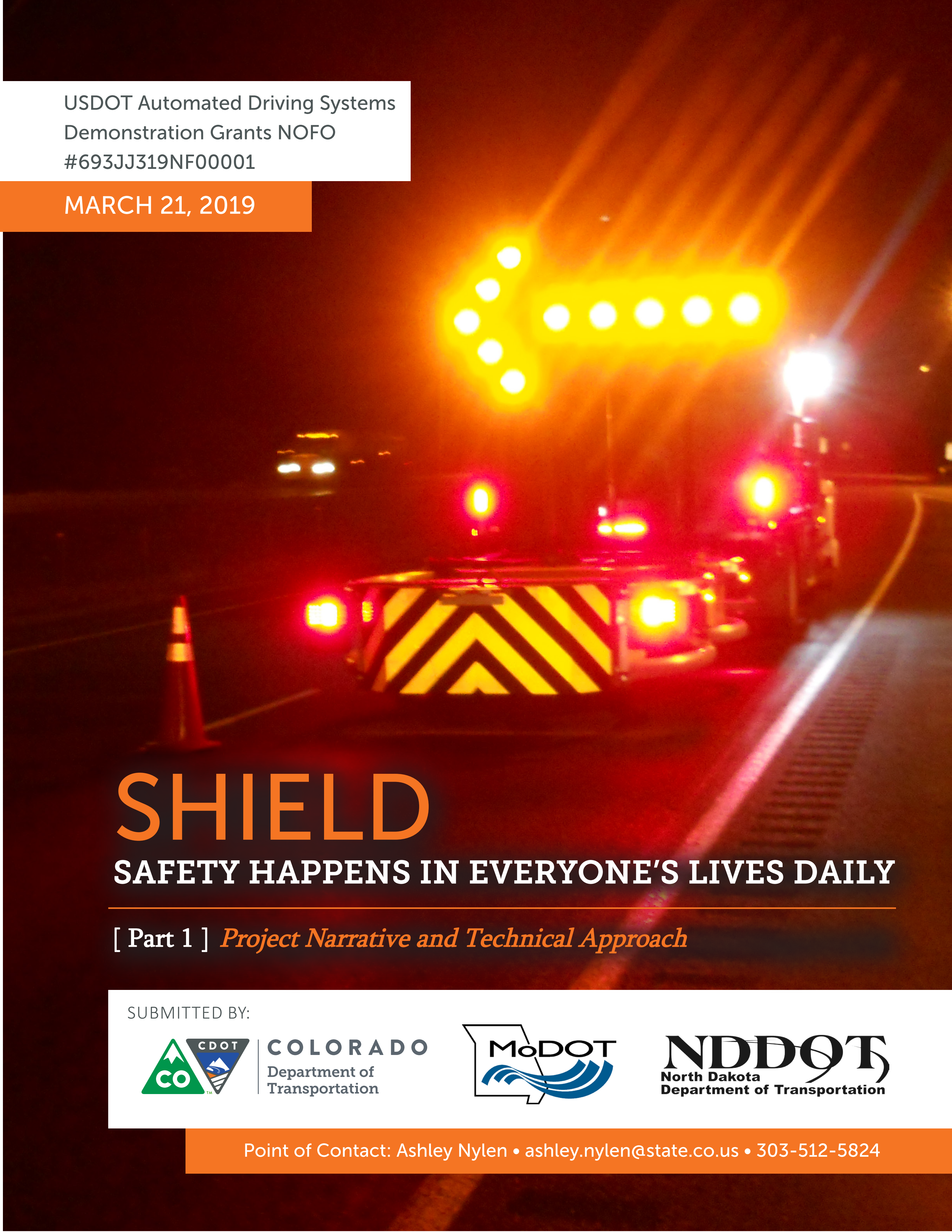

USDOT Automated Driving Systems Demonstration Grants NOFO #693JJ319NF00001

MARCH 21, 2019

SHIELD

SAFETY HAPPENS IN EVERYONE'S LIVES DAILY

[Part 1] *Project Narrative and Technical Approach*

SUBMITTED BY:

COLORADO Department of Transportation

MoDOT

NDDOT North Dakota Department of Transportation

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Summary Table

Project Name	Safety Happens in Everyone's Lives Daily (SHIELD)
Eligible Entity Applying to Receive Federal Funding	Colorado Department of Transportation 2829 West Howard Place Denver, CO 80204 www.codot.gov
Point of Contact	Ashley Nylen Connected & Autonomous Technology Program Manager Colorado Department of Transportation P 303.512.5824 | C 319.389.8664 ashley.nylen@state.co.us
Proposed Location	Colorado (statewide – interstate and highway deployment) North Dakota (statewide – interstate and highway deployment) Missouri (statewide – interstate and highway deployment)
Proposed Technologies for the Demonstration	Automated driving system for heavy duty maintenance vehicles based on the leader/follow retrofit kit. Lidar, radar, ultrasonic sensors, camera and vision systems, automated driving system datafeeds, and connected vehicle ecosystem and applications.
Proposed duration of Demonstration (period of performance)	June 1, 2019 – March 30, 2024
Federal Funding Amount Requested	$9,986,972
Non-Federal Cost Share Amount Proposed, if applicable	$3,720,500
Total Project Cost (Federal Share + Non-Federal Cost Share, if applicable)	$13,707,742

COLORADO
Department of Transportation
Office of the Executive Director
2829 West Howard Place, Suite 562
Denver, CO 80204

March 21, 2019

The Honorable Elaine Chao
Secretary, United States Department of Transportation
1200 New Jersey Avenue, SE
Washington, DC 20590

Dear Secretary Chao:

The Colorado Department of Transportation (CDOT) and co-applicants, Missouri Department of Transportation (MoDOT) and the North Dakota Department of Transportation (NDDOT) are pleased to submit our multi-jurisdictional application, Safety Happens in Everyone's Lives Daily (SHIELD) to the United States Department of Transportation for the Automated Driving Systems Demonstration grant program. We believe automated driving system technology has significant potential to improve safety in everyday DOT operation, and our application demonstrates the true data driven potential of this technology for DOTs nationwide.

Every day, hundreds of our workers within our departments risk their lives to keep our nation's roadway moving safely and efficiently. We put our very own workers in vehicles that are specifically designed to be struck, knowing the high likelihood of an impact by an un-expecting or distracted motorist as our maintenance crews perform mission critical roadway work. Recognizing this great danger in our work zones, CDOT has implemented a pilot program that removes the human from the impact protection vehicle or traffic mobile attenuator. CDOT and collaborators established a research pool fund that brings together government, researchers, and industry to help drive further understanding and deployment of this technology.

However, this is not enough. In 2015, nationwide, over 158,000 crashes occurred in our work zones. Greatly enhancing the foundational work by CDOT and the pool fund on autonomous maintenance vehicle technology, SHIELD demonstrates how integration of automated driving system (ADS) technology onto a variety of uses for heavy duty maintenance fleet vehicles can dramatically improve safety, identify safety performance metrics based on data, and foster collaboration. Collectively, we believe our efforts will not only lead to technology advances for heavy duty fleet automated driving systems, but the toolbox resources created in our Community of Practice discussed in our application will provide DOTs with the "How-to" on integrating automation in their everyday maintenance and roadway operations.

We look forward to your review of our unique multi-state, academic, and industry partnership outlined in our application.

Sincerely,

Shoshana M. Lew
Executive Director

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Project Narrative and Technical Approach

1. Executive Summary

Every year, men and women in department of transportations (DOTs) embark on hundreds of construction projects across our nation's roadways, and that does not include the daily maintenance and operation activities they do to keep our roadways safe. In 2017, a total of 158,000 total crashes occurred in our nation's work zones, accounting for 61,000 injuries. DOTs have deployed impact protection vehicles, referred to as truck mounted attenuators (TMA), designed to absorb a significant impact. However, in all too frequently, these protection vehicles are hit. In Missouri, since 2014, over 82 crashes have involved TMAs. In Colorado from 2013 – 2017, the state experienced over 26 traffic incidents that involved the TMA. These numbers pale in comparison to the number of crashes that occur in work zones every year. From 2008 – 2017, North Dakota experienced 664 crashes in their work zones, with over a half dozen involving a truck mounted attenuator.

Incident in Missouri, January 2017:

"We were patching potholes on US-50 and I was following the pothole patcher. I noticed a truck coming close to me so I hit my panic lights to try and get him to get over in the passing lane. He did not and he hit the TMA (truck mounted attenuator) I was in. Pushed me over 100 feet. We were both taken to the hospital. I couldn't pick up my kids, couldn't play with them, all because of someone's negligence. This is serious. This is our lives in danger."

- Michael Suber, Missouri DOT Maintenance Worker

Figure 1: Missouri DOT Truck Mounted Attenuator struck from behind by another vehicle in January, 2017.

Every day, we have hundreds of DOT and maintenance operators across the country, that put themselves in work zones and in a vehicle that is designed to get struck, risking their lives simply to improve the quality and safety of our roadways for all.

The Safety Happens in Everyone's Lives Daily (SHIELD) program features a multi-state application by the Colorado Department of Transportation (CDOT), Missouri Department of Transportation (MoDOT), and the North Dakota Department of Transportation (NDDOT). Each state will host at least one formal demonstration in their state of a DOT truck mounted attenuator vehicle in work zone operations retrofitted a specialty automated driving system (ADS) technology that allows the follow attenuator truck to completely remove the human from the vehicle designed to be struck. At the crux of the demonstration will be the fully connected automated attenuator, connecting to the central ADS data system repository, feeding into CDOT's connected vehicle ecosystem. The ADS technology data will be available to the public to consume from the program's website or directly from the application programming interface (API), made available by CDOT's network.

The SHIELD features the demonstration of variety of use cases (detailed below in the proposal) of ADS technology for every day roadway maintenance and operation. The ADS technology proposed for deployment features a leader and follower framework that retrofits ADS technology hardware and software on heavy fleet DOT vehicles.

CDOT serves as the lead applicant, organizer and coordinator of the SHIELD program. CDOT has an established pilot program to pursue, test, and deploy ADS technology for TMAs to drastically improve work zone worker safety. CDOT is a national leader in deployment of the ADS technology for highway maintenance, with an operational program in place and in maintenance operations for two years.

For this program, CDOT and the co-applicants have convened a robust consortium of government, academia, and industry leaders to deploy and demonstrate ADS technology in DOT work zone and maintenance operations. The use case(s) to be demonstrated will be unique to each state partner and will address the three goals of the program: safety, data evaluation, and community of practice. The demonstrations will greatly enhance the ADS technology available by building a baseline dataset that will serve to evaluate system performance, while also building a guidebook for other DOTs and maintenance operations to deploy this technology in their maintenance fleet operations.

At the crux of this program will be the ADS technology data. The program partners will work together to create a baseline dataset that will serve as the standard dataset for any vehicle deploying this ADS technology. The program features the academic expertise of Colorado State University, University of Colorado at Boulder, and the Missouri University of Science and Technology.

Figure 2: Truck mounted attenuator following a slow-moving work zone truck in an urban setting

Leveraging the activities with the Autonomous Maintenance Technology Pool fund (AMT Pool fund), CDOT, MoDOT, and NDDOT will utilize the pool fund community as an outlet to inform, educate, and share resources from the SHIELD program. The pool fund offers the perfect venue to build on the SHIELD demonstration efforts, well after the life of the grant award.

Given the lifecycle and asset management of DOTs, retrofitting ADS into the existing fleet offers a cost-effective way to introduce automation into vehicles, while simultaneously offering flexibility to utilize the vehicle in an automated or manual fashion through the life of the vehicle.

Many DOTs are grappling with constrained budgets and do not have access, resources or expertise to deploy this life-saving ADS technology. This program will not only address the goals outlined in the NOFO but offers considerable opportunity to DOTs across the nation to understand how to integrate these technologies within the fleet and operation, while providing an insight to how data of the ADS technology can help improve the safe operation of these systems.

The SHIELD Program, program managed by CDOT, will take on a task-based approach, featuring a period of performance of five years, culminating in the final evaluation report at the end of the first quarter of 2024. An overview timeline is featured below, with a full detail of the tasks in Section 5 – Approach.

Safety Happens in Everyone's Lives Daily (SHIELD)	2019				2020				2021				2022				2023				2024			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Task Description																								
Task 1: Kick-off and Procedural Test Planning		■	■	■	■																			
Task 2: Data Connection Feed Development and Proof-of -Concept						■	■	■	■															
Task 3: ADS Build and Installation and Field Tests										■	■	■	■											
Task 4: Pilot Tests														■	■	■	■							
Task 5: Demonstrations																		■	■	■				
Task 6: Final Report																					■			

Figure 3: SHIELD Program Schedule

2. Goals

Innovations in vehicle automation and integration of ADS technology into our fleet offers great promise to address some of the greatest issues plaguing our nation's roadways. Many transportation departments across the country are looking to understand how automated and connected technologies can help improve their overall goals of improving safety and mobility for their citizens. While vehicle automation has made great strides in the light passenger fleet, relatively few demonstrations or applications exist that focus on heavy-duty vehicles or vehicles that support various roadway maintenance efforts, such as construction work zones or roadway maintenance operations.

Building on the great success CDOT has experienced with introducing automation to maintenance operations, and together with the partners outlined in SHIELD and the AMT Pool fund, this application will feature the integration of ADS in roadway and maintenance operations, with phased demonstrations that seek to accomplish the three primary goals of safety, data evaluation, and collaboration as indicated by the U.S. DOT (see Figure 4).

Safety   Data Evaluation   Collaboration

Figure 4: SHIELD Data Goals

CDOT led the nation in overcoming challenges in an initial project pilot in 2017 that deployed the first in the nation autonomous impact protection vehicle. With the SHIELD Program, CDOT will build upon their existing pilot project with the AIPV to enhance the data capability of the ADS technology, evaluate the AIPV's ADS technology system performance based on identified data metrics and indicators, the connected vehicle ecosystem, and build greater external Human Machine Interface (e-HMI). CDOT, MoDOT, and NDDOT with the USDOT can continue providing a path forward for demonstration and deployment, legislation, purchasing, fleet integration, involvement of frontline employees that all driven by data of the ADS technology. CDOT and its co-applicants of the ADS Demonstration grant program will continue to guide autonomous technology in the relatively uncharted world of highway construction, maintenance and operations to lay the foundation of worker understanding and comprehension of the autonomous world that will drastically change how DOT's manage the nation's highway infrastructure. This proposal focuses on understanding the data systems and subsequent safety performance indicators of the automated driving system. This gateway concept will aid the growth and understanding of the public sector employee and drive innovation in the work zone environment. The innovation will accelerate the real-time work zone interaction with the public to benefit the public and DOT awareness.

a. Safety

Reducing hazard to roadway workers and achieving a safer environment for both roadway maintenance operators and the public is the paramount goal of this application. SHIELD will feature demonstrations of Level 3+ automated maintenance vehicle technology that will assist DOT and maintenance operations to accomplish activities related to their core mission, that improves safety for the DOT. The demonstrations remove the human from a vehicle that is intended to or highly likely be struck by another vehicle, while completing work activities. For example, in Colorado, an automated truck mounted attenuator has been utilized to follow a DOT vehicle that applies fresh paint to the roadway. In the past, the a CDOT worker drove a truck mounted attenuator, that would follow the paint striping truck that operates at a very slow speed in order to apply the paint correctly. The paint truck must operate not only on urban roads, but also on the highways and interstates, with surrounding traffic going at highway speed. In many instances, the (human driven) truck mounted attenuator has been struck by surrounding traffic that were not aware, prepared or focused on the driving task to avoid coming up on the slow-moving paint striping vehicle. **The primary goal of the SHIELD Program is to remove our safety, highway and maintenance roadway workers from situations and scenarios in which they are waiting to be struck by another vehicle.**

Figure 5: CDOT's Autonomous Truck Mounted Attenuator Pilot Program during testing in 2017

In the last eighteen months, the investment of staff hours and organizing effort of the pool fund has carefully built a foundation of collaboration lead by CDOT. Utilizing the pool fund will accelerate the grant deliverables using the established the framework needed to effectively and consistently deploy the technology. The grant opportunity will solidify the strategic direction of safety and collaboration and fully develop the data environment in a scalable fashion that DOT's can take and implement.

Building on CDOT's experience and the AMT Pool fund, SHIELD will deploy, test and demonstrate how ADS can be integrated into everyday roadway and maintenance operations across several states and jurisdictions. CDOT, MoDOT and NDDOT will all receive the autonomous impact protection vehicle retro kits that can be integrated into their DOT operations. Additionally, the program leverages partners within the pool fund to expand demonstrations to pool fund members that are not solely called out as individual partners in this program. Not only will SHIELD deploy and demonstrate the technology to a great capacity than currently done, but SHIELD will build on greatly enhance the ADS by deploying more complex technology into the maintenance vehicle's automated driving system via higher powered camera, radar, and connected vehicle technology. Recognizing the safety of the traveling public, including those operating around the automated maintenance vehicle, the SHIELD partners see tremendous benefit to applying connected vehicle technology to the automated maintenance vehicles to inform and alert other drives of the vehicle's presence.

Many transportation departments and DOT officials across the nation are grappling with how to integrate ADS into their operations: what technology is available, what is its viability, how does it fit into the asset management plan of the department, how can it be best integrated with current mission critical activities, etc. This program will integrate ADS on top of several different types of maintenance vehicles, addressing a variety of use cases related to roadway maintenance. Each state partner will have their own set of unique use cases for their state, that ultimately seeks to remove the human driver from the unsafe slow-moving vehicle.

b. Data Evaluation

The rapid technological innovation introduced into vehicles in the last few years, have transformed vehicles from mechanical-based systems to higher powered computer and electronic data systems. Vehicles today are increasingly connected with telematic and navigation systems, in addition to hundreds of sensors and cameras. Each of these items possess the capability to create information or data. Understanding how to capture, collect and analyze this data offers immense capability to evaluate the system performance of the ADS. All demonstrations in the SHIELD program will feature the evaluation of capturing data from the ADS, using that data for ADS performance evaluation and connected vehicle applications, and coming together to scientifically evaluate the data, share lessons learned in the Community of Practice to continually evolve and improve the robustness of the data.

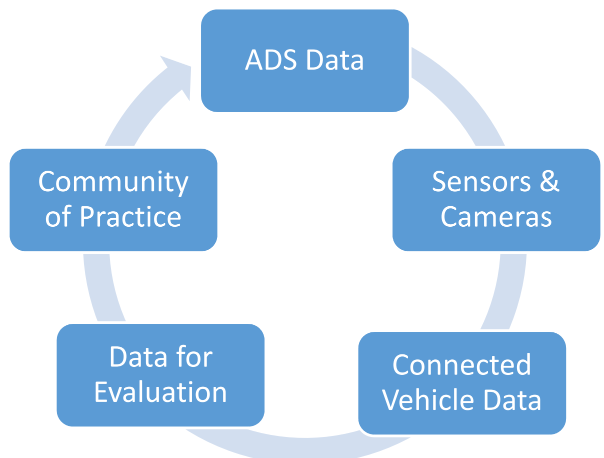

Figure 6: ADS Data Circle

Utilizing the collective expertise of the programmatic and academic partners, the crux of this program focuses on data. The data evaluation goals of this program features two components: (1) data evaluation of ADS performance for safety and (2) connected vehicle benefits of ADS that are discussed in detail in Section 4. Additionally, with the work of the academic partners, the team will evaluate the data for opportunities to provide insight and understanding to other elements such as data management needs and system security and privacy. All data collection and evaluation efforts seek to provide the USDOT and the fellow community with an ADS technology dataset that can inform ADS safety performance and serve as a proof of concept of the how ADS data can be collected, stored, and made available for public use.

The initial data evaluation goal of ADS system performance focuses on development of a methodology to evaluate the design, performance, and functionality of the ADS technology specific to each use case. Leveraging the collective expertise and experience of SHIELD's academic partners in computer science, systems engineering and human factors, the team will evaluate the system performance of the ADS, while developing a framework dataset that can be applied to a number of heavy-duty maintenance operation fleets utilizing similar automated driving system technology. This initial framework dataset and methodology will serve as a baseline for the USDOT to evaluate the data of an ADS as it is integrated on top of a production heavy-duty maintenance vehicle. This is a critical component, as integration of ADS on top of production vehicles may be viable, practical and cost-effective solution for DOTs and transportation officials across the country. The dataset will feature the integration of the production system and the ADS, including the system performance data that are available to be collected. Along with the university partners, the team will develop a full guidebook that explains how to collect data from the ADS and production vehicle, the data collected, the definitions and description of the data, and how to evaluate the data. Initial work will be completed alongside the USDOT to build the dataset. The academic partners will conduct thorough review of the possibility of data to be gleaned from the system and build the applicable hardware and software capability to collect and store the data during an automated operation of the vehicle.

U.S. DOT Preparing for the Future of Transportation, Automated Vehicles 3.0

"Voluntary data exchanges can help improve the safety and operations of ADS and lead to the development of industry best practices, voluntary standards, and other useful tools."
(Page 30, U.S. DOT, 2018)

The SHIELD Program will explore leveraging Colorado's connected vehicle ecosystem and data intelligence management system to connect all ADS demonstration datafeeds during testing and for the demonstrations. Building on this knowledge base and network development, CDOT will work their program partners to implement the API, cloud-based approach for the ADS technology datafeeds generated for the SHIELD Program, allowing free flow public access to the data system. Part 3 – Draft Data Management Plans fully details the assets and resources currently available that can serve the SHIELD Program. Additionally, CDOT commits to making the data available well after the period of performance and is agreeable to signing a data sharing agreement with the USDOT.

The secondary data evaluation goal focuses on the testing, deployment and evaluation of the connected vehicle benefits that are possible from the ADS integrated on maintenance operation vehicles. This goal features two elements. The program will evaluate the ADS performance data for utility to improve real-time operation and to inform the traveling public of the vehicle and/or the environment around the vehicle. For example, if a real-time data stream of the maintenance vehicle's slow speed on a high-speed corridor can be provided to roadway operators that in turn warn drivers via the infrastructure, then this may be connected vehicle information that can help improve safety immediately. A variety of use cases of the data will be evaluated for its benefit to improve safety to the traveling public that may interact with the vehicle. **Additionally, other connected vehicle applications will be assessed to help inform**

the system of possible dangers ahead and will be unique to the data systems available in each partner state.

The final data component of this program features the development and evaluation of an external Human Machine Interface (e-HMI) for communication with other road users. The e-HMI will pull various ADS data elements and use this data to communicate vehicle state and intent with nearby road users in two facets: communication on a message board and inputs to the connected vehicle data applications. The interface will be digital and dynamic in nature. It is not uncommon for current attenuator or other slow-moving maintenance vehicles operating on the roadway to have some external signage to alert nearby road users of the vehicle's slow speed or the job it is performing. However, many automated vehicles manufacturers and testers are recognizing the opportunity to have an external interface that communicates state and intent of the vehicle to other road users. The presence of an e-HMI system can help surrounding road users easily identify the presence of an automated vehicle (AV), the AV's state and intent, and the automated vehicle's awareness and confirmation that the AV also "sees" the surrounding road users.

Figure 7: An example of external messaging on a manually-operated attenuator truck

For example, leveraging the vehicle's ADS, the e-HMI could communicate the vehicle's intent to surrounding road users that the AV is about to come to a complete stop or decrease its speed. This information could not only be presented in the e-HMI interface, but also be featured in the connected vehicle ecosystem to communicate with drivers well before they come upon the vehicle. Led by the academic researchers, the program will investigate and explore the possible message types and e-HMI systems that can be placed and integrated on the back of the automated impact protection vehicle. As displayed in Figure 7, a very basic version of an external communication interface is commonly used on attenuator and other maintenance vehicles. However, by leveraging the data from the ADS technology, a more digital and dynamic interface can be implemented and utilized on the back of the vehicle to inform other drivers of the vehicle's Various messaging prototypes will be researched and identified by the project team and its academic partners. For example, several automakers are exploring the value of e-HMI in their ADS All message types will be tested and demonstrated throughout the demonstrations (see Figure 9 and Figure 8). Simultaneously, technology on the vehicle will capture surrounding road user's reaction and behavior to the automated maintenance vehicle, and this data can be evaluated in aggregate to understand the performance and possible effect of the e-HMI presence. Finally, the program partners will conduct surveys within their own states, targeted to those on the public roadway that traveled near the vehicle to solicit their quantitative and qualitative feedback on their experience, perceptions, and opinions of the e-HMI system.

Figure 9: The caution screen is an example of an e-HMI used by EasyMile, an autonomous shuttle company. This screen alerts nearby road users and pedestrians of the vehicle's intent and state. In this example, the vehicle is communicating it makes frequent stops and advises surrounding road users to not follow too closely.

Figure 8: An example of an e-HMI tested by Daimler to communicate that the ADS technology "sees" and detects the presence of the pedestrian.

c. Community of Practice

CDOT and its program partners have already realized the benefits of fostering a collaborative environment via the AMT Pool fund. Building on these efforts, the SHIELD program team will build a Community of Practice not only within our three DOT program partners but will also leverage groups such as the AMT Pool fund as the demonstrations are planned, developed, and deployed. Feedback from those in the pool fund will be a critical element as they can serve as peer reviewers to the testing and deployment of the ADS for maintenance vehicles, while also benefiting from the activities and lessons flearned from the demonstrations. The ADS technology utilized in the SHIELD program could easily be scaled and applied to the pool fund members that have this technology. The Community of Practice builds an outlet for collaborators, industry and academics to exchange information, best practices, data, and lessons learned around further testing and deployment of the ADS maintenance technology.

Colorado Department of Transportation (Lead Applicant)

Missouri Department of Transportation (Co-applicant)

North Dakota Department of Transportation (Co-applicant)

Colorado State University

Autonomous Maintenance Technology Pool Fund

Missouri University of Science and Technology

University of Colorado (Boulder)

North Dakota State University

Kratos

Royal

Figure 10: SHIELD Program Partners

The Community of Practice provides an ideal circle of constant learning, evaluation and improvement to the overall program and aligns with the spirit of the U.S. DOT Preparing for the Future of Transportation, Automated Vehicles 3.0. The SHIELD Community of Practice will facilitate government officials, industry and academic collaboration to consistently share lessons learned from the demonstrations, improve and strengthen each demonstration based on previous lessons learned, share data findings and opportunities, navigate through challenges (regulatory, technological, or data), and constantly improve the technology, standards, and subsequent practicality for deployment of these vehicles. Additionally, the Community of Practice will provide a welcoming atmosphere for others across the country and nation to be part of the monthly teleconferences and in-person workshops to engage directly with the deployers of the technology. Various educational and instructional materials will be created throughout the demonstrations and Community of Practice that will be made publicly available on the program's website.

3. Focus Areas

The demonstrations primarily feature four of the focus areas described in the NOFO: significant public benefit, addressing market failure or other compelling public need, complexity of technology, and diversity of project, but also reach to the remaining four focus areas. This section details how this program aligns with each of the four major focus areas.

Significant Public Benefit

Traffic incidents create unsafe situations for motorists and pedestrians, put motorists' and responders' lives at risk and cause delays. Roadway maintenance operations and work zones are a vital component to ensuring our nation's roadways are safe for the traveling public. Roadways throughout our nation endure heavy traffic, all four seasons and daily wear and tear. Keeping these roadways in pristine condition is an integral component for DOTs across the country to ensure people and goods can move freely among the region and nation. According to the U.S. Federal Highway Administration (FHWA) Fatality Analysis Reporting System (FAR), in 2015, there was an estimated 95,626 crashes in our work zones, with an average crash occurring every 5.4 minutes, 70 crash-related injuries every day, and 12 crash-related fatalities every week in our work zones (FHWA, 2015). Any crash on our nation's roadway greatly threatens the overall safety of our workers and traveling public and the mobility of our roadways. The most concerning element is that we have vehicles designed to be hit and we are fully aware of the significant likelihood they will be hit. Since 2014, MoDOT has had 82 crashes involved truck mounted attenuators for various work zone efforts. Reducing work zone crashes with automation offers the ability to immediately improve the safety of human life by removing the worker from the impact vehicle, while leveraging data to inform other drivers of the vehicle's presence. These demonstrations focus on leveraging and understanding how data can warn other drivers, road users, and operators of the presence of these vehicles to avoid crashes from beginning in the first place.

Addressing Market Failure and Other Compelling Public Needs

DOTs are faced with ever rising demands to maintain aging roadways, replace infrastructure, while ensuring smooth operation and mobility of our roadways. Many DOTs face competing budgetary requests between maintaining or replacing aging equipment, various infrastructure projects, while ensuring the greatest public benefit possible. While ADS technology offers great promise to drastically improve the safety of an employee, a DOT is faced with the decision to purchase one new technology vehicle kit versus replacing several fleet vehicles. The complexity and the recent introduction of the technology makes the entry into market considerably high and difficult to justify for DOTs that are facing competing procurement pressures. This program would not only demonstrate the technology's capability in everyday operations for DOTs but assist with greater deployment of the technology among the program partners, while encouraging collaboration and further research and development of the technology, which will continue to allow innovation to spur, hopefully bringing the overall cost of the technology down in future years.

Complexity of Technology

Vehicle automation efforts have largely focused on light duty fleet operations such as the passenger vehicle and small, slow speed buses. Due to the complex nature of heavy fleet vehicle's architecture system, few entities are demonstrating automated driving systems on heavy fleet vehicles. To date, CDOT has the only heavy fleet vehicle on the public roadway that has operated in autonomous mode, without a human in the vehicle. The demonstration will expand this pilot nationwide to remove as many workers from a vehicle that is designed to get struck, while evaluating ways we can improve communication and education regarding the ADS maintenance vehicle operation to surrounding road users.

Economic Vitality

One crash on our nation's roadway can consequently effect on travel times, congestion, operating costs, and environmental emissions. For example, between 2008 and 2014, Colorado experienced 21,898 crashes and 171 fatalities in work zones. Anytime a crash occurs, a lane blockage is highly likely to occur to address the crash scene. In Colorado, traffic is delayed by four minutes for every minute a lane is blocked. For example, if a lane is blocked for 30 minutes, traffic could easily be delayed up to 120 minutes.

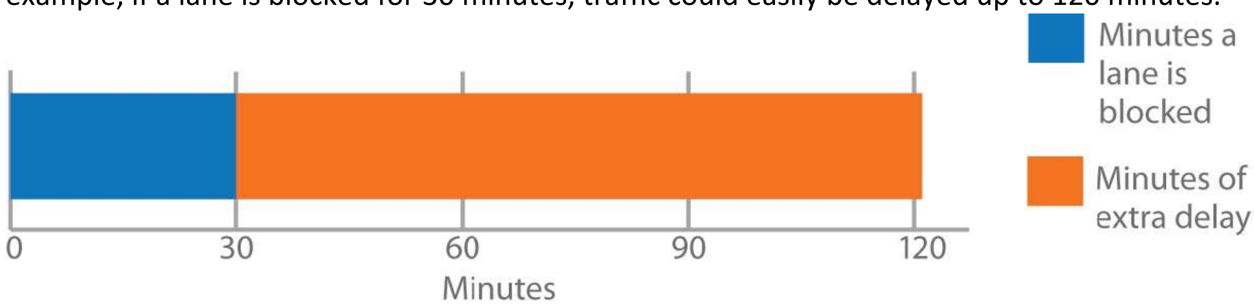

Figure 11: Time impact by one lane blockage (CDOT)

These numbers compound to other societal impacts as well. According to X, the amount of fuel wasted annually due to being stuck in traffic is 2.8 billion gallons. Being stuck in traffic impacts the free and efficient movement of people, goods, and services and disrupts our overall national productivity.

ADS technology that has the potential to improve the occupational safety of workers, may aid in addressing safety concerns and fears by individuals that would otherwise be interested in obtaining their commercial driver's license (CDL) and working in DOT and maintenance operation. Additionally, this technology offers new perspective and experience to those with their CDL. These technologies may spark interest and attract new talent to obtain their CDL by those interested in the technology and wanting to learn and be part of ADS technology.

Diversity of Projects

The demonstrations in this proposal will test and deploy ADS technology on roadway and maintenance operation heavy duty vehicles. The outcomes of these demonstration tests will prove the ADS technology in a variety of expanded maintenance operation use cases and may identify few opportunities within DOT, maintenance and work zone operations that are ripe for this automated technology. While CDOT and others in the AMT pool fund have had success with the automated truck mounted attenuator and other impact protection vehicles, demonstrations in the partner states will expand the use cases to operations such as paint striping, cone setting, work zone setting, mowing and others to be determined during test planning. The demonstrations offer the ability to scale this technology to maintenance, DOT, and roadway operations for any scenario that involves a slow-moving vehicle interacting with high-speed volume traffic. These concepts in these demonstrations can be applied to urban, rural, and suburban settings that require their slow-moving heavy

Prototypes

fleet to operate alongside higher speed or inter-city traffic volumes. Additionally, these demonstrations explore new prototype frontiers with e-HMI systems, rarely done in current deployments, proof of concepts and demonstrations.

4. Requirements

The demonstrations will feature a phased approach to prepare, evaluate, test, and deploy the maintenance vehicle ADS technology specific to each partner's specific use case(s). Each state will have at least one demonstration, but it is anticipated that there will be several demonstrations in each state throughout the period of the award. The section below details the overall demonstration and the ADS technology.

The Demonstrations

Each partner site will research, evaluate, plan, test, deploy and demonstrate the ADS leader/follower technology specific to their identified use cases, which will be determined by each partner following award (possible. As outlined above, the demonstrations focus on integrating technology into daily maintenance and roadway operational use cases. These demonstrations focus on slow-moving vehicle operations that are likely to get struck as they operate around higher speed road users that may not be paying attention or expecting a slow-moving operation.

Possible Use Cases

- Attenuator or impact protection vehicle in work zones
- Paint striping
- Work zone set up and cone setting
- Pothole and roadway repair

Figure 12: Possible Use Cases and Applications the Automated Maintenance Vehicle Demonstrations

These demonstrations expand and introduce the technology to greater additional use cases that are ripe for mobile traffic control zone barriers. These demonstrations will explore additional use cases within highway maintenance that a mobile traffic control zone could improve safety such as cone setting, mowing or right of way maintenance, and other work zone use cases. Additionally, this program will explore testing in more urban and suburban settings that a traffic control zone could improve the safety those work zone workers in urban settings as well. Additionally, technological improvements in the way of ultrasonic sensors, lidar, and improved software algorithms will be tested on the Colorado and Missouri autonomous impact projection vehicles. Colorado and Missouri will evaluate the improved technology's accuracy, safety performance and applicability to other use case scenarios to continue to scale the technology and improve its overall performance.

Each of the three DOTs will come together to finalize the overall phased demonstration plan including, each state's targeted demonstration use case(s), and prepare to execute the tests and demonstrations to be conducted in each state. The phased demonstration approach allows the Community of Practice to come back together at critical points in the program to leverage and build upon the experiences and lessons learned from each individual group, promoting the sense of collaboration and strengthening all demonstrations. Full description of the approach is detailed in Section 5, Approach.

Each state will have a significant testing period that will prepare the team for the deployment onto the roadway. Additionally, the testing period ensures correct setup and production of the ADS technology installation and the ADS Performance dataset. Each partner will plan, bench test, field test, pilot test, and finally deploy on the public roadway (Figure 13 showcases the differences between each phase).

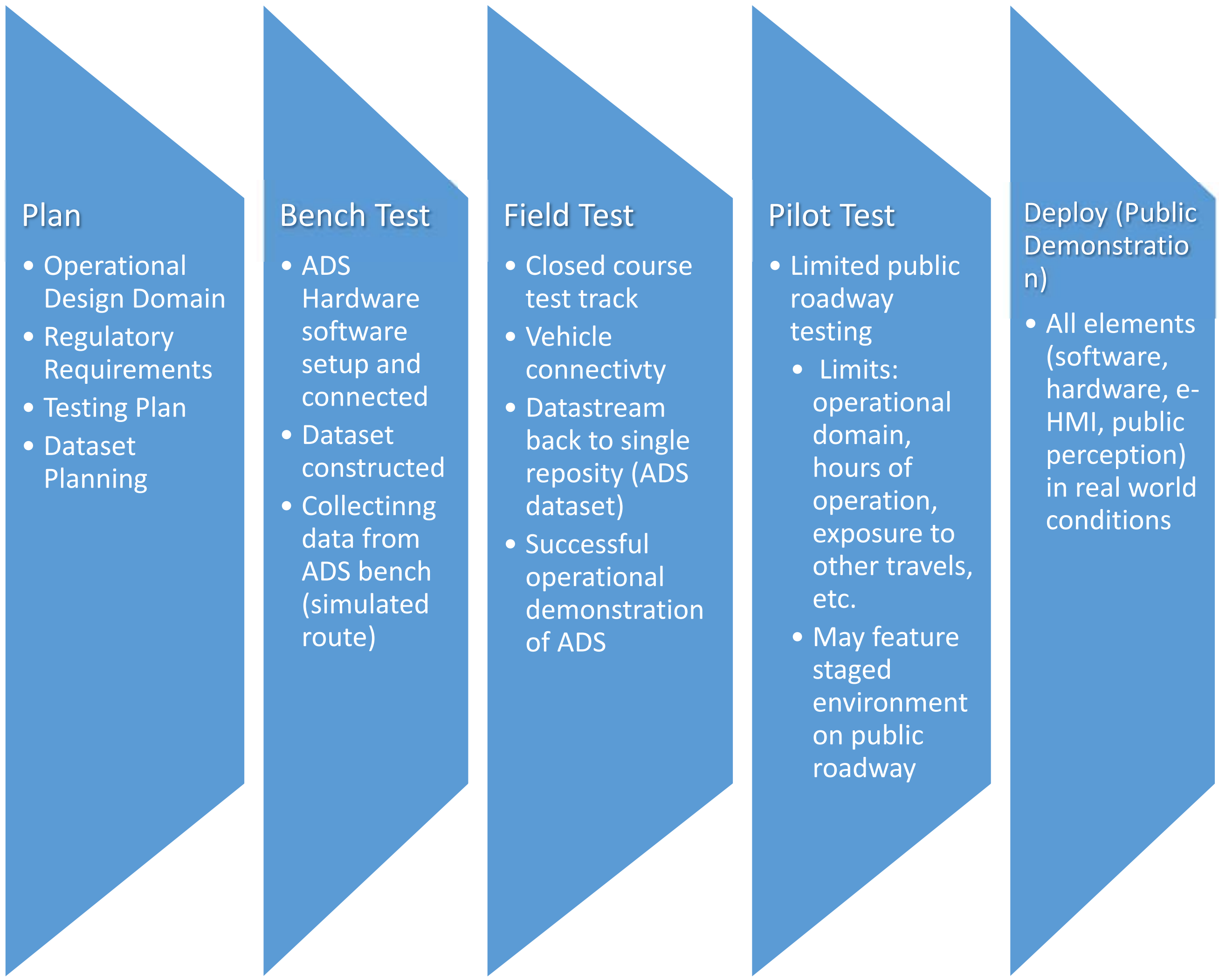

Figure 13: SHIELD Demonstration Deployment Plan

The academic partners will build the dataset repository necessary, based on initial bench tests of the ADS technology and its underlying technology. The academic partners will work together to build a standard dataset that will collect and massage the data that will be evaluated throughout the project and made available for public consumption. Data validation of the ADS technology performance, including all data elements and the dataset set up and connection to the vehicle will be conducted during the field tests. After the state has passed all testing components including: regulatory considerations, system performance validation, and data validation the state will identify and announce their initial demonstration that will occur on the public roadway. The demonstration will feature the unmanned follower impact protection vehicle, protecting the Leader vehicle carrying out its roadway maintenance operation. The demonstration will occur with the traveling public around the vehicle. Each demonstration will feature the four critical elements noted in Figure 14. Additionally, the academic partners will work closely with the DOTs to capture full operating procedural plans to capture and evaluate all tests and demonstrations, including video in the cab and exterior to be coded later, a pre- and post-drive evaluation to note any irregularities or safety concerns identified by the safety operators during the drive, that can later be assessed and evaluated by the academic partners.

Level 3+ Demonstrations	Data Collection	External Human-Machine Interface (e-HMI)	Community of Practice - Knowledge Transfer
•Autonomous Impact Protection Vehicle Demonstration on state highway and interstate in Colorado, Missouri, and North Dakota	•System Performance via ADS cameras, sensors, lidar •Connected vehicle application •Surrounding road users behavior collected from autonomous vehicle •Human factor considerations (lead driver, safety operator, and remote traffic operations receiving the connected vehicle data)	•Demonstration of external communication to other drivers via e-HMI prototypes (variable message sign, connected vehicles, navigation smart phone applications) •Public perception surveys	•Technical conference calls (open to the national) •Annual summit to share findings among partners and demonstrate the technology •Share research and data validation findings from ADS data

Figure 14: Automated maintenance ADS technology demonstration components

As outlined in the Section 5, Approach, the program team will create a public facing website that will serve as the repository of all program information, including upcoming technical meetings, workshops and summits by the partners, past meeting minutes and all program documents and reports, outreach materials, the guidebook, and all datasets. This will include public accessibility on the program website of the ADS Performance dataset from the point of the initial bench tests through the final demonstrations. The website will feature a guidebook how to set up the demonstration from the initial stages of planning for a vehicle purchase, to procuring the equipment, navigating regulatory challenges to all elements of deployment, including how to prepare and set up a dataset for an automated maintenance vehicle utilizing the Leader/Follower ADS technology featured in these demonstrations. The program team connect the website with the AMT pool fund to provide greater opportunity for the data and materials from the demonstrations to be available well beyond the five-year period of performance requirement.

As part of the Community of Practice – Knowledge Transfer demonstration component, the program will host an annual summit led by the CDOT, MoDOT, NDDOT and the academic and industry partners in this proposal. The summit will be fully open to the public and those in the industry interested in learning about the demonstrations and the opportunities they may have within their operations to integrate ADS technology into their maintenance and roadway operations. The summit will include deployment experience of the technology on a closed course track, information sharing by each partner in SHIELD, a "how-to" on integration and deployment of these systems in DOTs, data evaluation and data setup, and research conducted by the academic partners including: human factors and public perception, cyber security, and system performance. The SHIELD team believes in an open format of the entire program to support the overall AMT pool fund goal of increasing deployment. By encouraging nation-wide observation during all elements of the SHIELD program, the team believes freely available information and open-door collaboration will make it easier for burdened DOTs and transportation departments across all jurisdictions to have access to the resources they may not have within their own department or have the financial means to acquire such expertise or information. This program has true potential to empower and arm DOTs with information learned by the program partners to help spur greater deployments across the country, all the while building a community that can support, learn and grow together to improve safety on roads nationwide.

The Technology

The demonstration technology is a driverless Leader-Follower application solution adapted with redundant navigation, front/side view obstacle detection, encrypted vehicle to vehicle communication and emergency stopping/takeover systems. The ADS technology is added onto the production maintenance vehicles utilizes military innovation that features Leader/Follower technology of a Lead Vehicle (manned), followed by the unmanned Follower vehicle operated by ADS technology (see Figure 15). The ADS technology features a retrofit kit that is installed onto an existing fleet vehicle, making it cost effective for DOTs that may not have the funds to purchase a brand new vehicle. The technology, originally created for the U.S. military, and features the "bolt-on" Leader-Follower hardware that includes components installed in the Leader Truck (LT) and driverless (FT).

Figure 15: CDOT Leader/Follow ADS Technology

Operating on top of the hardware are the software control algorithms and modules that capture the movements of the Leader vehicle and are applied to the Follower vehicle. The software control algorithms have been optimized for work zone applications and have countless hours of testing and "lessons learned" incorporated for improvement of the ADS technology. The leader vehicle transmits high-accuracy speed, position, and heading information to the follower, so that the follower can exactly match the leader's path while maintaining a set gap distance. A radar provides obstacle detection capabilities and will cause the follower vehicle to stop if an object is detected in the vehicle's intended path. Emergency stop buttons in the leader vehicle and on the exterior of the follower vehicle provide a method of both stopping the follower and shutting the vehicle down. A human in the lead vehicle is tasked with monitoring the follower vehicle and is able to initiate an emergency stop at any time.

All operational aspects of the vehicle are controlled by the installed automated system, and the system inputs come from the movement of the leader vehicle, which is human driven. Monitoring of the vehicle systems and roadway is done through software in the automated system and through a front mounted radar unit. A human operator in the back of the lead vehicle, with the sole task of monitoring the performance of the follower, is present throughout the demonstration to provide backup monitoring of the roadway environment.

All tactical aspects are also controlled through the movements of the leader vehicle. If the leader vehicle changes lanes, moves to avoid an object, etc., the follower will make the same maneuvers at the position that the leader vehicle made them. Radar detection of an obstacle during any of these maneuvers will cause the vehicle to emergency stop before hitting the obstacle. The slow speed of the demonstration (7 mph) makes response to events relatively low risk due to the extremely short stopping distances at that speed.

The ADS technology features the components noted in Figure 16.

Functional Assembly	Leader	Follow
System Control Unit (SCU)	●	●
Independent Emergency Stop (E-Stop)	●	●
User Interface ToughPad™		●
Operator Control Unit (OCU)	●	●
External E-Stop Buttons		●
Steering, Brake, E-Brake & Accel. Actuators		●

Figure 16: The Follower Autonomous Impact Protection Vehicle System

The System Control Unit (SCU) serves as the central software component to the ADS technology operations and provides communication and programming technology between the Leader and Follower vehicle. The Independent E-Stop provides a failsafe for emergency stop capability that shuts down the automated follower vehicle. Loss of vehicle power or deterioration of the Independent E-Stop vehicle to vehicle communications automatically triggers an Independent E-Stop. Additionally, external E-stop buttons can be installed onto the left, right, and front exterior of the Follower vehicle. The principal hardware components that executive the driving task autonomously are the steering, brake and throttle actuators. The System Control Unit (SCU) interfaces with the three actuators to control the vehicle direction, speed, and braking. Finally, integrated into the overall ADS technology is obstacle detection that is based on radar on the front of the vehicle. When an obstacle is detected, an E-stop action is automatically triggered.

The technology kit includes an advanced user interface that provides full overview of the ADS to the safety operator. The interface (Figure 17) includes feedback of all system redundancy including navigation, obstacle detection, side view obstacle detection, live video view of the follower vehicle, and the vehicle to vehicle radio communication.

Figure 17: Automated Maintenance ADS Technology User Interface

5. Approach

The following section outlines the SHIELD program's technical approach. The team will execute a task-based approach to research, evaluate, plan, test, deploy and demonstrate the ADS maintenance technology over a period of five years from the date of award (the estimated schedule by task can be found in Figure 3). CDOT will serve as the lead entity to organize, coordinate and manage the program's activities and administrative requirements. The tasks outlined below all achieve the below program objectives:

I. Enhance DOT developments to move from pilot to real-time operations
II. Develop data driven focus with the university partners to evaluate the safety performance of the ADS technology, human factor considerations, and connected vehicle and e-HMI benefits
III. Expand deployment in multiple states by demonstrating the technology and its integration with real-time roadway maintenance operation

Tasks

The following tasks will be coordinated and led by CDOT, in cooperation with their program partners.

Task 1: Project Kick-off and Procedural Test Planning

Task 1 will bring all program partners to discuss the overall program and finalize the Project Management Plan (PMP) to prepare for execution of the overall program. The initial kick-off meeting will be three weeks after award with the key program staff and the USDOT to discuss scope, deliverables, major milestones, project execution, data management and the timeline. Following the kick-off meeting, CDOT will finalize the PMP, with input and coordination from the program partners.

Additionally, CDOT and its program partners will draft the Procedural Test Plan that will detail all test elements for each partner, including:

1. **Use cases** specific to each partner for deployment of the automated impact protection vehicle (paint striping, mowing, cone setting, etc). E-HMI prototyping.
2. **Retrofit Installation** of the technology into the partner fleet including timeline, validation testing, etc and development of the e-HMI component.
3. **Regulatory requirements** to be addressed by each partner specific to their jurisdiction.
4. **Bench tests** (location, coordination with academic partner, timeline, and finalization of the datafeed for the data exchange, e-HMI testing)
5. **Field tests** (location, timeline, datafeed integration, research evaluation, other requirements)
6. **Pilot tests** (location, timeline, datafeed test elements, research evaluation, other requirements)
7. **Deployment** (location, timeline, datafeed test elements, research evaluation, other requirements)

The Procedural Test Plan will cohesively bring together the deployments by each partner outlining the seven items bulleted above. The document will be made available on the program's website for others to understand all elements of the testing and deployment, including the data captured and evaluated at each phase.

Task 2: Data Connection Feed Development and Proof-of-Concept

Task 2 will include full assessment of the needs to build the datafeed connection to the ADS technology. The datafeed connections from the vehicle will serve three primary tasks: (1) capturing data for the safety performance of the ADS technology system, (2) e-HMI data inputs and data generation, and (3) capturing, storing, and presentation for all connected vehicle application. This task will evaluate the architecture necessary to build the framework for one central repository (hosted by CDOT) to capture all data for the safety performance assessment by the academic partners and evaluating which data can address various connected vehicle applications such as those identified in Figure 18.

Connected Vehicle Applications

- Stopped Vehicle
- Slow Moving Vehicle Warning
- Construction Zone Ahead
- Worker on Road Ahead

Figure 18: Examples of possible connected vehicle applications applicable to the impact protection vehicle

Figure 19: RTK Antenna located on the follower vehicle

Task 2 will begin with procurement of the vehicles, all ADS technology retrofit kits, and any datafeed storage capacity needs for the program[1]. This task will include establishing a cellular connection to the vehicle. By establishing a cellular connection from the underlying computer system and the ADS technology, the network team will evaluate the architecture necessary to capture and store data necessary for evaluating, while identifying the mechanism that can send and present connected vehicle data directly to roadway operators that can in turn inform roadway users of the autonomous vehicle. This may include assessment of software architecture needs in way of ensuring security, access to the data by the program partners, data broker needs, and other elements. This task will culminate in a bench test that proves out the datafeed connection from each partner's ADS technology to the data repository server on one network, and identification of the connected vehicle data and any segmentation needs to be presented and usable for daily roadway connected vehicle application needs by roadway operators. The bench test will utilize the software and hardware from the ADS prior to installation, to allow for flexibility of any necessary changes,

[1] All procurements will comply with the Buy American Act.

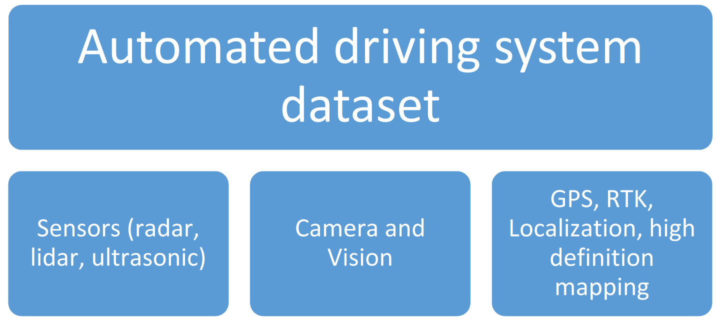

Figure 20: Inputs to the Automated Driving System Performance Dataset

based on the system architecture. The datafeed connections established during the bench test feature actual connection to the network repository server, where all data will be stored. CDOT offers a wide variety of experience in data system development and management. As outlined in Part 2 – Management Approach and Part 3 – Draft Data Management Plan, the program team will explore the various network and architecture options and decide which approach to utilize for the central data repository. Task 2 will also culminate in the creation of the proof of concept pilot dataset that will be utilized to capture the ADS technology performance. During this task, led by the academic partners, the researchers will evaluate the ADS elements such as the camera, sensors, localization and other vehicle architecture data in the CAN-bus that can be collected, captured and stored to evaluate the performance of the system. A pilot dataset will be created and made available on the program's website that details how each data element will be utilized for evaluation of system performance and link to the possible indicators of safety. For example, GPS and localization data combined with lidar data can help inform the lane level precision of the system and identify the metrics that indicate "safe" lane location. The researchers will compile the full profile necessary to indicate safe performance of the system including longitude and latitude control and critical elements of ADS technology's decision making, combined with the system's limitations. Each of these items will be mapped to components of the data elements that will be collected and stored in Figure 20, to identify the ADS Performance Dataset[2]. Every test and demonstration will capture all data elements in the ADS Performance Dataset, building immense data that can be evaluated throughout and after the program to evaluate and identify safety indicators. The bench test allows the team to adapt and make necessary changes, prior to the final installation into the vehicles identified by each partner.

Task 2 will also include the development and prototyping of the e-HMI that will be added onto each Follower vehicle. Led by the academic partners, each deployment will have an e-HMI element that will serve to present various information of the ADS state and intent to surrounding road users. All prototypes will be evaluated, tested and studied to understand minimize any distraction concerns. While the NHTSA guidelines may not uniquely apply to the e-HMI, the academic partners and the program will work closely with NHTSA and others to identify best practices to minimize surrounding road user distraction. The e-HMI prototyping development will also build the architecture necessary to capture the state of e-HMI as a

[2]Please note: Part III of the application package, Draft Data Management Plan provides further explanation into the ADS Performance Dataset.

datafeed, so this can be correlated with the data collection of surrounding road users to correlate possible e-HMI messaging with road user behavior.

Task 3: ADS Build and Installation and Field Tests

Task 3 will take all elements of the bench test and install the ADS technology into the Leader/Follower vehicle. After installation, the team will confirm all datafeed connections back

Figure 21: Field tests conducted by CDOT in 2017 on a defunct airfield (closed course track) owned and operated by Colorado State University. (Left: external view of the leader/follower during the field tests. Right: View of the inside of the automated truck mounted attenuator vehicle).

to the cloud repository and that the system is sending all data, as expected and identified in the bench tests. Additionally, Task 3 will feature the installation of the e-HMI prototype onto the vehicle. Additionally, this task will feature the collection of surrounding vehicle behavior with radar sensors installed on the vehicle. The radar sensors equipped on the follower vehicle detect surrounding vehicle’s speed speed. Utilizing the cellular connection in the vehicle, this data will be captured and stored in the cloud as its own datafeed.

Following installation of all ADS technology elements, each deployment will conduct a series of field tests on a closed course track. All program partners will work with their local jursidictions to identify suitable areas for closed course testing. Both CDOT and Missouri DOT have options currently available for closed course testing. CDOT can leverage a defunct aviation runway, owned and operated by CSU, while MoDOT has access to closed course testing within their university partner, Missouri University of Science and Technology.

The program partners will develop a pre-drive checklist that walks the operators through ensuring all systems are ready for autonomous operation. The checklist will ensure all the hardware and software is operating appropriately, free from debris or obstacles, and that the ADS technology is connected to the cloud for data collection. This checklist will be used any time the vehicle is tested (closed course and/or public roadway) and will be made available on the program website as well.

Task 4: Pilot Tests

Task will feature moving the vehicle to a real-world setting for testing and deployment. Pilot tests will feature the operation of the vehicles in Level 3 autonomy but will feature a safety driver during all pilot tests. As described in the Procedural Test Plan, each deployment will complete several tests that confirm the safe operation of the ADS technology, and that it performs within its expected operational design domain. Task 4 will include any communication to the public as identified during the procedural plan.

The pilot tests will allow the team to evaluate and ensure all ADS technology data is being collected and stored as expected, and the researchers will continue to evaluate the safety performance of the system. The pilot tests will allow the partners to evaluate system performance in a variety of conditions (environmental, traffic, time of day, etc), and compare the system performance as different conditions present themselves. During the pilot test phase, the academic partners will evaluate the ADS technology for system performance, as well as the technology collecting other road user behavior, alongside the e-HMI system. The pilot tests will also test the functionality of the connected vehicle ecosystem, ensuring operators can receive the vehicle information as intended and push it back out to connected vehicles and the roadway infrastructure.

As Task 4 includes the public's opportunity to interact and travel about the automated vehicle, the program partners will begin their outreach efforts to collect quantitative and qualitative data on other road user's perception and interactions around the vehicle. Each state will work with their program partner to identify the survey methodology and mechanisms to collect data from road users that interact with the vehicle. This may include a variety of outreach and marketing efforts prior to the vehicle's public roadway testing period to raise awareness of the vehicle, so that when others come upon the vehicle, they are informed of the vehicle, the tests, and what to expect and how to interact, when coming upon one of these slow-moving automated vehicles.

Task 5: Demonstrations

After the completion of the pilot tests, both DOTs will schedule their official demonstration test. Each state will complete their demonstration plan that identifies all aspects of the demonstration, including the time and day, all data elements to be demonstrated, and any outreach or marketing that may be done with the general public. The U.S. DOT will have significant notice to participate in the demonstration as they would like. Additionally, given there will be a video feed into the Leader/Follower vehicles, the program partners will have the option to display a remote live view into the demonstration. The live view will feature view of both vehicles, surrounding view

Figure 22: CDOT maintenance employees conducting early testing of the autonomous truck mounted attenuator (2017)

of other road users, the e-HMI system, and various data from the ADS technology capturing the vehicle's state and intent.

Task 6: Final Evaluation Report

Task 6 will include all necessary federal reporting throughout the term of the project and the final report for the U.S. DOT. The final report will capture all necessary information required by the funding, as well as lessons learned, benefits of the program, and the evaluative outcomes of deployment, and the full details of the ADS technology data for system performance and evaluation including a high-level overview of the data and research findings. The report will be made available on the program website.

Potential Regulatory, Legislative, Environmental or other obstacles

Regulatory and Legislative

As part of the Procedural Test Plan for each state, the DOTs will ensure any regulatory, legislative, environmental and other obstacles that may be caused by Federal, State, or local requirements are addressed. Both Colorado and Missouri already have mechanisms and the process necessary in place to conduct testing that does not meet federal and state standards, and both states have the framework necessary to conduct the demonstrations and testing detail in this application. NDDOT has conducted exploration into the deployment of autonomous vehicles and will utilize those existing resources to deploy and assist with the demonstrations.

Though not anticipated, the SHIELD project team understands that regulations and legislation could always arise that hinders free development or use of these technologies. The SHIELD project team is comprised of a number of individuals who are highly-respected in the state's transportation community. Their expertise and connections will greatly help to mitigate the risks associated with new regulations that may arise at the state level. The program will build on CDOT's success of initial deployment of the technology. The current deployment of CDOT's automated truck mounted attenuator is overseen by the Colorado Autonomous Mobility Task Force. CDOT Division of Highway Maintenance in partnership with CSU, has continued already completed a robust test plan that included the application to the task force and various field validation tests detailing the technology performance. Efforts in Colorado will build on an enhance the currently approved application by the Autonomous Mobility Task Force. Additionally, the SHIELD Program can utilize the existing field validation tests as a building block for the Procedural Testing documents.

In 2017, MoDOT issued a request for proposal to test the use of automated vehicles in striping operations. The testing is overseen by district personnel, and the endeavor features a multidisciplinary team including Maintenance, Communications, Innovations, Risk and Benefits, General Services, and the Chief Counsel's Office.

Both CDOT, MoDOT, NDDOT will leverage the avenues, channels, and organizations necessary should this grant be awarded. The vehicles will be plated, owned and operated by each DOT. As detailed in the support letters, both organizations have full commitment from those already involved in various elements of the current deployments.

Federal Safety Standards

The ADS technology planned for this program focuses on hardware and software retrofitted on top of a production heavy fleet vehicle. Because the heavy fleet vehicles are production vehicles purchased for state DOT operations, they meet all Federal Motor Vehicle Safety Standards as the standard vehicle. The retrofit kit does not decrease the functionality of any of the interfaced components or remove any components or functionality.

Risk Management

SHIELD will be led, managed and conducted by CDOT, in partnership with MoDOT, and NDDOT. The SHIELD team is staffed with a diverse range of engineers, developers, technicians, researchers, project managers, and communications experts with experience in implementing innovative automated and connected technologies. CDOT's project management teams brings a wealth of experience not only in risk management, identification and mitigation for a variety of project, but the team has unique experience in risk management with connected and autonomous vehicle technologies. The team will utilize Project Management Institute (PMI) best practices for risk identification, mitigation, and management. The dedicated project manager from each state will work with the overall program management team (PMT) to maintain and track all identified risks, which will be maintained in the project risk register. The risk register will be updated weekly between the three state DOT project managers, with coordination occurring bi-weekly to track and manage the risks accordingly. Additionally, an escalation process will be put into place for any critical risks, with the team assigning risk scoring, based on the probability and impact of the risk (see Figure 23).

Probability				
	Very Likely	Acceptable Risk (medium – 2)	Unacceptable Risk (high – 3)	Unacceptable Risk (extreme – 5)
	Likely	Acceptable Risk (low – 1)	Acceptable Risk (medium – 2)	Unacceptable Risk (high – 3)
	Unlikely	Acceptable Risk (low – 1)	Acceptable Risk (low – 1)	Acceptable Risk (medium – 2)
	Ocurrence / Impact	Low	Moderate	High
Probability x Impact = Risk		Impact (how serious is the risk?)		

Figure 23: Risk score analysis calculation

Data Sharing

As discussed as a major goal of the grant, the program will leverage the AMT Pool fund members to create a Community of Practice, along with participation from the U.S. DOT. The Community of Practice will provide an outlet for the three DOTs to share all elements of the SHIELD program. Collectively, the resources and outputs of the program will cohesively form a guidebook or "how-to" that other DOTs or those involved in work zone maintenance can utilize to understand and deploy the ADS technology within their fleet.

CDOT will lead development, coordination and management of a program website that will host all programmatic elements that others can utilize as a resource. Upcoming technical calls, agendas, meetings, procedural test plans, the ADS Performance dataset, live demonstration information, and the final report will be on the website. Since the website will be hosted by CDOT and become part of AMT Pool fund efforts in the future, the website has sustainment well beyond the five years of the grant award.

Commitment to Cost Share

While the award does not require a cost share, each of the program partners had committed non-federal funds to support the overall project as detailed in Figure 24 below. The PMP will finalize how the non-federal funds will be tracked and accounted for, in accordance with any U.S. DOT requirements, including in any federal management system. CDOT, MoDOT, and NDDOT are committing a total of $3,720,500 in cost share for the program.

Cost Share Source	Description	Match (Cost Share)
Colorado Department of Transportation, Division of Highway Maintenance and Intelligent Transportation Systems	• Two Leader/Follower automation kits retrofitted on four vehicles • Existing procedural test and validation plans • 3,000 staff hours • Connected vehicle ecosystem and predictable analytics access	$2,500,000
Missouri Department of Transportation	• One Leader/Follower automation kit retrofitted on two vehicles Pilot • 13,000 staff hours in support	$450,000
North Dakota Department of Transportation	• Two Leader/Follower automation kits retrofitted on two vehicles • Staff Time	$770,500
Total		$3,720,500

Figure 24: Cost share commitment by SHIELD program partners