PROGRAM PROGRESS PERFORMANCE REPORT

Connected Vehicle/Infrastructure University Transportation Center (CVI-UTC)

PPPR #10

June 1 to November 30, 2016

Morgan State University
Virginia Tech Transportation Institute
University of Virginia
VDOT

Connected Vehicle/Infrastructure University Transportation Center (CVI-UTC)

The mission statement of the Connected Vehicle/Infrastructure University Transportation Center (CVI-UTC) is to conduct research that will advance surface transportation through the application of innovative research and using connected-vehicle and infrastructure technologies to improve safety, state of good repair, economic competitiveness, livable communities, and environmental sustainability.

The goals of the Connected Vehicle/Infrastructure University Transportation Center (CVI-UTC) are:

- Increased understanding and awareness of transportation issues
- Improved body of knowledge
- Improved processes, techniques and skills in addressing transportation issues
- Enlarged pool of trained transportation professionals
- Greater adoption of new technology

Disclaimer

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Program Progress Performance Report for University Transportation Research Centers (PPPR #10)

Prepared for the Research and Innovative Technology Administration (RITA); U.S. Department of Transportation (US DOT)

Grant Project Title:

Advanced Operations Focused on Connected Vehicles/Infrastructure (CVI-UTC)

Consortium Members:

Virginia Tech Transportation Institute (VTTI)
University of Virginia (UVA) Center for Transportation Studies
Morgan State University (MSU)

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Report Term: June – November 2016

Submission Date: November 30, 2016

Accomplishments

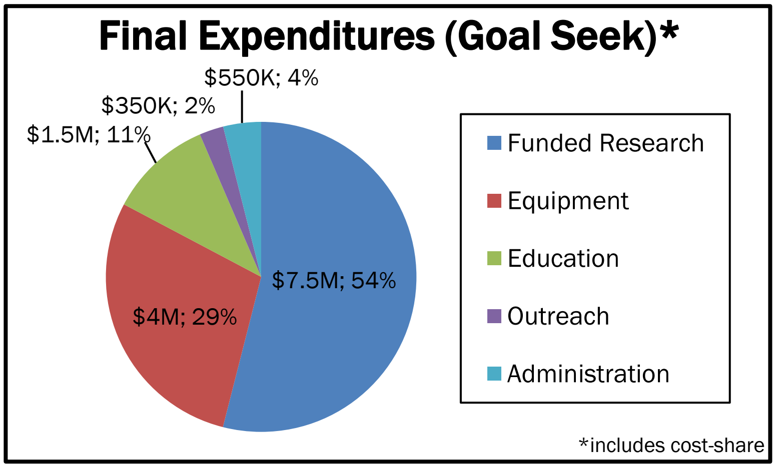
What are the major goals and objectives of the program?

The goals of the Connected Vehicle/Infrastructure University Transportation Center (CVI-UTC) are:

- Increased understanding and awareness of transportation issues
- Improved body of knowledge
- Improved processes, techniques and skills in addressing transportation issues
- Enlarged pool of trained transportation professionals
- Greater adoption of new technology

Focused on the following strategic goals:

- Safety
- State of Good Repair
- Economic Competitiveness
- Livable Communities
- Environmental Sustainability



What was accomplished under these goals?

During the June – November 30, 2016 reporting period covered by this PPPR, the following was accomplished:

Major activities:

- Research projects: 8 final research reports finalized during this reporting period (all 24 research projects completed)
- Funded UGA and GRA direct tuition and work study (including many underrepresented students)
- Graduated 2 students (1 Master's, 1 Ph.D.) which continued to pursue a higher degree or was placed in employment post-graduation
- Continued data collection and research on the Smart Road and Northern Virginia Connected Vehicle Testbeds
- 17 presentations and publications that were submitted, accepted and/or published by national and international transportation conferences, institutions, and publishing entities during this reporting period
- CVI-UTC research displayed at the Women in Transportation Seminar - The Future of Transportation, August 31-September 1, 2016, Blacksburg, VA.
- CVI-UTC research displayed and demonstrated at VDOT 12th Annual Transportation Career Fair, October 6, 2016, Manassas, VA.
- Hosted and presented CVI-UTC research to many community groups, businesses, and academic groups during multiple tours of the Virginia Smart Road and VTTI facilities
- Continued website development and updated content
- CVI-UTC Final Report Published: https://issuu.com/vtti/docs/cvi_utc_final_report_7_for_issuu_wi

Specific objectives:

Major Activities:	Safety	State of Good Repair	Economic Competitiveness	Livable Communities	Environmental Sustainability
CVI-UTC research projects	X	X	X	X	X
Funded UGA and GRA direct tuition and work study	X		X	X	
Graduated 2 students (pursued higher education or placed in employment post-graduation)	X	X	X	X	X
Continued data collection and research on the Smart Road and Northern Virginia Connected Vehicle Testbeds	X	X	X	X	X
17 presentations and publications submitted, accepted and/or published by national and international transportation conferences and institutions	X	X	X	X	X
CVI-UTC research displayed at the Women in Transportation Seminar – The Future of Transportation, August/September 2016	X	X	X	X	X
CVI-UTC research displayed and demonstrated at VDOT 12th Annual Career Fair, October 2016	X	X	X	X	X
Hosted and presented CVI-UTC research to many community groups, businesses, and academic groups during multiple tours	X			X	
Continued website development and updated content	X	X	X	X	X
CVI-UTC Final Report Published	X	X	X	X	X

Significant results, including major findings, developments, and conclusions:

Eight final reports finalized:

- **Connected Vehicle Applications for Adaptive Overhead Lighting: M. Palmer (VTTI), R. Gibbons (VTTI), A. Medina (VTTI); finalized July 2016.**
  - Survey results indicate acceptance of the on-demand lighting concept with participants often rating the system to be safe for the speeds they were driving (35 and 55mph).
  - Participants were able to detect pedestrians on the side of the road under the on-demand conditions nearly as well as under the continuous lighting conditions, but the differences were not statistically significant.
  - These results indicate there is potential to utilize this system to reduce the cost of operating overhead street lighting while maintaining the safety benefits of the lighting.
- **Emergency Vehicle-to-Vehicle Communication: P. Murray-Tuite (VT); finalized August 2016.**
  - Based on microsimulation, for a small network, pre-emption (without V2V communication) improved the emergency vehicle's (EV) travel time by approximately 1.5 – 5.0 minutes (11-37% improvement), depending on traffic volumes and cycle lengths.
  - Increasing the desired speed of the EV had only small effects on its travel time in a congested network, where the EV's speed was limited by other vehicles on the road.
  - For the simulation network and specified conditions, the benefits of V2V communication in addition to signal pre-emption were 20-32% improvement in the EV's travel time over scenarios with pre-emption alone.
  - Based on a field test of a prototype, reaction times to messages were not equal to 2.7 seconds.
  - A linear regression model of reaction times identified the following factors as significant: (1) preference for listening to loud music while driving, (2) speed at the time the brake is applied, (3) speed at the time the drivers take their feet off the accelerator, and (4) throttle position at the time the message is received.
  - Based on these four variables, the model without an intercept gave the best R-squared value of 0.93. The estimated reaction times varied from 1.4 to 5.9 seconds.
  - Numerical case analysis for a small, uniform section of roadway with a limited number of non-EVs revealed our mixed integer non-linear program is capable of optimizing the behavior of non-EVs to maximize the speed of the EV.

- **Intersection Management using In-vehicle Speed Advisory/Adaptation: H. Rakha (VTTI), I. Zohdy (VT); finalized August 2016.**
  - iCACC has the ability to model any type of intersection control and accepts the following inputs: approach volumes, intersection characteristics, weather conditions, vehicle specifications, and the percentage of equipped vehicles at the intersection.
  - iCACC optimizes all levels of automation, from legacy vehicles to fully autonomous vehicles. (Video may be found at: http://bit.ly/iCACC).
  - The iCACC system logic was compared to conventional intersection control in terms of delay and fuel consumed on a per-vehicle basis for different traffic demand cases (16 cases); simulation results showed significant savings by using the iCACC tool compared to other conventional controls (signal, stop-sign, and/or roundabout) for the same demand level.
- **Reducing School Bus/Light-Vehicle Conflicts Through Connected Vehicle Communications: K. Donoughe (VTTI), A. Alden (VTTI); finalized September 2016.**
  - Initial analysis of results indicate that the "school bus ahead" alert provided by the on-board HMI was effective at providing an enhanced awareness of school bus loading ahead.
- **Measuring User Acceptance of and Willingness-to-pay for CVI Technology: H. Shin (Morgan State), M. Callow (Morgan State), Y. Lee (Morgan State), A. Farkas (Morgan State); finalized September 2016.**
  - Participants generally accept selected connected-vehicle technologies.
  - Results to date indicate that price will be the main factor in deciding to purchase a connected-vehicle technology, and safety benefits are most appealing to drivers.
  - Comparisons of willingness-to-pay with several socioeconomic variables found that drivers between the ages of 40 and 49, African-Americans, those with less than a bachelor's degree, and a higher budget for vehicle purchase are positively related to willingness-to-pay.
  - Early adopters or innovators of connected-vehicle technologies are willing to pay more for such systems.
- **Applications of Connected Vehicle Infrastructure Technologies to Enhance Transit Service Efficiency and Safety: Y. Lee (Morgan State), K. Hancock (VT), H. Rakha (VTTI); finalized September 2016.**
  - This project developed a rudimentary architectural framework for two CVI applications which is conceptual and designed to generically map communications and linkages between components that make up the applications:
    1. an application for dynamic demand-response transit (DRT) services and,
    2. an enhanced traveler safety application that allows individuals to notify a transit vehicle that they are within a specified distance of the vehicle's current stop.
  - A limited simulation was performed to evaluate the potential of using this location with respect to a transit vehicle to provide flexibility for that vehicle to remain at a stop for a limited time minimizing passenger wait time and exposure to potential safety issues, specifically during night operations. The simulation exposed some limitations in the initial design, specifically routes with closely spaced transit stops. The concept is valid but additional logic is necessary to ensure that information provided to both the driver and traveler is consistent and unambiguous.
  - An annotated bibliography of resources used for this study was developed.
  - A handheld mobile app for users, a mobile app for transit drivers, and a management server program are being developed, and they are in the final debugging process.
    - A user mobile app can request a trip and users can confirm their travel and they can check the location of the bus.
    - Bus driver can check the locations of the users, bus stops, and who are going to board and alight, so they can make sure that all the passengers can be picked up.
  - Once the programs are finalized, the apps and the server program will be field-tested at Morgan State University for the following purposes
    - Communication between the handheld mobile app and the data server
    - GPS accuracy for the passenger safety purpose

    - Communication latency and droppage
  - Currently, surveys are being conducted to find out user perceptions whether this kind of user location based transit mobile app can improve ridership and safety (especially during the night time)
- **Vehicle-Based BSM Generator for Accelerating Deployment: R. Viray (VTTI), Z. Doerzaph (VTTI); finalized October 2016.**
  - The team has developed an algorithm that estimates the velocity and GPS position of radar targets from the perspective of a moving host vehicle.
  - This algorithm was improved upon through iterations of validation with Model Deployment naturalistic driving data.
  - The research team has developed an on-board vehicle system that utilizes the algorithm to transmit dynamic BSMs on behalf of remote vehicles that are not equipped with connected vehicle technologies.
  - The system can transmit BSMs on behalf of up to 4 non-connected vehicles at one time.
  - Testing the system in a controlled environment yielded data that is currently being used to further improve the algorithm.
- **Mobile User Interface Development for the Virginia Connected Corridors: M. Mollenhauer (VTTI); finalized October 2016.**
  - This project has resulted in the development of the Northern Virginia Connected Vehicle Test Bed Mobile Application component of the overall connected vehicle program. The mobile application is an Android phone based application that provides the driving public in Northern Virginia with a downloadable user interface application where drivers can receive traveler information messages from the VDOT traffic operation systems and make reports of driving conditions back to a cloud system.
  - The mobile application has been designed to provide a configurable user interface and interaction model that is designed to be appropriate for use while driving. Distraction reducing features including large format visual message presentation, automated message filtering, text-to-speech message annunciation, and a speech-to-text driver reporting capability.
  - The mobile application includes a best path message routing capability that will make use of DSRC message communication infrastructure when equipped with an on-board DSRC radio and within range or cellular data communications when the phone is stand-alone and not within range of a roadside DSRC radio unit. The result is a flexible system that can be used to present traveler information messages to drivers anywhere within the state of Virginia with a minimum Android smart phone device.
  - The mobile app interfaces with the cloud computing environment to access a variety of messages that are constantly updated from VDOT Operations computing systems and the 511 Virginia driver information system. Categories of information include:
    - Traffic congestion messages indicating the location and duration of traffic backups
    - Traffic incident events such as crashes, stalled vehicles, special incidents such as sporting events, and other traffic relevant roadway anomalies
    - Special weather events such as slick bridges, snow packed roads, standing water, fog and rain
    - Work Zone information including general work zone locations and speeds, specific areas of work zones where work is actively occurring, and special driver instructions such as lane shifts or flagging operations, etc.
    - Dynamic message sign content such as the information that is currently shown on overhead signs along the Northern Virginia transportation corridors
    - Future additions to be added soon include ATM information regarding prescribed travel speeds, dynamic lane operations, and HOV requirements and EMS information regarding the presence and status of emergency responder vehicles
  - Drivers may use the system to report various roadway conditions to provide crowdsourced information back to the cloud computing environment. These reports are classified, validated, and

converted into additional messaging for other drivers that happen to be navigating through the same area

Sixteen reports finalized in previous periods:

- **Safety, Operational, and Energy Impacts of In-Vehicle Adaptive Stop Displays Using Connected Vehicle Technology: A. Noble (VTTI), T. Dingus (VTTI), Z. Doerzaph (VTTI), H. Rakha (VTTI), B. Katz (VT); finalized July 2015.**
  - The performance of participants using the adaptive stop display indicates no difference in stopping behavior in terms of driver input when compared to a traditional stop sign. However, the increased level of compliance to the stop display is something that should be noted; participants were not missing valuable information and were more willing to stop when using the adaptive stop display.
  - A stop made in compliance with the adaptive stop display had a compliance level of 62.11 percent compared to a stop made at a traditional stop sign (12.44 percent compliance).
  - When participants were presented with the "proceed with caution" display, they exhibited more risk-averse behaviors that were appropriate when responding to situational changes that required higher levels of attention, such as an increase in traffic.
  - Mean glance durations and frequencies decreased rapidly with increased driver experience with the in-vehicle system.
  - The mean eyes-off-road time and number of glances to the in-vehicle device when functioning normally are comparable to that of checking the speedometer (Dingus et al.[1]).
  - Participants were generally able to learn how to use the display quickly.
  - Additionally, the number of glances to the display decreased to about one glance per intersection approach after the first six to eight exposures to the system.
  - Scanning behaviors increased during situations of higher traffic levels, which was a sign that they were not relying totally on the system and still sought information from their surroundings before committing to proceeding through the intersection.
  - For one intersection with an ADT of 1,950 vehicles per day controlled by adaptive stop display compared to traditional stop signs the savings to society in terms of CO_2 emissions is $24,349.14 over 45 years.
- **Infrastructure Pavement Assessment & Management Applications Enabled by the Connected Vehicles Environment – Proof-of-Concept: S. Katicha (VTTI), H. Zeng (UVA), H. Park (UVA), B. Smith (UVA), G. Flintsch (VTTI); finalized September 2015.**
  - Proposed method can correctly identify between 80 and 93 percent of deficient pavement sections.
  - Transportation agencies should consider using this low-cost application for pavement condition network screening to identify locations where repairs are needed.
  - Application can serve as a surrogate pavement roughness assessment method for local transportation agencies.
- **An Innovative "Intelligent" Awareness System for Roadway Workers Using Dedicated Short-Range Communications: D. Bowman (VTTI), T. Martin (VT); finalized October 2015.**
  - Approach enables detection of roadside workers in situations where existing solutions may fail due to visual occlusions or environmental conditions.
  - Experimental results show that the warning system can distinguish between a near miss, complete miss, and collision with a worker with 91% accuracy.
  - Accurate warnings can be provided 5 to 6 seconds before any potential collision, allowing time for mitigating solutions.
- **Infrastructure Safety Assessment Using Connected Vehicle Data: R. Kluger (UVA), B. Smith (UVA); finalized December 2015.**

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[1] **Dingus, Thomas A., Klauer, Sheila G. (2008). The Relative Risks of Secondary Task Induced Driver Distraction SAE Technical Paper Series. Detroit, Michigan.**

  - Utilized naturalistic driving data to classify crash and near-crash events with elements of the Basic Safety Message (BSM).
  - Successfully developed a model to detect crashes and near-crashes and also designed a methodology to apply hot spot identification.
  - Project findings outline an approach to identify crash hotspots utilizing connected vehicle data, once testbed data is widely available.
- **Prototyping and Evaluating a Smartphone Dynamic Message Sign (DMS) Application in the CVI-UTC Test Bed: B. Smith (UVA), J. Ma (UVA); finalized December 2015.**
  - The developed VDMS application has satisfying technical performance in terms of battery life, latency, and location accuracy.
  - Positive attitude among participants (21 total) towards VDMS in terms of both usefulness and satisfaction.
  - Most participants (80.95 percent) perceived that VDMS is a safer way to receive information; most (66.67 percent) felt more comfortable receiving information from the VDMS compared to a DMS.
- **Connected Vehicle Enabled Freeway Merge Management – Field Test: B. Smith (UVA); finalized January 2016.**
  - Based on the compliance data, it is evident that the highest compliance rates are achieved for large and medium gap size scenarios, with no significant difference of compliance rates between these gap sizes.
  - Though the small gap scenario has resulted in the lowest compliance rates (58%), it implies that some drivers were comfortable following advisories when available gaps were relatively smaller and accept gaps that they would have otherwise rejected. This indicates that the Merge Management Advisories have the potential to improve merging operation even in highly congested condition
  - A valuable lesson from this study is that it is important to design advisory messages in straightforward way so that drivers can readily understand and with which the desired outcomes are easily achieved.
  - In most cases, no significant differences in compliance rates between male and female participants were found.
  - Older participant drivers (65 years and above) demonstrated statistically significant lower compliance rate when compared with all other age groups.
  - In terms of response time, for both MCA and LCA strategy, we can observe similar trend in the average reaction times across the different gap sizes with comparatively slower response for VSL advisory. Also, as gap size decreased, the average reaction time also increased, this may be due to drivers becoming more cautious about lane changing as the available gap size decreased.
- **Connected Motorcycle Crash Warning Interfaces: M. Song (VTTI), S. McLaughlin (VTTI), Z. Doerzaph (VTTI); finalized January 2016.**
  - Connected vehicle technology (CVT) - based motorcycle crash warning systems (CWS), through its prototype crash warning interface (CWI) and applications, delivered positive impact on participants and was considered beneficial.
  - Combined auditory and haptic displays show considerable promise for implementation.
  - Auditory display using in-helmet headset system was successful in presenting warnings. The presentation of directional information turned out to be a weak point, using speech in addition to various channels may be a good solution.
  - Riders could easily distinguish between the haptic warnings and handlebar vibration. As with visual displays, the haptic design performed well at presenting directional information.
  - Visor-mounted LED light strips were level with eyes which make them hard to be ignored. However, naïve users may look at them when triggered. Moving the strips further apart, deep into the peripheral vision or up to the edge of the visor might discourage riders from looking directly at them and getting distracted.

- Mirror-mounted LED light strips were good for situations like lane changes when mirrors are more likely to be checked.
- Environment could influence the performance of CWI, so it would make sense to develop a smarter CWI by adjusting alerts based on environmental measure, such as self-adjusted brightness of visual alerts based on lighting conditions.
- CWS applications overall received slightly lower scores from sport riders than cruiser and touring riders, who might put more emphasis on riding comfort and safety. Cruiser and touring riders preferred the in-helmet headset over other displays, while sport riders showed no preference.
- Style and better integration of motorcycle CWSs would help improve their acceptance. Incorporating additional capabilities into protective gear and helmets will likely promote adoption by riders.
- Findings would not only benefit CVT based motorcycle CWS design, but also traditional CWS design for motorcycles.

- **Connected Motorcycle System Performance: R. Viray (VTTI), Z. Doerzaph (VTTI), S. McLaughlin (VTTI); finalized January 2016.**
  - Across the various tests, it was quite apparent that rider occlusion and ranges impacts communication performance. In situations where the motorcycle has direct line of sight with the vehicle, a noticeable increase in performance is seen.
  - For the dynamic range tests, it was observed that the forward mounted antenna had an overall wider communication range of -300m to +300m in the open sky environment. For the rear mounted antenna, a -300m to +100m in the open sky environment.
  - Having a wider overall communication range allows for effective detection of motorcycles in crash avoidance applications. Depending on the specific crash avoidance application, however, such distances may mean more or less in different configurations. For example, if a vehicle and a motorcycle are approaching each other head on, having a longer communication range in the ahead direction proves more valuable.
- **Next-Generation Transit Signal Priority with Connected Vehicle Technology: B. Park (UVA), J. Hu (UVA), Y. Lee (Morgan State); finalized January 2016.**
  - Field evaluation test confirmed that the transit signal priority (TSP) under connected vehicle technology work as expected.
  - A simulation-based study shows that the TSP under Connected Vehicle significantly improves both bus travel time as well as network delay when compared to Conventional TSP and No TSP cases.
  - TSP under connected vehicle developed in this study can handle multiple buses as well as coordination with adjacent intersections.
- **Human Factors Evaluation of an In-Vehicle Active Traffic and Demand Management (ATDM) System: K. Sykes (VTTI), A. Noble (VTTI), Z. Doerzaph (VTTI); finalized February 2016.**
  - According to the eye glance reduction analysis, all of the NHTSA distraction guidelines were met; therefore, the IVD would not be considered a distraction to drivers.
  - None of the in-vehicle alerts were distracting or annoying based on in-vehicle and post-drive survey responses.
  - When asked if they would use an in-vehicle device that provided HOV, lane management, speed limit, and VMS if such system existed, 98% of participants said they would use the device in both the pre-drive and post-drive surveys.
  - A vast majority of the participants found the in-vehicle VMS to be clear and concise based on post-drive survey responses (95%).
  - Of the twenty-seven participants who provided price ranges, 48% were willing to pay $100 - $500 for the in-vehicle system.
- **A Connected Vehicle-Enabled Virtual Dynamic Message Sign System Demonstration and Evaluation on the Virginia Connected Vehicle Testbed: H. Park (UVA), B. Smith (UVA), D. Recht (UVA); finalized March 2016.**

  - The VDMS system is intended to be used by TOC operators; therefore, the operational testing of the VDMS system was conducted with actual operators at PSTOC and the results are being analyzed.
  - The goal of this operational testing is to evaluate the VDMS system as a tool to support TOC's efforts to manage traffic. More specifically, it is to gain feedback from TOC operators on the usability, and the effectiveness of the VDMS system as an information dissemination tool to support advanced traffic management.
- **Developing Connected Vehicle Freeway Speed Harmonization Algorithms: H. Rakha (VTTI), H. Yang (VTTI); finalized March 2016.**
  - When the algorithm was applied, the speed of the equipped vehicles decreased gradually to restrict the arrival rates at the downstream bottleneck and mitigate traffic congestion.
  - With increased market penetration rates of the equipped vehicles, the discharge flow rate of the bottleneck was greater, the traffic stream delay was reduced, and vehicle emissions and fuel consumption levels were reduced.
- **Field Demonstration of Cumulative Travel-time Responsive Intersection Control Algorithm under Connected Vehicle Technology: B. Park (UVA); finalized March 2016.**
  - The cumulative travel-time responsive (CTR) algorithm was enhanced by adopting adaptive Kalman filter (AFK) algorithm that works much better under low market penetration rates of connected vehicles. The AKF seems outperform existing actuated signal control at a lower market penetration rate of 15%.
  - Developed hardware in the loop simulation environment featuring actual controller used in the Northern Virginia, CID, and VISSIM microscopic traffic simulator.
  - A field testing of the Bluetooth readers indicated that the market penetration rate of the Bluetooth devices was much lower than expected -- approximately 10% (compared to some literature indicating about 20%). This might lead to significant disadvantage in the field deployment.
- **Field Testing of Eco-Speed Control using Vehicle-to-infrastructure Communication: H. Rakha (VTTI), H. Chen (VTTI), M. Almannaa (VTTI), R. Kishore (VTTI), I. El-Shawarby (VTTI), A. Loulizi (VTTI); finalized April 2016.**
  - The Eco-CACC system computes and recommends a fuel-efficient speed based on Signal Phasing and Timing (SPaT) data received from the traffic signal controller via V2I communication.
  - The computed speed profile can either be broadcasted as an audio alert to the driver to manually control the vehicle, or be implemented in an automated vehicle (AV) to automatically control the vehicle.
  - From an algorithmic standpoint, the proposed algorithm addresses all possible scenarios that a driver may encounter while approaching a signalized intersection. Additionally, from an implementation standpoint the research addresses the challenges associated with communication latency, data errors, real-time computation, and ride smoothness.
  - The system was tested on the Virginia Smart Road Connected Vehicle Test Bed. Four scenarios were tested for each participant, including a base scenario considering an uninformed drive, a scenario that the driver was provided with a red indication countdown, a manual Eco-CACC scenario where the driver to follow an audio recommended speed profile, and finally an automated Eco-CACC scenario that controls the vehicle's longitudinal motion.
  - The field test demonstrated the benefits of the Eco-CACC system in assisting vehicles to drive smoothly in the vicinity of intersections and therefore reduce the fuel consumption levels.
  - Compared to the uninformed drive, the longitudinally automated Eco-CACC system controlled vehicle resulted in savings in fuel consumption levels and travel times in the range of 37.8 and 9.3 percent, respectively.
- **Connected Vehicle Virginia Test Bed System Performance: R. Viray (VTTI), R. Sarkar (VTTI), Z. Doerzaph (VTTI); finalized May 2016.**
  - Evaluated the performance by assessing three standard communication parameters: Packet Error Rate, Latency and Inter-Packet Gap.

- Associated with several intrinsic and extrinsic factors including heading, speed, ahead, across, range, roundabouts.
- Initial results indicate that physical obstacles in the roadway may be impacting communication performance between vehicles and RSEs. Such obstacles include overpasses, underpasses, highway barrier walls, and/or tree foliage.

- **Bicycle Naturalistic Data Collection: M. Elhenawy (VTTI), A. Jahangiri (VTTI), H. Rakha (VTTI), T. Dingus (VTTI); finalized June 2016.**
    - The system architecture that embodied cyclist violation prediction models was demonstrated. It was shown how connected vehicle technology can be adopted for different parts to communicate amongst themselves. Communication between different system entities was shown to have different purposes:
        1. Sending required variables for violation prediction models such as bicycle speed, acceleration, and current location.
        2. Sending warning to the drivers/riders in potential danger.
        3. Sending a "control change" order to change the signal setting.
    - A naturalistic cycling data collection system was conducted that can be used to develop bicycle violation prediction models. Violation prediction models were developed for stop-controlled and signal-controlled intersections based on kinetic information. The kinetic data such as speed and acceleration were obtained through instrumented bicycles.
    - Different monitoring periods to extract kinetic data were considered. However, the monitoring period length did not significantly change the model performance. Another factor to define a monitoring period was the end point of the period (the time at which the predictor calculations and the prediction task start). The closer the end point was to the intersection the higher the prediction accuracy was achieved. However, the trade-off was that higher accuracies are associated with less time for endangered users to react.
    - The RF model was also compared with three other learning algorithms and was identified as the best according to the highest TP and at the same time the lowest FP.
    - In case of signal controlled intersections, it was found that it is more likely that a cyclist violates a red light when making right turns. Also, the probability of red light violation decreases when there is side traffic at the intersection or when there is traffic in front of the cyclist.
    - In case of stop controlled intersections, it was found that the likelihood of violating a stop sign increases when there are no other users present.

Key outcomes or other achievements:

The Northern Virginia Connected Vehicle and Virginia Smart Road Test Beds are now completely operational allowing translational research toward deployment to be conducted. All 24 CVI-UTC research activities have been completed and many utilized the test bed environments. The connected vehicle applications which were developed by CVI-UTC research projects were evaluated for real-world deployment on the Northern Virginia Connected Vehicle Test Bed through the CVI-UTC research project "Mobile User Interface Development for the Virginia Connected Corridors", which has completed research activities under the CVI-UTC and has moved into further research/deployment stages through external funding sources. The results from this research project are expected to aid in the next phase of application development and ultimate deployment of CVI systems in Northern Virginia.

In addition, the CVI-UTC has produced a Final Report, which summarizes all research, education and workforce development, outreach, and technology transfer activities conducted under the grant from inception (2012-2016). This report will be widely disseminated, in order to reach a broad audience of private and public sector transportation professionals, those studying transportation-related careers, and the public, to provide greater awareness of the accomplishments under the CVI-UTC program and encourage implementation of results.

Discussion of stated goals not met:

Nothing to report.

What opportunities for training and professional development has the program provided?

Educational programming completed this reporting period includes:

- VDOT 12th Annual Transportation Career Fair
- Presented CVI-UTC research to many community groups, businesses, and academic groups during multiple tours of the Virginia Smart Road and VTTI facilities

As the CVI-UTC grant (FY2012) funding period officially ends November 30, 2016, the consortium has completed all outreach activities associated with the CVI-UTC.

How have the results been disseminated? If so, in what ways?

Our main source of dissemination has been through publishing research results in national and international archival journals. We have also utilized invitations to speak at conferences, conference presentations, and general attendance in professional conferences and networking events hosted by consortium universities or large scale industry events to disseminate research results to a professional audience. CVI-UTC research has also been featured in a number of publications, including press releases at the department and university-levels. In addition, we have employed virtual sources, such as our UTC website and the TRB database to disseminate research results.

What do you plan to do during the next reporting period to accomplish the goal's end objectives?

As the CVI-UTC grant (FY2012) funding period officially ends November 30, 2016, there are no planned activities for the next reporting period. All close-out activities have concluded, including completion of all research activities including development and research aimed towards ultimate deployment of CVI applications, finalization of all project reports, and dissemination of research through presentations and publications. In addition, CVI-UTC outreach goals were fulfilled during this period through continued activities which present CVI-UTC research to the public.

Products

What has the program produced?

- **Research Presentations:**

  The following are research presentations from CVI-UTC research projects that were submitted, accepted and/or published during this reporting period (June 1 – November 30, 2016).

  - **Park, B.B., Choi, S., Lee, J. & Son, S. H. (2016, October). Assessment of Cumulative Travel-Time Responsive Traffic Signal Control Algorithm using Vissim Presented at the PTV Group Annual Traffic User Group Meeting, Arlington, VA**
  - **Phoowarawutthipanich, A. & Murray-Tuite, P. (2017, January). Drivers' Reaction Times to Emergency Response Vehicle-to-Vehicle Movement Instructions. Poster to be presented at the 96th Transportation Research Board Annual Meeting, Washington, D.C.**
  - **Yang H. and Rakha H. (2017). Reinforcement Learning Ramp Metering Control for Weaving Sections in a Connected Vehicle Environment. To be presented at the 96th Transportation Research Board Annual Meeting, Washington DC, January 7-12. [Paper # 17-03689]**
  - **Hao Chen, Hesham A. Rakha, Amara Loulizi, Mohammed Almannaa and Ihab El-Shawarby (2016). Development and Field Testing of an Eco-Cooperative Adaptive Cruise Control System in the Vicinity of Signalized Intersections. Presented in ITS America, San Jose, CA, June 12-16**
  - **Song, Miao (2016). Crash Warning Systems for Connected Vehicles: Motorcycle Applications. Presented at the Motorcycle Research and Technology Workshop, Fifth International Symposium on Naturalistic Driving Research, August 30-September 1, 2016, Blacksburg, VA**
  - **Lee, Y.-J., Thomas, C., and Dadvar, S. (submitted). Perception and Acceptability Analysis on User Location-Based Transit Mobile Application. Submitted to the 96th Transportation Research Board Annual Meeting, Washington, D.C.**
  - **Jahangiri A., Elhenawy M., Rakha H., and Dingus T. (2016). Investigating Cyclist Violations at Signal-Controlled Intersections Using Naturalistic Cycling Data. 19th IEEE Intelligent Transportation Systems Conference, Rio de Janeiro, Brazil, Nov. 1-4.**

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- Bichiou Y. and Rakha H. (2017). Real-Time Optimal Intersection Control System for Autonomous-Cooperative Vehicles. To be presented at the 96th Transportation Research Board Annual Meeting, Washington DC, January 7-12. [Paper # 17-00202]

- **Publications:**

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  - Phoowarawutthipanich, A. & Murray-Tuite, P. (2017). Drivers' Reaction Times to Emergency Response Vehicle-to-Vehicle Movement Instructions. Transportation Research Record.
  - Hao Chen, Hesham A. Rakha, Amara Loulizi, Ihab El-Shawarby and Mohammed Almannaa (2017). Field Implementation of an Eco-cooperative Adaptive Cruise System at Signalized Intersections. 95th Annual Meeting Transportation Research Board, Washington D.C.
  - Mohammed Almannaa, Hao Chen, Hesham A. Rakha, Amara Loulizi, Ihab El-Shawarby and (2017). Controlled-Field Evaluation of Effectiveness of Infrastructure-to-Vehicle Communication in Reducing Vehicle Fuel Consumption and Delay at Signalized Intersections. 95th Annual Meeting Transportation Research Board, Washington D.C.
  - Song, M., McLaughlin, S., and Doerzaph, Z. (2017). An On-Road Evaluation of Connected Motorcycle Crash Warning Interface with Different Motorcycle Types. Transportation Research Part C: Emerging Technologies.
  - Lee, Y.-J., Thomas, C., and Dadvar, S. (submitted). Perception and Acceptability Analysis on User Location-Based Transit Mobile Application. Submitted to Transportation Research Record.
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  - Bichiou Y. and Rakha H. (2017). Real-Time Optimal Intersection Control System for Autonomous-Cooperative Vehicles. 96th Transportation Research Board Annual Meeting, Washington DC, January 7-12. [Paper # 17-00202]
  - Sykes, K.P. (2016). Human Factors Evaluation of an In-Vehicle Active Traffic and Demand Management (ATDM) System (Master's thesis). Retrieved from https://vtechworks.lib.vt.edu/bitstream/handle/10919/65003/Sykes_KP_T_2016.pdf

- **Websites; other Internet:**

  CVI-UTC maintains a website to document consortium-related activity (http://www.cvi-utc.org)

- **Technologies, techniques:**

  All research projects have completed experimental activities which designed, developed, improved or evaluated CVI applications, including the following:
  - A V2V communication prototype was developed by VTTI that 1) provided an alert via the vehicle's infotainment system in the vehicle and 2) instructed drivers to move to the left, move to the right, or stay put. (CVI-UTC project: Emergency Vehicle-to-Vehicle Communication)
  - An advanced messaging application was developed on a smart phone (Android platform) through this research project which provides drivers with information about road conditions ahead. This application works with DSRC and LTE communications and allows a substantial component of connected vehicle technology to be experienced by a large number of users, without the cost of purchasing a new vehicle, allowing for rapid, near-term deployment of connected vehicle technology. The application provides a means to expand functionality from a variety of applications into an integrated display system. (CVI-UTC project: Mobile User Interface Development for the Virginia Connected Corridors)
  - A Virtual Dynamic Message Sign (VDMS) system was developed by the UVA CTS team, in collaboration with VTTI, which 1) provides audio messages of existing text messages on Dynamic

Message Signs (DMSs) to drivers, and also 2) can be used to create additional virtual DMSs for better traffic operations. (CVI-UTC project: Prototyping and Evaluating a Smart Phone Dynamic Message Sign Application in the CVI-UTC Testbed)
- The UVA CTS team developed a more advanced, second generation of the Virtual Dynamic Message Sign (VDMS) system that is fully integrated in the DSRC environment of the Virginia Connected Vehicle Testbed, suitable for demonstration and evaluation. To provide more specifics, highlights of the enhancement of the VDMS system include: 1) this system utilizes four DSRC-based Roadside Equipment (RSE) for communications, 2) the VDMS manager software application has the capability to virtually "build" (or create) new DMSs as opposed to only using the geographic zones corresponding to fixed existing DMSs, and 3) the information to be presented can be customized to provide more details. (CVI-UTC project: A Connected Vehicle-Enabled Virtual Dynamic Message Sign System Demonstration and Evaluation on the Virginia Connected Vehicle Testbed)
- An in-vehicle application was developed which provided HOV, lane management, speed limit, and variable message signs to drivers while they traveled along a section of I-66 along the Northern Virginia Connected Vehicle Test Bed. The application also deployed various alerts to notify the driver when information was updated. (CVI-UTC project: Human Factors Evaluation of an In-Vehicle Active Traffic and Demand Management (ATDM) System)
- A CTR algorithm has been developed and enhanced by adopting an adaptive Kalman filter algorithm. (CVI-UTC project: Field Demonstration of Cumulative Travel-time Responsive Intersection Control Algorithm under Connected Vehicle Technology)
- An application for providing an alert to driver's approaching a loading school bus was developed and evaluated for driver response and overall efficacy. (CVI-UTC project: Reducing School Bus/Light-Vehicle Conflicts Through Connected Vehicle Communications)
- A test control application was developed to send merge advisories. (CVI-UTC project: Connected Vehicle-Enabled Freeway Merge Management – Field Test)
- A Road Side Equipment (RSE) Basic Safety Message (BSM) generator was developed to run on the RSE and generate BSM traffic data across the Northern Virginia Connected Vehicle Test Bed network. For this application, the user has the ability to define the transmission frequency and total number of BMSs to generate. The primary purpose of this application is to test the scalability of the end-to-end test bed network. (CVI-UTC project: Connected Vehicle Virginia Test Bed System Performance)
- An algorithm and software application was developed to generate a BSM using VTTI-equipped forward radar, transmitted over the air. (CVI-UTC project: Vehicle-based BSM Generator for Accelerating Deployment)
- A user location-based mobile application and server program were developed to request and provide transit services. (CVI-UTC project: Applications of Connected Vehicle Infrastructure Technologies to Enhance Transit Service Efficiency and Safety)
- A Transit Signal Priority (TSP) application has been developed and tested on the Virginia Smart Road. (CVI-UTC project: Next Generation Transit Signal Priority with Connected Vehicle Technology)
- A naturalistic cycling data collection system was developed that can be used to develop bicycle violation prediction models. (CVI-UTC project: Bicycle Naturalistic Data Collection)

- **Inventions, patent applications, licenses:**

  Nothing to report (note activities in this category under previous reporting periods).
- **Other:**

  Nothing to report.

Participants & Collaborating Organizations

Have collaborators or contacts been involved?

As all research activities were concluded during this period, no new collaborations or contacts were involved. Throughout the life of the CVI-UTC grant, many collaborations and contacts were made with others within the lead or partner universities, especially interdepartmental or interdisciplinary collaborations; with others outside the UTC; and with others outside of the United States or with international organizations. The relationships fostered through CVI-UTC research and other activities have been vital to the continued success of research performed by consortium universities.

Impact

What is the impact on the development of the principal discipline(s) of the program?

With the completion of the Northern Virginia and Smart Road test beds, the research being conducted under the CVI-UTC has moved into a translational research phase, where the applications developed to assist travelers and the overall roadway transportation system are moving toward the ultimate goal of deployment of CVI technologies. In particular, the mobile application that was developed as part of the CVI-UTC research project "Mobile User Interface Development for the Virginia Connected Corridors" is transferring technology by providing drivers in Northern Virginia a downloadable user interface application where drivers can receive traveler information messages from the VDOT traffic operation systems and make reports of driving conditions back to a cloud system, actualizing the results of many CVI-UTC research projects. These CVI technologies will also greatly aid in paving the way to connected automation, enabling vehicles to communicate with one another and the infrastructure, and respond accordingly.

In addition, the CVI-UTC Final Report was published in November 2016, which summarizes all research, education and workforce development, outreach, and technology transfer activities conducted under the grant from inception (2012-2016). As this report will be widely distributed and provides information on each of the 24 research projects completed under the CVI-UTC as well as links to each final report and contact information for further information, it will particularly impact both public and private-sector transportation professionals and students in transportation-related career fields. It is expected that this publication and the activities covered therein will impact the transportation field through the implementation of results in both the public and private-sectors and increase the body of knowledge studied by transportation professionals and students in transportation-related career fields, thus better preparing them to work with CVI technologies.

What is the impact on other disciplines?

The CVI-UTC has continued to conduct education and outreach activities which increase awareness about CVI technology across multiple disciplines. Major educational outreach events during this reporting period include:

- VDOT 12th Annual Transportation Career Fair
- Presented CVI-UTC research to many community groups, businesses, and academic groups during multiple tours of the Virginia Smart Road and VTTI facilities

In particular, CVI-UTC researchers showcased CVI technology at the VDOT 12th Annual Transportation Career Fair in Manassas, VA, which allowed researchers to encourage high school students to enter careers in all fields related to transportation, building the future workforce. This event drew over 100 employers and 1,400 high school students from the area.

What is the impact on the development of transportation workforce development?

During the entire course of the grant and during this reporting period, the CVI-UTC supported numerous undergraduate, masters, and Ph.D. level students at each consortium university. The research projects conducted under the CVI-UTC provided opportunities for the students to conduct research, many toward course projects, theses, and dissertations, and gain valuable knowledge and training in the transportation field toward future employment.

In particular, Morgan State's participation in our UTC has been able to majorly affect underrepresented groups through their research projects and outreach and education opportunities. Inner-consortium research work with Morgan State has allowed UVA and VTTI to work with more underrepresented groups. Morgan State also directly offers programs for Baltimore-area high school students and teachers, which include underrepresented populations, and has allowed UTC research to directly affect future generations of potential engineers and human factors professionals.

Furthermore, the CVI-UTC funds many females and individuals from other underrepresented groups across all consortium universities, many of which had a lead role in research projects. The CVI-UTC has sought to provide opportunities for members of underrepresented groups to gain experience in transportation through research projects.

What is the impact on physical, institutional, and information resources at the university or other partner institutions?

The CVI-UTC grant funding was instrumental in providing the foundation for the Northern Virginia and Virginia Smart Road Connected Vehicle Test Beds and the connected vehicle and connected motorcycle fleets which were used to perform research and collect data for the CVI-UTC research projects. These resources offered the consortium universities opportunities for research that would not have been possible without this grant. These test beds will continue to be utilized for research long after the CVI-UTC grant ends, eventually resulting in deployments of CVI systems. In addition, the grant funding has allowed educational and outreach programs to be implemented and/or continue at consortium universities that would not have been possible otherwise.

What is the impact on technology transfer?

During this period, results of CVI-UTC research continued to be disseminated through national and international journals and publications, student theses and dissertations, conferences, and through outreach and educational events, facilitating technology transfer to students, researchers, and the general public. Through these avenues, as well as the publication of the CVI-UTC Final Report, it is expected that results from CVI-UTC research will have a translational impact on the future of CVI technologies, being used extensively to inform emerging connected vehicle deployments.

What is the impact on society beyond science and technology?

The CVI-UTC has and is expected to continue to make an impact beyond STEM and academia. The research activities completed on the Northern Virginia and Virginia Smart Road Connected Vehicle test beds have reached a broad audience; in particular, the mobile application that was developed as part of the CVI-UTC research project “Mobile User Interface Development for the Virginia Connected Corridors” provides VDOT with a mobile phone application that can be downloaded by the general public to begin receiving important traveler information messages that may improve safety and mobility. Although the CVI-UTC portion of the project has ended, this project has continued with VDOT seeking eventual deployment, which will bring CVI technology into the hands of the general public. In addition, the research, education and workforce development, outreach, and technology transfer activities conducted under the CVI-UTC have been broadly disseminated in a variety of ways, including the CVI-UTC Final Report, which will help to inform the public of these technologies, and assist transportation professionals in ultimate implementation of CVI-UTC research results.

Changes/Problems

Changes in approach and reasons for change:

Nothing to report.

Actual or anticipated problems or delays and actions or plans to resolve them:

Nothing to report.

Changes that have a significant impact on expenditures:

Nothing to report.

Significant changes in use or care of animals, human subjects, and biohazards:

Nothing to report.

Additional Information Regarding Products and Impacts

Outputs:

Research projects awarded:

Research Projects:	Safety	State of Good Repair	Economic Competitiveness	Livable Communities	Environmental Sustainability
Safety and Human Factors of Adaptive Stop/Yield Signs Using Connected Vehicle Infrastructure	X	X	X	X	X
Connected Vehicle Applications for Adaptive Overhead Lighting	X	X	X	X	X
Intersection Management Using In-Vehicle Speed Advisory/Adaptation	X		X		X
Field Testing of Eco-Speed Control Using V2I Communication	X		X		X
An Innovative "Intelligent" Awareness System for Work Zone Workers Using Dedicated Short-Range Communications	X	X		X	
Emergency Vehicle to Vehicle Communication	X			X	
Connected Vehicle Enabled Freeway Merge Management - Field Test	X				
Infrastructure Safety Assessment Using Connected Vehicle Data	X	X	X	X	X
Infrastructure Pavement Assessment and Management Applications Enabled by the Connected Vehicle Environment Research Program - Phase I: Proof-of-Concept	X	X	X	X	X
Connected Vehicle-Infrastructure Application Development for Addressing Safety and Congestion Issues Related to Public Transportation, Pedestrians, and Bicyclists	X	X	X	X	X
Connected Motorcycle Crash Warning Interfaces	X				
Connected Motorcycle System Performance	X				
Developing and Evaluating a Smartphone Application Aimed at Reducing Crashes Involving Bicyclists	X			X	
Developing Connected Vehicle Freeway Speed Harmonization Algorithms	X		X		X
Reducing Bus/Light-Vehicle Conflicts Through Connected Vehicle Communication	X			X	
Next Generation Transit Signal Priority with Connected Vehicle Technology	X		X		X
Prototyping and Evaluating Smart Phone Dynamic Message Sign Application in the CVI-UTC Testbed	X	X	X	X	X
Measuring User Acceptance of and Willingness to Pay for CVI Technology	X	X	X	X	X
A Connected Vehicle-Enabled Virtual Dynamic Message Sign System Demonstration and Evaluation on the Virginia Connected Vehicle Testbed	X	X	X	X	X
Connected Vehicle Virginia Test Bed System Performance	X	X	X	X	
Vehicle Based BSM Generator for Accelerating Deployment	X	X	X	X	
Effect of In-Vehicle ATDM on Traffic Management, Distraction, and Desirability	X	X	X	X	X
Field Demonstration of Cumulative Travel-time Responsive Intersection Control Algorithm under Connected Vehicle Technology	X		X		X
Mobile User Interface Development for the Virginia Connected Corridors	X	X	X	X	X

- **Research Presentations:**
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Websites; other Internet:

CVI-UTC maintains a website to document consortium-related activity (http://www.cvi-utc.org)

Technologies, techniques:

Many research projects are currently underway and several have completed experimental activities which designed, developed, improved or evaluated CVI applications. The CVI applications that were developed during the reporting period include the following: (Note: Since this list is also requested/listed under the Products section, the duplicate list below is truncated and shown in a smaller font size to save reporting space.)

- V2V communication prototype (CVI-UTC project: Emergency Vehicle-to-Vehicle Communication
- Advanced messaging application (CVI-UTC project: Mobile User Interface Development for the Virginia Connected Corridors)
- Virtual Dynamic Message Sign (VDMS) system (CVI-UTC project: Prototyping and Evaluating a Smart Phone Dynamic Message Sign Application in the CVI-UTC Testbed)

  - Advanced, second generation of the Virtual Dynamic Message Sign (VDMS) system (CVI-UTC project: A Connected Vehicle-Enabled Virtual Dynamic Message Sign System Demonstration and Evaluation on the Virginia Connected Vehicle Testbed)
  - An in-vehicle application (CVI-UTC project: Human Factors Evaluation of an In-Vehicle Active Traffic and Demand Management (ATDM) System)
  - CTR algorithm (CVI-UTC project: Field Demonstration of Cumulative Travel-time Responsive Intersection Control Algorithm under Connected Vehicle Technology)
  - School bus alert application (CVI-UTC project: Reducing School Bus/Light-Vehicle Conflicts Through Connected Vehicle Communications)
  - Test control application (CVI-UTC project: Connected Vehicle-Enabled Freeway Merge Management – Field Test)
  - Road Side Equipment (RSE) Basic Safety Message (BSM) generator (CVI-UTC project: Connected Vehicle Virginia Test Bed System Performance)
  - Algorithm and software application (CVI-UTC project: Vehicle-based BSM Generator for Accelerating Deployment)
  - User location-based mobile application and server program (CVI-UTC project: Applications of Connected Vehicle Infrastructure Technologies to Enhance Transit Service Efficiency and Safety)
  - Transit Signal Priority (TSP) application (CVI-UTC project: Next Generation Transit Signal Priority with Connected Vehicle Technology)
  - Naturalistic cycling data collection system (CVI-UTC project: Bicycle Naturalistic Data Collection)
- **Outreach Activities:**
  - VDOT 12th Annual Transportation Career Fair
  - Presented CVI-UTC research to many community groups, businesses, and academic groups during multiple tours of the Virginia Smart Road and VTTI facilities

Outcomes:

	Increased understanding and awareness of transportation issues:	Improved body of knowledge:	Improved processes, techniques and skills in addressing transportation issues:	Enlarged pool of trained transportation professionals:	Greater adoption of new technology:
CVI-UTC research projects	X	X	X	X	X
Funded UGA and GRA direct tuition and work study	X			X	
Graduated 2 students (pursued higher education or placed in employment post-graduation)	X	X	X	X	X
Continued data collection and research on the Smart Road and Northern Virginia Connected Vehicle Testbeds	X	X	X	X	X
17 presentations and publications submitted, accepted and/or published by national and international transportation conferences and institutions	X	X	X	X	X
CVI-UTC research displayed at the Women in Transportation Seminar – The Future of Transportation, August/September 2016	X	X	X	X	X
CVI-UTC research displayed and demonstrated at VDOT 12th Annual Career Fair, October 2016	X	X	X	X	X
Hosted and presented CVI-UTC research to many community groups, businesses, and academic groups during multiple tours	X				
Continued website development and updated content		X		X	
CVI-UTC Final Report Published	X	X	X	X	X

Impacts:

	Safer driver behavior:	Increased travel time reliability:	Increased intermodal transportation operations:	Reduction in carbon and other harmful emissions from transportation sources:
CVI-UTC research projects	X	X	X	X
Funded UGA and GRA direct tuition and work study	X	X	X	X
Graduated 2 students (pursued higher education or placed in employment post-graduation)	X	X	X	X
Continued data collection and research on the Smart Road and Northern Virginia Connected Vehicle Testbeds	X	X	X	X
17 presentations and publications submitted, accepted and/or published by national and international transportation conferences and institutions	X	X	X	X
CVI-UTC research displayed at the Women in Transportation Seminar – The Future of Transportation, August/September 2016	X			
CVI-UTC research displayed and demonstrated at VDOT 12th Annual Career Fair, October 2016	X			
Hosted and presented CVI-UTC research to many community groups, businesses, and academic groups during multiple tours	X			
Continued website development and updated content	X			
CVI-UTC Final Report Published	X	X	X	X

Special Reporting Requirements

Not applicable for CVI-UTC.