Auburn University

-DOT Designation of Automated Vehicle Proving Ground-

Auburn University Program for Automated Vehicle Evaluation (AU-PAVE)

Submission to Docket No.: DOT-OST-2016-0233

Auburn University (AU) is pleased to present this proposal to designate AU-PAVE, the University's long running testing program for vehicle automation technology, as a USDOT Automated Vehicle Proving Ground. AU-PAVE serves as the operational mechanism and outdoor laboratory for Auburn University's Transportation Research Initiative. We look forward to utilizing AU-PAVE to co-create and engage as an active member of the Community of Practice envisioned by the USDOT "to develop and share best practices around the safe testing, demonstration and deployment of automated vehicle technology." As an academic campus, Auburn University is eligible for this designation.

At Auburn University, we understand that an integrated, comprehensive and systematic approach is necessary to tackle today's transportation challenges. We know that there is not one single solution and it truly takes a collaborative approach to uncover the most effective solutions. We believe this systems approach must merge expertise across all Engineering disciplines to understand the best and most innovative pathway to today's transportation challenges. The recognized challenges of the industry include issues of energy, environment, safety, congestion, and materials utilization. Successful solutions to these issues offer significant potential benefit to the industry when addressed individually; but far greater impact is achieved when these opportunities are viewed and solved collectively. (Figure 1)

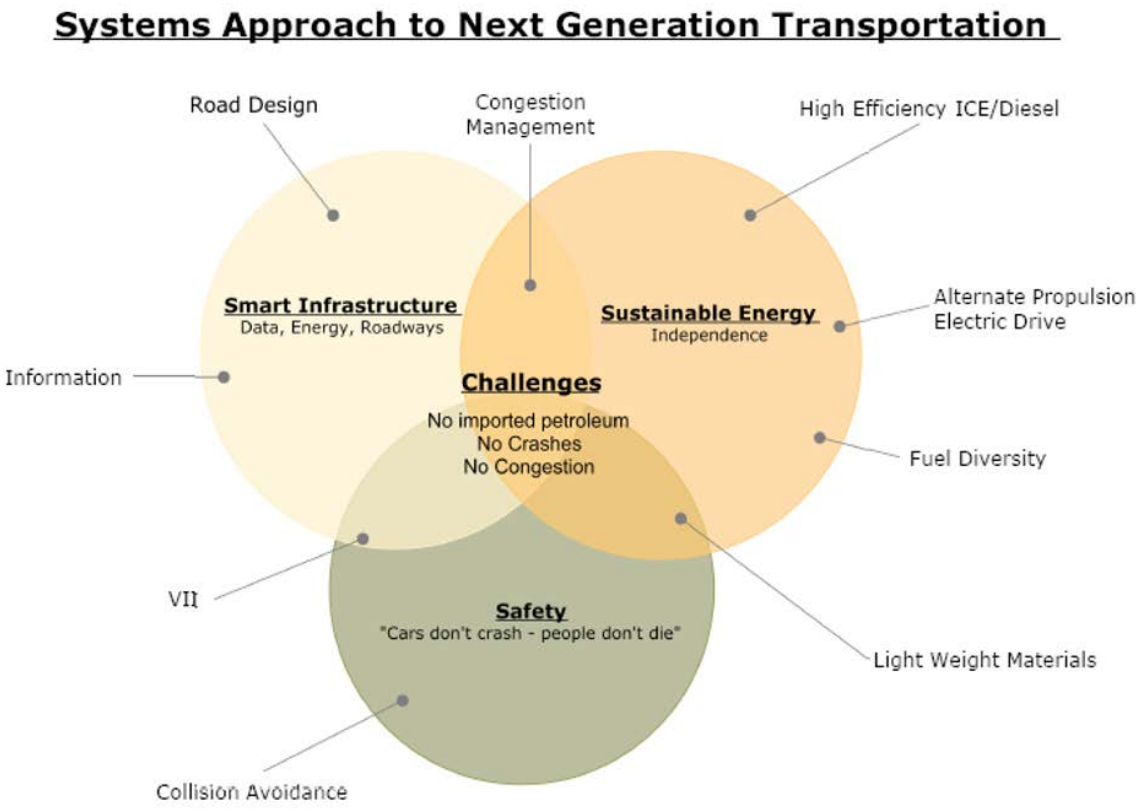

Figure 1

In this respect, AU has the mechanism in place to test new and innovative approaches through the Auburn University Program for Automated Vehicle Evaluation (AU-PAVE). AU-PAVE serves as the operational platform and outdoor laboratory for Auburn University's Transportation research initiative. It provides a professionally managed, safe, and secure testing space to evaluate both car and truck technology. AU-PAVE is made possible by the ongoing research program at the National Center for Asphalt Technology's (NCAT) Pavement Test Track. NCAT, www.ncat.us, is a cooperative venture between the National Asphalt Pavement Association's (NAPA) Research and Education Foundation and Auburn University (AU).

We enthusiastically commit to sharing our approaches and resources that come together in addressing these challenges to our Nation's transportation needs. With a USDOT Authorization as a Designated Automated Vehicle Proving Ground, all outside users will have access to these supporting Engineering Transportation entities.

Our response to the mandatory criteria is included below:

1. AU-PAVE Fully Meets USDOT Criteria for Automated Vehicle Proving Grounds

AU-PAVE Safety Officer Dr. Buzz Powell, NCAT Track Manager, will serve as the Designated Safety Officer for the USDOT-designated Proving Ground. In this role he will be responsible for the AU-PAVE's safety management plan as well as participate in the Community of Practice's regular quarterly meeting of Safety Officers.

Dr. Powell brings significant expert in safe track testing operations, having been in the role of NCAT Track Manager and Safety Officer since 1999. Safety policies established by Dr. Powell at the NCAT track for testing in past years include:

- truck operations protocols
- driver training and protocols
- protocols re interactions with other vehicles on track

AU-PAVE is strongly committed to sharing our approaches to safety developed over the last 16+ years of NCAT track operations, plus safety data generated through testing and operation

2. AU-PAVE Contributions to the Community of Practice are Substantial and Multi-faceted

AU-PAVE meets USDOT's stated criteria for Automated Vehicle Proving Grounds with regard to being an academic campus with a Designated Safety Officer in place.

AU has an established automated vehicle program through AU-PAVE. AU-PAVE represents a coming together of substantial efforts across the College of Engineering for many years, as noted by the activities described below. Our efforts in Automated Vehicle evaluation are occurring both independently and through industry supported partnerships.

AU-PAVE provides leadership in making national and regional contributions addressing both long-range and immediate mobility challenges through the testing and deployment of automated vehicle technology. AU provides this leadership through a systems approach. This approach can quickly and efficiently focus research on the most critical elements of the industry by linking its 13 fully staffed, fully functioning transportation research facilities to accelerate efforts in achieving break-thru solutions to the challenges shown in Figure 2. Each of the 13 centers provide engineering expertise and leadership directed at solving the multiplicity of automotive industry issues from lower cost energy to safe and efficient automobiles using lightweight, smarter materials powered by alternative propulsion systems.

Auburn University
Systems Approach to Next Generation Transportation

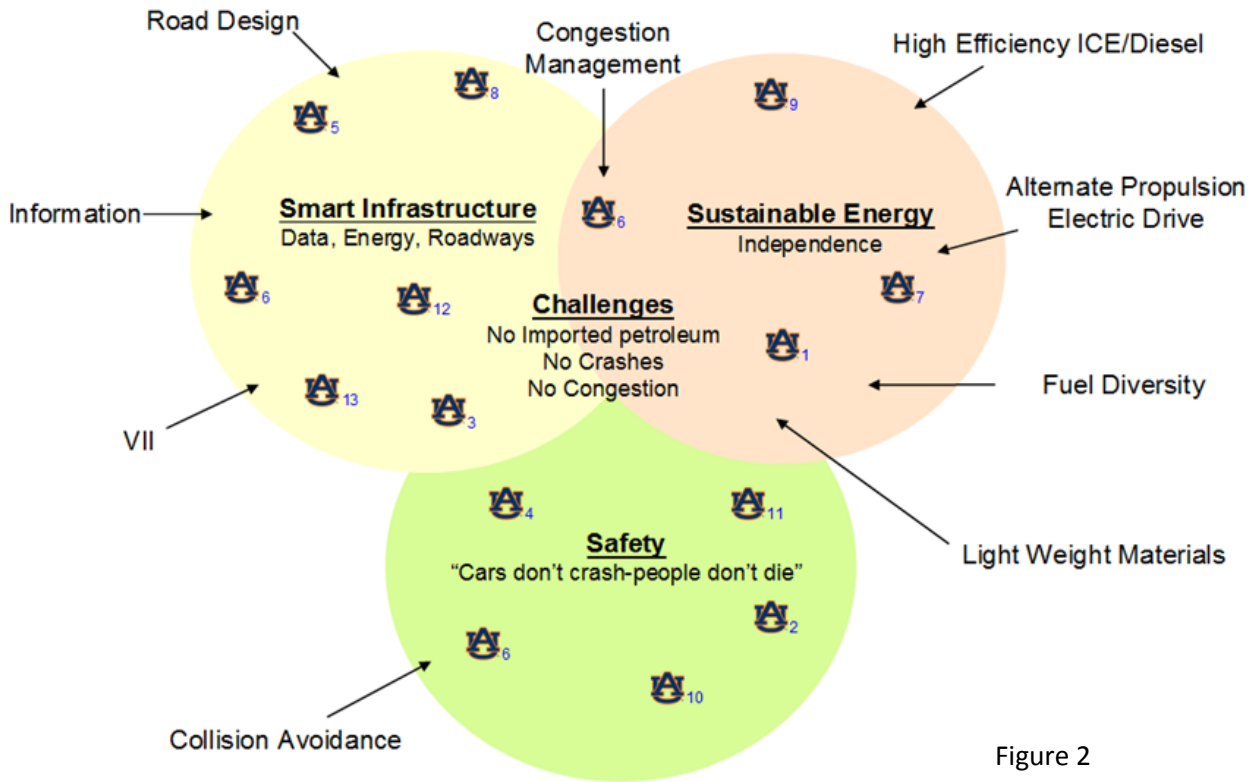

Figure 2

Each Engineering Research Center is briefly described below with its corresponding numerical notation.

1 **Center for Advanced Vehicle Electronics (CAVE)**

Development of new technologies for the manufacture and packaging of electronics with special emphasis on cost, harsh environment and reliability requirements of the automotive industry.

2 **Alabama Microelectronics Science and Technology Center (AMSTC)**

New concepts in automotive electronic research such as multichip module design, fabrication and reliability, stress and thermal management, and low-high temperature integrated-circuit operation.

3 **Center for Innovations in Mobile, Pervasive and Agile Computing Technologies (IMPACT)**

Development of advances in mobile and embedded communication systems that are wirelessly networked and that interact directly with people for civilian and military transportation applications.

4 **Materials Research and Education Center (MREC)**

Development of advances in composites, manufacturing, materials characterization, materials, optics, and smart materials fabrication for the automotive industry.

5 **National Center for Asphalt Technology (NCAT)**

Development of mix designs to provide safer, more durable and cost effective roadways.

6 **Wireless Engineering Research and Education Center**

Design of both hardware and software for wireless devices and networks. Special Emphasis on GPS and VII integrated systems for vehicle navigation, collision avoidance, and safety.

7 **Alternative Energies Institute**

Development of sustainable and renewable energy sources, fuel testing and evaluation and mobile production of bio-fuels.

8 **Highway Research Center (HRC)**

Applied research to solve problems in the planning, design, construction and maintenance of highway systems, especially traffic analysis and control, safety, and environmental issues.

9 **Alternative Propulsion Laboratory**

Development of hybrid propulsion systems using alternative fuels and energy sources.

10 **Material Processing Center (MPC)**

Development of materials processing for the metal casting industry including solidification science, thermophysical properties of liquid metals, particulate molding and heat treating.

11 **National Center of Excellence for Research in the Intermodal Transport Environment**

Comprehensive research and development of air-quality, environmental control systems, detectional mitigation of biological threats in cabin environments.

12 **Center for Microfibrous Materials Manufacturing (CMMM)**

Design development and technology transfer of microfibrous materials predominate in filtration systems for the automotive industry.

13 **Occupational Safety, Ergonomics, and Injury Prevention (OSE/IP)**

Practical applications of advanced research, i.e. postural stability of commercial truck drivers, occupant characteristics in performance-based evacuation modeling.

These Centers at Auburn University have focused their transportation research objectives by implementing approaches that integrate all aspects of the highway system from the pavement to the vehicle to the driver to the highway design to the environment. The specific goals of our research is to:

A) Improve the durability, cost effectiveness and safety of our nation's highways

B) Increase vehicle performance, fuel efficiency, and safety; and

C) Improve transportation systems with modeling and simulation software tools.

In addition to the resources at Auburn University, AU-PAVE's research has already been recognized internationally. In particular, Auburn University exhibits leadership with regard to truck platooning as one of only a handful of research institutions worldwide that have performed significant investigations on this topic (supported by the FHWA EAR program). Multiple papers have been published based on each of the EAR projects discussed in section 4.

AU also demonstrates leadership by participating in the Community of Practice. This is fundamental to AU-PAVE activities and promises to be enhanced by the designation as a USDOT Automated Vehicle Proving Ground, as described further below. Future projects will make further use of Stakeholder Advisory Boards as has been successfully done in past projects. Dissemination of research results is accomplished via technical journals, conference papers, and providing overview presentations at key industry events. Additionally, AU-PAVE representatives participate in stakeholder and technical committees including:

a. Transportation Research Board annual meeting and committees
b. SAE World Congress and Commercial Vehicle Engineering Conference, plus technical committees
c. ITS World Congress presentations and panel participation
d. Future Truck Automated Driving and Platooning Task Force within the American Trucking Association Technology and Maintenance Council
e. Automated Vehicles Symposium
f. AASHTO meetings and committees
g. State DOT Annual Meetings

A prime example of AU-PAVE's commitment to the Community of Practice stems from the DATP project research team's involvement with the Technology and Maintenance Council (TMC)'s Automated Driving and Platooning Task Force. Interim project research results were central to the development of a TMC Information Report, "Automated Driving & Platooning: Issues & Opportunities," TMC IR 2015-2, published by American Trucking Association (ATA) in late 2015. This was ATA's first-ever publication relating to truck platooning. In turn, Task Force comments on ongoing DATP research have been invaluable to addressing practical feasibility of such systems.

For TMC in particular, Auburn NCAT staff have participated in TMC's Annual and Fall meetings for over a decade. This relationship has been important to attracting truck-focused testing. As TMC (and ATA in

general) become more active in AV truck systems, the role of AU-PAVE as a technology and testing resource is expected to grow.

Existing and future partnerships will be central to AU-PAVE's process of disseminating best practices in AV evaluation. USDOT recently awarded a Regional University Transportation Center grant to the Southeastern Transportation Research, Innovation, Development and Education Center consortium (STRIDE). The grant will provide up to $14 million for the next five years, focused on developing novel strategies for reducing congestion. The Consortium is led by the University of Florida Transportation Institute, with Auburn University as a major founding member. Other consortium members are The Citadel, Florida International University, Georgia Institute of Technology, Jackson State University, North Carolina State University, Tennessee Technological University, University of Alabama at Birmingham, and the University of North Carolina at Chapel Hill. We are pleased that this very strong research group includes Jackson State University, an HBCU.

The STRIDE consortium will address congestion through the use of new technologies available in vehicles, telecommunications capabilities, and shared autonomy in transportation. The potential for traffic congestion to be alleviated by automated vehicles is significant, and Auburn's work in Driver Assistive Truck Platooning plus other activities of the GAVLAB, described in section 4.2, plays an important role in advancing the state of the art.

AU-PAVE has provided leadership for the Community of Practice across the AV spectrum and most strongly in truck platooning. Auburn's work here has incorporated technical development (AV/CV), technology evaluation, traffic engineering, and stakeholder outreach. Ongoing AV-related research within the AU-PAVE program was highlighted in recent years as follows:

- 2015: Alabama Transportation Conference, Minnesota Transportation Conference, Wisconsin Transportation Conference, ITS World Congress, Automated Vehicles Symposium, Kiasco Automated Truck Conference, ATA TMC.
- 2016: Minnesota Trucking Association, Ohio Planning Association, Florida Automated Vehicle Summit, Freight Market Intelligence Summit, ITS World Congress, Transportation Research Board, ATA TMC.

As previously noted, AU-PAVE has the technical means to share test data in real time and will determine the most fruitful data sharing approach based on specific projects and proprietary aspects. Overall, these broadly applicable research thrusts are expected to continue, based on the specific needs of research sponsors.

As a new initiative, based on a designation as a USDOT AV Proving Ground, AU-PAVE will work with its regional partners to host an annual Southeast Automated Vehicles Testing Symposium. This event will bring together key persons involved in testing cars, trucks, and "robo-taxi" systems across the Southeast with engineering and policy-makers from across the region to share testing principles and practices and understand the contributions that testing can make to deployment. We will leverage our longstanding relationship with the Gulf Region Intelligent Transportation Society (GRITS), as well as the new STRIDE UTC, to optimize the value of this event to practitioners.

AU-PAVE has existing strong relationships with relevant USDOT research program offices and will maintain and deepen these relationships. Auburn University is proud to have had continuous work with the FHWA Exploratory Advanced Research program since its inception (GAVLAB, described in section 4.2, is now engaged in its fourth EAR project). Auburn researchers have extensively presented results of this work,

crediting and enhancing USDOT's role in the research community. We will work with USDOT to enhance data sharing for USDOT-sponsored work. This research has been joint, with Auburn University providing cost-share to each of these projects. Auburn's work is well-known to the ITS Joint Program Office and NHTSA; the University is hopeful to develop a mutually beneficial dialogue with FMCSA given the fast development pace of automated trucking technology. Alabama DOT will be included in these communications as appropriate.

AU-PAVE will submit Proving Grounds Activity Reports to USDOT on a semi-annual basis, or on a schedule seen as most useful to USDOT.

3. AU-PAVE is Fully Committed to Safety in Testing

In conducting all operations at the NCAT track, risk management and safety is foremost. Safety management plans incorporating robust safety precautions have been in place since on-track truck operations began in 2000. Protocols address safety of all personnel at the track, as well as vehicle operations. All drivers in the pavement test vehicles are professional truck drivers with Commercial Drivers Licenses (CDL).

Operations at the NCAT track have not been without incident. In the process of running over 8 million miles on the track, only one accident has occurred that involved driver injury and significant damage to the tractor and triple trailer train. This occurred in February of 2016 after approximately 7¾ million miles. The post incident investigation determined this accident to be the result of an unpredictable high wind event. No incidents have occurred during automated vehicle testing conducted to date. AU-PAVE will publish our safety management plan based on these many years of experience with general testing plus specifics relative to AV testing.

The engineering researchers conducting AV-related research at the track adhere to safe design, deployment, and operation of automated devices under test. The GAVLAB, described in section 4.2, has experience both designing custom e-stop systems, as well as integrating commercial estop systems such as those used in the DARPA Grand Challenge vehicle competitions. Furthermore, researchers can take advantage of the professional truck drivers running the day-to-day pavement tests, as needed. Regarding on-road testing, discussions are in-process with Alabama DOT which will build upon demonstrations of planned on-road activities on the track.

In addition, Auburn University is part of a team led by the Virginia Tech Transportation Institute which is supporting NHTSA via an IDIQ contract on Electronic Systems Safety. The scope of this IDIQ extends to automated vehicle operations.

4. Research, Application and Data Sharing

AU-PAVE commits to open data, sharing performance metrics, and results of objective tests with the permission of public sector clients and to the degree possible with private sector clients. As one aspect of AU-PAVE's commitment, NCAT will leverage its longstanding membership in the American Trucking Association's Technology and Maintenance Council. Through this membership, NCAT's fleet professionals contribute to the process for development and reconsideration of standard fleet practices.

AU-PAVE will strongly advocate for sharing of information so as to serve the larger community. Key aspects of shared data, performance metrics, and test results will be included in the Proving Ground semi-annual report.

AU-PAVE has significant strengths in carrying out the activities and programs based on the University-wide technical capabilities. Within the University's Samuel L. Ginn College of Engineering, the groups which comprise AU-PAVE are listed and described below:

a. National Center for Asphalt Technology
b. GPS and Vehicle Dynamics Laboratory (GAVLAB) within the Mechanical Engineering Department
c. Wireless Engineering Research and Education Center within the Computer Sciences and Software Engineering Department
d. Highway Research Center within the Civil Engineering Department
e. Industrial and Systems Engineering Department (ergonomics and operations research)
f. Numerical System Simulation & Aerodynamic Modeling Research Work Group within the Aerospace Engineering Department
g. Auburn University Cyber Initiative

4.1. National Center for Asphalt Technology (NCAT) Test Track

NCAT was created in 1986 through an agreement between the National Asphalt Pavement Association (NAPA) Research and Education Foundation and Auburn University. NCAT is a major scientific force in pavement research, with a testing program incorporating an oval track built to interstate standards located about 20 miles from Auburn's campus. The photo provides an aerial view of the track.

Aerial View of AU-PAVE NCAT Test Track

A practical vehicle testing program evolved at Auburn as a consequence of the ongoing research activities at the NCAT Pavement Test Track. In order to damage experimental pavements on the 1.7-mile test oval, it is necessary to run a fleet of heavily loaded Class 8 tractor-triple-trailers over ¾ million miles a year (approximately 3400 miles per day). The photo below illustrates the truck-based track operations.

Since 2003, these trucking operations at the test track have provided an excellent opportunity to study issues that are important to the trucking industry in a highly controlled, practical, and cost effective manner.

AU-PAVE NCAT Track Operations

Track fleet operations provide an opportunity to affordably evaluate new technologies while simultaneously providing fleets with reliable and unbiased performance data. Past research efforts have focused on timely issues such as fuel economy improvement and pollution reduction of performance enhancing technologies, long-term durability of tractor-trailer components and parts, comparison of synthetic versus conventional fuels and lubricants, cab vibration reduction and driver fatigue, reduction of carbon in exhaust gases, next generation hydrogen fuel cell bus performance, and tire wear rate and life in the track's high scrub, accelerated wear environment.

The facility also includes a 260-foot diameter skid pad, 2½-mile off-road track with DOD-defined obstacles, multiple access points to the paved track for on-road/off-road duty cycles, and abundant emergency access. The wireless network is extensive, incorporating 802.11 trackside wireless internet, extensive wireless video monitoring of experiments, and 802.11p DSRC V2X. The NCAT wireless network enables sharing of (non-proprietary) test data in real time to researchers worldwide. Physical facilities include a covered open garage for vehicle maintenance and development, plus private garage space available for technology developers.

Gantry supporting V2I DSRC Radio's at NCAT Track

The NCAT track serves as the key infrastructure element of AU-PAVE. For many years, this trucking operation has served as a platform for a wide range of truck-based vehicle technology research. It is especially suited for high mileage testing. Additionally, given the two lane configuration, testing of other vehicles is performed on the track by GAVLAB (described in the next section). Automated vehicle testing at NCAT goes as far back as 2007, when teams vying for a slot in the DARPA Urban Challenge were required to perform pre-qualifying trials for DARPA observers at a test facility of their choice. NCAT was chosen by

Team Lux, fielded by Ibeo Automotive Sensors, for this purpose. The skid pad area of the track was mocked up as an intersection and street environment. Observed by DARPA personnel, the driverless Level 4 Team Lux vehicle passed the pre-qualification and moved on to the final rounds.

The NCAT track staff are experienced in running highly precise fuel economy tests. NCAT has specialized fuel tanks and other equipment necessary to run the Joint TMC/SAE Fuel Consumption Test Procedure – Type II and/or Type III. These procedures are an integral part of the American Trucking Association's Guidelines for Qualifying Products Claiming a Fuel Economy Benefit (TMC RP 1115). Assessment of fuel economy is essential for the trucking industry in evaluation of all automated vehicle technologies, in particular truck platooning operating at various automation levels.

4.2. Mechanical Engineering / GAVLAB

The GPS and Vehicle Dynamics Laboratory (GAVLAB) within the Mechanical Engineering Dept., focuses on the control and navigation of vehicles using GPS in conjunction with other sensors, such as Inertial Navigation System (INS) sensors. GAVLAB plays the primary role in testing of AV systems at the NCAT track. The laboratory research thrusts include sensor fusion/integration, on-line system identification, adaptive and robust control algorithms, and vehicle state and parameter estimation. These are focused towards vehicle dynamics and transportation, including heavy trucks, passenger cars, off-road vehicles, as well as autonomous and unmanned vehicles. The GAVLAB has also undertaken several tasks, including developing simulations of sensor technology using CarSim and TruckSim, writing algorithms for sensor fusion for robust positioning, estimation of truck properties including mass and engine torque, and live implementation and testing of systems.

In addition, the laboratory consists of various GPS receivers, Inertial Measurement Units (IMUs), vehicle radars, an instrumented Infiniti G-35, an instrumented Hyundai Sonata, an instrumented Ford Explorer, and other vehicles as well as access to the NCAT test track and trucks. The GAVLAB has developed a pair of Cooperative Adaptive Cruise Control capable Peterbilt trucks that are also a valuable resource for cooperative testing on the NCAT track. Auburn in conjunction with Peterbilt and TRW may seek to add automated steering to the trucks in the near future.

Use of the NCAT test facility has been fundamental to many GAVLAB projects. GAVLAB uses the track for testing navigation algorithms, as the team has accurate (cm-level) maps of the lanes and lane markings for validating navigation and sensor fusion based navigation. Plus, roadside signs are mapped for examining map registration algorithms. Several projects involving V2V or V2I elements have taken advantage of the track's V2X communications environment. Including the three projects discussed below:

a. (2006-2008) Funded by FHWA's Exploratory Advanced Research program, the Intelligent Sensor Fusion for Lane Detection project included a requirement to know vehicle position in the lane to 50cm. Perception sensors were augmented with GPS and inertial sensors to achieve the accuracy and maintain lane position when GPS is not available. Both algorithms were combined with GPS to demonstrate 50cm accuracy.

b. (2007-2008) This work, funded by Intermap and Eaton, investigated fuel savings possible using 3D road geometries and a predictive cruise controller and automatic gear shifting algorithm to calculate optimal vehicle speed and gear selection. Vehicle models were validated using Eaton's engine and dynamometer data as well as NCAT experiments.

c. (2009-2012) Next Generation Vehicle Positioning in GPS-Degraded Environments for Vehicle Safety and Automation Systems, DTFH61-09-R-00004. Funded by FHWA's Exploratory Advanced Research program, this project explored means of positioning when GPS is not available, examining radio frequency ranging based on DSRC radio technology, visual odometry, and terrain-based localization. These latter two techniques rely on foreknowledge of road features – in essence, a feature-enhanced version of a digital map (this becomes feasible in the "connected vehicle" future, in which tomorrow's vehicles have access to quantities of data orders of magnitude greater than today's cars, as well as the ability to share data at high data rates). Based on testing and characterization of these technologies at the NCAT test track, Auburn defined a combined Integrated Positioning System (IPS) for degraded GPS environments. For this project an Industry Advisory Board (IAB) was established consisting of automotive OEMs and Tier 1 suppliers. Interim project results were shared with IAB members and they participated along with FHWA in demonstrations at the NCAT track at the project's conclusion.

Peterbilt/GAVLAB Vehicles Equipped with DATP under Test at AU-PAVE NCAT Track (assessing the ability of the control system to accurately maintain gap spacing)

Using the NCAT track and other capabilities, GAVLAB has also done extensive work for the automotive industry, including General Motors (Integrating Production GPS with Electronic Stability Control Sensors For Improved Vehicle State Estimation), Honda (GPS testing), and Continental. GAVLAB has also placed four interns at Mercedes Benz research in Germany during the last two years, and some graduates of the program are now working on automated vehicle development for car-makers. This tight integration with the vehicle industry ensures that the testing capabilities offered by AU-PAVE remain relevant to emerging AV needs, with research results benefitting the global community of AV system developers.

4.3. Wireless Engineering Research and Education Center

The main objectives of this group are design, implementation, and evaluation of vehicle-to-vehicle (V2V) communications. Critical requirements for wireless networks that support automated truck platooning and other applications are satisfied by providing high reliability in the transmission of control information, security against various forms of attacks, and high data rates for rapid delivery of large amounts of control and driver feedback data.

In past years, the NCAT facilities and environments have provided excellent conditions for wireless networking research. Following are some examples of previous research conducted in these facilities.

a. (2010) Commercial Vehicle Secure Network for Safety and Mobility Applications. This work, conducted at the NCAT track, was sponsored by the National Transportation Research Center Inc. University Transportation Center. The main objective of this project was to develop a secure, reliable, high throughput and integrated wireless network for vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) and intra-vehicle communications. Novel techniques and communication protocols were developed to ensure that safety messages are transmitted reliably, securely and efficiently. The results of our studies on the integrated wireless vehicle networks for V2V, V2I and intra-vehicle networks show that the integrated network can satisfy the security, reliability and throughput performance requirements of Electronic Stability Control systems and other connected vehicle safety applications. The demonstration of the intra-vehicle wireless networks on the commercial tractor trailers at the NCAT test track for supporting ESC systems showed that this is feasible in real-world vehicle networks under normal operating conditions.

b. (2013-2017) Heavy Truck Cooperative Adaptive Cruise Control: Evaluation, Testing and Stakeholder Engagement (DTFH61-13-H-00019). Making use of the NCAT track, the wireless group conducted an empirical study of DSRC V2V performance in truck platooning scenarios. Real-world experiments were conducted with commercial DSRC radio's and semi-trailer trucks with various antenna configurations. Static and dynamic tests were conducted to explore DSRC performance under different situations. Test results verified initial hypotheses. For example, hilly roads can affect delivery ratio and antennas mounted on opposite sides of a truck can suffer from low delivery ratio at curved roads. The team also found that antennas can sometimes suffer from low delivery ratio even when the trucks are on straight roads, possibly due to reflections from the nearby terrain. These effects were quantified and published, along with data documenting improvements gained by using the two side antennas alternately.

4.4. Civil Engineering Highway Research Center (HRC)

The HRC is composed of Civil Engineers in the specialty of Transportation, and focuses on highway operations such as planning, safety, and traffic management/analysis. The HRC conducts traffic simulation using VISSIM, and statistical analysis of data obtained from these simulations. One example of a traffic simulation model of heavy trucks has been developed as a part of the study of Driver Assistive Truck Platooning recently conducted by Auburn for FHWA, a civil engineering group on the research team. The models, developed in the traffic simulation software CORSIM, included heavy trucks operating under reduced headways enabled by connected vehicle technology. These trucks were in traffic with vehicles of all types and capabilities. In this study, traffic was modeled on an Interstate highway in a rural and small urban area. The market penetration levels of DATP among heavy vehicles were varied incrementally from 20% to 100%. Time gaps between the platooned trucks were varied between 0.5 and 1.4 seconds. The DATP-enabled trucks were operating in mixed traffic in which passenger vehicles did not have any CV/AV capabilities. Results of the models show small improvements (reductions) in travel time for heavy trucks while platooned. These differences were statistically significant for some combinations of market penetration and time gap. This type of research complements on-track work to assess aspects of feasibility for transportation operations.

4.5. Industrial and Systems Engineering

Researchers in the Industrial and Systems Engineering Department (ISE) contribute to automated vehicle research via both ergonomics and operations research. This also incorporates the Laboratory for Occupational Safety, Ergonomics and Injury Prevention which includes a Human Factors Lab, Biomechanics Lab, and Gait/Work Simulation Lab. Most data collection gear is portable and can be easily configured for field data collection under realistic or actual conditions, and can be used in roadway /

vehicle environments. Engineering faculty and students are certified to conduct IRB-based human subject's research. The IRB, Institutional Review Board, at AU is responsible for the ethical and regulatory requirements related to the protection of human participants in research.

Within the FHWA-funded DATP research, the operations research group analyzed real-world trucking traffic data to identify critical freight corridors in which truck platooning operations are likely to be viable. This analysis addressed the feasibility of platoon formation in real world settings, the determination of estimated expected platoon sizes, impacts to delivery schedules, and waiting times for trucks to join a platoon. This type of research complements on-track work to assess aspects of commercial feasibility.

4.6. Aerospace Engineering Numerical System Simulation & Aerodynamic Modeling Research Work Group

Within the FHWA-funded DATP research, this group has developed a high-fidelity aerodynamic model of the two-truck leader-follower platooning configuration. The model estimates the decrease in drag coefficient that is achieved through platooning to develop a correlation between leader-follower separation distance and the absolute drag reduction, which in turn enables estimates of vehicle fuel savings. The effects of lateral offset of the follower truck have also been modeled, producing results highly relevant to the trucking industry which have been presented at both the SAE World Congress and SAE Commercial Vehicle Engineering Conference. Aspects of this work will be presented in detail at TRB 2017. Work at the NCAT track has been vital to validate aspects of the model.

4.7. Auburn Cyber Research Center

The Auburn University Cyber Initiative brings a powerful array of expertise to bear in addressing cyber-threats. Recently recognized in a joint resolution passed by the Alabama Legislature, AUCI is home to capabilities and facilities that provide critical support for the military, federal agencies, state agencies, intelligence community and commercial entities. The Center seeks to develop designs for novel and useful engineering prototypes, technology spin-offs, and licensable artifacts. The Center also focuses on educating a superior cyber workforce and supporting state and regional economic development. The National Security Agency has designated Auburn as a National Center of Academic Excellence in Cyber Operations. The Center's capabilities support AU-PAVE in assessing vehicle security plus V2X communications.

4.8. Alabama Technology Transfer Center

The Alabama Technology Transfer Center was created to bring the newest developments in technology to state and local public works agencies in Alabama. The Center combines the resources of USDOT, the Alabama Department of Transportation, and Auburn University. Training Seminars are a part of the Technology Transfer (T2) Center using the expertise of professionals from throughout the region. Topics covered in the past by Alabama LTAP seminars have included value engineering, public works management, railroad highway grade crossing improvements, and traffic control in construction. The Center's capabilities and network will be leveraged to share relevant results of automated vehicle research with practitioners across the State and region.

5. Demonstrated Investments

Initial investments to create the NCAT test facility were $7.5M from Alabama DOT plus $.5M from Auburn University. On the extensive activities under the FHWA EAR work, Auburn has cost-shared approximately 20% in each project. Section 2 provides information regarding the significant AV testing ongoing at Auburn University. This activity includes cost share provided by Auburn University with its partner

Peterbilt. The FHWA EAR DATP project focuses specifically on feasibility of truck platooning; stakeholder outreach plus Alabama DOT and STRIDE UTC discussions addressing deployment. AU-PAVE will work with the STRIDE UTC to address regulatory challenges of automation levels 3-5, in which the human driver is out of the control loop for some or all of the time. This will include engaging Alabama DOT and local communities as to the nature and types of regulation needed at the state and local level.

Additionally, in cooperation with Alabama DOT, NCAT test operations can potentially extend onto public roadways when needed, based on NCAT's strong history/ relationship with Alabama DOT. In conjunction with the FHWA EAR DATP project, the Alabama DOT has provided a letter stating that they are willing to consider a testing permit for two-truck Level 1 platooning on I-65, I-85, and US 280 based on test results at the NCAT track plus joint development of testing protocols. This on-road testing is under consideration for 2017 during Phase Three of the project.

6. Readiness: AU-PAVE Open for Testing Since 2000

The AU-PAVE NCAT facility has been open and supporting vehicle technology testing since 2000. The designated Point of Contact is Dr. Buzz Powell, NCAT Track Manager and Designated Safety Officer for the USDOT-designated Proving Ground. The NCAT facility is frequently used by multiple users simultaneously, including the NCAT pavement wear trucks and vehicles under test by GAVLAB or others. As noted in Section 2, non-proprietary data generated by the AV testing at the proving ground will be shared publicly with the support of our sponsors.

For any potential testing on public roads, AU-PAVE will engage with affected local communities in addition to ongoing discussions with Alabama DOT described above. Our relationship with the City of Auburn is very strong and is facilitated by our involvement with and participation on various agencies; specifically the Industrial Development Board, the Economic Development commission and the Technology Research Foundation.

7. Adherence to Laws, Regulations, and Federal Policy

All AU-PAVE testing will adhere to state and local laws and federal regulations. Our relationships with the City of Auburn, Lee County, and Alabama DOT provide good communications channels for assessing how existing laws apply to on-road AV testing we propose.

In particular, public road testing will fully adhere to NHTSA Policy for Automated Vehicles for testing and deployment of L3-L5 automated vehicles. For on-road testing, this will include the following:

- Full compliance with DOT's Vehicle Performance Guidance and all sections of the AV Policy
- Automated vehicles will meet all applicable FMVSS or seek an exemption from NHTSA
- Provision of a Safety Assessment letter to NHTSA
- Test operators are responsible for following all traffic rules and will be responsible for all traffic violations.
- If enacted by the state of Alabama,
    - AU-PAVE will submit an application to Alabama DOT for testing of HAVs and comply with all information requirements, including Auburn's safety and compliance plan for testing vehicles
    - Vehicles used in testing will be operated solely by trained persons with a valid State driver's license designated by AU-PAVE
    - A summary of the training provided to those performing the testing will be provided to Alabama DOT

- All crashes involving test vehicles will be reported in accordance with Alabama law
- All operators will be made available for a background check including, but not limited to, a driver history review and a criminal history check.

8. Additional Information Regarding Key Personnel

Dr. R. Buzz Powell, AU-PAVE Designated Safety Officer for the USDOT-designated Proving Ground

Dr. Powell earned his B.S., M.S., and Ph.D. degrees in Civil Engineering from Auburn University (1990, 1996, and 2006, respectively) with emphasis in pavements and geomaterials. He completed his professional internship with the Alabama Department of Transportation (ALDOT) in site characterization and geotechnical construction. While with ALDOT, he gained a total of 10 years of experience in pavement management, pavement design, pavement research, and pavement materials characterization. Following a 12-year career with ALDOT, he worked for 2 years as the Principal Engineer for an engineering consulting firm. Dr. Powell has served as NCAT's Test Track Manager since 1999, and he has been an Assistant Director at NCAT since 2007. The focus of his research at Auburn University is accelerated pavement testing, pavement performance measurement, and pavement construction. Dr. Powell is a registered professional engineer in the State of Alabama.

Dr. David Bevly, AU-PAVE Principal Investigator

Dr. Bevly is a Professor in the Department of Mechanical Engineering at Auburn University where he joined the faculty in August of 2001. He serves as Principal Investigator for AU-PAVE. Dr. Bevly directs Auburn University's GPS and Vehicle Dynamics Laboratory (GAVLAB). His research interests include State and Parameter Estimation, Vehicle Dynamics and Control, GPS and Sensor Fusion, and Control of Dynamic Systems. Dr. Bevly received his Ph.D. in the Department of Mechanical Engineering at Stanford in 2001, M.S. in Mechanical Engineering from the Massachusetts Institute of Technology in 1997 and B.S. in Mechanical Engineering from Texas A&M University in 1995. Dr. Bevly holds the following patents: a) GPS Control of a Tractor Towed Implement (Patent No. US 6,434,462); b) Determination and Control of Vehicle Sideslip Using GPS (Patent No. US 6,681,180); c) Method and Apparatus for Vehicle Control, Navigation, and Positioning (Patent No. US 6,732,024). Recently, Dr. Bevly was one of ten professors from around the world who were selected to receive SAE International's Ralph R. Teetor Educational Award. Established in 1953, the award recognizes outstanding engineering educators.

9. Conclusion

In conclusion, Auburn University looks forward to joining with USDOT and the Community of Practice to extend the knowledge base and deployment prospects for safe automated vehicle operations. We applaud USDOT in taking this step "to foster the safe deployment of advanced automated vehicle technologies to achieve national goals while understanding the long-term societal and ethical impacts that these technological advancements may impose." AU-PAVE is prepared and organized to engage in these exciting challenges.