CENTER FOR CONNECTED AND AUTOMATED TRANSPORTATION

Semi-Annual Progress Report for University Transportation Centers

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Center Director:	Henry Liu CCAT Director Professor of Civil and Environmental Engineering Phone: (734) 647-4796 Mobile: (651) 260-5876 Email: henryliu@umich.edu
Submitted By:	Debby Bezzina CCAT Managing Director Phone: (734) 763-2498 Mobile: (734) 751-1778 Email: dbezzina@umich.edu
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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 April 1, 2019 through September 30, 2019.

1.A Current Research Status

CCAT researches have over 40 active 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 2019. Project updates for the other projects are available upon request. Additionally, for full project descriptions, visit the CCAT website.

University of Michigan Projects

Real-time Distribution Optimization of Traffic Signal Timing (Y. Yin, S. Shen, Y. Feng). This project started in April 2019. The team finished the literature review and identified two key methods for further development: (1) solving a centralized formulation using ADMM and (2) max pressure. The development of a centralized formulation based on link transmission model is underway that will test the efficiency of ADMM. At the same time, the team has explored options to extend max pressure control.

How Vehicle Connectivity Based Eco-Routing Choices Will Impact Driver Decision Making (S. Bao, J. Sayer). To date, 20 participants have completed the Eco-routing study and the data collected. It is expected that data from 40 participants will be collected by the end of the next reporting period. The initial 20 participants generated valid data for 462 trips. Preliminary results indicate that in only about 10% of the valid trips, drivers followed the recommended route directions correctly.

Accelerated Training for Connected and Automated Vehicles Based on Adaptive Evaluation Method (H. Liu, Y. Feng). This period, the following were completed: (1) The adaptive evaluation method for both on-line and off-line stages was developed; and (2) the first training stage of CAV model was completed based on the state-of-the-art deep reinforcement learning (DRL) techniques.

Reliable V2V Communication Networks: Applications in Fuel-Efficient Platooning (S. Lakshmanan). The PIs of this proposed research have identified specific use cases where V2V communication between vehicles fails when using DSRC. These edge cases for DSRC have one thing in common: a challenging radio frequency environment consisting of noise clutter and multipath reflections. This period, development of the embedded radio software for recording Key Performance Indicators (KPIs) was completed. The KPIs include GPS-tagged received signal strength indicator; packet latency; packet error rate; inter-packet gap; network utilization; packet reception ratio. This period, new software as testing on semi-truck platoons at NCAT test track (Opeleika, AL), PMG test track (Montreal, Canada) and the I-

85 public highway (Auburn, AL). The development of the computer simulation that will validate against field test data (Ford test track, Fowlerville, MI) was started. CV2X radio vendors were also evaluated.

Development of machine-learning models for autonomous vehicle decisions on weaving sections of freeway ramps (B. Lin, D. LeBlanc, J. Sayer, S. Xu). Automated freeway driving is being developed by all major automotive OEMs. To date no system can recommend when and how lane changes should be made in weaving sections with limited length to ensure that traffic stays safely and smoothly separated. This period a literature review was completed. In addition, the naturalistic data query was conducted. Lastly, the work plan for implementing the computation models in and Mcity AV was constructed.

Augmented Reality Testing Environment Development – Phase II (Y. Feng, H. Liu). Building on the augmented reality framework implemented in Phase I above, this project will upgrade the system implemented at Mcity to be compatible with the new vehicle development and communication standards (i.e., SAE J2735 published March 2016), include new functionalities, and design new testing scenarios. This period, the new Mcity high-resolution map was utilized to upgrade the VISSIM simulation network, which is an exact match to the real world. Based on the new map, new map algorithms were developed that allow flexible routing and dynamic vehicle generation and removal. Now CAVs can be generated anywhere and execute any route within Mcity. In addition, two new testing scenarios were developed and implemented: signal priority and roundabout merging. Finally, a new demo video was made and can be found at: https://youtu.be/-DQ4dGo-Nxs.

Purdue University Projects

Investigation of AV Operational Issues using Driving Simulator Equipment (S. Labi, B. Pitts). During the reporting period, the research team carried out planning for the driving simulation experiments. This included design of the statistical experiment for the sampling, design of the virtual environment, human-subject recruitment strategies. The statistical design of experiments and the design of the virtual driving (road) environment were completed. Additionally, request for IRB approval for the human subject experiments was submitted.

Enhanced Methodology for Exploring Autonomy-enabled Multi-mode Regional Transportation (D. DeLaurentis). This project began in September 2019. The research team has been identified and assembled. A kick-off meeting was held.

Smart Interaction – Pedestrians and vehicles in a CAV environment (J. Fricker). This is a sequel project to "Pedestrian-Vehicle Interaction in a CAV Environment –Explanatory Metrics." If the appropriate sensor and control technology can lead to an alternative to "CAVs always yield to pedestrians", we will have achieved a form of "smart interaction", which can be a useful element of smart mobility. Planning the development of simulation methods that would (1) replicate behaviors seen in the first study, and (2) permit the testing of scenarios that include autonomous vehicles has begun. Progress so far has included the acquisition of VisWalk software, to determine its applicability to the needs of the research project. Current work is focused on the degree to which the software can replicate the findings of the previous study.

Ridesharing, Active Travel Behavior, and Personal Health: Implications for Shared Autonomous Vehicles (K. Gkritza). This project started in September 2019. It will assess the relationship between ridesharing (as a proxy for shared travel behavior), and active travel behavior (often measured as the number of trips made by walking or biking) and identify personal health-related outcomes expected due to the adoption of shared AVs (SAVs).

A Virtual Reality Framework to Measure Psychological and Physiological Responses of the Self-Driving Car Passengers (C. Mousas). To date, an extensive literature review has been conducted. Moreover, software and hardware needed for this project has been evaluated. A basic prototype virtual environment developed and set up. The team also developed a number of behaviors that can be assigned to the autonomous car. In addition, a preliminary study was conducted to investigate the reactions of users when interacting with the virtual environment.

Using Driving Simulator Environment to Determine Interactions between User Behavior and Infrastructure Design under Autonomous Vehicles (S. Peeta). The team has installed the RTI RSD 2000 full-cab driving simulator and added the SimDriver function for autonomous vehicle control mode. A dynamic network traffic simulator was also developed which entailed establishing the data exchange service between the driving simulator and traffic simulation using socket.io real-time engine, and preparing mixed-platoon traffic simulation scenarios.

Facilitating electric-propulsion of autonomous vehicles through efficient design of a charging-station network (S. Labi). A framework will be developed for the transportation planner for gradually installing electric charging stations at repurposed existing gas stations and /or at new locations. The framework duly considers the anticipation of an ICEV-to-AV transition phase where the existing gas stations will be decommissioned gradually in favor of electric charging stations. The framework will consider two trip-making scenarios: intracity trips that capture traffic congestion, and intercity trips that are characterized by longer distances. The analysis is 20% complete and will be continued in the next reporting period.

University of Illinois Urbana-Champaign Projects

Multi-front Approach for Improving Navigation of Autonomous and Connected Trucks (I. Al-Qadi, Y. Ouyang). This period, A bi-level optimization framework has been developed to minimize the total cost of autonomous truck freight operation on a network level. Additionally, using traffic data provided by DiDi, we performed data cleaning, conducted a literature review, constructed and trained our data-driven predictive model based on deep neural networks, analyzed and interpreted the results, and compared the performance of the predictive model with other data-driven models common in the literature. To assess the effects on pavement performance, nine different cases were run (at three temperatures and three speeds). By post-processing the nine cases, critical combinations were identified. Lastly, several materials were identified that could modify electromagnetic properties of rigid pavement. Lab testing on the materials were conducted. The effects are being investigated.

University of Akron Projects

Development of a Prototype Safety Advisory System to Aid Senior Citizens in Gap Selection (P. Yi, Y. Sozar). This project started in May 2019. During this reporting period, the literature review has been completed and the site identification and preparation is 40% completed.

Central State University Projects

CAV Systems Incorporating Air Pollution Information from Traffic Congestion (K. Nedunuri). This period, an inventory of priority pollutant and greenhouse gas emissions from on-road vehicles in Franklin County was conducted.

CAV Developed Vehicles as Real-Time Sensors for Assessing Greenhouse Gases (K. Nedunuri). A continuation of the above. Resulting air pollution from emissions will be determined using a dispersion model and compared with GHG standards for emissions. 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 approaching congested areas.

1.B Tech Transfer metrics for this period

For this period, CCAT overachieved on all but one 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 continues to work with its Technology Advisory Board (TAB) to ensure that our project selections can be directly transferred to industry and government for implementation and deployment. This summer, the TAB convened to generate areas of interest for each of the six CCAT research thrusts. Those areas were documented and incorporated into the request for proposal (RFP) package for 2020 funding. The RFP has been issues and proposals are due next period. The TAB will review the proposals and complete the selection process in Q1 2020.

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 the City of Akron and PathMaster, Inc. to share design of experiments for the project “Access Control at Major-Minor Intersection through CAV in Mixed Traffic” (P. Yi).
- Regular team meetings with Ford to collaborate on test cases and provide program status for the project “Reliable V2V Communication Networks: Applications in Fuel-Efficient Platooning” (S. Lakshmanan). The meetings are held every two weeks (10 total this period).
- Regular team meetings with Indiana Department of Transportation every quarter to provide progress updates on the project “Behavioral Intention to Ride in AVs and Impacts on Mode Choice Decisions, Energy Use and Emissions” (K. Gkritza).

Table 1: CCAT Technology Transfer Goal Targets and Actual Performance

Technology Transfer Goals			
1. **OUTPUTS**	**Research Performance Measures**	**CCAT Target**	**CCAT Actual**
1.A. Disseminate research results through publications, conference papers, and policy papers	Technical reports	10	4
	Papers at conferences, symposia, workshops, and meetings	3	73
	Peer-reviewed journal articles	6	30
1.B. Develop inventions, new methodologies, or products	Annual number of research deployments	5	4
1.C. Research projects funded by sources other than UTC and matching fund sources	Number of projects	3	35
	Dollar amount of projects	$300,000	$7,288,137
2. **OUTCOMES**	**Research Performance Measures**		
2.A. Incorporate new technologies, techniques or practices	Number of technology transfer activities that offer implementation or deployment guidance	2	6
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**		
3.A. Increase the body of knowledge and safety of the transportation system	Number of instances of technology adoption or commercialization	2	2
	Number of conferences organized by the CCAT consortium members	2	21
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	3

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

On May 15, 2019 CCAT continued its Distinguished Lecture Series by hosting Paul Ajegba, MDOT director. His presentation, Connecting Infrastructure and Technology for Sustainable Safety and Mobility, was well received by the eighty-eight (88) attendees from industry, government, and academia. His lecture was also posted to the CCAT YouTube channel. Our next distinguished lecture in the series is scheduled for November 21, 2019 and will feature Dr. Larry Head, Professor of Systems and Industrial Engineering, University of Arizona, who will explore V2X applications for safety and mobility.

Dr. Henry Liu, Director of CCAT and Professor of Civil and Environmental Engineering, testified before the House Committee on Science, Space and Technology, Subcommittee on Research and Technology on July 11, 2019. As the FAST Act is set to expire in September of 2020, Dr. Liu attested to the importance of the UTC programs and the research that they conduct. Further funding would allow for more research with real-world impacts including reductions in driver fatalities, traffic congestion, and fuel consumption. Liu recommended that the UTC program be fully reauthorized at no less than $150 million per year.

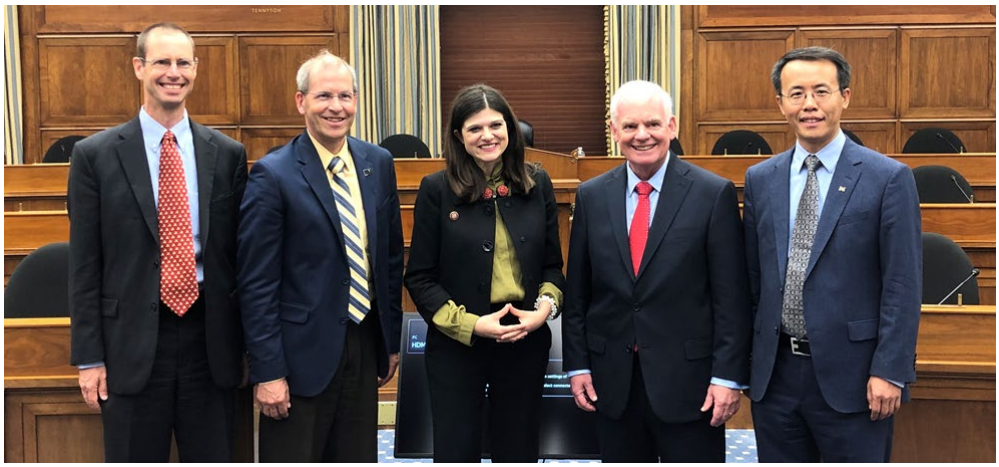

Figure 1: (from left to right) Darcy Bullock, Purdue; Timothy Henkel, MinnDOT; Haley Stevens, Chairwoman; Brian Ness, Idaho DOT; Henry Liu, CCAT

This period, CCAT launched its research review webinars. The inaugural webinar was held on September 6, 2019 with speaker Dr. Sridhar Lakshmanan who reviewed his project Reliable V2V Communication Networks: Applications in Fuel-Efficient Platooning. In total, twenty-eight (28) people attended the webinar. Our next research webinar is set for November 19, 2019 and features Dr. Walter Lasecki who will be discussing Machine Learning, Human Factors and Security Analysis for the Remote Command of Driving: An Mcity Pilot. We hope to grow the attendance through vigorous marketing.

On September 25 &26, 2019, ITS Michigan held its annual conference. CCAT is very active in ITS Michigan and Debby Bezzina, CCAT Managing Director, holds a positon on their Board of Directors and is the immediate past president. For this event, CCAT provided in-kind support in exchange for high-level visibility at the event, including advertising for our upcoming events. The support including developing the panel discussions; inviting keynotes, moderators, and speakers; creating and printing the program; and student volunteers for the technology demonstrations that were held at the American Center for Mobility. There were over 140 attendees, 10 exhibitors, and 5 technology demonstrators at this two-day event.

The Government Accountability Office visited CCAT at the University of Michigan Transportation Research Institute on July 30, 2019. The meeting started with a comprehensive review of CCAT research and technology transfer. The GAO also toured the traffic lab and the connected vehicle installation facilities, and had a live demonstration of the connected vehicle technology on the streets of Ann Arbor.

Lastly, GAO conducted a CCAT team interview. GAO is developing an on-line questionnaire and used this visit to hone their tool. In essence, CCAT was the beta site.

This period, continued maintenance of the CCAT website was accomplished. The CCAT website provides a wide array of information for those that work within and outside the CCAT umbrella. New additions to the website include a letter from the director, a page that utilizes graphics to breakdown research projects by CCAT's six main thrusts, a mailing list sign-up form, links to social media profiles, and a page for principal investigators that contains resources including reporting/presentation templates and CCAT logos. Over the last six months, the website has received over 1,000 unique sessions, 85.8% of which were new users. Across those sessions, there were over 5,000 page views and an average session duration of over 6 minutes.

Since May of 2019, CCAT has put forth efforts to build an online presence outside of its personal site. CCAT launched their Twitter, LinkedIn, and YouTube channels to reach a wider audience and to provide more content for their followers. CCAT has leveraged Twitter as an event promotion tool, and over three months, has a 1.2% engagement rate, earning over 4,200 impressions and 21 followers. CCAT utilizes the LinkedIn profile to promote upcoming sponsored events including Distinguished Speaker Series, Research Review, and Global Symposium and averages 10 impressions per post. Finally, CCAT uploads videos to their channel for those that are not able to attend in person. So far, this has included one Distinguished Speaker Series event with Paul Ajegba, one Research Review webinar with Sridhar Lakshmanan, and one lecture from CCAT Director Henry Liu at Next Generation Transportation Systems Seminar. CCAT's YouTube analytics include an average of 10 views per video and a watch time of 12 minutes.

This period, planning for next year's Global Symposium for Connected and Automated Vehicles and Infrastructure was kicked off. The symposium will be held April 14 &15, 2020. The symposium will be a two-track, two-day event. Panel topics will include the "realities" of CAVs (are they all they promise to be?) and how these technologies can improve the lives of those that need it the most (historically underserved communities, older drivers etc.). We will also take a deep dive into the legal and insurance aspects of these technologies and of course - security! Diana Furchtgott-Roth, is the opening keynote and will speak on matters close to her role - with an emphasis on research needed to deploy connected and automated vehicles (and mobility systems) nationwide. The audience will be interested in understanding OST-R's vision, mission, timeline, as well as how research will continue to be funded.

Members of our consortium are regularly called upon as connected and automated transportation experts and participate as subject matter experts in such organizations as the Smart Belt Coalition, ITS America Automated Vehicle Task Force, CAT Coalition, V2I Deployment Coalition, ITS America V2X Task Force, and the Mobility on Demand Alliance, ITS America AV Cybersecurity and Privacy Task Force among others. In addition, several of our PI's hold leadership positions, sharing their expertise on a national and global level. For example, Huei Peng is on the Board of Directors for both the American Center for Mobility and ITS America.

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

Workforce Development Training Accomplishments:

- Developed the Emerging Sector Workforce Training Matrix of Classes providing a training pathway for Advanced Transportation and Mobility Careers, ranging from Foundational, Navigation/ Localization, Networks, Cybersecurity to Analytics [Data Analysis and AI]. Grant funds are being used to pay for additional instructional design that will provide high level features in the Analytics class by Oct. 31.
- Initiated the development of training classes- Microsoft Excel for Mobility Data & Analytics.
- Continued development of training class- Artificial Intelligence [AI] & Computer Vision for AV's.
- Offered a class in Automated Vehicle Localization Techniques to three participants.
- Completed development & began offering the training class- Introduction to UNITY Basic Maps/Apps.
- Contracted with the WorldEducation.net to globally syndicate the ITS training modules and classes outline above.

Credit Education Certificate and Degree Programs Accomplishments:

- Placed three new Automotive Technology students in paid internships with UMTRI for the vehicle deployment of DSRC V2X communications.
- Continued to develop and integrate ITS Technologies with Automotive Technologies in curricula to emulate industry occupational career skillsets.
- Continued to develop academic-leading curricula in Automotive Cybersecurity.
- Updated IT Networking and Communications curricula and courses with the addition of DSRC automotive network communications, especially in course CST185.
- Fostered cross-functional learning experiences for students between IT and Automotive programs during the Winter/Fall 2019 terms, including laboratory experiences using actual vehicles and signal-analyzing oscilloscopes.
- Re-assessed/renewed a Pre-Engineering Program based upon industry/alumni feedback, and initiated occupational career pathway promotions to Engineering Technology.
- Initiated equipment/supply purchases for hands-on laboratory experiences in CAV/ITS vehicle and infrastructure. The equipment included:
    - A fifth oscilloscope for Automotive CAN-BUS signal analysis, including additional diagnostic supplies for the Automotive Labs.
    - C++ Computer Programming supplies for Middle School workshops.
    - Four additional LEGO Mindstorm Kits and "Donkey Cars" for K-12 Camps.

K-12 STEM Technology Awareness & Insight Accomplishments:

- Participated in Square One Education Network's Innovative Vehicle Design Challenge Event for K-12 schools at Kettering University, May 11, 2019. WCC instructors evaluated project entries, and provided a Repair Trailer to assist student project teams in making critical repairs to their project vehicles. Thirty-six high school project teams competed.

- An additional K-12 Computer Programming Training series was planned for the Ann Arbor Scarlett Middle School, for Dec. 2019, using the ten LEGO Mindstorm Program Kits. Fifteen students are expected to participate in "create and command" robotic vehicle exercises.
- Conducted two K-12 Summer V2X Connected Vehicle Youth Camps in July 2019 as follows:
  - On WCC's Campus, 15 students total, 11 Grant funded.
  - At Parkridge Community in Ypsilanti, MI, for 13 Grant-funded students.
- Conducted sessions for an Artificial Intelligence and Automated Vehicle Camp at the Livingston County Educational Services facility in Howell, MI, June 24-28, 2019, utilizing "Donkey Cars" and a Vehicle Simulator for approximately 28 interested youth. Co-sponsors of the event included NAVYA, NVIDIA, American Center for Mobility, and the Livingston Education Association.
- On May 11, a WCC Staff member participated with the Ann Arbor Autonomous Vehicle Group and the Detroit Autonomous Vehicle Group in delivering a Kids Autonomous Vehicle Hackathon Workshop for approximately 15 youth ages 12-17, and their parents, at Lawrence Technological University in Southfield, MI. This event was held in conjunction with the National AutoSens Conference week of events. Scale model autonomous vehicles and a vehicle simulator were used to provide the youth the opportunity to build their own scale model AV's.

University of Michigan

Hosted or participated in twenty-seven outreach engagements this reporting period. Audiences included industry, government, academia, and the community. In total, CCAT research was shared with over 1100 people. The University of Michigan CCAT outreach log is available upon request.

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	City of Akron (Traffic Engineering Department)	Akron, OH	Personnel support, in-kind support, facilities.
Akron	PathMaster, Inc.	Twinsburg, OH	Personnel and technical support.
CSU	Transportation Research Board (TRB) and FHWA	Washington, DC	Facilitates recognition of CCAT research by students through Minority Student Fellows Program
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 and cost sharing.
Purdue	Purdue University	West Lafayette, IN	Financial support.

Purdue	Georgia Institute of Technology	Atlanta, GA	• 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	• Collaborative research
UM	University of New South Wales	Sydney, Australia	Collaborative research.
UM	Mcity	Ann Arbor, MI	$82,911 cash contribution
UM	Ford Motor Company	Dearborn, MI	In-kind support for facilities and technical collaboration. Some overlap for modeling and simulation exists with the beam forwarding project that is funded separately, a benefit to this project.
UM	Florida Center for the Blind	Ocala, FL	Provided body-worn cameras for conducting participant observations of how blind and low vision people use ridesharing services in practice.
UM	Clemson University	Clemson, SC	Served as the research site for conduction interviews during the participant observation of how blind and low vision people use ridesharing services in practice.

3. Outputs

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

University of Michigan

- A randomized mechanism for ridesharing (N. Masoud)
- Analytical models including a randomized mechanism, and a column generation method for allocation (N. Masoud)
- Developed an algorithm to match the recommend routes with real driving data (S. Bao)
- Developed an innovative infrastructure-based solution to address the connectivity gap of CABs and a new modeling framework to evaluate its impacts (Y. Yin)
- Developed a new modeling framework to optimize the incentive policies for CAVs (Y. Yin)
- Data set of vehicle dynamic data and video in weaving sections was created by extracting from existing naturalistic databases (B. Lin)

- John Joon Young Chung, Jean Y. Song, Sindhu Kutty, Sungsoo (Ray) Hong, Juho Kim, and Walter S. Lasecki. 2019. Efficient Elicitation Approaches to Estimate Collective Crowd Answers. Proc. ACM Hum. Comput. Interact. 3, CSCW, Article 62 (November 2019), 25 pages. https://doi.org/10.1145/3359164 **(Best Paper Honorable Mention).** Accepted for publication in July 2019. To be presented in November 2019.
- John Joon Young Chung, Fuhu Xiao, Nikola Banovic, Walter S. Lasecki. 2019. Towards Instantaneous Recovery From Autonomous System Failures via Predictive Crowdsourcing. In Proceedings of the ACM Symposium on User Interface Software and Technology (UIST 2019). New Orleans, LA. Accepted for publication in August 2019. To be presented in October 2019.
- Zhang, Y, Yu, B, Bao, S., Feng, Y., Wang, Y., Yang, C. Real-time Prediction of Hard-braking Behavior when Following: A Hybrid SVM-based Method. Accepted by 2020 Transportation Research Board Annual Meeting.
- 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 (under revision)[1]
- S. Lakshmanan et. al., "Cooperative Adaptive Cruise Control (CACC) in Controlled and Real-World Environments: Testing and Results" NDIA Ground Vehicle Systems Engineering and Technology Symposium (GVSETS), Novi (MI)
- Yang, Z., Feng., Y., and Liu, H.X., Integrated Traffic Signal and Vehicle Trajectory Control in a Mixed Traffic Condition. Submitted to Transportation Research Board 2020 Annual Meeting.
- Understanding Trust, Transportation, and Accessibility through Ridesharing (May 2019, conference paper, CHI)
- Stories from the Front Seat: Supporting Accessible Transportation in the Sharing Economy (November 2019, journal paper, PACM HCI and presented at CSCW conference)
- Research Projects funded by sources other than UTC and matching fund sources:
    - TRI - Human-Augmented Computer Vision for Robust 3D Scene Reconstruction at Scale (Performance Period: 1/1/18 - 12/31/20; Award Amount: $540,019)
    - TRI - Building Mental Models Under Uncertainty in Human-AI Teams (Performance Period: 9/1/19 - 8/31/20; Award Amount: $110,000)
    - "POTENTIAL IMPACTS OF AVs ON TRANSPORTATION AND LAND USE: A RESEARCH SYNTHESIS" funded by Toyota Motor Engineering & Manufacturing North America
    - Beam Forming, Ford Alliance Project, $221,125 (including $22,113 cost-share from University of Michigan). Start date: May 1, 2019

[1] Joint publication with the Purdue faction of the CCAT consortium (S. Peeta, GA Tech)

Purdue University

- A database of more than 2000 interactions between pedestrians and motorists (J. Fricker).
- A data set on prospective infrastructure changes in AV era. (S. Labi)
- A new CAV-related course approved by Purdue administration, to start the spring of 2020 (S. Labi)
- New theoretical model to assess behavioral intention (K. Gkritza)
- Methodology to assess value of travel time savings based on a choice experiment (K. Gkritza)
- Survey data for Indianapolis (K. Gkritza)
- Macrosimulation model of Indianapolis metropolitan area (K. Gkritza)
- New methodologies that identify market segments and assess transportation disadvantaged areas. Additionally, survey data for both Indianapolis and Chicago were generated. (K. Gkritza)
- Zhang, Yunchang and Jon D. Fricker,Technical Report, "PEDESTRIAN-VEHICLE INTERACTIONS AT “SEMI-CONTROLLED” CROSSWALKS: EXPLANATORY METRICS AND MODELS", Lyles School of Civil Engneering, May 2019.
- Zhang, Yunchang and Jon D. Fricker, “Smart Interaction – Pedestrians and Vehicles in a CAV Environment”, 1st Annual Conference on Next-Generation Transport Systems, Purdue University, 31 May 2019
- Jon D. Fricker and Yunchang Zhang, ""Modeling Pedestrian and Motorist Interaction at Semi-Controlled Crosswalks: The Effects of a Change from One-Way to Two-Way Street Operation"", June 2019, Transportation Research Record Journal of the Transportation Research Board, DOI: 10.1177/0361198119850142
- 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.
- Tabesh, M., Miralinaghi, M., Labi, S. (2019). Location of the parking facilities in the era of autonomous vehicles. 1st Annual Conference on Next-Generation Transport Systems, W. Lafayette, IN, May 31, 2019.
- Alabi, B.N.T., Alinizzi, M., Guo, Y., Labi, S. (2019). Urban infrastructure management in an era of smart cities, 1st Annual Conference on Next-Generation Transport Systems, W. Lafayette, IN, May 31, 2019.
- Labi, S., Saeed, T., Sinha, K. (2019). Preparing our infrastructure for CAV operations: The challenges and opportunities, 1st Annual Conference on Next-Generation Transport Systems, W. Lafayette, IN, May 31, 2019.
- Ghahari, S., Ghotbi, S., Assi, S. (2019). Hydrogen Fueling System Infrastructure – Challenges and Opportunities for the Fully Automated Vehicles, Presented at ASCE T&DI ICTD Conference, Alexandra, VA, June 12-15, 2019.
- Labi, S., Miralinaghi, M., Tabesh, M. (2019). Parking Facility Location in the Era of Automated Vehicles, Presented at ASCE T&DI ICTD Conference, Alexandra, VA, June 12-15, 2019.

- Saeed, T., Alabi, B.N.T., Labi, S., Miralinaghi, M., Sinha, K., Volovski, M. (2019). Preparing Highway Infrastructure for the Emerging Era of CAVs, Presented at ASCE T&DI ICTD Conference, Alexandra, VA, June 12-15, 2019.
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- Research Projects funded by sources other than UTC and matching fund sources awarded for "Assessment of an Offset Pedestrian Crossing for Multilane Arterials", SPR-4301, with Indiana Department of Transportation, begun 1 May 2019 ($63,140).
- New CAV course approved by Purdue administration, to start spring 2020.

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.

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.

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 (Division: Applications of Artificial Intelligence, Machine Learning, and Data Analytics in Environmental Science and Engineering: Current Status and Future Directions). Although the work was completed in the last reporting period, it was inadvertently left out of the report and is therefore being included for this reporting period.

4. Outcomes

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

University of Michigan

- The research conducted on the project “Machine Learning, Human Factors and Security Analysis for the Remote Command of Driving” addressed the concern for accurate environment and object recognition as a precursor to devising the complex solutions needed to ensure that autonomous vehicle takes accurate and effective actions when encountering rare situations and obstacles.
- Increased the understanding of drivers’ behavior in freeway weaving sections.
- The project output 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 situational awareness challenges for people with vision impairments.
- Increased the understanding of safety concerns of people with vision impairments regarding in-vehicle experiences.

Purdue University

- Increased the understanding of behavior of pedestrians and motorists in a variety of situations at the same site was derived from the project “Pedestrian-Vehicle Interaction in a CAV Environment –Explanatory Metrics” (J. Fricker). This can form the basis of an analysis of the performance of similar crossing facilities when new technologies are employed for vehicles and pedestrians.
- Identified infrastructure changes needed in the CAV era through the research project “Design and Management of Highway Infrastructure to Accommodate CAVs” (S. Labi).
- Increased the awareness of current deficiency of road infrastructure to accommodate CAVs through the research project “Design and Management of Highway Infrastructure to Accommodate CAVs” (S. Labi).
- Increase the knowledge on behavioral intention to ride in AVs, their impact on mode choice, and energy use and emissions through the research project "Behavioral Intention to Ride in AVs and Impacts on Mode Choice Decisions, Energy Use and Emissions" (K. Gkritza).
- Increase the understanding on implications of AVs on disadvantaged areas through the research project "Public Acceptance and Socio-Economic Analysis of Shared Autonomous Vehicles: Implications for Policy and Planning" (K. Gkritza).
- Increase the understanding of the impact on personal health from transportation innovations through the research project "Ridesharing, Active Travel Behavior, and Personal Health: Implications for Shared Autonomous Vehicles" (K. Gkritza).

University of Illinois at Urbana Champaign

- Enabled by autonomous and connected vehicle technology, freight carriers are motivated to platoon their fleets to reduce operational cost from fuel consumption at the cost of faster pavement deterioration. The result from this model provides insights for highway administration to identify the extra pavement rehabilitation cost induced by channelized traffic, and the necessity of imposing dynamic control on highway segments to alleviate the additional cost. With historical knowledge of the O-D and the demand of freight flow over a highway network, restrictive actions can be taken to diverge the traffic flow to prevent the vicious cycle between pavement deterioration and congestion.
- In this period, we have developed a machine-learning model for traffic speed prediction for road sections with no available traffic data. We have reported the results in the form of a presentation at the local CCAT meetings. During the next period, we plan to extend the developed model to be capable of making stochastic predictions for traffic flow, for a more reliable traffic system management. By the end of the next period, we plan to aggregate the results of this and the next period and present it in form of a peer-reviewed article
- Critical combination (temperature and speed) affecting the pavement response is identified which can be used later to identify the truck spacing.

- Identified material and passive sensing detectors to enhance AV and pavement interaction. Tested ferromagnetic materials successfully in normal and adverse conditions that were embedded into concrete 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

- The characterization of the failures of autonomous vehicles contributes to generalizable knowledge on how we can deal with the failures of other autonomous systems (e.g., a robot in physical environments). The published paper "Efficient Elicitation Approaches to Estimate Collective Crowd Answers" has a broad impact that not only informs other researchers and crowd-system builders how to leverage peer prediction in the system, but also has the potential of guiding better coordination in the real-time recovery from failures of autonomous vehicles by leveraging answer and annotation distributions.
- New policies were developed to accelerate the diffusion of AV technology and evolve the infrastructure to support automated driving because of the research conducted for the project "Adapting Land Use and Infrastructure for Automated Driving." These policies contribute to a commercial solution for AVs.
- 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.
- The project "Supporting People with Vision Impairments in Automated Vehicles: Challenges and Opportunities, developed several guidelines that will improve the way people with vision impairments will interact and use ridesharing, including automated, vehicles:
    - Let drivers know, before picking up a passenger, whether they needed additional help due to a vision impairment.
    - Implement changes to the ride app that penalizes drivers who use the above information in ethically suspect ways, such as taking a longer route.
    - We provide suggestions for alternative forms of in-vehicle spatial awareness such as consider Incorporation of tactile displays with increase spatial awareness and trust.

Purdue University

- Database and identifying factors that affect pedestrian and motorist behavior (J. Fricker)
- Increased the body of knowledge regarding (a) the need for infrastructure retrofit for CAVs, and (b) the specific infrastructure changes needed (S. Labi)
- Developing a virtual reality framework that can be used for testing in cases where the real-world situation is either too dangerous or not feasibly testable.

University of Illinois at Urbana Champaign

- Optimization results demonstrate great potential of savings for both highway administration and freight carriers. This model may serve as a decision-support tool for freight carriers on daily route-planning, and for highway administration to design regulations and/or engineering

guidelines on rehabilitation of infrastructure, predicting location and intensity of congestion due to platooned traffic, pricing for heavy duty vehicle permits, and proactive decisions to diverge traffic in the highway network.

- The proposed model can potentially result in accurate traffic speed prediction, which is essential for individuals and business sectors in helping them make optimal travel decisions. The uncertainty-aware model for stochastic traffic flow prediction can potentially contribute to reliable and timely traffic flow predictions, which is vital for advanced traffic management in intelligent transportation systems (ITS) . Ultimately, the proposed models can contribute to mitigate traffic congestion, improve the level of service, and consequently provide reliable, safe and green transportation.
- Pavement damage is accelerated with close truck spacing. By identifying the critical loads and responses, the damage can be retarded and the truck positioning on the highway can be optimized.
- Identification of materials and sensors that work successfully at normal and adverse conditions and demonstrate the robustness of system as a backup for AV computer vision and GPS outages.

Central State University

The CCAT grant afforded opportunities to CSU students that would have otherwise been unachievable. Daniel R. Lee and Jasmine Walker are the TRB Minority Fellows for 2019. Support from this grant has contributed to their retention and graduation. Lee's paper "Estimating the Contribution of On-road Mobile Vehicles to the Near-Road Air Pollutant Concentrations at a Highway Intersections" has been accepted at the 2020 TRB Annual Meeting. Furthermore, Walker was the team leader for the Mission Marauders.

6. CHANGES/PROBLEMS:

This period, OST-R approved the equipment purchase for additional oscilloscopes at Washtenaw Community College. The equipment is to be used in WCC's Automotive Service credit curriculum.

Below is a description of problems, and sometimes solutions, encountered during the normal course of doing research.

University of Michigan

For the project "Reliable V2V Communication Networks: Applications in Fuel-Efficient Platooning", there has been a significant in acquiring CV2X radios directly from vendor due to the state of the industry. The risk was mitigated by using CV2X radios acquired by Principal (Champion), namely Ford.

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" (S. Labi) was extended due to data collection delays. The new end date is September 30, 2020. RiP will be updated accordingly.