CENTER FOR CONNECTED AND AUTOMATED TRANSPORTATION

Semi-Annual Progress Report for University Transportation Centers

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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 October 1, 2019 through March 31, 2020.

1.A Current Research Status

During this reporting period, projects for the 2020 calendar year were selected. This year's focus is on making an impact. We requested proposals for research that would significantly influence the future of transportation. A high weight was given to the potential for deployment and the strength of their industry and government partners. Responses were received in mid-November. The project proposals were sent to the Technology Advisory Board (TAB) for evaluation. The TAB convened in January of 2020 and the year 4 projects were selected. The TAB consists of member from industry, government, and academia including:

- 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

For 2020, the following projects were selected for funding:

2020 International Symposium on Transportation Data and Modeling: University of Michigan, Dr. Yafeng Yin. Organize the 2020 International Symposium on Transportation Data and Modeling (ISTDM) in Ann Arbor on June 24- 26, 2020. The theme of the conference is achieving connected, cooperative and automated mobility. The theme perfectly matches the mission of CCAT. This conference aims to gather transportation researchers and practitioners across the globe for exploring the frontiers of big data, modeling and simulation to advance transportation research. It is a perfect venue for CCAT researchers to disseminate their results and conduct outreach activities. It will help highlight CCAT's achievements and strengthen its reputation particularly in the international transportation research community. The conference provides a much discounted registration fee to students and is thus expected to attract many student attendees around the world. It will help recruit new entrants into the transportation field and improve the skills of the existing workforce to effectively address today's

transportation system challenges. Jointly sponsored by Didi Chuxing. Due to the COVID-19 pandemic, this conference has been postponed to June 2021.

Deep Scenario: City Scale Scenario Generation for Automated Driving System Testing & Evaluation: University of Michigan, Dr. Henry Liu, Dr. Yiheng Feng, 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. Under different routes and environmental conditions, the simulation platform will generate testing scenarios dynamically along the route to interact with the CAV and systematically evaluate its performance. Meanwhile, a set of corner cases regarding vulnerable road users (VRUs) will be identified and added to the generated scenario library. The project leverages and extends existing work by the PIs in scenario generation and integration with VISSIM, CARLA, and Autoware. The platform will also be integrated with the augmented reality (AR) test environment currently deployed at Mcity, and potentially other test facilities, to enable the testing of real CAVs. Industry partners include Aptiv, Toyota, the American Center for Mobility, FCA, and State Farm.

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 road side units which collect traffic data via cameras and cellular vehicle-to-everything (CV2X) communication. Heavy duty trucks of different levels of automation will utilize the collected data when selecting their lane and controlling their longitudinal motion in order to maximize their fuel economy and minimize their travel time. The impact of these trucks on the rest of the traffic flow will also be evaluated. Industry partners include Navistar, Commsignia, and Ford. The Michigan Department of Transportation is the government partner.

Year 2 approval of Real-time Distributed Optimization of Traffic Signal Timing: University of Michigan, Dr. Yafeng Yin, Dr. Yiheng Feng, and Dr. Siqian Shen. Leveraging recent advancements in distributed optimization, and the growing connectivity and computational capability of vehicles and infrastructure, 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.

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, as better and more diversified services are demanded by the motorists. In particular, to take advantage of connected and automated vehicle technologies a condition-dependent, time-resolved approach for estimating driving resistance should be developed and implemented. 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 2/2/20. During this period, task 1 – literature study was completed.

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. The development platform will be a small electric vehicle to provide students the opportunity to have a hands-on development environment that can be safely used on campus without extensive coordination necessary for large commercial vehicles. This project leverages the JTRP project SPR_4322 Development of an Intelligent Snowplow Truck that Integrates Telematics Technology, Roadway Sensors, and Connected Vehicles. The Indiana Department of Transportation has championed this project.

Development of AI-based and Control-based Systems for Safe and 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 framework to be developed in this study is intended to improve operational efficiency without compromising safety unduly, through the use of joint decision-making protocols and sharing of real-time information that is

made available via vehicle connectivity. The Indiana Department of Transportation is the government champion.

Year 2 approval to continue 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 two levels. At the network level, ACT's shipment routing and scheduling strategy for freight transportation that minimizes total cost will be developed. At the corridor level, real-time optimization will be performed; hence, ACT and platoons can adjust their configuration as they roll and external conditions change (e.g., wind speed, pavement condition). Accurate pavement damage prediction and ACT positioning affect successful deployment of the optimization in both levels. Accuracy of pavement damage prediction will be increased by including resting period, so the effect of truck separation in a platoon can be quantified. ACT positioning control will be enhanced by modifying material characteristics to allow better communications with the pavement. The principal government agency is the Illinois Department of Transportation.

Approval for continuation of CAV Systems Incorporating Air Pollution Information from Traffic Congestion: Central State University, Dr. Krishna Kumar Nedunuri and Dr. Ramanitharan Kandiah. CSU proposes to study 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. Our prior work has determined typical hot spots in Ohio along freeways that are prone to high traffic densities and possible congestion. MOVES will be used to generate these scenarios to determine emissions from vehicles in a simulated traffic congestion scenario. ODOT traffic data will be used these scenarios. Resulting air pollution from emissions will be determined using a dispersion model and compared with NAAQS. A model will be developed to assess severity of air pollution, which will be used to forecast air quality index for the congested areas on freeways. CAV technology will then be deployed to communicate the information to travelers on freeways on radio channels approaching congested areas. The focus for 2020 will be to complete similar analysis across I-71/I-480 in Cleveland, and I-70/I-74 in Cincinnati. CAV technology will be deployed with the assistance from CCAT developed mobile systems for traffic alerts to communicate the information to travelers on freeways on radio channels approaching congested areas.

The following final reports have been completed and are currently being edited for 508 compliance. They will be submitted to the research hub in the next reporting period.

- CAV-Based Intersection Maneuver Assist Systems and Their Impact on Driver Behavior, Acceptance, and Safety (A. Pradhan, S. Bao, H. Jeong)
- An Investigation of User Responses to Connected and Autonomous Vehicles using Prompted Choice Experiments (T. Bills)
- Machine Learning, Human Factors and Security Analysis for the Remote Command of Driving: An Mcity Pilot (W. Lasecki, S. Bao, R. Hampshire)
- Driving Etiquette (H. Peng)
- Supporting People with Vision Impairments in Automated Vehicles: Challenges and Opportunities (R. Brewer, N. Ellison)
- Enhancing Network Assignment Models (N. Masoud, Y. Yin)
- Infrastructure Enhancements for CAV Navigation (S. Dahal, J. Roesler)
- Optimization of Lateral Position of Autonomous Trucks (O. Gungor, I. Al-Qadi, Y. Ouyang)
- Development of a Flexible Pavement Design Framework for Autonomous and Connected Trucks (O. Gungor, I. Al-Qadi)
- CDF Analysis and Prediction Model for Air Resistance on Platooned Freight Trucks (R. She, Y. Ouyang)

CCAT researches have 45 active projects, including those awarded in 2020. Due to page limitations, individual accomplishments are not provided in this report, but can be found on the CCAT website, along with the full project descriptions.

1.B Tech Transfer metrics for this period

For this period, CCAT overachieved on most technology transfer goal (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 to enhance technology transfer opportunities. This period, several research reviews with conducted with the industry and government collaborators. Some examples are:

- 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 results influenced Ford’s internal modeling and simulation effort.
- Collaboration with Econolite. Econolite is the industry champion for the project “Real-time Distributed Optimization of Traffic Signal Timing.” The team has met with Econolite, who is providing the radar sensors for data collection, to discuss sensor and edge device selection. The discussion focus on the requirements for detection range, tracking accuracy, and proxy message generation. Econolite plans to ship the radar sensors and edge devices during July and August 2020.

- Maintaining an ongoing relationship with the Area Plan Commission of Tippecanoe County, whose staff is engaged in data collection of pedestrian, bicycle, and scooter activity at busy locations downtown Urbana, IL and near the UIUC campus. We share data and analysis of "hotspots". In addition, an ongoing project with INDOT is a perfect complement to CCAT projects, in that it offers opportunities to apply a variety of designs and control methods to other types of crossing locations.
- Meeting with Indiana Department of Transportation to discuss ridesharing.

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

Technology Transfer Goals			
1. **OUTPUTS**	**Research Performance Measures**	**CCAT Target***	**CCAT Total**
1.A. Disseminate research results through publications, conference papers, and policy papers	Technical reports	10	9
	Papers at conferences, symposia, workshops, and meetings	3	56
	Peer-reviewed journal articles	6	18
1.B. Develop inventions, new methodologies, or products	Annual number of research deployments	5	3
1.C. Research projects funded by sources other than UTC and matching fund sources	Number of projects	3	12
	Dollar amount of projects	$300,000	$2,743,166
2. **OUTCOMES**	**Research Performance Measures**		**CCAT Total**
2.A. Incorporate new technologies, techniques or practices	Number of technology transfer activities that offer implementation or deployment guidance	2	2
2.B. Improve the processes, technologies, techniques in addressing transportation issues	Number of research deliverables disseminated from each research project	4	9
3. **IMPACTS**	**Research Performance Measures**		**CCAT Total**
3.A. Increase the body of knowledge and safety of the transportation system	Number of instances of technology adoption or commercialization	2	0
	Number of conferences organized by the CCAT consortium members	2	7
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

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

CCAT members hosted or participated in more than 75 outreach engagements this reporting period. Audiences included industry, government, academia, media, and the community. In total, CCAT research was shared with over 4675 people in the last six months. This is in addition to the 4000 plus views on our website. The University of Michigan CCAT outreach log is available upon request. The CCAT newsletter was issued in November 2019 and February 2020. CCAT will now be delivering the newsletter on a quarterly basis.

This period, CCAT increased the frequency of the research reviews. Originally, we planned reviews twice per year. Once the COVID-19 pandemic struck, we increased to monthly, and added additional research reviews in April as a lead-up to the 20/20 Global Symposium. The monthly cadence will continued into next period, where we already have speakers lined up for May and June. All are available on CCAT's YouTube channel (links below).

- 2/25/2020: Collision Avoidance Framework for Autonomous Vehicles under Crash Imminent Situations (Dr. Samuel Labi and Dr. Sikai Chen, Purdue)
- 3/24/2020: Safety Assessment of Highly Automated Driving Systems - a New Framework (Dr. Yiheng Feng and Dr. Shuo Feng, University of Michigan)
- 4/7/2020: On the Road to the CCAT 20/20 Global Symposium – Automated Precision Brine Application (Dr. Darcy Bullock, Purdue)
- 4/9/2020: On the Road to the CCAT 20/20 Global Symposium – CAVs for Assessing Green House Gases (Dr. KrishnaKumar Nedunuri and Dr. Ramanitharan Kandiah, Central State University)
- 5/7/2020: From Data to Actions, From Observations to Solutions: A Summary of Operations Research and Industrial Engineering Tools for Fighting COVID-19 (Dr. Siqian Shen, University of Michigan)
- 6/2/2020: How Vehicle Connectivity-based Eco-Routing Choices Will Impact Driver Decision Making (Dr. Shan Bao, University of Michigan)

CCAT also continued the Distinguished Lecture Series (DLS) this period and hosted Dr. Larry Head, University of Arizona on 11/19/2020. While in Ann Arbor, Dr. Head met with several UM faculty and toured the Mcity test facility, the Michigan traffic lab, and saw a connected vehicle and infrastructure demonstration on the streets of Ann Arbor. Dr. Head discussed the multi-modal intelligent traffic signal system (MITTS) deployed in Arizona and how it improves mobility. He also discussed a connected vehicle work zone for freight vehicles that improves safety. Dr. Azim Eskandarian, Virginia Tech., was scheduled for 3/24/2020 but the event was cancelled due to the COVID-19 pandemic. All future lectures in the DLS have been put on hold until travel and social distancing restrictions have been relaxed.

CCAT continued efforts planning the 3rd Annual Global Symposium on Connected and Automated Vehicles and Infrastructure scheduled for April 14th &15th, 2020 in Ann Arbor. This two-day, two-track event includes panel discussions as well as deep dives on current CCAT research initiatives. The 20/20 Global Symposium for Connected and Automated Vehicles and Infrastructure focuses on overarching research issues related to CAV research, technology, testing and deployments, equity, policy, as well as education, training, and workforce development. It is intended to give a perspective of the last decade in connected and automated transportation as well as where it is heading in the next decade. The attendees include industry, government, and academia. We were expecting between 130 and 150 attendees. During March, it became apparent that this in-person event could not happen because of the COVID-19 restrictions in place in our state, on our campus, nationally, and globally. The CCAT team quickly pivoted to an online event. The online event was restructured to a one-day event on April 14th and was a combination of panels and research reviews. The conference was being offered free of charge. By the end of March, 290 people had registered for the event. In this period, all keynotes, moderators, panelists and presenters were identified and confirmed for the newly structured online event.

Social Media Efforts for this period produced a significant expansion of the CCAT following and engagement online. CCAT has used the Twitter platform as an event promotion and outreach tool. Compared to the last six months, CCAT twitter impressions increased by 41,000, meaning we are

reaching a much larger audience. Our number of followers increased by 73% to 67. The visits to our Twitter profile grew by 634. CCAT uses the LinkedIn platform, in part, as a way to promote upcoming events and to reach students in the field. Our number of followers on LinkedIn grew from 8 to 71 in the six-month period and our engagement has increased to 6.41%. This engagement rate translates to people registering for our webinars, reading our newsletter, or reading our final reports. Our YouTube channel provides video on demand for those that cannot attend our webinars live. Here, our Distinguished Lecture Series, Research Reviews, or other CCAT events get uploaded in their entirety. In the past six months, we have seen 107 views across six videos, a combined number of minutes watched of 438, a subscriber growth of seven, and impressions of 1,360. This high growth in the past six months is in part due to our participation at the Transportation Research Board Annual Meeting in January, our participation in online "chats" with other transportation groups including Continental USA, the University of Michigan, and ITS America, and our outreach with student groups including the Michigan Transportation Student Organization.

The CCAT website provides a wide array of information for those that work within and outside the CCAT umbrella. All research projects and their UTC and Final Report forms are available along with Semi-Annual Progress Reports. New additions to the CCAT website include an archive of our quarterly newsletter and separated pages for our signature events (Distinguished Lecture Series, Global Symposium, and Research Review). In the past six months, our number of website sessions were 1,532 with our number of users totaling 951, and a number of page views equaling 4,069. An interesting note, our number of new visitors was 82.6% of our traffic and our top three countries were the United States, China, and England. This large number of new visitors may be in part due to our heavy advertisement of our website and social media presence during our events. Compared to the last six months, these numbers are a slight dip in traffic, but we can equate that to moving much of our registration for events to the Eventbrite platform. This is because Eventbrite is a much larger platform and allows us to increase the number of possible registrants significantly.

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

Workforce Development Training Accomplishments:

- Developed to higher levels the Emerging Sector Workforce Training Matrix of Classes, especially:
    - Completed development of three Microsoft Excel for Mobility Analysts classes that map to Microsoft Core Excel certification including: Essentials of Excel for Mobility Analysts, Intermediate Excel for Mobility Analysts and Core Excel for Mobility Analysts.
    - Development started on fourth Expert Microsoft Excel for Mobility Analysts class, which will map to Microsoft Expert Excel certification.
    - Completed development of Applied Machine Learning class, in which individuals are trained in the use of software tools for the detection of traffic and road signs.
    - Completed Development Unity Basics: Maps and Apps class that introduces trainees to 3D animation and related mapping tools.

- Held two WCC Career & Internship Fairs, promoting Advanced Transportation & Mobility programs and Pre-Engineering pathways, Oct. 8, 2019 and Mar. 11, 2020.
- A staff member attended the 2019 Florida Automated Vehicles Summit in Miami, FL, and participated in AV demonstrations, Nov. 2019.
- A staff member delivered a presentation Dec. 5, 2019 on WCC's Advanced Transportation Center programs to the "2019 Propulsion Quebec Workforce Talent Summit" in Montreal, Quebec, Canada.
- A WCC Vice President presented in Jan. 2020 at the American Association for Community Colleges in Fernandina Beach, FL, about WCC's Advanced Transportation Center, Mobility and SMART Cities emerging sector workforce programs.
- Participated in four ITS Professional Capacity Building Community College Discussion Webinars.

Credit Education Certificate and Degree Programs Accomplishments:

- Developed a Center of Excellence in Cybersecurity, including curricula/competency mapping, and internal Curricula Committee approvals. Preparing for next step NSA approval.
- Faculty leadership formed a WCC student-centered Cybersecurity Activity Team to participate in regional/national cybersecurity challenges. Students competed individually and as a team in the National Cyber League competition during Fall/Winter/Spring 2019-20 semesters, finishing 62nd out of 931 teams in the Spring 2020 event.
- Updated IT Networking & Communications curricula & courses with the addition of Cellular-V2X [5G] automotive network communications [courses CST185/CST225] including joint IT-Automotive Labs.
- Three Automotive Technology students completed paid internships with UMTRI for the installation and verification of V2X communications in AACVTE test vehicles.
- Continued to develop and integrate ITS and Cybersecurity Technologies with Automotive Technologies in joint cross-functional class sessions utilizing equipment such as the signal-analyzing oscilloscopes.
- Added more promotions/options to the Pre-Engineering Program occupational career pathways leading to engineering related degrees at partnering universities, as well as an Engineering & Design Technology Certificate.
- Received Scholarship Endowment from an alumna for Engineering Transfer Students to Universities.
- Received and applied a fifth Oscilloscope into the curriculum for Automotive CAN-BUS signal analysis, and purchased additional auxiliary diagnostic supplies.
- A Professional Faculty Instructor in Cybersecurity participated in the following industry conferences representing WCC and the CCAT UTC:
    - 2019 AUTO-ISAC Annual Summit, Oct. 2019 at Toyota Motor Regional Headquarters, Plano, TX.
    - MI Governor's NA International Cyber Summit, Oct. 2019, instructor plus 11 CIS students.
    - National Initiative for Cybersecurity Education [NICE] Conference, Nov. 2019, Phoenix, AZ.
    - National Defense Industrial Association [NDIA] Cyber Physical Systems Conf. Mar. 2020, Troy, MI.
- Held a Library Student Engagement Session on CAV/Mobility Careers, featuring two Automotive Program students and a moderator, Jan. 2020.

K-12 STEM Technology Awareness & Insight Accomplishments:

- Exhibited Automotive Occupational Technologies and Cybersecurity Educational Workbench to approx. 9000 high school students at the Nov. 8, 2019 MiCareerQuest Southeast event in Novi, MI.
- Contracted with the Square One Education Network to conduct two 2-Day Masters of Mobility Workshops for regional high school project team participants [~45], with continuing education credits for teachers in Oct. 2019, and Jan./Feb. 2020.
- WCC held STEM/STEAM Week Feb. 3-7, 2020, invited greater Ann Arbor K-12 schools to hear curricula presentations and see live demonstrations of occupational career skills, including the Advanced Transportation Center and Mobility Career pathways.
- Recruited approximately 15 students and delivered Computer Programming training at Ann Arbor Scarlett Middle School in Mar. 2020.
- Recruited approximately 45 youth students to participate in two Summer CAV Camps planned for delivery in the summer 2020.

General Outreach:

- Hosted the Society of Women Engineers Event- "Self-Driving Symposium" in Nov. 2019, with leading industry presenters for approximately 75 attendees.
- Held a Student Engagement Session on Mobility Careers at the WCC Library, Jan. 2020, with two Automotive Technology students and a moderator. Approximately 15-20 students attended.
- Held STEM/STEAM Week presentations and demonstrations of CAV/Mobility technologies, Feb. 2020.
- Presented Advanced Transportation Center program overviews to the Ann Arbor-Ypsilanti Regional Chamber of Commerce on Leadership Education Day, Feb. 20, 2020.
- A Feb. 27 WCC Newsletter article "High School Students Win Scholarships & Prizes at Skills USA [Automotive Technology] Competition at WCC", posted on WCC website community news.
- The Feb. 27, 2020 On-the-Record Newsletter published endorsements of the Advanced Transportation Center and the CCAT programs to Washtenaw County Residents by the following persons:
    - Jeff Irwin, Michigan State Senator
    - Debby Bezzina, Managing Director, CCAT
    - Mark Schlissel, President, Univ. of Michigan
    - Jason Morgan, Chair, Washtenaw County Bd of Comm.
- ITS Michigan Winter 2020 Newsletter summarizing the 2019 Annual Meeting at WCC, and plus a Technical Tour of the American Center for Mobility and the WCC ATC exhibits.
- Bi-monthly hosted/led a public "Meetup- Ann Arbor Autonomous Vehicle Group", collaborating on CAV projects of an automated tomato vegetable disease detection vehicle and personal wheelchair.

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.
Akron	Concordian at Summer Independent Living Program	City of Copley, Ohio	Project support, older driver selection
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	Purdue University	West Lafayette, IN	Financial support.
Purdue	Georgia Institute of Technology	Atlanta, GA	Collaborative research including: • Provides a networked simulator system: ○ RTI RDS-2000 full cab driving simulator and other equipment and helps in the development of the dynamic network traffic simulator ○ Desktop simulators • Contributes to developing an interactive environment Atlanta: ○ For analyzing the participants' interactions with other vehicles and urban environments ○ With different AV facilities
Purdue	Chongqing University of Posts and Telecommunications	Chongqing, China	• Driving simulator equipment, laboratory space, and facilities • Student exchange
UIUC	Illinois Department of Transportation	Springfield, IL	Initiate project on platooning to complement the project work.
UIUC	iSEE	Champaign, IL	Living lab
UM	Argonne National Laboratory (ANL)	Lemont, IL	Co-development of an eco-routing phone app
UM	NYU Shanghai	Shanghai, China	Collaborative research
UM	Mcity	Ann Arbor, MI	$82,911 cash contribution
UM	Ford Motor Company	Dearborn, MI	Financial support ($221,125), in-kind support for facilities and technical collaboration.
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 prediction model of drivers' route choices when interacting with eco-routing systems was established by a MLRF algorithm (S. Bao)
- An eco-routing smart phone app was developed jointly by the Argonne National Laboratory (ANL) and the University of Michigan Transportation Research Institute (S. Bao)
- A real-time algorithm predicting hard-braking behavior by using machine learning methodology (Y. Feng)
- A software application to generate critical scenarios for CAVs (Y. Feng)
- Feng, S., Feng, Y., Sun, H., Bao S., Zhang, Y., and Liu, H.X., Testing Scenario Library Generation for Connected and Automated Vehicles, Part II: Case Studies. Submitted to IEEE Transactions on Intelligent Transportation Systems. (Accepted)
- Feng, S., Feng, Y., Yu, C., Zhang, Y., and Liu, H.X., Testing Scenario Library Generation for Connected and Automated Vehicles, Part I: Methodology. 2020. IEEE Transactions on Intelligent Transportation Systems. (Accepted)
- Zhang, Y, Yu, B, Bao, S., Feng, Y., Wang, Y., Yang, C. Develop a Hybrid SVM-based Method to Predict Hard-braking Behavior when Following. Journal Manuscript in Development.
- Yang, Z., Feng, Y., and Liu, H.X., A Cooperative Driving Framework for Urban Arterials in Mixed Traffic Conditions.
- Feng, S., Feng, Y., Yan, X., Shen, S., Xu, S., and Liu, H.X., Safety Assessment of Highly Automated Driving Systems in Test Tracks: A New Framework.
- A model of non-line-of-sight (NLOS) scenarios using WinProp (S. Lakshmanan)
- A simulation of packet reception ratios for connected vehicle technologies (S. Lakshmanan)
- Technique to validate modeling and simulation results against test track data (S. Lakshmanan)
- Sridhar Lakshmanan: presentations on "Reliable V2V Communication Networks: Applications in Fuel-Efficient Platooning"
- Ersal Tulga, Ilya Kolmanovsky, Neda Masoud, Necmiye Ozay, Jeffrey Scruggs, Ram Vasudevan, and Gábor Orosz. Connected and automated road vehicles: state of the art and future challenges, Vehicle System Dynamics. April 2020.
- Tafreshian Amir and Neda Masoud. Trip-based Graph Partitioning in Dynamic Ridesharing, Transportation Research Part C: Emerging Technologies. 114: 532-553, 2020.
- Mojtaba Abdolmaleki, Neda Masoud, and Yafeng Yin. Transit Timetable Synchronization for Transfer Time Minimization, Transportation Research Part B: Methodological, 131: 143-159, 2020.
- Xian Yu, Siqian Shen, "Multistage distributionally robust mixed-integer programming with decision-dependent moment-based ambiguity sets," submitted to Mathematical Programming Series B, 2020. http://www.optimization-online.org/DB_HTML/2020/02/7651.html.
- The alternating direction method of multipliers (ADMM) algorithm for solving large-scale mixed-integer programming cell transmission models for traffic signal control (Y. Yin)
- Data set that reflects real-world traffic on Plymouth Road. Videos were recorded from all six intersections along the Plymouth Road corridor simultaneously at peak operating hours (4:00 – 5:00 PM). The raw video data was then processed to obtain vehicle volume for each movement, turning rations at each approach and signal phase and timing data of each intersection (Y. Yin)

- Luo, Q, Sigal, R., Chen, Z. and Yin, Y. Accelerating the Adoption of Automated Vehicles by Subsidies: a Dynamic Games Approach. Transportation Research Part B, 129, 226-243, 2019;
- Zhang, X, Liu, W., Waller, S.T. and Yin, Y. Modelling and Managing the Integrated Morning-Evening Commuting and Parking Patterns under the Fully Autonomous Vehicle Environment. Transportation Research Part B, 128, 380-407, 2019
- Li, Y., Chen, Z., Yin, Y. and Peeta, S. Deployment of Roadside Units to Overcome Connectivity Gap in Transportation Networks with Mixed Traffic. Transportation Research Part C, 111, 496-512, 2020
- New methodology that created an innovative infrastructure-based solution to address the connectivity gap of CAVs and a new modeling framework to evaluate its impacts (Y. Yin, S. Peeta)
- A new modeling framework to optimize the incentive policies for CAVs (Y. Yin, S. Peeta)
- Research Projects funded by sources other than UTC and matching fund sources:
    - Design Testing and Evaluation Scenarios for Connected and Automated Vehicles-Phase II, began 9/2019 ($100,000)
    - Fuel-efficient platooning in mixed traffic highway environments, began 1/1/2020 ($428,201)
    - Safety Application Using Connected Vehicle Trajectories: A Demo, began 10/1/19 ($163,727)
    - Learning-based Distributionally Robust Optimization Method for Route Planning, began 1/1/19 ($149,853)
    - LEAP HI: On-Demand Multimodal Transit Systems, began 8/1/2019 ($417,120)
    - Improving Didi's Operations via Enhanced Matching, Repositioning and Contract Design, began 9/1/2019 ($100,000)
    - Potential Impacts of Automated Vehicles on Transportation and Land Use: A Research Synthesis, began 10/1/2019 ($89,555)

Purdue University

- "Multi-State Semi-Markov Modeling of Recurrent Events: Estimating Driver Waiting Time at Semi-Controlled Crosswalks", Yunchang Zhang and Jon D. Fricker, Purdue University, Paper 20-01032, Session 1692, Poster B345, Wed. 1/15/2020.
- Qiao Yu, Yunchang Zhang, Jon Fricker. "Investigating Pedestrian Wait Time at Semi-Controlled Crossing Locations: Application of Multi-State Models for Recurrent Events Analysis", accepted 1/8/2020 for publication in Accident Analysis and Prevention.
- Yunchang Zhang and Jon Fricker, "Multi-State Semi-Markov Modeling of Recurrent Events: Estimating Driver Waiting Time at Semi-Controlled Crosswalks", under review by Analytic Methods in Accident Research.
- A database of more than 2000 interactions between pedestrians and motorists has been assembled (J. Fricker)
- Behavioral Intention to Ride in AVs and Impacts on Mode Choice Decisions, Energy Use and Emissions. Draft Final Report submitted. (K. Gkritza)
- New theoretical model to assess behavioral intention; methodology to assess value of travel time savings based on a choice experiment (K. Gkritza)
- Survey data for Indianapolis and Chicago (K. Gkritza)
- Macrosimulation model of the Indianapolis metropolitan area (K. Gkritza)

- New methodology to identify market segments and assess transportation disadvantaged areas (K. Gkritza)
- Database for transportation health-related factors in both Chicago, IL and Indianapolis, IN (K. Gkritza)
- Active travel in the Autonomous Vehicles' Era. Conference Presentation at the 2019 North American Regional Science Conference, Pittsburgh, PA, 2019 (S. Labi)
- Ridesharing and Health: Is being a frequent rider associated with good self- reported health status? Poster Presentation at the Health and Disease Poster Session, Purdue University, March 2020 (S. Labi)
- Data on prospective infrastructure changes in AV era (S. Labi)
- New CAV-related course approved by Purdue administration to start spring term 2020 (S. Labi)
- A. Koilias, C. Mousas, B. Rekabdar "The Effects of Driving Habits on Virtual Reality Car Passenger Anxiety" EuroVR 2019, pp. 263-281, 2019
- Li, Y., Chen, Z., Yin, Y. and Peeta, S. Deployment of Roadside Units to Overcome Connectivity Gap in Transportation Networks with Mixed Traffic. Transportation Research Part C, 111, 496-512, 2020
- An innovative infrastructure-based solution to address the connectivity gap of CAVs and a new modeling framework to evaluate its impacts (S. Peeta, Y. Yin)
- A new modeling framework to optimize the incentive policies for CAVs (S. Peeta, Y. Yin)
- 1 conference paper submitted to Human Factors and Ergonomics Society Proceedings. And 1 journal paper in preparation for submission to: Transportation Research: Part F (S. Peeta)
- Lin, Lei, Weizi Li, and Srinivas Peeta. "Efficient Data Collection and Accurate Travel Time Estimation in a Connected Vehicle Environment Via Real-Time Compressive Sensing." Journal of Big Data Analytics in Transportation 1, no. 2 (2019): 95-107.
- A. Zhoe, S. Gong, C. Wang, S. Peeta. “Smooth-Switching Control-Based Cooperative Adaptive Cruise Control by Considering Dynamic Information Flow Topology.” TRR Journal of the Transportation Research Board 2020.
- Dustin J. Souders, Shubham Agrawal, Yujie Li, & Srinivas Peeta. Highlighting the Driver’s Responsibilities when Using Conditional Driving Automation: Effects on Take-over Performance and Monitoring. Proceedings of the Human Factors and Ergonomics Society (submitted).
- Dustin J. Souders, Shubham Agrawal, Yujie Li, & Srinivas Peeta. Highlighting the Driver’s Responsibilities when Using Conditional Driving Automation: Effects on Attitudes, Monitoring, and Take-over Performance. Transportation Research: Part F (draft).
- Research Projects funded by sources other than UTC and matching fund sources:
    - Assessment of an Offset Pedestrian Crossing for Multilane Arterials, SPR-4301, with Indiana Department of Transportation, began 5/1/19 ($63,140).
    - Northrop Grumman COrp REALM – Research in Applications for Learning Machines Consortium, began 9/21/18 ($135,000)

University of Akron

Data set generated from intersections where a vehicle on the minor street enters the major road by selecting a gap between approaching vehicles on the major road. Additional sites have been identified near independent living facilities at which more data will be collected to add to the existing data set.

University of Illinois at Urbana Champaign

- Dynamic programming scheme to optimize freight truck platooning pattern with nonlinear pavement deterioration behavior
- Development of a data-driven model for traffic speed prediction using spatially-limited data collected by autonomous vehicles.
- Finite element model is fine-tuned to be used with multiple truck tire loads with reduced amount of time
- Identified methods, materials, and built device to use electromagnetic waves for safer navigation of AVs during adverse weather condition.
- An invention disclosure has been submitted on the passive sensing of autonomous vehicles using V2I technology.

Central State University

Ramanitharan Kandiah, Krishna Kumar Nedunuri. Decadal Changes in Highway Emissions: Comparison of Six Urban Ohio Counties. Abstract submitted to ACS 2020: 259th ACS Conference, Philadelphia, PA.; Mar 22 - 26, 2020. The abstract was reviewed and accepted, but the conference was cancelled due to COVID-19.

4. Outcomes

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

University of Michigan

- 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."
- The project outputs from "Reliable V2V Communication Networks: Applications in Fuel-Efficient Platooning" may inform regulatory, legislative, or policy organizations such as NHTSA, FHWA, or other agencies 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.

Purdue University

- Increased understanding of 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.
- Identification of infrastructure changes needed in the CAV era.
- Increased awareness of current deficiency of road infrastructure to accommodate CAVs.

University of Illinois at Urbana Champaign

- Enabled by autonomous and connected vehicle technology, freight carriers are motivated to platoon their fleets to reduce operational costs from fuel consumption at the expense of rapid pavement deterioration. The results from this model provide insights for highway administrators to identify extra pavement rehabilitation costs induced by channelized traffic and the necessity of imposing dynamic control on highway segments to alleviate additional costs. With historical knowledge of the O-D and the demand of freight flow over a highway network, restrictive actions can be taken to diverge traffic flow to prevent the cycle between pavement deterioration and congestion.
- An accurate, data-driven stochastic model to predict probabilistic traffic flow and better inform decision makers and traffic managers was created. In addition to the developed data imputation, the resulting traffic-prediction model will be more accurate and resilient against unavailability of traffic data in future ITS.
- The maximum responses and recovery for each set of temperature and speed were obtained. From the responses, transverse strain and vertical shear strains are critical. Transverse strain takes time to recover, resulting in strain accumulation. The strain for a dual axle of 1.2 m (4 ft) spacing can be 50% to 100% more than that of a single axle. In addition, the recovery of a dual axle is different than that of a single axle not following a specific trend.
- Electromagnetic materials were successfully tested during normal and adverse weather conditions when embedded into concrete material. A designed and developed sensor array was tested to transfer the concept from the laboratory to real-world lane keeping.

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

- Improves 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.
- Increased body of knowledge regarding (a) need for infrastructure retrofit for CAVs (b) specific changes needed.

University of Illinois at Urbana Champaign

- The results from the bi-level optimization model provide insights for highway administrators to identify extra pavement rehabilitation costs induced by channelized traffic and the necessity of imposing dynamic control on highway segments to alleviate additional costs. With historical

knowledge of the O-D and the demand of freight flow over a highway network, restrictive actions can be taken to diverge traffic flow to prevent the cycle between pavement deterioration and congestion.

- This study on accurate traffic estimation and prediction can potentially contribute to robust and timely traffic-flow predictions, which is vital for advanced traffic management in ITS. Ultimately, the proposed models will contribute to mitigating traffic congestion, improving the level of service, and providing reliable, safe, and green transportation.
- Responses due to a rear axle of the front truck and steering axle of the following truck can be modelled as the strain recovery analysis was carried out for single and dual axles. Therefore, pavement damage can be calculated accurately for multi-axle loadings, which can be utilized in optimizing truck spacing in the platoon.
- Materials and sensors that work during normal and adverse weather conditions were tested successfully. Autonomous vehicles can use this robust system as a backup or along with camera and GPS sensors for lane keeping. The system appears to be more advantageous than camera and GPS sensors during harsh weather conditions.

Central State University

Daniel R Lee and Jasmine Walker, funded through this project, graduated in May 2020 with degrees in Environmental Engineering. The UTC grant contributed to their retention and graduation. Both were TRB Minority Fellows in 2019. Jeremy Burns, a junior in environmental engineering is the new TRB scholar from CSU.

6. CHANGES/PROBLEMS:

In this period, CCAT found itself living in the new COVID-19 world. In a general sense, campuses were closed, making it hard to bring on students to complete needed research for our projects. Hiring freezes were then enacted, exacerbating the problem. Also, we were restricted from interacting with human subjects that generate some of the data for our research. With the social distancing protocols currently in place and not likely to be lifted during the summer, we will find some of our research to lag behind original schedules. And we may see additional delays for projects with deployments planned in the near future. As of now, we aren't sure what this will look like in the fall. There is still a lot we are learning about the virus, and how to get back to a new normal while keeping it at bay. All of our colleges and universities in this Region 5 UTC are working on protocols to reopen our campuses while keeping everyone safe. Below is a summary of specific impacts from the COVID-19 pandemic.

University of Michigan

Several meetings with visiting scholars and other industry leaders were cancelled due to travel restrictions including Mr. Agenawa, Toyota (Japan) and Dr. Azim Eskandarian, Virginia Tech. The Distinguished Lecture Series has been put on hold. This year's annual global symposium was changed to an online event (as described above). We increased our outreach efforts to host more research reviews, also described above. The International Symposium on Transportation Data and Modeling conference was postponed to 2021. Research-wise, COVID-19 has negatively impacted the following projects:

Reliable V2V Communication Networks: Applications in Fuel-Efficient Platooning. Delayed data collection efforts with Ford. This, in turn, delayed the data analysis, modeling, and simulation. It also delayed a planned hardware experiment with Ford. Because of this, the project has been extended through 12/31/2020.

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 added risk to the project. It is hard to estimate the City of Ann Arbor's schedule when normal operations are resumed. Delays in the deployment may occur as a result.

Akron

The team has been unable to bring a new student on board to train to develop the communication system for the project "Development of a Prototype Safety Advisory System to Aid Senior Citizens in Gap Selection." New student recruitment has been stopped due to the University of Akron campus closure in March. The work is expected to continue when the students are allowed to come back to campus in the fall. Training and hardware system development will be expedited at that point. For this project, the team was in the process of recruiting older drivers from the senior living complex and senior activity centers. Recruitment was discontinued for fear of infecting vulnerable older people. For the project "Impact analysis of Roadway Surface and Vehicle Conditions on Fleet Formation for Connected and Automated Vehicles," meetings with the Ohio DOT in Columbus and the Goodyear and Firestone companies in the greater Cleveland area were cancelled. The meetings were to discuss tire condition related issues as an input into understanding the impact of data collection.

W**CC**

- Cancelled 2020 NA Int'l Auto Show [NAIAS] Outreach and CAV Technologies Exhibit in the PlanetM Automobili-D area
- Cancelled three "Cars the Communicate: V2X Technologies" STEM Youth Camps for disadvantaged populations in Ypsilanti and other areas
- Cancelled Square One Masters of Mobility high school project vehicle team Challenge Event at Kettering University
- Cancelled WCC participation in the ITS America Professional Capacity Building College Workshop for the Transportation Workforce
- Deferred or cancelled a WCC-hosted Lunch & Learn State-wide Collegiate Instructor Workshop to present the process of integration of ITS Technologies into Automotive programs
- Cancelled or deferred WCC Staff participation in ITS/CAV/SMART City Professional Development Conferences
- Deferred or delayed Workforce Development Training Modules in the following subjects:
  - Basics of Autonomous Vehicle Machine Learning
  - Introduction to Connected Car C-V2X
  - Development of in-depth 5G C-V2X
  - Exploration and feasibility of IEEE eLearning Modules

Purdue

Design of Urban Landscape and Road Networks to Accommodate CAVs – Phase 2 and ***Using Driving Simulator Environment to Determine Interactions Between User Behavior and Infrastructure Design Under Autonomous Vehicles.*** The two projects require not only that researchers return to the campus, but also persons from outside campus be brought to the driving simulator lab. Since simulator-based experiments involve in-person interactions (e.g., help participants wear physiological sensors and monitor participants' level of motion sickness), the Institutional Review Board (IRB) paused all simulator studies until further notice. To mitigate the impacts of the COVID-19 situation, we are considering updating our research protocols (e.g., providing masks and sanitize the driving simulator after each experiment) to ensure the safety of both subjects and researchers. As soon as the renewed protocols are approved by the IRB, we will restart the simulator-based experiments.

In addition to the complications from the COVID-19 pandemic, below is a description of problems, and sometimes solutions, encountered during the normal course of doing research.

Purdue University

The project "Design and Management of Highway Infrastructure to Accommodate CAVs" (S. Labi), was delayed due to the slow pace of infrastructure data acquisition. Subsequently, the infrastructure providers were contacted directly, which was successful for data delivery. The project "Changes in Highway Agency Expenditures and Revenue in an Era of CAVs" also experienced delays in data collection, but is expected to be completed by September 2020.

Akron

Due to the unexpected death of a student, the project "Development of a Prototype Safety Advisory System to Aid Senior Citizens in Gap Selection" has been delayed. A new student will be hired and, once trained, tasks 3 and 4 will resume. This is dependent on the COVID-19 pandemic polices yet to be determined.