CENTER FOR CONNECTED AND AUTOMATED TRANSPORTATION

# Semi-Annual Progress Report for University Transportation Centers

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# Semi-Annual Progress Report for University Transportation Centers

## 1. Accomplishments

The University of Michigan at Ann Arbor (UM), in partnership with Purdue University, University of Illinois at Urbana-Champaign (UIUC), University of Akron (UA), Central State University (CSU), and Washtenaw Community College (WCC), established the USDOT Region 5 University Transportation Center: Center for Connected and Automated Transportation (CCAT). The FAST Act research priority area for CCAT is promoting safety and CCAT will focus its efforts in the field of comprehensive transportation safety and congestion management by taking advantage of connected vehicles, connected infrastructure, and autonomous vehicles. This report documents the progress for the reporting period April 1, 2020 through September 30, 2020.

### 1.A Current Research Status

During this reporting period, the project "Motion Sickens Alleviation via Anticipatory Control of Active Seats in Autonomous Vehicles" was awarded $250,000. Dr. Shorya Awtar is the principal investigator and Dr. Monica Jones will act as an expert consultant. In this project, a test vehicle equipped with be equipped with active seats capable of roll, pitch, and yaw motions that can be controlled preemptively based on apriori knowledge of the driving conditions in a closed-track testing facility (M-City). Dr. Awtar's team will develop algorithms that preemptively control the Active Seat, for example starting to tilt the seat towards the direction of a turn slightly before the turn happens. The hypothesis is that such preemptive correction will provide anticipation and reduce body movement, thereby lowering the incidence of passenger motion sickness. The project will start October 1, 2020.

Also in this period, a request for proposals was issued for 2021 (year 5 funding). Proposals are due November 15, 2020. The proposals will be reviewed by the technology advisory board (TAB) and the final project portfolio will be selected at the January 2021 TAB meeting. The TAB consists of member from industry, government, and academia including. This period we added a new TAB member – Reuben Shankar, CEO the American Center for Mobility. Existing members include:

- Central State University
- Econolite
- Ford
- General Motors
- Illinois Department of Transportation
- Indiana Department of Transportation
- Michigan Department of Transportation
- Purdue
- Toyota
- University of Akron
- University of Illinois at Urbana-Champaign
- University of Michigan
- Washtenaw Community Collee
- WSP

CCAT researches have 40 active projects and seven completed projects. During this reporting period, work was performed on all of them, but due to page limitations, a status update is only provided for those projects awarded in 2020. Project updates for the other projects are available upon request. Additionally, for full project descriptions and final reports, visit the CCAT website.

***2020 International Symposium on Transportation Data and Modeling: University of Michigan, Dr. Yafeng Yin.*** The theme of the conference is achieving connected, cooperative and automated mobility.

The theme perfectly matches the mission of CCAT. The planning for the conference has been initiated and will be held in June 2021. Guidance from health officials is been followed closely. The event will be on-line, in-person, or hybrid, depending on the status of the COVID-19 pandemic. The call for papers has been issued and submission are due December 15, 2020. The conference website has been update to reflect the ongoing effort.

***Deep Scenario: City Scale Scenario Generation for Automated Driving System Testing & Evaluation: University of Michigan, Dr. Henry Liu, Dr. Shan Bao, and Dr. Jim Sayer.*** This project will build a city-scale scenario generation and simulation platform for automated driving systems (ADS) testing and evaluation. In this period, the methodology for scenario generation for autonomous vehicle testing with highway driving was completed. The implementation for scenario generation with SUMO and CARLA for highway driving scenarios was completed as well.

***Improving the Efficiency of Trucks via CV2X Connectivity on Highways: University of Michigan, Dr. Gabor Orosz, Dr. Jerry Lynch, Dr. Yafeng Yin, and Dr. Harvey Bell, IV.*** Deploy a connected smart infrastructure (CSI) on a highway in order to collect and aggregate traffic information that can be used by heavy-duty trucks traveling the corridor to improve their efficiency. The system will consist of a set of roadside units, which collect traffic data via cameras and cellular vehicle-to-everything (CV2X) communication. We have made preliminary studies about the deployment locations of the RSUs. This included a theoretical study about how the coverage depends on the traffic conditions and on the penetration rate of V2X equipped vehicles as well as experimental studies along I-275. These studies allowed us to pinpoint the locations of the RSUs we are planning to deploy along I-275. We also connected the RSUs to our server at U of M, which will allow us to operate the devices remotely. Finally, we have applied for FCC to obtain an experimental license.

***Real-time Distributed Optimization of Traffic Signal Timing: University of Michigan, Dr. Yafeng Yin, and Dr. Siqian Shen.*** This research will revolutionize real-time adaptive signal control via distributed optimization. The proposed research consists of three thrusts. Thrust 1 focuses on advancing distributed optimization and parallel computing techniques for solving network-level signal optimization models with discrete variables, nonconvex/nonlinear objective function and/or constraints. Thrust 2 further distributes the computation task to individual vehicles, by further decomposing distributed intersection-level sub-problems to smaller problems that can be solved at the vehicle level, or treating them as fully independent economic agents that negotiate the right-of-way through intersections. Thrust 3 uses simulation to validate results and deploy the system developed in Thrust 1 in the City of Ann Arbor. Industry partner Econolite joins the project through academic partner Mcity.

A two-stage stochastic Cell Transmission Model (CTM) involving stochastic traffic demand and turning ratio of vehicles was constructed. A Benders Decomposition and intersection-based decomposition algorithms for solving the corresponding stochastic integer programs for general grid network structure (in addition to the Plymouth corridor tested before) was developed. Numerical tests using synthetic and real-world traffic data, to demonstrate the computational efficacy of different approaches was run. In addition, a generalized max-weight control including a switching rule that can dynamically adjust the switching frequency according to the congestion level was hypothesized.

***Impact Analysis of Roadway Surface and Vehicle Conditions on Fleet Formation for Connected and Automated Vehicles: University of Akron, Dr. Ping Yi and Dr. Ethan Shajiei.*** Factors that largely affect rolling resistance and emergency braking distance include not only pavement friction, but also tire condition, vehicle's braking system, and environmental conditions. Those conditions change with road sections and may vary from one vehicle to other. Therefore, passive estimation and use of a friction coefficient for safety assessment, which has been a common practice for decades, cannot sufficiently meet the requirements of advanced transportation system today. This project proposes to study how such roadway and vehicle-based factors, when working together, can jointly affect the braking distance and influence inter-vehicle spacing and flow dynamics of a connected and automated vehicle fleet. Industry partner PathMaster, Inc. will provide valuable insight into the deployment viability of this project. This project was started on February 1, 2020 and it includes six tasks: 1 - Literature Study; 2 - Data Collection/Study; 3 - Model Development; 4 - Design of Study Scenario; 5 - Simulation Test; 6 - Data Analysis/Evaluation. In this period, Task 2 was initiated and data collected that relates braking distance to pavement and tire conditions. Task 3 - model development was also started.

***Intelligent Sidewalk De-icing and Pre-treatment with Connected Campus Maintenance Vehicles: Purdue University, Dr. Darcy Bullock.*** Develop an automated system for precision application of de-icing chemicals on campus and urban sidewalks that will reduce excessive chemical application and will result in less environmental impact, reduced infrastructure aging, and cost savings. Work completed this period includes procurement of test vehicle, and development of real time rate control (and application rate measurement) of de-icing chemicals. In addition, this period, the following work was started:

- Development of GIS map of Purdue campus sidewalks
- Coordination with campus officials to develop protocol for testing/deploying
- Coordination with campus officials to develop protocol for testing/deploying
- Coordination with campus officials to perform winter operations on select sidewalks

***Development of AI-based and Control-based Systems for Safe, Efficient Operations of Connected, and Autonomous Vehicles: Purdue University, Dr. Samuel Labi, Dr. Sikai Chen, and Dr. Mohammad Miralinaghi.*** This research is in three parts. The first part, recognizing the range limitations of onboard sensors such as LiDAR and cameras, will develop an Artificial Intelligence control system that fuses sensed (local) information and longer-range information to make CAV lane-changing decisions. Then, by integrating both information sources, the CAV can fully characterize its surrounding environment to facilitate long-term motion planning and short-term local planning. A Deep Reinforcement Learning based approach will be used to provide an end-to-end solution that incorporated a fusion approach and decision processor. The framework will help identify the optimal connectivity range for each domain of prevailing operating traffic density. The second part will develop a method to demonstrate a CAV's catalytic efficacy for addressing the lack of smoothness in the traffic flow. Such instability is caused by human drivers who naturally engage in spontaneous behavior including sudden speed changes. Such sudden actions generate perturbations that cascade to form amplified stop-and-go waves upstream. This traffic instability adversely affects operational efficiency, fuel economy, emissions, travel time, and driver/passenger comfort. The research will therefore investigate the efficacy of using a CAV to catalyze

the mitigation of instabilities in mixed stream traffic. The third part of the research will develop a collision avoidance framework for CAVs, to reduce the likelihood of collision with surrounding vehicles, particularly HDVs that drive aggressively or have uncertain or unpredictable behavior. The analysis is 80% complete, which resulted in 17 accepted conference abstracts, papers, and oral and poster presentations. Additionally, three journal papers are under review.

***Multi-front Approach for Improving Navigation of Autonomous and Connected Trucks: University of Illinois at Urbana-Champaign, Dr. Imad L. Al-Qadi and Dr. Yanfeng Ouyang.*** Connected and autonomous vehicles (CAV) and autonomous and connected trucks (ACT) reduce congestion, increase efficiency, and improve safety, but they also increase pavement damage. This project will optimize the benefits and drawbacks of ACT at both the network and corridor levels. The following was completed this period.

- A bi-level optimization framework minimizes the total cost of autonomous truck freight operation on a network level. The lower level finds the optimal platooning pattern for various numbers of trucks on a corridor that minimizes total cost considering fuel consumption, pavement rehabilitation and traffic congestion. The upper level considers the network flow equilibrium, and it simultaneously suggests decisions for both highway administration to plan platooning-enabled subnetworks and shipment carriers on whether to platoon. A binary variable is associated with each highway section to indicate the presence of a dedicated lane for platooning. This is only available to trucks that consent to the optimal platooning configuration from the lower level. Carriers may choose to either platoon or use the regular lane. The overall model is solved as a traffic-assignment problem with a surrogated model to evaluate link cost as a function of traffic volume.
- For Guangzhou data, we performed short-term traffic flow prediction using our proposed data imputation method. The accuracy and stability of imputation and following prediction outperform those of other methods. Such an accurate prediction is essential for real-time optimization of truck platooning.
- The main goal is to incorporate the effect of a rest period on pavement damage using correlation functions. The correlation functions were developed using finite-element (FE) models in ABAQUS. The correlation function can be calculated in two steps. It namely entailed converting the single axle to a baseline configuration, such as a specific speed and temperature, then followed it by using different resting periods. The first step ran 240 cases with different parameters. It contained five axle loadings, three temperature profiles, two pavement structures, both thin and thick; three speeds; three tire types; and two materials, both strong and weak. The second step is in progress, and it entails FE cases being run using FE models. The input parameters were provided to conduct the experiment to see the effect of a resting period on pavement responses. One paper has been sent to TRB for review regarding the rest period effects. On the experimental side, one asphalt mixture sample and design were acquired from the industry at Arizona. Four different mixes were reproduced in the laboratory to characterize the effect of the binder type on the rest period. An experimental program was developed to consider the rest period's effects using temperature, stress level and pulse duration. Forty percent of the experimental matrix was completed. The first phase of the experiments included the characterization of flow number for a point close to the pavement surface.

- Laboratory testing has been done with a variety of electromagnetic materials in concrete and asphalt specimens. Recent work focuses on balancing the volume of paving material that requires mixing with the electromagnetic material in order to achieve a signal detection. We have been exploring traditional construction materials that have high magnetic permeability. We have explored manufactured materials that have magnetic permeability 100 times larger to determine the feasibility of detection in low dosages as well as constructability with the material in concrete or asphalt. We have planned on a field site demonstration in the fall and/or winter to test the sensor-material combination at the Advanced Transportation Research and Engineering Laboratory both in normal and adverse condition.

***CAV Systems Incorporating Air Pollution Information from Traffic Congestion: Central State University, Dr. Krishna Kumar Nedunuri and Dr. Ramanitharan Kandiah.*** CSU is studying air pollutants under different traffic congestion scenarios along selected freeways in Ohio. The study captures pollution intensities in different seasons of the year representing different atmospheric stabilities and concentration of pollutants as a function of hold up times and traffic densities. This period, development of a methodology for using the extracted MOVES data was created. The traffic data will be used to develop an app for real-time prediction for above-road greenhouse gases on highways.

## 1.B Tech Transfer Metrics for this Period

For this period, CCAT surpassed all technology transfer goals, most by a significant margin (reference Table 1). CCAT continues to put technology transfer on the forefront of all activities, and is directly attributable to the success of the center. CCAT maintains a strong Technology Advisory Board (TAB) to ensure that our project selections can be directly transferred to industry and government for implementation and deployment.

For all projects awarded in 2019 and beyond, a research champion is required. This increases the amount of direct interaction with industry and government organizations to enhance technology transfer opportunities. This period, several research reviews with conducted with the industry and government collaborators. Some examples are:

- Meetings with Goodyear and Firestone engineers as subject matter experts on how tire conditions affect braking distance.
- Discussions with the City of Akron and PathMaster, Inc. to exchange information on the project "Access Control at major-Minor Intersection through CAV in Mixed Traffic."
- McGavic Outdoor Power and INDOT personnel have been directly involved in the research through meetings, demonstrations, and presentations:
    - McGavic Outdoor Power: Extensive meetings, hands-on work sessions, and webinars were held with personnel from McGavic Outdoor Power during the development of the prototype vehicle used for intelligent sidewalk de-icing and pre-treatment.
    - Indiana Department of Transportation: On-going collaboration with INDOT involves weekly communications regarding winter operation activities. Formal Study Advisory Committee meetings for the "Intelligent Sidewalk De-icing and Pre-treatment with

Connected Campus Maintenance Vehicles" project were held on October 2, 2019 and September 9, 2020.

- Bi-weekly calls with NASA Langley Research Center to review the status of the project "Enhanced Methodology for Exploring Autonomy-enabled Multi-mode Regional Transportation."
- Collaboration with Ford Motor Company. Ford is the industry champion for the project "Reliable V2V Communication Networks: Applications in Fuel-Efficient Platooning." In this period, Dr. Lakshmanan and his team held 10 WebEx meetings with Ford. At each meeting, detailed presentations of project status as well as methodologies and findings were exchanged. The meetings have influenced and guided Ford's internal modeling and simulation effort.
- Collaborated with the American Center for Mobility (ACM) to discuss scenario testing, which was subsequently used to developed the methodology for testing autonomous vehicles while highway driving.
    - Discussions with Econolite led to upgrading the hardware for the "Real-time Distributed Optimization of Traffic Signal Timing" project deployment to their latest product, which has a longer range and higher precision.

*Table 1: CCAT Technology Transfer Goal Targets and Actual Performance for this Period*

## Part II: CCAT UTC Specific Performance Indicators
## CCAT October 1, 2019 - September 30, 2020

**Technology Transfer Goals**

| 1. OUTPUTS | Research Performance Measures | CCAT Annual Target | OCT-MAR | APR-SEP | CCAT Total |
|---|---|---|---|---|---|
| 1.A. Disseminate research results through publications, conference papers, and policy papers | Technical reports | 10 | 9 | 9 | 18 |
| | Papers at conferences, symposia, workshops, and meetings | 3 | 56 | 55 | 111 |
| | Peer-reviewed journal articles | 6 | 18 | 22 | 40 |
| 1.B. Develop inventions, new methodologies, or products | Annual number of research deployments | 5 | 3 | 7 | 10 |
| 1.C. Research projects funded by sources other than UTC and matching fund sources | Number of projects | 3 | 12 | 9 | 21 |
| | Dollar amount of projects | $300,000 | $2,743,166 | $1,518,841 | $4,262,007 |
| **2. OUTCOMES** | **Research Performance Measures** | | | | **0** |
| 2.A. Incorporate new technologies, techniques or practices | Number of technology transfer activities that offer implementation or deployment guidance | 2 | 2 | 19 | 21 |
| 2.B. Improve the processes, technologies, techniques in addressing transportation issues | Number of research deliverables disseminated from each research project | 4 | 9 | 48 | 57 |
| **3. IMPACTS** | **Research Performance Measures** | | | | **0** |
| 3.A. Increase the body of knowledge and safety of the transportation system | Number of instances of technology adoption or commercialization | 2 | 0 | 3 | 3 |
| | Number of conferences organized by the CCAT consortium members | 2 | 7 | 12 | 19 |
| 3.B. Improve the operation and safety of the transportation system | Number of instances of research changing behavior, practices, decision making, policies (including regulatory policies), or social actions | 3 | 0 | 4 | 4 |

## 1.C Dissemination of Research and Other Outreach, Education, Leadership and Workforce Development

CCAT members hosted or participated in 74 outreach engagements this reporting period. Audiences included industry, government, academia, media, and the community. In total, CCAT research was shared with over 3,075 people in the last six months. This is in addition to the 9,950 views on our website. The University of Michigan CCAT outreach log is available upon request. The CCAT newsletter was issued in May, July, and September of 2020.

The largest event this period was the third Annual CCAT Global Symposium on Connected Vehicles and Infrastructure held on April 14, 2020. Due to COVID-19, the symposium was reformatted to an on-line event. The symposium was held near the start of the pandemic, so was one of the first events of its kind. The event was free and was so successful that we had to add an overflow "room" on YouTube. We had 300 people on Zoom plus 349 people on YouTube, with an additional 246 video on demand views after the symposium. Typically, the event would have included a student poster competition. However, the student poster competition was delayed until October 28, 2020. In this period, the nine volunteer judges were selected and the request for posters was sent out to many universities and all UTCs. The format developed was that the judges would select the top four posters. Those students would be invited to a zoom meeting where they would have 10 minutes to present their work, followed by questions from the judges. The judges evaluate the presentations and the top two winners would receive $1000 each. The scholarship prizes are sponsored by ITS Michigan and the University of Michigan. Planning has begun on next year's 4th Annual CCAT Global Symposium on Connected Vehicles and Infrastructure that will be held on April 12 & 13, 2021. We are planning for a hybrid in-person and virtual event but will, in parallel, plan for a fully on-line event if required. We envision three tracks: (1) keynotes speakers and moderated panel sessions; (2) CCAT research reviews; and (3) student posters.

This period, CCAT continued the monthly research reviews and added "Lunch and Learn" events, which will continue into next period (reference Table 2). All are available on CCAT's YouTube channel (links below). The Lunch and Learn events are intended to share important information to our stakeholders that is within the expertise of the CCAT consortium, but is not necessarily from a specific research project.

*Table 2: Research Reviews and Lunch and Learn Events for the Reporting Period 4/1/2020 – 9/30/2020*[1]

| Date | Title (Link) | Presenters | Registrants | Attendees | Views |
|---|---|---|---|---|---|
| 4/7/20 | On the Road to the CCAT 20/20 Global Symposium – Automated Precision Brine Application | Dr. Darcy Bullock Purdue | 61 | 24 | 61 |

[1] None of the presentations and videos are listed in the output section to save space and omit redundant reporting.

| | | | | | |
|---|---|---|---|---|---|
| 4/9/20 | On the Road to the CCAT 20/20 Global Symposium – CAVs for Assessing Green House Gases | Dr. KrishnaKumar Nedunuri<br>Dr. Ramani Kandiah<br>Central State University | 41 | 26 | 36 |
| 5/7/20 | From Data to Actions, From Observations to Solutions: A Summary of Operations Research and Industrial Engineering Tools for Fighting COVID-19 | Dr. Siqian Shen<br>University of Michigan | 116 | 59 | 59 |
| 6/2/20 | How Vehicle Connectivity-based Eco-Routing Choices Will Impact Driver Decision Making | Dr. Shan Bao<br>University of Michigan | 124 | 43 | 83 |
| 6/25/20 | How COVID-19 Curbs the Demand for Mobility on Demand | Amy Ford, Director<br>Sara Davidson<br>ITS America | 91 | 57 | 56 |
| 7/29/20 | Supporting People with Vision Impairments in Automated Vehicles: Challenges and Opportunities | Dr. Robin Brewer<br>Dr. Nicole Ellison<br>University of Michigan | 189 | 104 | 54 |
| 9/29/20 | Vehicle to Pavement Sensing for Lateral Lane Position | Dr. Jeffery Roesler<br>Purdue | 107 | 45 | 311 |

CCAT is planning to continue the Distinguished Lecture Series (DLS) next period in a virtual format. We have scheduled Trevor Pawl, Chief Mobility Officer for the State of Michigan on October 21, 2020. He will be presenting his vision of the future of Michigan mobility and electrification.

Since April 1, 2020, CCAT has expanded their audience significantly. This is, in part, due to the success of our annual Global Symposium. When COVID-19 struck the United States, we were forced to move the event from in-person to online. With this, we removed registration fees and saw in explosion in attendance. In the past six months, CCAT has used the Twitter platform for event promotion, final report releases, and general outreach. Compared to the last six months, CCAT Twitter impressions increased to over 86,000, our largest growth yet. Our Twitter following increased from 67 to 166. The visits to our Twitter rose to 1,400. CCAT uses the LinkedIn platform, in part, as a way to promote upcoming events, to increase student engagement, and to announce the release of final reports. Our number of followers on LinkedIn grew from 71 to 201 in the six-month period and our engagement currently sits at 4.23%. This engagement rate translates to people registering for our webinars, reading our newsletter, or viewing our final reports. Part of this growth is due to the creation of our student group on LinkedIn. It is used to promote job listings, networking opportunities, and more in the transportation space. Our YouTube channel provides VOD for those that cannot attend our webinars live. Here, our Distinguished Lecture Series, Research Reviews, or other CCAT events are uploaded in their entirety. In the past six months, we have seen 1,900 views across 25 videos, a combined number of hours watched of 558, a subscriber growth of from seven to 125, and impressions of 26.500. An interesting aside is that IEEE started advertising our events on their website, unsolicited. This widens our audience even more, although not reflected in the reported metrics.

The CCAT website provides a wide array of information for those that work within and outside the CCAT umbrella. All research projects along with their corresponding UTC and Final Report forms are available. All Program Progress Performance Reports and Semi-Annual Progress Reports are viewable. New additions to the CCAT website include individual pages for all research projects as well as for each principal investigator under the CCAT umbrella. In the past six months, our number of website sessions were 2,413 (an increase of 1,000 from the last period) with our number of users totaling 1,522 (an increase of 600 from the last period), and a number of page views equaling 9,950 (an increase of over 5,000 from the last period). Our top three countries for this period were the United States, China, and the UK. A new build of the CCAT website is currently in the works and will include faster loading speeds and a search function.

In this reporting period, we experienced success with our leadership development efforts:

- Under the guidance of CCAT PI, Neda Masoud, students at the University of Michigan won the Transportation Technology Tournament. The tournament is hosted by the National Operations Center of Excellence (NOCoE) and the U.S. DOT ITS JPO PCB program. The team was organized by the Michigan Transportation Student Organization (MiTSO), and their focus was on curb space management for multi-modal transportation in downtown areas. Watch the announcement here.
- Under the guidance of CCAT Director, Henry Liu, Shuo Feng was awarded 2nd place in the IEEE ITS Best Dissertation Award for "Testing Scenario Library Generation for Connected and Automated Vehicles." The award is given annually for the best dissertation in any ITS area that is innovative and relevant to practice. This award is established to encourage doctoral research that combines theory and practice, makes in-depth technical contributions, or is interdisciplinary in nature, having the potential to contribute to the ITSS and broaden the ITS topic areas from either the methodological or application perspectives.

Debby Bezzina, CCAT Managing Director, as an industry subject matter expert, contributed to an IEEE Spectrum story on technology for connected vehicles.

In addition to the above, WCC completed the following workforce development, education, K-12 STEM, and outreach activities:

**Workforce Development Training Accomplishments:**

- Completed the development of MS Excel for Mobility Analysts with an Expert Certification Exam 77-728, transferred to World Education for national distribution, and loaded the course into the WCC Blackboard College Resource site.
- Advanced the development of Basics of Autonomous Vehicle Machine Learning, received lab project ideas from the Academic side of WCC using new Umlaut designed test benches.
- Continued development of Data Analytics training module, which was revised and transformed from the on-hold Connected Car C-V2X Technologies.
- Transferred MS Excel for Mobility Analysts with Core Certification Exam 77-727 to World Education for national distribution.
- Completed Introduction to Artificial Intelligence and converted title to Applied Machine Learning. Transferred to World Education for national distribution.

- Contracted with IEEE to establish a WCC resource library of IEEE eLearning Library topical education modules for use by instructors and students. Loaded eLearning Library Modules into the WCC Blackboard resource center to serve both Academic Credit and Non-Credit areas.
- The ATC Director participated in the fifth and sixth ITS Professional Capacity Building Community College T3 "Talking Technology & Transportation" Discussion Webinars, 3/25/2020 and 6/17/2020.

**Credit Education Certificate and Degree Programs Accomplishments:**

- Developed a virtual Outreach Mobility Row Exhibit for Sept. 25 with Ann Arbor SPARK during the COVID-19 pandemic that contained Russell Video filmed technology exhibits of WCC's Automotive Cybersecurity Educator; Umlaut-designed Cybersecurity Attack Modules; and Polaris Slingshot vehicle with installed sensors, V2X communications and other CAV equipment.
- Launched an Automotive Cybersecurity Certificate Program. The 19-credit certificate program includes a combination of Computer Systems, Computer Science, and Automotive Services courses, designed to meet the emerging demand for highly skilled automotive cybersecurity professionals. WCC was named a designated National Center of Excellence in Cyber Defense Education, releasing two new approved Certificates: (1) Automotive Cybersecurity Certificate, and (2) Advanced Automotive Services Technician Certificate.
- Completed an upgrade in Network/Communications with Cellular V2X for release in key courses.
- Promoted the formation and engagement of a National Cyber League Team [WCC White Hat Society] to participate in cybersecurity challenges such as the NDIA Cyber Physical Systems Conference. This team ranked 51st out of 931 teams in the spring 2020 team competition round. Note- Three other activities like this were cancelled due to restrictions enforced during the COVID-19 pandemic.
- Cancelled a Lunch & Learn Statewide College Instructor Workshop on the process of integration of ITS Technologies into Automotive Technology Programs due to the COVID-19 pandemic.
- Completed an online Virtual Summer Cybersecurity Camp for high school students with coordination among instructors across the State of Michigan during the COVID-19 restriction era.
- CAV/CAT Equipment for WCC Educational Labs:
  - Specified and ordered Umlaut-designed Automotive Cybersecurity Lab Testers for integration into the Cybersecurity Lab System. The Academic Credit unit will guide the Workforce Development unit in creating Employer/Incumbent Worker Training Modules.
  - Specified and ordered 3-D LiDAR equipment for Automotive Technologies programs to teach students functionality of 3-Dimensonal Object Detection sensors, and display the technology on the showcase Polaris Slingshot exhibit vehicle.
  - Specified and ordered equipment to develop classroom/lab simulations that identify object detection, segmentation and scene classification in conjunction with 3D LiDAR and Camera Sensors. The equipment consists of a dash camera, MATLAB/MathWorks software license and a Ground Truth Labeler application- an Automated Driving Toolbox.

**K-12 STEM Technology Awareness & Insight Accomplishments:**

- Due to COVID-19 response policies, cancelled Square One Education Network "Cars that Communicate: V2X Technology" live Youth Camp due to COVID-19 pandemic, and replaced it with a virtual event described below. Note- this was a no-charge awareness event for disadvantaged youth in the Ypsilanti/Eastern Washtenaw County area.

- Conducted Computer Awareness Training at Scarlett Middle School in Ann Arbor, to the point of stoppage, due to the COVID-19 pandemic.
- Delivered a virtual camp at the Parkridge Facility for disadvantaged youth to provide awareness in microprocessor computers. In addition, contracted with Square One Education Network to deliver Micro-Bit Computer virtual awareness education at a second youth camp at the Parkridge community.

**General Outreach:**

- 2020 NAIAS Automobili-D Exhibits [June 2020] cancelled and deferred to the 2021 NAIAS event; Outreach planning activities continued.
- ITS PCB Community College Workshop Webinar- WCC presentations on education/training programs and collaboration partners, July 8, 2020.
- Ann Arbor SPARK Virtual Mobility Row CAV Technology Exhibits, including Automotive Cybersecurity, September 25, 2020.
- Ann Arbor SPARK Student Trek/Tech Trek registration, allowing interested WCC students virtually to attend the session with area technology companies seeking to hire field candidates, Sept. 25, 2020.

## 2. Participants and Other Collaborating Organizations

One of the CCAT goals is to collaborate with other organizations within the CCAT consortium, within Region 5, and nationally. The following table summarize the collaborations that occurred during this reporting period.

| CCAT Org. | Org. | Location | Contribution |
|---|---|---|---|
| Akron | ODOT District 4 | Akron, OH | Data sources and project support. |
| Akron | PathMaster, Inc. | Twinsburg, OH | Personnel and technical support on algorithm testing, data sources. |
| Akron | City of Akron | Akron, OH | Personnel and technical support. |
| Akron | Concordian at Summer Independent Living Program | City of Copley, Ohio | Project support, older driver selection. |
| Purdue | McGavic Outdoor Power | Noblesville, IN | Development of electric vehicle de-icing prototype, which included integration of automated application equipment and Raven controller into GEM electric vehicle. |
| Purdue | Area Planning Commission of Tippecanoe County | Lafayette, Indiana | Mutual assistance in counting vehicles, pedestrians, and other users of selected locations on city streets. |
| Purdue | Indiana Department of Transportation | Indianapolis, IN | Collaborative research (in-kind) and cost sharing (cash). |
| Purdue | Georgia Institute of Technology | Atlanta, GA | Collaborative research |
| UM | Ford Motor Company | Dearborn, MI | Financial support ($221,125), in-kind support for facilities and technical collaboration. |
| UM | City of Ann Arbor | Ann Arbor, MI | Financial Support ($82,911) |

| | | | |
|---|---|---|---|
| UM | Econolite | Anaheim, CA | Providing radar sensors, edge computing devices and technical support. |
| UM | DENSO | Ann Arbor, MI | Providing video cameras for 6 intersections for the Plymouth Road corridor data collection and implementation. |

## 3. Outputs

In this reporting period, the CCAT consortium produced the following products and other outputs:

**University of Michigan**

- A system for the simulation of EM Field propagation via stochastic ray tracing (S. Lakshmanan).
- Publication to appear in AMTA 2020: Publication to appear in AMTA 2020 (42nd Annual Meeting and Symposium of the Antenna Measurement Techniques Association): "A Validated Model for Non-Line-of-Sight V2X Communications." T. Kleinow, S. Lakshmanan, P. Richardson, V. Elangovan (UM), S. Schmidt, J. Locke, M. Crowder (Ford Motor Company).
- Submitted invention disclosure to UM Tech Transfer Office (OTT 2021-031): "A System for the Simulation of EM Field Propagation via Stochastic Ray Tracing." Inventors: T. Kleinow, S. Lakshmanan, P. Watta (UM). ***There is already interest from a commercialization partner.***
- MS Thesis completed: "Simulating RF Field Propagation with Stochastic Ray Tracing." T. Kleinow. http://hdl.handle.net/2027.42/156108 (under embargo for 1 year due to patent filing).
- Validated V2X Model of NLOS scenarios using WinProp (DSRC and CV2X) (S. Lakshmanan).
- Weaving models with MATLAB modules and C++ on Mcity AV platform.
- Feng, S., Yan, X., Sun, H., Feng, Y., and Liu, H.X. (2020) Intelligent Driving Intelligence Test for Autonomous Vehicles with Naturalistic and Adversarial Driving Environment, Second round review with Nature Communications.
- Liu, L., Feng, S., Feng, Y., Zhu, X., and Liu, H. X. (2021). A Learning-based Stochastic Driving Model for Autonomous Vehicle Testing, to be Presented at TRB 100th Annual Meeting, 2021.
- Sun, H., Feng, S., Yan, X., and Liu, H. X. (2021). Corner Case Generation and Analysis for Safety Assessment of Autonomous Vehicles, to be presented at TRB 100th Annual Meeting, 2021.
- Yan, X., Feng, S., Sun, H., and Liu, H. X. (2021). A Data-driven Simulation of Naturalistic Driving Environment for Autonomous Vehicle Testing, to be Presented at TRB 100th Annual Meeting, 2021.
- Naturalistic and adversarial driving environment for testing and evaluation of autonomous vehicles (H. Liu).
- Naturalistic and adversarial driving environment using SUMO and CARLA (H. Liu).
- Xian Yu, Siqian Shen, "Multistage Distributionally Robust Mixed-Integer Programming with Decision-Dependent Moment-Based Ambiguity Sets," minor revision submitted to Mathematical Programming Series B, 2020.
    - A data set was generated for the paper.
- The alternating direction method of multipliers (ADMM) algorithm for solving large-scale, stochastic mixed-integer programming cell transmission model (CTM) for traffic signal control. Benders decomposition and intersection-based heuristic decomposition approaches for stochastic CTM solved for grid networks.
- Research Projects funded by sources other than UTC and matching fund sources:

- Invited to submit Ford Alliance proposal for spin-off research. “Hardware in the Loop for C-V2X Platform Development.” Amount: $207,686.24. Period of Performance: April 2021 - March 2023.

**Purdue University**

- The integration of precision agriculture controllers with winter de-icing equipment is a new method that has generated considerable interest by private sector companies.
- Poster: Precision Brine Application for Urban Campus Roads and Sidewalks.
- Poster: Automating Brine Application to Highways to Reduce Operator Workload and Distraction.
- Video: How to Operate the Raven CR7 Controller - https://youtu.be/AY3JnTUyKEM.
- Maheshwari, A., Mudumba, S., Sells, B., E., DeLaurentis, D., A., and Crossley, W. A., Identifying and Analyzing Operations Limits for Passenger-Carrying Urban Air Mobility Missions. In AIAA AVIATION 2020 FORUM (p. 2913).
- Yunchang Zhang and Jon Fricker, "Multi-State Semi-Markov Modeling of Recurrent Events: Estimating Driver Waiting Time at Semi-Controlled Crosswalks", was published by Analytic Methods in Accident Research.
- Accident Analysis and Prevention, "Investigating Pedestrian Waiting Time at Semi-Controlled Crossing Locations: Application of Multi-State Models for Recurrent Events Analysis", by Yu Qiao, Yunchang Zhang, and Jon D. Fricker, was published in the Accident Analysis and Prevention Journal.
- A database of more than 2000 interactions between pedestrians and motorists assembled last period was refined this period (J. Fricker).
- A paper was written and submitted to TRB on Ridesharing, Active Travel Behavior, and Personal health: Implications for Shared Autonomous Vehicles. Decision expected October 2020.
- Jiqian Dong, Sikai Chen, Yujie Li, Runjia Du, Aaron Steinfeld, and Samuel Labi, “Facilitating Connected Autonomous Vehicle Operations Using Space-Weighted Information Fusion and Deep Reinforcement Learning Based Control” (under review: Transportation Research Part C: Emerging Technologies).
- Yujie Li, Sakai Chen, Paul *Young Joun) Ha, Jiqian Dong, Aaron Steinfeld, and Samuel Labi, “Leveraging Vehicle Connectivity and Autonomy to Stabilize Flow in Mixed Traffic Conditions: Accounting for Human-Driven Vehicle Driver Behavioral Heterogeneity and Perception-Reaction Time” (under review: Transportation Research Part C: Emerging Technologies).
- Paul (Young Joun) Ha, Sikai Chen, Runjia Du, Jiqian Dong, Yujie Li, Samuel Labi, “Vehicle Connectivity and Automation: a Sibling Relationship” (under review: Frontiers in Built Environment).
- AI-based and control based systems for safe and efficient operations of connected and autonomous vehicles (demonstrated using simulation).
- New CAV-related coursework approved by Purdue administration started the spring term of 2020.
- Manuscript titled “Promoting Autonomous Vehicles using Travel Demand and Lane Management Strategies, by Sania Seilabi, Mahmood Tabesh, Amir Davatgari, Mohammad Miralinaghi, Samuel Labi, published in Frontiers in Built Environment, Transportation & Transit Systems Section, in July 17, 2020

- Manuscript titled “Considerations of Smart Cities Concepts in Municipal Infrastructure Management” by Bortiorkor N.T. Alabi, Runjia Du, Yuntao Guo, Majed Alinizzi, and Samuel Labi, was submitted to the ASCE Journal of Infrastructure Systems, on September 30, 2020.
- Manuscript titled “Preparing Road Infrastructure to Accommodate Connected and Automated Vehicles – A System-Level Perspective” by Tariq Usman Saeed; Bortiorkor Nii Tsui Alabi; Samuel Labi, was accepted for publication in ASCE’s Journal of Infrastructure Systems, on September 9, 2020."
- Data set generated on prospective changes in AV era.
- Manuscript titled “Managing Urban Vehicular Emissions Through the Efficient Design of Electric Charging Station Infrastructure", by Mohammad Miralinaghi, Gonçalo Correia, Sania Seilabi, and Samuel Labi, was accepted on Sept 30, 2020 for presentation at the 2021 TRB Annual Conference
- Manuscript titled “Design of Electric Charging Station Network to Minimize Vehicle Emissions, by Mohammad Miralinaghi, Gonçalo Correia, Sania Seilabi, and Samuel Labi, was accepted Sept 9, 2020, for presentation at the ISTS Forum 2020, Delft, Netherlands
- Manuscript titled “Minimizing Urban Vehicular Emissions through the Efficient Design of Electric Charging Station Network, by Mohammad Miralinaghi, Gonçalo Homem de Almeida Correia, Sania E. Seilabi, and Samuel Labi, was submitted Sept 20, 2020 to Networks and Spatial Economics Journal.
- Manuscript titled “An Empirical Discourse on Forecasting the Use of Autonomous Vehicles Using Consumers’ Preferences,” by Tariq Usman Saeed, Mark W. Burris, Samuel Labi, and Kumares C. Sinha, was published in the Technology Forecasting & Social Change journal, in June 30, 2020.
- A. Koilias, C. Mousas, B. Rekabdar, C.N. Anagnostopoulos ""Passenger Anxiety about Virtual Driver Awareness during a Trip with a Virtual Autonomous Vehicle"" International Symposium on Visual Computing, 2020.
- A. Dalipi, D. Liu, X. Guo, Y. Chen, C. Mousas ""VR-PAVIB: The Virtual Reality Pedestrian-Autonomous Vehicle Interaction Benchmark"" International Conference on Automotive User Interfaces and Interactive Vehicular Applications, pp. 38-41, 2020.
- "Optimal Mixed-traffic Operation with Lanes Dedicated to Autonomous Vehicles", Accepted for Presentation at 2020 INFORMS Annual Meeting, Virtual, 2020 (S. Peeta).
- The final report for the project “Cooperative control mechanism for platoon formation of connected and autonomous vehicles” was completed this period and will be edited for 508 compliance and submitted next period.
- A draft of the final report for the project "Development of in-vehicle information dissemination mechanisms to reduce cognitive burden in the information-rich driving environment - Phase 2" was completed this period.
- “Cooperative Driving in Mixed-flow Traffic of Connected Vehicles and Human-driving Vehicles: A State Estimation Approach", accepted for presentation at 2021 Transportation Research Board Annual Meeting, Washington, DC, 2021 (S. Peeta).
- “A Proactive Control Model to Prevent Lane-Changes from Human Driving Vehicles under Mixed Traffic Environments", accepted for presentation at 2020 INFORMS Annual Meeting, Virtual, 2020 (S. Peeta).

- Research project funded by a non-CCAT source this period was “Winter Operations Best Practices and Training for Local Agencies” for Indian LTAP ($100,222)

**University of Akron**

Baseline data collected at site chosen to test the prototype safety advisory system to aid senior citizens with gap selection. This baseline data will be compared to future data collected after system installation. Additional data was collected at sites near independent living facilities and added to the existing data set. The data was collected from intersections where a vehicle on the minor street enters the major road by selecting a gap between approaching vehicles on the major road. Research methods and model development material were also generated.

**University of Illinois at Urbana Champaign**

- Bi-level modeling that simultaneously optimizes (1) platooning configuration and (2) network traffic assignment with platooning decision.
- A new imputation method was proposed and tested for traffic data, which outperforms other imputation methods based on generative adversarial networks (GAN).
- The influence of axle (single and tandem) on pavement responses and viscoelastic recovery was studied extensively and a research paper has been submitted. The first step of correlation functions to include the effect of rest period is completed.
- Sensitivity analysis for different electromagnetic materials in the pavement structure"

**Central State University**

Invited Student Paper: Estimating the Contribution of On-road Mobile Vehicles to the Near-Road Air Pollutant Concentrations at a Highway Intersection paper for TRB 2020 conference, Washington DC, on January 16, 2020. This paper was inadvertently omitted from the last report.

## 4. Outcomes

The application of outputs has produced the following outcomes during this reporting period:

**University of Michigan**

- The project output of “Reliable V2V Communication Networks: Applications in Fuel-Efficient Platooning” will inform regulatory, legislative, or policy organizations such as NHTSA, FHWA, etc. regarding the impact of V2V communications on truck platooning. This will include supporting data regarding its performance in a variety of high-speed environments. The data will also allow these organizations to assess the current performance of directly competing V2V communication technologies, namely, DSRC and CV2X.
- Increased the understanding of drivers’ behavior in freeway weaving sections through the project “Development of machine-learning models for autonomous vehicle decisions on weaving sections of freeway ramps.”

**Purdue University**

- Successful development of an automated precision brine application prototype vehicle.
- Dissemination and training on the use of the automated vehicle for brine application to academia, state DOTs, and local agencies.

- Building on the findings of previous reporting periods, patterns in the data for "Smart Interaction – Pedestrians and Vehicles in a CAV Environment" have been discovered. The influence of gaps rejected, time in queue, and time of day have been identified.
- Increased the body of knowledge by applying the concept of multi-state semi-Markov models to the recurrent events inherent with the gap acceptance phenomena at crossing locations.
- Acquired further improved understanding of the behavior of pedestrians and motorists in a variety of situations at the same site. This can form the basis of an analysis of the performance of similar crossing facilities when new technologies are employed for vehicles and pedestrians.
- Improved processes, technologies, techniques and skills in addressing transportation issues.

**University of Illinois at Urbana Champaign**

- In this period, we have formulated the network-level optimization model that simultaneously suggests decisions on routing, platooning and platoon configuration at equilibrium. Solution method is proposed. An abstraction of the highway network of the State of Illinois was obtained for numerical study.
- The proposed imputation method was successfully applied to short-term traffic data prediction.
- Correlation functions will be useful in avoiding running large FE models and thus, saving lot of time. As resting period decreases, fatigue life decreases but from experimentation, it is shown that permanent deformation increases as resting period increases.
- Tested electromagnetic materials successfully in normal and adverse conditions that were embedded into concrete and asphalt material.

## 5. Impacts

In addition to the impacts that CCAT outreach has on the body of knowledge and technology, these additional impacts were derived from CCAT research this reporting period.

**University of Michigan**

A commercially viable truck platooning application developed for the project "Reliable V2V Communication Networks: Applications in Fuel-Efficient Platooning," will improve the operation and safety of trucking transportation. Furthermore, it will provide a practical solution to the shortage in truck drivers.

**Purdue University**

- Knowledge gained in the research and initial deployment of the automated brine application system has developed capabilities in the connected and automated space for small campus vehicles and will provide information needed to scale precision application of de-icing chemicals to highways and airports.
- Research product from the project "Pedestrian-Vehicle Interaction in a CAV Environment – Explanatory Metrics" helps enhance the operation and safety of semi-controlled crosswalks by developing a database and identifying factors that affect pedestrian and motorist behavior. This information will be used to test the impact of new technologies on crosswalk safety and performance.
- Increases the body of knowledge and technologies for understanding the behavioral intention to ride in AVs and impacts on mode choice decisions, energy use and emissions.

**University of Illinois at Urbana Champaign**

- This study proposes modeling and solution tools to determine key components in the futuristic autonomy-based freight transshipment on a highway network. Useful insight may be extracted for highway administration and shipment carriers to aid in operational decision making. Potential cooperation may be considered to further achieve economic optimality.
- Traffic data are usually incomplete. This affects the accuracy of any inference from them, which is the basis for ITS. The proposed imputation methods address this challenge particularly in the face of big data.
- The pavement FE model considers parameters like moving loads; complex material properties, like stress-hardening and softening and temperature-dependent materials; and layer interactions. Thus, having a correlation function based on the FE model will help capture the effect accurately. It is also important to note that the resting period affects fatigue and rutting oppositely. Thus, the resting period's impact on truck spacing in a platoon can be optimized.
- Materials and sensors that work successfully in normal and adverse conditions tested successfully for concrete and asphalt specimens. Autonomous vehicles can use this robust system as a backup, or along with a camera and GPS sensors, for lane keeping. The system also works in adverse weather conditions, giving it an advantage over the camera and GPS in such harsh conditions.

## 6. Changes/Problems:

In this period, CCAT continued to struggle with the impacts of COVID-19. Although campuses were reopened, many restrictions remained, such as a delay in bringing student researchers back on campus until the fall semester, and banning human subject interactions until proven methodologies for ensuring the safety of the participants and researches could be established. Another impact that cannot be overlooked is the general decrease in traffic. Many of our studies involve collecting data in a live environment. However, the environment looks much different today than it did a year ago. For example, on Plymouth Road in Ann Arbor, in September of 2020, vehicle traffic has decrease 63% and pedestrian traffic has decreased by 92%, as compared to September of 2019.

Below is a summary of changes and problems for each of our consortium members, including issues stemming from COVID-19.

**University of Michigan**

- COVID-19 continues to interrupt the project "Reliable V2V Communication Networks: Applications in Fuel-Efficient Platooning," causing:
  - Delayed CV2X radio acquisition
  - Delayed data collection with Ford
  - Delayed subsequent data analysis, modeling and simulation
  - Delayed hardware experiment with Ford
  - Shortage of commercial drivers for platooning testing
  - New project end date: 12/31/2020
- New project end dates also established for the following projects:

- Development of Machine-learning Models for Autonomous Vehicle Decisions on Weaving Sections of Freeway Ramps. Delayed testing on the AV platform and at Mcity.
- Real-time Distributed Optimization of Traffic Signal Timing. The COVID-19 pandemic has affected the availability of the City of Ann Arbor's schedule to install the deployment hardware.

**Akron**

Work on the project "Development of a Prototype Safety Advisory System to Aid Senior Citizens in Gap Selection" was slowed down due to campus wide restrictions on lab work and face-to-face meetings. Additionally, low traffic volume due to the prolonged pandemic limited the amount and scope of data that could be collected to assess the access control at major-minor intersections for CAVs in mixed traffic.

**WCC**

- Instead of supporting students to attend conferences, WCC has redirected their efforts to buy supplies for students, deliver then to their houses, for the students to participate remotely.

**Purdue University**

- COVID-19 has dramatically affected ridesharing and other forms of shared and/or public transportation. This has impacted the project Ridesharing, Active Travel Behavior, and Personal Health: Implications for Shared Autonomous Vehicles.
- For the project "Design of urban landscape and road networks to accommodate CAVs – Phase 2," 50 participants were to be recruited to conduct the simulator-based experiments. However, due to the COVID-19 crisis, the schedule of the simulator-based experiments has not yet been determined.

**CSU**

CSU is trying to acquire portable emissions measurement system (PEMS) for monitoring CO2, NOx, Particulate Matter (PM), Carbon Monoxide (CO), Hydrocarbons(HC), CH4 and H2O. They are also trying acquiring near-road air quality monitors. Several vendors have been reviewed and a few contacted. The prices on the equipment has exceeded budgetary limits for the grant ($100-130K). Students have participated in identifying this equipment. CSU is exploring selection of a few sensors to bring it within the budget."

## 7. Special Reporting Requirements: Final Reports

This period, the following final reports were completed, edited to meet 508 compliance, and posted to the CCAT website. All have been submitted to the Transportation Library; the Volpe National Transportation Systems Center; the Federal Highway Administration Research Library; and the National Technical Information Service. In the next quarter, all of the corresponding outputs, outcomes, and data sets will be submitted as well.

- Pradhan, A.K., Jeong, H., Bao, S. (2020). Connected and Automated Vehicle Based Intersection Maneuver Assist Systems and Their Impact on Driver Behavior, Acceptance, and Safety. Final Report. USDOT CCAT Project No. 2 Identifier: http://hdl.handle.net/2027.42/156048

- Feng, Y., & Liu, H.X. (2019). Development of an Augmented Reality Environment for Connected and Automated Vehicle Testing. Final Report. USDOT CCAT Project No. 2. Identifier: http://hdl.handle.net/2027.42/149453
- Peng, H. & Huang, X. (2019). Driving Etiquette. Final Report. USDOT CCAT Project No. 1Identifier: http://hdl.handle.net/2027.42/156052
- Masoud, N. (2019). Enhancing network equilibrium models for capturing emerging shared-use mobility services. Final Report. USDOT CCAT Project No. 4. Identifier: http://hdl.handle.net/2027.42/162823
- Lasecki, W.S., Chung, J.J.Y., O'Keefe, S.D., Hampshire, R.C., Bao, S., & Song, J.Y. (2020). Machine Learning, Human Factors and Security Analysis for the Remote Command of Driving: A Mcity Pilot. Final Report. USDOT CCAT Project No. 9. Identifier: http://hdl.handle.net/2027.42/156392
- Bills, T (2020). On Transportation Equity Implications of Connected and Autonomous Vehicles (CAV) A Review of Methodologies. Final Report. USDOT CCAT Project No. 5. Identifier: http://hdl.handle.net/2027.42/162824
- Dahal, S., Hernandez, J., & Roesler, J. (2018). Infrastructure enhancements for CAV navigation (Report No. ICT-20-008). Illinois Center for Transportation. https://doi.org/10.36501/0197-9191/20-008
- Gungor, O. E., She, R., Al-Qadi, I. L., & Ouyang, Y. (2018). Optimization of lateral position of autonomous trucks (Report No. ICT-20-009). Illinois Center for Transportation. https://doi.org/10.36501/0197-9191/20-009
- Gungor, O. E., Al-Qadi, I. L., & Ouyang, Y. (2018). Development of a flexible pavement design framework for autonomous and connected trucks (Report No. ICT-20-010). Illinois Center for Transportation. https://doi.org/10.36501/0197-9191/20-010
- She, R., Ouyang, Y., & Al-Qadi I. L. (2018). CDF analysis and prediction model for air resistance on platooned freight trucks (Report No. ICT-20-011). Illinois Center for Transportation. https://doi.org/10.36501/0197-9191/20-011
- Brewer, R. & Ellison, N. (2020). Supporting People with Vision Impairments in Automated Vehicles: Challenge and Opportunities. Final Report. USDOT CCAT Project No. 11. Identifier: http://hdl.handle.net/2027.42/156054