards to FDOT current standards for different pavement markings.

Table 2: NCUTCD Recommended Pavement Markings for Immediate AV Needs

Category	NCUTCD Recommendation	FDOT Standard Plans and Specifications
Edge line width	6″	6″
Lane line width	6″	6″
Centre line width	6″	6″
Broken lane line dimension	15’ with a 25’ gap	10’ with a 30’ gap
Dotted line width	6″	6″
Gore and other Normal Markings	10”	8” and 18”
Retro reflectivity (edge line, lane line and center line)	Minimum 35 mcd dry.	White and yellow profiled thermoplastic markings that will attain an initial retro-reflectance of not less than 300 mcd/lx·m^2 and not less than 250 mcd/lx·m^2, respectively.
Ceramic Buttons	Discontinue ceramic buttons (Bott’s Dots).	No ceramic buttons.
Retroreflectivity of pavement markings is measured in mcd/lx/m^2. mcd = milli candela for luminous intensity lx = the luminous flux index on a surface per area m^2 = square meter of the surface unit area		

The *MUTCD* states that the width of the normal longitudinal line shall be four to six inches wide. Currently, Florida maintains a pavement marking standard of six inches for the solid edge line and lane line and has done so since introducing the *7-2002 Design Standards Workbook*. The recommendation was made in the *1992 Traffic Design Standards* to align with the “Older Road-User Program.” By adopting and implementing a six-inch standard, Florida saw a need with improving the safety and mobility of its elder driver population. Florida aspires to study pavement markings with AVs and evaluate the need for enhanced pavement markings for all roadway users, especially those employing AVs. According to the FHWA’s *Safety Evaluation of Wet-Reflective Pavement Markings* Report (FHWA-HRT-15-065), the wet reflective pavement marking showed significant safety effectiveness due to improved level of retroreflectivity in the before and after analysis.

Studying pavement markings for AVs is a focus for SAE and the automobile industry. SAE is researching pavement marking performance effects on machine vision for LDW.[2] Automobile manufacturers are actively mapping the roads including pavement markings for their AVs. They hope that their AVs will detect good pavement markings, and those needing improvements.

With enhanced pavement markings, drivers will be more aware of their surroundings and make informed decisions. AVs depend on sensors, and the variety of pavement markings can confuse them. Large intersections with multiple lanes at every approach, work zones, and changes from

[2] https://www.sae.org/publications/

flexible to rigid pavement can also be perplexing to AVs. With this project, the state can develop future-ready standards and specifications which can be portable, scalable, and applicable nationally.

1.6 Geographic Area or Jurisdiction of Demonstration

The Stage 1 demonstration will focus on SunTrax[3] testing. SunTrax is located off Interstate 4 (I-4) between Orlando and Tampa. It is a large-scale, innovative facility dedicated to the research, development, and testing of emerging transportation technologies in safe and controlled environments. SunTrax's 400-acre site has 200 acres for connected and automated (CAV) testing. It will be fitted with various levels of pavement surfaces, varying thickness of pavement markings, and different lighting. The weather will be monitored, and testing will be scheduled when weather conditions are present to adequately test and demonstrate the AVs' ability to navigate the roadways under adverse conditions with various pavement marking applications. The testing at SunTrax will determine the threshold for resurfacing and restriping based on the data and performance of an AV. The new pavement products from 3M with the latest standards and specifications for AVs can be tested in the SunTrax facility for both normal traffic and work zone conditions. Figure 2 shows the layout of SunTrax. The number represents the type of facility as listed below:

1. Main Access and Building Facilities
2. High-Speed Oval
3. Dynamic Test Pad
4. Pick-Up/Drop-off/Multi-Modal
5. Urban
6. Complex Urban
7. Roadway Geometry Track
8. Environmental Test Chamber
9. Loop Track
10. Ring Track

The High-Speed Oval (2) is 2.25 centerline miles with a design speed of 70 miles per hour. SunTrax will have varied lighting conditions at its mock toll gantry. More flexibility, using temporary and movable lighting, will be available at build out. SunTrax will be able to accommodate work zone scenario testing using the high-speed oval, which will be completed by summer 2019. Because the infield facilities will not be completed in time for the Stage 1 testing at SunTrax, the weather will be monitored so that data can be collected in inclement weather. Weather conditions in Florida and at SunTrax are discussed in Section 1.5.1.

[3] http://www.suntraxfl.com/

Figure 2: SunTrax Facility

Additionally, a 2.5-mile test track along U.S. 301 in Clay County, Florida[4], may be used for concrete pavement marking testing by collecting ADS data and performing data analytics. The northbound U.S. 301 is concrete pavement test area and the southbound US 301 is asphalt pavement. Both are maintained for live traffic operation, including freight operations.

Several AVs equipped with retro-reflectometers, cameras, and other video/sensor technologies will collect data on the pavement surface type and pavement markings of I-10 and part of I-75 in Florida during Stage 2. Because of their nationwide and statewide importance, defining state pavement marking standards on these corridors will support the National Multimodal Freight Policy goal of "*using innovation and advanced technology to improve safety, efficiency, and reliability of the National Multimodal Freight Network*."

1. I-10 (362 centerline miles or 1,510 lane miles) is vital for testing freight operations including truck platooning. The ADS grant project will be used in anticipation of the I-10 Driver Assistive Truck Platooning (DATP) project to help validate the field data collection for technologies and methodologies for pavement markings. The I-10 DATP can be the first test case for the new pavement marking standards and specifications based on their performance.
2. I-75 from the I-275 North in Manatee County to the Georgia State Line (242 centerline miles or 1,428 lane miles) is a major freight route and a major route for visitors to Florida by car, bus, and motor homes. Traffic crashes cause complete closure of I-75 every nine

[4] https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/content/materials/pavement/research/reports/stateroad/301.pdf?sfvrsn=40837b02_0

days on average with more than one lane closure incident per day. In addition to being a major freight corridor, I-75 serves as an important hurricane evacuation route for Florida's largest metropolitan areas such as Miami and Tampa. The I-75 Florida's Regional Advance Mobility Elements (FRAME) project will deploy Roadside Units (RSUs) every two miles along I-75 at existing CCTV locations. The RSUs will send and receive messages to and from Connected Vehicles (CV), including passenger, transit, freight, and emergency vehicles, as well as other RSUs using 5.9 GHz Dedicated Short-Range Communications (DSRC). The AVs can leverage this technology when collecting pavement marking data and disseminating any basic safety messages (BSMs) or traveler information messages (TIMs).

The AVs will collect data on the pavement surface type and pavement markings in real-world work zones in Stage 3. Stage 3 facilities include:

1. SunTrax with mock-up work zone setups in the various pavement, lighting, and weather conditions completed during initial testing in Stage 1.
2. Real-world data collection on active work zones based on the construction schedule.

1.5.1 Florida Weather Conditions

Because weather affects driving conditions and pavement marking visibility, this project will monitor and schedule testing when weather conditions are present. This will adequately test and demonstrate AV ability to navigate the roadway under adverse conditions with various pavement markings. The combination of rainfall and high sun glare could make it very challenging for AVs to detect pavement marking; this will be one of the test cases at SunTrax. Figure 3 shows rainy weather contributing to poor pavement marking visibility.

Figure 3: Poor Pavement Marking Visibility in Rainy Weather

Rain is not the only hindrance to pavement marking visibility in Florida. On January 29, 2012, eleven people died while traveling on I-75, south of Gainesville, Florida due to almost-zero visibility from smoke and fog[5]. Figure 4 shows foggy weather conditions, reducing pavement marking visibility ahead for a human driver.

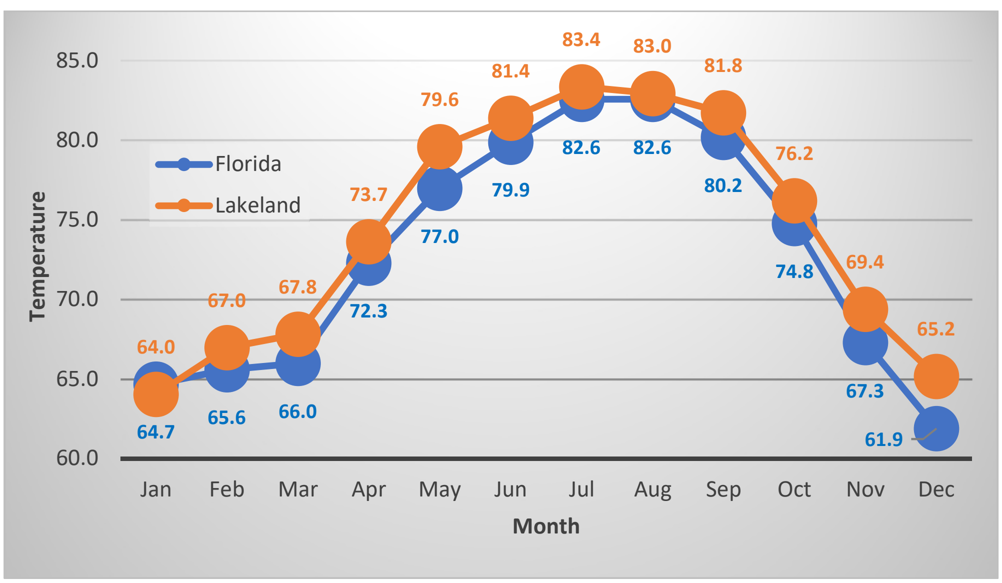
[5] https://www.ocala.com/news/20120204/anatomy-of-a-tragedy-i-75-crashes

Figure 4: Poor Pavement Marking Visibility in Foggy Weather

According to the Florida Climate Center[6] at Florida State University, the average temperature in Florida for 2017 was 72.7°F. The coldest month was December (61.9°F) and the hottest months were July and August (82.6°F). Florida received 58.52 inches of rain in 2017. March had the lowest rainfall of 1.20 inches; whereas, June had the highest rainfall at 11.78 inches.

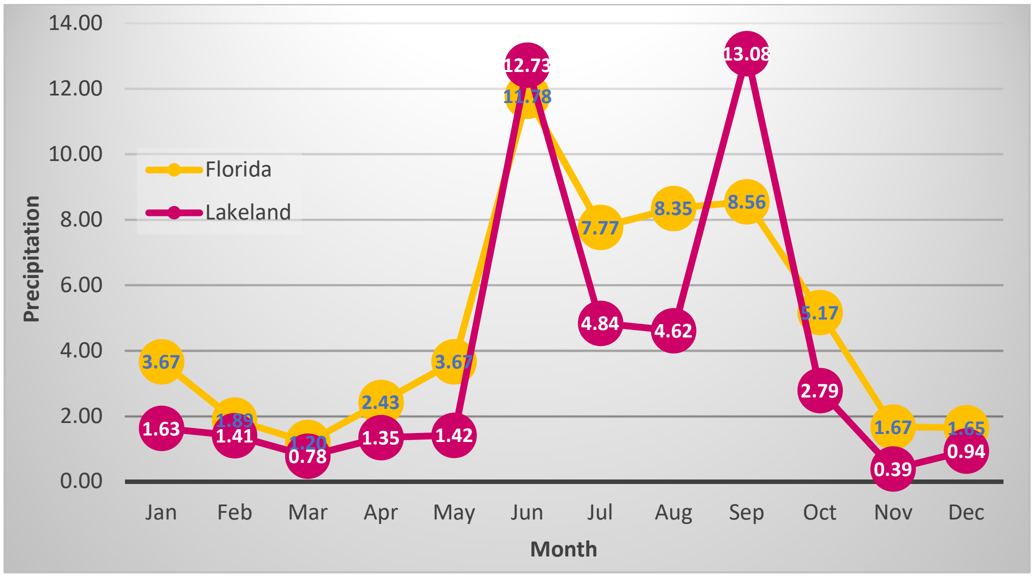
SunTrax, where Stage 1 testing will occur, is located outside of Lakeland, Florida. Lakeland had an average temperature of 74.4°F for 2017. Its coldest month was January with an average temperature of 64.0°F, and its hottest month was July with 83.4°F. Lakeland received 45.98 inches of rain in 2017. November had the lowest rainfall of 0.39 inches; whereas, September had the highest rainfall at 13.08 inches. Figures 5 and 6 show the monthly temperature and precipitation, respectively, for Florida and Lakeland.

Figure 5: Florida and Lakeland Monthly Temperature



[6] https://climatecenter.fsu.edu/

Figure 6: Florida and Lakeland Monthly Precipitation



1.7 Period of Performance and Schedule

The following table shows the period of performance of 2½ years and a high-level schedule of the project.

Table 3: Period of Performance and Schedule

Task	Description	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
1A	Notice to Proceed; System Management Plan; Develop Test Plans and Scenarios for Controlled Testing at SunTrax; Prepare Project Data Warehouse and DIVAS										
1B	Collect and Process Data for FDOT using Test Plans and Scenarios from Task 1A; Developing Work Zone Test Plans and Scenarios										
1C	Collect and Process Data for FDOT using Work Zone Test Plans and Scenarios from Task 1B										
2A	Develop Real-World Test Plan and Scenarios for I-10 and part of I-75; Collect Data										
2B	Collect and Process Data for FDOT using Test Plans and Scenarios from Task 2A; Identify and Fill in Gaps; Develop Standards and Specifications Framework										
3A	Develop Real-World Test Plan and Scenarios for Work Zones; Identify Corridors with Upgraded Pavement Markings; Monitor Construction Activities and Lane Shifts										
3B	Collect and Process Data for FDOT using Test Plans and Scenarios from Task 3A; Identify and Fill in Gaps; Develop Standards and Specifications Framework; Establish Guidelines for Future Construction Projects; Complete Real-World Work Zone Data Collection										
4	Draft and Final Evaluation Report										

2. Goals

2.1 Safety

First, this project will serve as a model for other states to prepare their roads for AV operations and realize the safety benefits with updated pavement surfaces and pavement markings. A state can use the framework for data collection and analysis to set its own pavement marking standards and specifications to make their roads AV-ready and safer.

Second, the project findings and standards can be shared with other states to improve safety of their roads. A state with similar weather patterns and geography to Florida can assess its roads; adjust its minimum pavement marking standards based on the project's recommendations and findings; address deficiencies in its upcoming work programs; enhance its roadway inventory; and prepare its roads for AVs, including travel through work zones.

Third, the demonstration also includes research into human factors and will compare machine and human vision relative to the pavement marking detection thresholds. The human driver age will be a documented data element. Many people have a perception that AVs are not safe. AVs can provide transportation to the elderly and disabled populations, but AVs first need to navigate the roads safely. Having enhanced pavement markings will result in reduced liability to AVs and seeing more AVs on the road will increase public confidence in using them for transportation. Human drivers will also benefit because the framework for maintaining pavement markings will increase their visibility during rainy, foggy, and nighttime conditions, which will reduce the number of crashes during unfavorable circumstances.

2.2 Data for Safety Analysis and Rulemaking

This project will mostly focus on collecting and analyzing data to determine desirable minimum levels of pavement markings that work on all likely conditions. AVs depend on sensors, and the variety of pavement markings can confuse them. Large intersections with multiple lanes at every approach, work zones, and changes from flexible to rigid pavement add challenges to AV operations. Furthermore, weather and lighting conditions can also compound safety risks facing ADS integration. The project is expected to collect the following data for developing the minimum standards and specifications:

- Vehicle data – location, direction, speed, and how well the AV navigates the roadway.
- Human driver – age.
- Yaw – an angular deviation from ideal straight-line motion, in which the positioning table rotates around the vertical axis as it translates along its travel axis.
- Roll – an angular deviation from ideal straight-line motion, in which the positioning table rotates around its axis of travel as it translates along that axis.
- Pitch – an angular deviation possible in positioning systems, in which the table leading edge rises or falls as the table translates along the direction of travel. This represents rotation around a horizontal axis, perpendicular to the axis of travel.
- Pavement marking retro-reflectivity – both dry as per the American Society for Testing and Materials (ASTM) E1710 and wet continuous as per ASTM E2832.
- Pavement marking width.
- Pavement marking depth.

- Pavement marking color.
- Pavement marking nighttime color.
- Pavement marking line type.
- Pavement marking material type – thermoplastic, paint, and tape.
- Pavement contrast – asphalt and concrete.
- Contrast measurements.
- Refractive index.
- Lighting – day and night with and without street lighting.
- Pavement condition – wet and dry.
- Pavement type – rigid and flexible.
- Weather condition – sunny, dry, clear, rainy, foggy, or smoky.
- Temperature.
- Humidity.
- Date and time.
- GPS coordinates for pavement markings.
- Confidence value.
- Look ahead distance.
- Direction of travel.
- Engagements and disengagements.
- Telemetry alerts.
- Lane sensor system failure due to unclear or invisible lane markings.

Using the data collected above, the demonstration will set baselines for safety ADS operation because AVs will be used as the test vehicles on SunTrax and the interstates.

As the future of AVs continues to evolve, the data collected can be used to create test cases for future AVs and reveal which variables largely impact their safety performance. USDOT and NCUTCD can use the data to guide future *MUTCD* language, which has centered around the human driver and not AVs. This information can also be applied to create guidance documents for states on ODDs for AVs.

FDOT will negotiate and sign a mutually agreeable data-sharing agreement with USDOT ensuring data accessibility for at least five years after the performance period.

2.3 Collaboration

Section 1.2 identified key partners and team members that will help to develop the project. FDOT continues to explore ways to deploying CAV technologies, especially with transit and freight operations. As a part of this process, FDOT has partnered with Florida's premier research universities on numerous research projects, including efforts to establishing interfaces for collecting, storing, mining and disseminating potential CAV and ADS data.

Internal collaboration with other FDOT offices will be integral to implementing this project. They will assist each FDOT District and will use the standards and specifications for pavement markings to address deficiencies to develop more robust maintenance schedules in their work programs.

Private partner collaboration is the key to the success of this project. The purpose and goal of each private partner is listed below:

1. SunTrax will serve as the initial testing ground and its staff will assist in setting up pavement types, pavement markings, and weather conditions for all AV testing.
2. 3M will sell pavement markings and may oversee contractors during installation by the FDOT contractor at SunTrax, assist in analyzing pavement marking data for machine vision with the FDOT ADS Project Team, and test experimental products for AVs.
3. Cisco will participate in data collection and analysis from the AVs wireless gateway during SunTrax as well as during testing in the real-world data collection environment. It will prepare the data packages for 3M and Starsky Robotics as well as work with UFTI.
4. UFTI will participate in collecting, analyzing, and storing data and making it accessible to USDOT and third parties. They will conduct the before-and-after analysis, make recommendations, and contrast human vision and machine vision.
5. Starsky Robotics will provide their AVs at SunTrax for testing and will collect data to create a framework for establishing new pavement marking standards and specifications. They will work with 3M on analyzing the data and fine tuning their vehicle algorithms to detect pavement markings.

3. Focus Areas

3.1 Significant Public Benefits

The project will encompass a data collection effort on pavement types and pavement markings under various conditions on different real-world roadway facilities. The findings from the testing at SunTrax to develop the minimum threshold for pavement markings and the validation effort from real-world testing will help establish a framework for maintaining pavement marking conditions and increase their reflectivity to reduce crashes. Findings from this project will be portable and expandable to other similar situations, communities, and conditions.

3.2 Addressing Market Failure and Other Compelling Public Needs

FDOT understands that elder driver population will need transportation, especially if they can no longer drive themselves. People with disabilities will also need transportation services. AVs can fill this gap and make this aging population an important part of the society, but AVs must first prove that they can operate safely. Because AVs rely on pavement markings for navigation, it is important that they are AV-ready. Starsky Robotics will participate in the testing at SunTrax, collect pavement marking data, and test new pavement markings based on the updated standards and specifications. Better pavement markings benefit not only AVs but human drivers as well. UFTI will study the effects of the data on human drivers as well as AVs.

3.3 Economic Vitality

This project supports economic vitality by supporting various aspects of industry and societal benefits including truck platooning, AV readiness, automobile industry products development, and high technology. The automobile industry will benefit from the demonstration findings and develop products and services that meet the recommended standards and specifications as well as leveraging existing technologies. The study findings will be shared with the USDOT and subsequently with other states to implement pavement marking standards for AV readiness. All the testing will be done in the United States, specifically in Florida, and will use U.S.-based companies and U.S. workers. The project will comply with the Buy American Act and meet all other NOFO requirements to promote domestic industrial and intellectual development.

3.4 Complexity of Technology

There are a variety of technologies AVs could use and have used to support lane keeping. These technologies range from cameras to differentially-corrected Global Positioning System (GPS) navigation and machine learning. The primary means by which transportation agencies define lanes and lane boundaries is through lane or pavement markings. Occasionally, transportation agencies widen or modify roadways requiring new lane boundaries and markings. For these reasons, the FDOT ADS demonstration focuses on the ability of AV camera and lane keeping sensor systems to read lane markings safely and efficiently the first time and every time an AV drives on a roadway at posted speed limits or other speeds as appropriate for conditions.

The project will use AVs equipped with SAE Level 3 automation or higher, which means the driver is needed but is not required to monitor the environment and the driver must be ready to take control of the vehicle at any time with notice. In addition to the AV LKAS and LDW systems, the AVs will be equipped with retro-reflectometers, cameras, and other technologies to collect data. Starsky Robotics will provide data and assistance in data processing, analysis, and dissemination. The data collection technologies will monitor AV lane-keeping performance in various weather, light, and pavement conditions at SunTrax, I-10, and I-75. In addition, pavement markings will be tested with AV technology within other complex environments, such as work zones. The goal of the testing and demonstrations at SunTrax is to determine both minimum acceptable and optimal pavement marking reflectivity for the worst-case pavement surface, weather, and lighting conditions on both permanent lane configurations and in work zones with temporary lane configurations.

As part of this project, private parties and the FDOT Data Integration and Video Aggregation System (DIVAS), which currently provides information to Florida 511 and third-party feeds, will be utilized.

The AVs will also collect data on part of I-75. I-75 has CCTV cameras and a portion of this interstate facility will have RSUs as well as CV applications installed on the I-75 FRAME project. Consequently, depending on the AVs technology and equipment, this project can test vehicle-to-infrastructure and vehicle-to-vehicle communications. Exploring additional data collection technologies will be discussed by the FDOT ADS Project Team.

AV technology is moving at a fast pace. The FDOT ADS Project Team may explore other emerging technologies, such as the application and use of Light Detection and Ranging (LiDAR), the number of LDW and LKAS alerts, travel smoothness, and pixel density of the lanes, as part of the project.

3.5 Diversity of Projects

The project demonstrations will occur at SunTrax before the AVs collect the pavement marking data on I-10 for truck platooning and I-75 with normal operations. I-10 and I-75 are recognized as being vitally important to Florida's economy and mobility with their Strategic Intermodal System (SIS) designation and conveyance of significant interstate commerce. They have a mix of urban, suburban, and rural populations. Additionally, several of the counties along I-10 are designated as economically disadvantaged areas. Table 4 shows Annual Average Daily Traffic (AADT) for 2017 and truck percentages.

Table 4: I-10 and I-75 AADT and Truck Percentages

Roadway	Count ID	County	Location	AADT	Truck %
I-10	480156	Escambia	0.6 miles west of SR 297	45,494	14.8%
	489949	Escambia	1.6 miles east of SR 297	57,750	11.5%
	570318	Okaloosa	At Antioch Road	28,283	20.3%
	600366	Walton	1.3 miles west of Boy Scout Road	24,487	22.6%
	600287	Walton	50 feet west of CR 280A Overpass	22,546	24.1%
	610152	Washington	At CR 273, southeast of Chipley	21,912	24.9%
	530218	Jackson	1 mile east of US 231	25,075	25.4%
	550304	Leon	1 mile west of Thomasville Road	68,594	13.0%
	540375	Jefferson	East of CR 257	30,346	22.5%
	359902	Madison	1.81 miles east of CR 53	28,770	21.2%
	370238	Suwannee	0.15 miles west of CR 136	30,699	22.7%
	290269	Columbia	0.45 miles east of US 41	23,403	27.1%
	299936	Columbia	At CR 250 Overpass	23,458	25.9%
	720109	Duval	At CR 217	53,000	20.8%
I-75	320112	Hamilton	0.5 miles north of SR 143	44,703	28.3%
	329956	Hamilton	North of SR 6	44,361	28.3%
	360317	Marion	0.23 miles north of Williams Road	94,509	19.9%
	189920	Sumter	3.5 miles south of Florida's Turnpike	49,000	19.8%
	180358	Sumter	0.5 miles north of SR 48	49,342	20.6%
	140190	Pasco	1.0 mile north of SR 56	93,555	12.8%
	109953	Hillsborough	No Description	148,347	8.7%

Source: *FDOT Florida Traffic Online*

The project AVs will collect pavement marking data on various roads within Florida as stated in Stage 2. Stage 2 will help to refine the pavement marking standards established in Stage 1. The data also will identify the desirable pavement markings which could be addressed in upcoming maintenance contracts and work programs.

Stage 3 will encompass AV testing in real-world work zones. FDOT's Five-Year Work Program will be closely-monitored including active construction activities. FDOT will coordinate with the Districts where these construction projects are located to conduct real-world testing with the AVs.

3.6 Transportation-Challenged Populations

Florida has the largest number of aging road users in the nation. The *FDOT 2018 Highway Safety Plan* states, "An 80-year-old woman driver is seven times more likely to be killed as a 45-year-old woman in trips that are the same distance."[7]

AVs can fill the need to transport the transportation-challenged population, and connect them to various shopping malls, restaurants, and healthcare centers. The AV services and last-mile

[7] FDOT 2018 Highway Safety Plan

connectivity give them an alternative to driving while maintaining or increasing their socialization. For example, going to the grocery store makes older adults feel they are a part of society. Older adults prefer continuously running services because they are predictable and connections to transit because it expands their world. This project will test how AVs navigate various roadways with pavement markings. It will raise the confidence of the older adults living in these senior-living communities that AVs are safe and can enhance their quality of life.

Because pavement markings are necessary for an AV's LKAS or LDW, the better they are, the more prepared the roadways will be for them. Furthermore, enhanced pavement markings will reduce the AV's liability and make their mobility benefits more of a reality.

As a part of this project, UFTI will research the human factors aspect of AVs and will compare machine and human vision relative to the pavement marking detection thresholds.

3.7 Prototypes

The FDOT ADS Project Team will develop a prototype for testing at SunTrax and will carry out the implementation of the data collection effort with relevant roles by various partners.

4. Requirements

4.1 Research and Development of Automation and ADS Technology

The project will use the SAE Level 3 or higher automation AVs equipped with retro-reflectometers, cameras, and other technology including advanced pavement marking material to collect data on pavement markings under different weather, pavement, and visibility and lighting conditions. Multiple test runs will be conducted under various controlled environments at SunTrax, and thresholds for pavement marking will be established. After the thresholds are established, the AV runs will be completed on other real-world roads and criteria will be refined to help develop standards and specifications for pavement markings.

As part of this project, the wireless gateway within vehicles will be tested to transfer data to a cloud-hosted environment from a real-world data collection effort. Cisco will facilitate edge computing, data analysis, and cloud hosting to support the project for deployment.

4.2 Physical Demonstration

The physical demonstrations will occur at SunTrax before the process of using the AV for collecting data on pavement markings is executed in a real-test environment. Other real-world demonstrations on I-10 and part of I-75 will be conducted after the initial fine tuning of pavement marking thresholds are completed.

4.3 Data Gathering and Sharing

FDOT will work with UFTI and Cisco for preparing interfaces, collecting, and analyzing data, and developing findings and recommendations for the new pavement marking standards and specifications. Because the FDOT ADS Project Team is spread out geographically, we understand the need for creating user input and output interfaces for exchanging data and knowledge. As per the NOFO requirement, the project data will be shared with the USDOT by providing secured access to the data warehouse and will be made available for the required five-year duration. The

FDOT ADS Project Team will host the data with input-output user interfaces on ADS and related applications.

In addition, the FDOT DIVAS platform and cloud-hosting services will be used to pass through data. Access to the data will be defined in the MOU.

FDOT will negotiate and sign a mutually agreeable data-sharing agreement with USDOT ensuring data accessibility for at least five years after the performance period.

4.4 Input and Output User Interfaces

This demonstration will include input and output user interfaces on the ADS and related applications that are accessible and allow users with varied abilities to input a new destination or communicate route information and to access information generated by the ADS. As part of this effort, Cisco and UFTI will track the route change or definition.

4.5 Scalability and Outreach

The project is scalable and can be applied to other national roads. The FDOT ADS Project Team will explore defining the thresholds for standing water and snow and ice conditions, respectively, that can be scaled to other similar condition roads. Florida will share data, findings, and harmonize methodologies to help make the project worthwhile for the nation. The demonstration project results findings on pavement marking standards and specifications for ADS readiness will be shared with the USDOT and other states. The FDOT will participate in national webinars if requested to provide updates and status reports of the project. In addition, FDOT will host project information and schedule updates on its CAV webpage. A final evaluation report will be prepared and shared with the USDOT and made available on the FDOT website.

5. Approach

5.1 Technical Approach

5.1.1 Controlled Testing at SunTrax

SunTrax will be fitted with various levels of pavement surfaces and varying thicknesses and reflectivity of pavement markings during various lighting conditions. 3M will provide commercially available materials but will not provide pavement markings with varying retro-reflectivity. Weather conditions will be tracked to test AV performance in inclement weather. The testing will determine the minimum and optimum visibility standards so that thresholds for resurfacing and re-striping are based on the data and performance of the AVs. Starsky Robotics will provide the AVs for testing. 3M will sell pavement markings and may oversee contractors during installation by the FDOT contractor as well as determine which factors in the pavement surfaces affect machine vision and learning for pavement marking detection, LKAS, and LDW. 3M’s latest products could be tested at SunTrax.

A test case at SunTrax will encompass various pavement types typical of work zones. The same AVs used in the initial testing for setting the minimum thresholds for pavement markings will also be used for the work zone scenarios.

5.1.2 Real-World Data Collection

As stated previously, I-10 and I-75 will comprise the real-world data collection with the possibility of including non-freeway roads. Surveying I-10 is important for the I-10 DATP project to validate the field data collection for technologies and methodologies for pavement markings from Stage 1. The AVs will collect data on a significant portion of I-10 beginning in Escambia County at the Alabama State Line to Duval County at I-95. The data will be collected on the mainline and all interchange ramps and compared to the minimum standards and specifications identified from the SunTrax testing. 3M will explore assisting Starsky Robotics in identifying the factors influencing the vehicle algorithms pavement marking detection and LDW and LKAS. Cisco will package the data to be used by others. The data collected by UFTI will be analyzed with cloud computing and made available to third parties. FDOT will continue to refine the minimum standards and specifications. Deficient pavement markings will be addressed in the districts' maintenance contracts or work programs.

I-10 data collection will serve as a model for the real-world data collection elsewhere. The same methodology would be applied on I-75. The AVs will gather pavement marking data on I-75 (242 centerline miles). The data collected will be measured against the minimum standards and specifications. These standards may be refined, but the respective districts or municipalities will address the deficiencies in the pavement markings in their work programs or maintenance contracts. The other partners specializing in collecting, analyzing, storing, and disseminating data will serve in their same roles.

Although it is not the purpose of this project, the data collected will be categorized so that it may be used by RCI for MIRE 2.0. In July 2017, FHWA's Safety Program issued MIRE 2.0 to advance data collection of key roadway safety elements. MIRE 2.0 provides a comprehensive listing of roadway and traffic data elements, including pavement markings, and an accompanying data dictionary that serves as a model for a robust inventory to support data-driven safety decision making. This project will help the state implement MIRE 2.0. States must submit a Traffic Records Strategic Plan incorporating specific, quantifiable, and measurable improvement for collecting MIRE FDE by July 1, 2017. States must have access to complete collection of the MIRE FDE elements for all public roads by September 30, 2026.

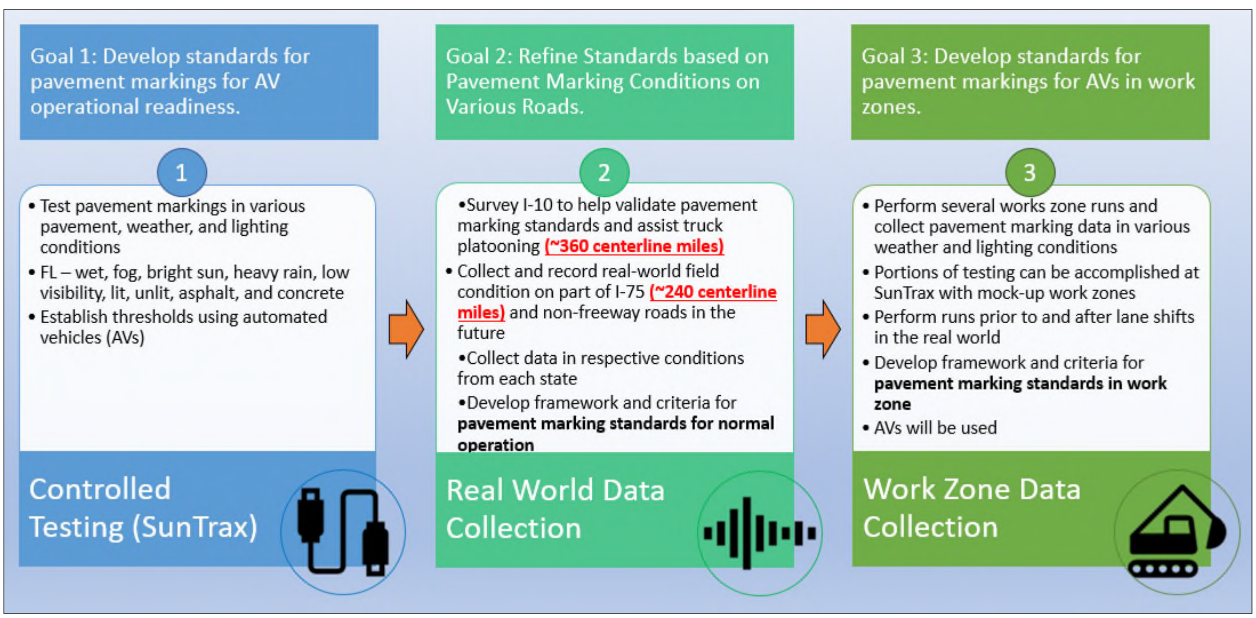
5.1.3 Work Zone Data Collection

The project AVs will be used to review the pavement markings in work zones immediately before and after lane shifts are opened to traffic to ensure that the pavement markings provide desirable delineation, based on the findings of Stages 1 and 2. The FDOT ADS Project Team will be involved in the work zone testing. Figure 7 shows a real-world work zone that would be challenging for an AV and could be a test case for Stage 3 work zone testing. While the figure shows a tiger tail for the lane striping, 3M would provide a side-by-side contrast lane striping for the potential test case.

Figure 7: Real-World Work Zone

Figure 8 shows the three-part concept of the entire project graphically.

Figure 8: Project Approach and Phases Concept



5.2 Approach to Address Legal, Regulatory, Environmental Obstacles

Florida has enacted legislation authorizing the operation of AVs. Chapters 316.003, 316.85, 316.86, 319.145, 339.175, and 339.64 of the *Florida Statutes* are AV-related legislation. Chapter 316.85 states that a person who possesses a valid driver license may operate an autonomous vehicle in autonomous mode on roads if the vehicle is equipped with autonomous technology.

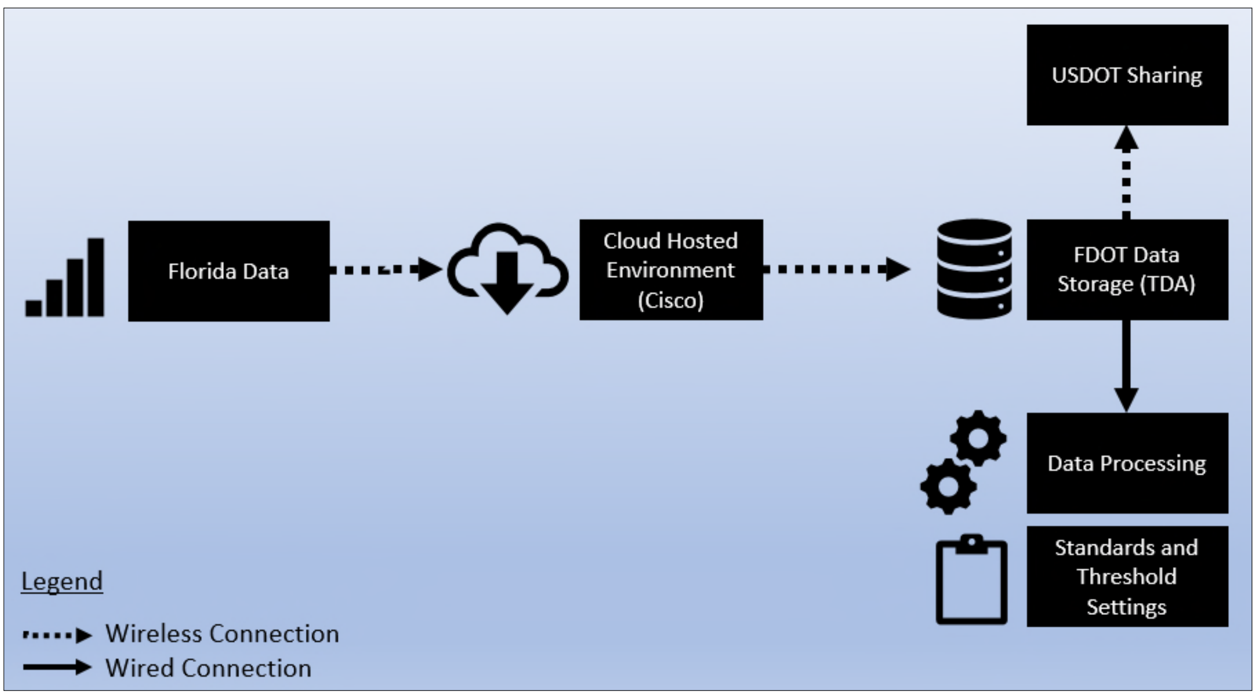
The project will not require any exception to the requirements in the Buy American Act, 41 U.S.C. §§ 8301–8305, as implemented at 48 C.F.R. Subparts 25.1–25.2. The FDOT ADS Project Team will be U.S.-based companies or entities.

This project does not require an exemption from either the Federal Motor Vehicle Safety Standards (FMVSS), Federal Motor Carrier Safety Regulations (FMCSR), or any other regulation. FDOT also understands that the National Highway Traffic Safety Administration (NHTSA) HS-7 exemption is required for AVs in the micro-transit category and will work with the project team to ensure the requirements are followed.

5.3 Commitment to Provide Data and Participate in the Evaluation of Safety Outcomes

The FDOT ADS Project Team will be responsible for data collection, analysis, and dissemination of project data and results. UFTI will collect and store the data and Cisco will perform the cloud computing/analytics and provide access to the data. The USDOT and other researchers can access the project data through these entities. The FDOT will make its project data available through its DIVAS. Figure 9 shows how data collection will translate into standards and threshold settings.

Figure 9: Technical Concept



UFTI, with other team members, will help design testing experiments and with conducting before/after study and analysis. 3M will assist the research partners in data analysis. Based on the findings and recommendations of the researchers with the assistance from other FDOT offices specializing in pavement and pavement marking performance, FDOT will develop or update minimum standards and specifications.

UFTI will conduct a before-and-after analysis of the AVs on their performance in lane keeping. Actual trajectory information under a variety of pavement marking scenarios will be evaluated to test conformance with pavement markings. We expect all the key partners and team members to assist in determining the measure of effectiveness.

5.4 Risk Identification, Mitigation, and Management

A risk management plan will be developed before any demonstration testing commences. The project risk management strategy is to identify and handle project risks, both technical and nontechnical, before they become concerning issues or cause serious cost, schedule, or performance impacts. The project will continuously and proactively assess critical areas identified to determine specific risks, analyze their potential impacts, determine mitigation actions, and monitor the risks.

The project will utilize several methods for identifying risk:

- Examine the work breakdown structure to uncover risk areas.
- Conduct a risk assessment.
- Interview subject matter experts (i.e., engineering, manufacturing, etc.).
- Review risk management efforts from similar products.
- Examine lessons-learned documents or databases.
- Develop design specifications and agreement requirements.

The project will analyze each risk to isolate its cause and to determine its effects. The project will rate the risk in terms of its probability of occurrence and its severity of impact to cost (i.e., dollars), schedule (i.e., time), and technical performance, as applicable.

This probability will be expressed in qualitative terms (i.e., high, medium, or low).

Overall risk assessment is the product of combining the probability of occurrence with the severity of impact. Table 5 shows an example of risk assessment.

Table 5: Risk Assessment

Probability of Occurrence	Severity of Impact	Overall Project Risk
High	High	High
High	Medium	
Medium	High	
High	Low	Medium
Low	High	
Medium	Medium	
Medium	Low	Low
Low	*Medium*	
Low	*Low*	

Once the risks are assessed, they will be categorized into defined risk categories, providing a means of assessing risks according to their source or taxonomy, and will be prioritized from 1 to n, 1 being the most effective area to which resources for mitigation are applied to achieve the greatest positive impact to the project.

When the risks have been identified and categorized, a course of action for each risk will be selected and implemented to keep it within the project constraints and objectives. Table 6 shows the risk ratings and the recommended handling strategy for each.

Table 6: Risk Handling

Overall Risk Assessment	Handling Strategy
High	The project manager and project engineer update the risk status daily until the risk is closed. The risk owner documents risk avoidance actions (i.e., actions taken to avoid or eliminate the source of the risk, and reduce the probability of occurrence to zero), risk mitigation actions (i.e., actions taken to mitigate the severity of the impacts of a risk and reduce the consequence to zero), and contingency actions (i.e., actions taken to protect the attainment of the project goals and to lower risk items).
Medium	This strategy provides the same handling as that for high risks, but on a less frequent basis (i.e., periodic risk status reviews, instead of daily).
Low	The project manager and project engineer add the risk to the "watchlist" for possible escalation.

To effectively control and manage risks during the work effort, the project will regularly monitor the risks and the status and results of risk-handling actions. This includes establishing a schedule for each risk-handling activity that includes the start date and anticipated completion date, a list of commitment of resources for each to allow successful execution of the risk-handling activities and the ultimate results of the actions taken.

While the risk management plan will require a more comprehensive risk analysis, some project risks have been identified and assessed with recommended mitigation strategies as shown in Table 7. Overall, the project is a medium risk project without a full risk management plan assessment.

Table 7: Project Risk Assessment

Occurrence	Probability of Occurrence	Severity of Impact	Overall Project Risk	Mitigation
Data Collection Equipment Malfunction	Low	High	Medium	The data should be collected in a cloud-based environment and uploaded frequently. If the connection to the cloud is lost, then data collection should stop until the connection to the cloud has been restored. The data should be backed up for equipment taking measurements.
Vehicle Equipment Malfunction	Low	High	Medium	There will be a driver and a researcher professional for every AV. The driver will monitor the vehicle characteristics, and the researcher will monitor the data collection equipment. If the vehicle equipment malfunctions, the driver monitoring the vehicle characteristics should take control of the vehicle.

Occurrence	Probability of Occurrence	Severity of Impact	Overall Project Risk	Mitigation
Adverse Weather Conditions	Medium	Medium	Medium	While data collection should continue in inclement weather, but in case the weather is so severe or sporadic that data cannot be collected on schedule, the schedule should have enough float as to not impact the overall project.
Driver Fatigue	Low	Low	Low	The FMCSR requirements including hours of service must be followed.
Crash	Low	Medium	Low	Notify the appropriate law enforcement dispatch (911) immediately. The driver can dial *FHP for assistance in the case of a breakdown.
Theft/Vandalism	Low	Low	Low	The driver should store the vehicle in an FDOT maintenance or construction yard. The driver should lock the vehicle every time he or she exits it. The drivers must start and end at the same place. The project should have a statewide logistics manager to plan the routes that the AVs will travel for data collection. All vehicles and equipment mounted outside of the vehicle will be equipped with GPS tracking systems to assist with theft recovery.
Partnership Pullout	Low	High	Medium	Find a new partner as soon as possible or use an existing partner to fill in the gap left from the exiting partner.
Data Collection System Failure	Low	High	Medium	Work with UFTI and Cisco to ensure that data is uploaded frequently and backed up.
Data Sharing Pullout	Low	High	Medium	Consult the partnership agreement or memorandum of understanding. Find a new partner as soon as possible or use an existing partner to fill in the gap left from the exiting partner.
Roadway Closure Incident	High	Medium	High	Work with FHP and local law enforcement to anticipate when the road will be open; find an alternative route.

5.5 Approach to Contribute and Manage Non-Federal Resources (Cost Share)

FDOT's approach towards contribution for the project is by way of utilizing its full-time employees/staff and providing university partners for data analysis. Part of the grant funding will be used for the AV fleet to defray the operational costs of private partners choosing to participate in the testing voluntarily. *Part 6: Budget Detail* shows the breakdown for the cost and details regarding managing both federal and non-federal resources.

FDOT will manage funds based on award requirements and ensure that the funds are identified appropriately beforehand and categorized accordingly. FDOT has both professional services and contractual services programs that follow the state and federal procurement requirements.

FDOT

United States Department of Transportation
Notice of Funding Opportunity Number 693JJ319NF00001
Automated Driving System Demonstration Grants