CENTER FOR CONNECTED AND AUTOMATED TRANSPORTATION

Program Progress Performance Report

Sponsoring Office:	Office of the Assistant Secretary for Research and Technology
Grant Number:	69A3551747105
Project Title:	Center for Connected and Automated Transportation (CCAT)
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Submission Date:	October 30, 2018
DUNS No.:	073133571
TIN No.:	38-6006309
Awarded To:	Regents of the University of Michigan 3003 S. State Street Ann Arbor, MI 48109
UM Account No.:	F045674-00
Period of Performance:	November 30, 2016 - September 30, 2022
Reporting Period:	April 1, 2018 – September 30, 2018
Report Frequency:	Semi-Annual
Signature:	

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, 2018 through September 30, 2018.

1. A Research Progress

The following are the active research projects from each partner organization:

University of Michigan

1. ***Driving Etiquette.*** Apply deep learning techniques to establish standards and serve as basis to ensure autonomous vehicles drive "like safe human drivers." This project will collect a large amount of naturalistic driving video data from the Ann Arbor CV deployment and selected partner organizations' areas (equip 50 volunteers' cars with a smart phone). The data will be used to train algorithms to learn about "what is appropriate" (use a combination of machine learning and Monte Carlo tree search techniques).
   PI: H. Peng
   Status: The team has queried naturalistic data from the Safety Pilot Model Deployment (SPMD) project lead by the University of Michigan Transportation Research Institute (UMTRI). In the past quarter, the team has finalized the query of data, and the statistical analysis of many key driving behavior variables that are useful for the design of automated vehicles. These variables include: Free Flow Speed, Time Headway in Car-Following, Range of Longitudinal Acceleration, Minimum Time Headway and Time to Collision (TTC) in Car-Following, Correlation between Acceleration and Range, Correlation between Acceleration and Range Rate, Maximum yaw rate during lane change, Range at the initiation of a lane change, Time to Collision (TTC) at the initiation of a lane change, and Duration of lane changes. A journal paper was submitted, to the Transactions on Intelligent Transportation Systems. The paper is currently under review.
2. ***CAV Data Infrastructure and Access.*** Develop process for general access to CAV data generated by researchers at UM. Also, develop codebooks for data deposits. The main purpose is to give more access to the data, while maintaining the integrity of the PII involved.
   PI: H. Liu, Carol Flannagan
   Status: Phase 1 is complete. The data release form and data access process is actively utilized. Although an on-line format was planned, a hybrid system that is not fully automatic

was actually implemented. The manual tracking remains in place and will continue for the duration of the project. Phase 2 of the project has been started and the metadata repository has been created. Additionally, the data oversight committee has been established. The oversight committee meets regularly to review data access requests.

3. ***AV IQ Test (Design an evaluation system to determine the intelligence of AVs***). Testing and evaluation is a critical step in the development and deployment of connected and automated vehicles (CAVs). It is essential to identify appropriate testing scenarios to evaluate the "intelligence" of the vehicle, similar to a driver's license test, which indicates whether a CAV can drive safely and efficiently without human intervention. The objective of this project is to design a testing scenario library that can evaluate a CAV in terms of safety, functionality and mobility.
   PI: Y. Feng, S. Bao, A. Misra
   Status: A general framework for the testing scenario library generation (TSLG) problem is proposed with four identified research problems: (1) scenario description, (2) index design, (3) library generation, and (4) CAV evaluation. The following novel methods are proposed to solve the research problems: (1) a hierarchical structure is designed to describe testing scenarios, i.e., functional, environmental, and specific scenarios; (2) progressive performance indexes are designed including safety, functionality, mobility, and rider's comfort; and (3) the functional and environmental scenarios are identified by expert knowledge and data analysis. To determine specific scenarios, the criticality of scenarios for CAV evaluation is mathematically defined, called testing values. A small set of critical scenarios are obtained based on optimization and seed-fill methods. (4) The CAV is evaluated with the generated library including three steps: scenario sampling, CAV testing, and index value estimation. Three case studies are designed and implemented to demonstrate the proposal methodologies. First, a cut-in case is designed for safety evaluation as well as to provide answers to three particular questions. Second, a highway-exit case is designed for functionality evaluation. Third, a car-following case is designed to show the ability of the proposed method in handling high-dimensional scenarios.
4. ***Development of an Augmented Reality Environment for Connected and Automated Vehicle Testing.*** Using real vehicles as background traffic for CAV testing in a closed test facility is not only costly, but also difficult to coordinate and control. To address the limitation, in this project we develop an augmented reality testing environment, in which background traffic is generated in microscopic simulation and provided to testing CAVs to augment the functionality of the test facility. The augmented reality combines the real-world testing facility and a simulation platform, in which movements of testing CAVs and traffic signals in the real world can be synchronized in simulation, while simulated traffic information can be provided to testing CAVs' communication system.
   PI: H. Liu

Status: The augmented reality testing platform is developed and is now operating at Mcity with several designed testing scenarios. A recent update enables the environment to support flexible CAV routes in the simulation platform. The road maps have been re-designed and modeled to support this functionality. After the testing CAV designating its destination, the vehicle is able to find a feasible path automatically. In addition, a new feature is under development to support signal prioritization for testing CAVs.

5. ***CAV-Based Intersection Maneuver Assist Systems and Their Impact on Driver Behavior, Acceptance, and Safety (CAVIMAS).*** The objective of this project is to conceptualize, prototype, and evaluate an intersection maneuver assistance system in a simulated driving environment to empirically examine driver behaviors and mental models. The goal is to study driver behaviors related to use of (1) in-vehicle driver interfaces for warning, (2) automated intersection maneuver assistance controls, and (3) integrated driver display warning and vehicle control systems, including drivers' perception and acceptance of these systems.
   PI: A.K. Pradhan, S. Bao, J. Sullivan
   Status: The experimental design (including intersection types, human-machine interface design, modalities) has been finalized. The driving simulation scenarios is near completion. A postdoc (Jeong) was hired to assist and oversee the entire project. A student (Desai) was hired to design human-machine interfaces and recruit/run subjects. The human-machine interface design has been completed. IRB application processes in progress and the application will be complete with the finalized survey instruments. Data collection will take place until the end of November 2018.
6. ***Enhancing Network Assignment Models for Capturing Emerging Shared-Use Mobility Services.*** Develop a simulation model for shared mobility that explicitly models the behaviors of both service operators and travelers.
   PI: N. Masoud, Y. Yin
   Status: The modeling of decentralized (in which vehicles choose which areas to serve based on their individually defined utility functions) and centralized (in which a shared-use mobility service provider optimally assigns vehicles to requests based on a system-level objective function) systems have been fully completed. We are currently implementing both approaches in the study area to enable comparisons.
7. ***An Investigation of Population Segmentation in Responses to Connected and Autonomous Vehicles.*** Review the current state of methods for modeling demand responses to CAV technologies, particularly for transport-disadvantaged communities. Conduct empirical demonstration of methodological challenges, in order to highlight clear gaps and research needs.
   PI: T. Bills
   Status: Started in January 2018. The goal of this phase of the work is to review and identify methods for modeling the expected impacts of CAV technologies on transport-

disadvantaged communities. Based on the initial literature review that was completed in summer 2018, a demonstration of utility-based welfare comparison measures in underway (using the 2017 National household travel survey). This is to determine clear research needs for measures capable of comparing potential CAV related impacts across income classes and other disadvantaged group definitions.

8. ***Trajectory Based Traffic Control with Low Penetration of Connected and Automated Vehicles.*** This project aims at developing new science and technology of vehicle trajectory based traffic control, especially under lower penetration of CAVs. A two-stage research plan is proposed with corresponding key research questions. The first stage corresponds to the period that human-driven vehicles start to become connected vehicles (CVs). The key research question is how to utilize a limited number of CV trajectories to perform detector-free real-time adaptive traffic control at a corridor and network level. The second stage corresponds to a mixed traffic condition. The critical research question at this stage is how to control CAV trajectories and traffic signals jointly to further improve the intersection operations regarding safety, mobility, and sustainability.
   PI: H. Liu, Y. Feng
   Status: A microscopic simulation platform based on VISSIM has been constructed to support the modeling work. The platform combines VISSIM simulator, Driver model API, emission API and a queue length prediction algorithm written in C++. The Driver model API provides interfaces for controlling vehicles in the VISSIM environment. The emission API calculates real-time fuel consumptions and emissions from the vehicle trajectories in simulation. The queue length prediction algorithm predicts queuing profiles at intersections based on data from traffic signals, vehicle trajectories and loop detectors. A mixed optimization framework is proposed. Traffic signals and vehicle arrival times are optimized at the intersection level with a central controller, while detailed vehicle trajectories are optimized within each individual vehicle based on a trigonometric speed profile.
9. ***Adapting Land Use and Infrastructure for Automated Driving.*** Develop quantitative modeling frameworks to analyze the impacts of automated vehicles on land use and infrastructure
   PI: Y. Yin (UM), S. Peeta (Purdue)
   Status: We have completed the literature review on modeling the impacts of automated vehicles on land use and infrastructure, and infrastructure adaptation planning. A model is being developed for optimal deployment of roadside units to improve the operations of automated vehicles when the market penetration of AVs is low. At the same time, we are also developing another model to capture the interactions of shared automated mobility services and parking provision.
10. ***Machine Learning, Human Factors and Security Analysis for the Remote Command of Driving: A Mcity Pilot.*** Both human drivers and autonomous vehicles are now able to drive relatively well in 'typical' (frequently- encountered) settings, but fail in exceptional cases.

Worse, these exceptional cases often arise suddenly, leaving human drivers with a few seconds at best to react—exactly the setting that people perform worst. This work proposes methods for leveraging groups of remote operators to provide assistance on- demand. Unlike prior work, we introduce collective workflows that enable groups of operators to significantly outperform any of the constituent individuals on control and correction tasks. We propose to develop a software platform for Mcity that enables a group of remote operators to command the autonomous test vehicles at Mcity. A pilot study will be conducted at the Mcity Test Facility.
PI: R. Hampshire, W. Lasecki, S. Bao
Status: Project started September 2018. The initial focus has been on literature review. Additionally, the team has started the development of workload/queueing models to determine how many remote operators would be needed to support the deployment of driverless vehicles at scale.

11. ***Supporting People with Vision Impairments in Automated Vehicles: Challenge and Opportunities.*** Autonomous and automated vehicles (AVs) will provide many opportunities for mobility and independence for people with vision impairments (PwVI). This project will provide insights on the challenges and potential barriers to their adoption of AVs. We will examine adoption and use of ridesharing services, which are similar means of single-rider transportation for PwVI, by conducting observations and interviews. In addition, we will investigate social receptiveness of sighted people and PwVI towards the use of AVs through focus groups. From these studies, we will be able to provide recommendations to AV manufacturers and suppliers for how to best design vehicles and interactive systems that mitigate barriers that PwVI face.
PI: R. Brewer, N. Ellison
Status: In March of 2018, we partnered with the Greater Detroit Agency for the Blind and Visually Impaired (GDBAVI) to conduct two focus groups with blind and low vision people on perceptions of fully and semi-autonomous vehicles. These focus groups included design activities where participants worked together to design voice-based and tactile solutions to perceived problems in autonomous vehicles. This work went through a rigorous peer-review process, has been published at the Association for Computing Machinery (ACM) SIGACCESS Conference on Computers and Accessibility (ASSETS), and will be presented at the conference on October 23rd in Galway, Ireland. Over the summer, we interviewed 16 blind and low vision people on how they use ridesharing services, as a close proxy for autonomous vehicles. Findings from this work highlight how and why drivers are important. We submitted a paper on these findings to the ACM CHI Conference on Human Factors in Computing Systems. This work motivated the next phase of this project, interviews with ridesharing drivers. From hiring GSRA in September 2018 and Master's student Amy Austin, we recently submitted an IRB to interview Uber and Lyft drivers who have had experiences with people with vision impairments to understand challenges and opportunities for design

in the context of autonomous vehicles. We expect to interview 20 drivers by 2019. Additionally, we began observations of people with vision impairments this past summer to understand challenges they encounter in vehicles. In partnership with Dr. Julian Brinkley and the Florida Center for the Blind in Ocala, FL, we plan to continue observations in early 2019.

12. ***Design and Operation of Efficient and Budget-Balanced Shared-Use Mobility Systems.*** Shared-use mobility systems allow individuals traveling along the same routes to share (parts of) their trips. Routing/scheduling and pricing of shared-use mobility services are often considered as two separate problems due to the high computational complexity of solving the joint problem. This approach disregards the fact that both agent types (i.e., riders and drivers) in ridesharing systems are utility maximizers, and therefore the operational feasibility of a joint trip does not necessarily translate into the agents' willingness to participate. In this project we devise a mechanism that solves the allocation and pricing problems jointly, guaranteeing individually rational and incentive compatible (within bounds) ridesharing proposals, while seeking a budget-balanced solution that does not require the system to be subsidized.
    PI: N. Masoud
    Status: We have finished modeling, and are currently in the process of coding and debugging. We have selected our study area (New York City), have obtained and cleaned our dataset (New York Taxi data), and are using the data for debugging our codes.

<u>**University of Akron**</u>

Access Control at Major-Minor Intersection through CAV in Mixed Traffic. This research studies potential gap utilization at intersection entrances when CAV is mixed with ordinary vehicles (non-CAV). Study of gap characteristics helps the design and implementation of responsive signal control schemes that utilize CAV to adjust gaps for minor street vehicles to enter the intersection. Field testing will demonstrate the feasibility of application and evaluate the reliability and effectiveness of the improved control logic.

PI: P. Yi
Status: We have finished the gap characteristics study and completed model development work. Initial lab simulation is done and will continue with adjustments to the algorithm if needed. Trial test of integrated system hardware and software has been conducted and experimental design for field test is being prepared.

<u>**Purdue University**</u>

1. ***Development of a Dynamic Network Traffic Simulator for Mixed Traffic Flow under Connected and Autonomous Vehicles.*** Develop a unified car-following modeling framework that models mixed-traffic streams under different market penetration rates of CAVs. It will also perform stability analyses to explore implications for safety and mobility.
    PI: S. Peeta

Status: Started January 2018. For this reporting period, a unified car-following model for different CAV types was developed. Efforts continued on developing a mixed flow multi-lane cell-transmission model to describe the mixed traffic flow characteristic by considering both longitudinal and lateral improvement by CAV technology. The stability analysis was completed. Generated the control inputs of CAVs by considering the interactions between HDVs and CAVs and the performance of the mixed flow platoon to design a cooperative decentralized controller. Analyzed potential factors that can influence HDVs car-following behavior when interacting with CAVs. Work has begun to develop a novel car-following model for HDVs that describes the interaction when an HDV follows a CAV. Next period, the stability analysis of the mixed traffic platoon including CAVs and HDVs will be initiated.

2. ***Develop In-Vehicle Information Dissemination Mechanisms to Reduce Cognitive Burden in the Information-Rich Driving Environment.*** Understand the impacts of real-time information characteristics and multiple dissemination sources on driver cognition, and its effects on the driver decision-making process and ability to comprehend information safely.
   PI: S. Peeta
   Status: Started January 2018. Data analysis, and research reporting and dissemination, are currently in progress. The year 2 phase of the project was kicked off in this reporting period. The team completed the design and preparation of the driving simulator environments as well as the pilot testing and preparing the IRB application. The team is currently recruiting participants to perform the experiment. To date, data has been collected for 72 participants. Once the data is collected, it will be analyzed and research reports generated for outreach and technology transfer.
3. ***Non-Connected Vehicle Detection Using Connected Vehicles.*** Develop a model to identify non-CV locations/trajectories that will be integrated with a cooperative situation awareness framework to analyze real-world vehicle trajectory data to aid the situational awareness of CVs under low market penetration rates.
   PI: S. Peeta
   Status: Started January 2018. Significant progress was made this reporting period to complete all but one remaining tasks including (1) Investigate the characteristics of driving behaviors under various congestion levels and network characteristics; (2) Develop a probabilistic inference model for the unequipped vehicle location estimation; (3) Integrate the proposed HMM model and cooperative-perception framework; (4) Establish car-following model for connected vehicle via extending Intelligent Driver Model with linear combinations of acceleration and speed difference from preceding vehicles; (5) Conduct stability analysis (include local stability and string stability) for mixed traffic flow containing connected vehicles and human driving vehicles; (6) with different penetration rates, analyze the effect introduced by connected vehicles in traffic flow (e.g. attenuate traffic oscillation, increase capacity, reduce delay, etc.). Next period, the task of using the driving simulator to calibrate the CV car-following model will be initiated.

4. ***Cooperative Control Mechanism for Platoon Formation of Connected and Autonomous Vehicles.*** Design cooperative control mechanisms for a CAV platoon under realistic vehicle-to-vehicle (V2V) communication environments to maximize platoon performance.
   PI: S. Peeta
   Status: Started January 2018. This period, an optimal controller for CAV platoon was developed that maximized platoon performance. Work began on developing a stochastic model predictive control problem for CAV platoon to accommodate the uncertainty of the leading vehicle's future state on safety of CAV platoon. Next period efforts to optimize headway and platoon size to improve fuel efficiency will be initiated.
5. ***Design of Urban Landscape and Road Networks to Accommodate CAVs.*** Analyze and develop urban landscape and road network designs to accommodate CAVs that can maximize safety and comfort for all road users, including motorists, public transit users, cyclists and pedestrians.
   PI: S. Peeta
   Status: Started January 2018. The four types of roadway designs for a downtown one-one-way street with different foci on mobility, safety, accessibility, and sustainability created last reporting period were tested this reporting period. The survey to capture people's attitude towards different roadway designs and how these designs can affect their willingness to pay for CAVs is in the final stages of IRB approval. Once approved, the survey will be implemented. The data will be analyzed and the final report written. Year two efforts were kicked off this period to design and prepare the driving simulator environments.
6. ***Pedestrian-Vehicle Interaction in a CAV Environment – Explanatory Metrics.*** Measure the interaction between pedestrians and motorists, so that the variety of expected interactions between pedestrians and autonomous vehicles can be documented.
   PI: J. Fricker
   Status: Started January 2018. This period focused on "two-way" videos. A report that summarizes the activities of the study is being prepared, with a target date of December 2018. A paper was submitted to TRB for presentation at the January 2018 Annual Meeting. The paper was accepted for presentation, with an invitation to resubmit the manuscript for possible publication. A second paper is being drafted, based on statistical analysis done since the first paper was submitted to TRB.
7. ***Autonomous Vehicle's Impacts on Energy Use and GHG Emissions.*** Examine the potential effects of autonomous vehicles on energy demand and GHG emissions by improving projections of future travel demand and patterns in response to using a behavioral experiment (survey), and estimating the energy and carbon intensity of vehicle travel.
   PI: K. Gkritza
   Status: Started January 2018. Data collection was started in April of 2018. The IRB approved survey instrument was distributed online during the first three weeks of April 2018. The target population for the survey included adult residents of the Indianapolis metropolitan

area. Four hundred (400) responses were collected. The data analysis is in progress and will include (1) a descriptive analysis of the survey responses; (2) modeling behavioral intention to ride in AVs in Indianapolis; (3) The analysis of the mode-choice experiment is part of ongoing work, and is expected to finish during the next quarter. The rules and assumptions for the simulation network are currently under development. The simulation experiments will be conducted next report period.

8. ***Design and Management of Highway Infrastructure to Accommodate CAVs.*** Examine how the various maturity levels of connected and autonomous vehicle (CAV) implementation will influence the design and management of highway infrastructure.
   PI: S. Labi
   Status: Started January 2018. An inventory of the physical infrastructure features of these highways is in progress.
9. ***Public Acceptance and Socio-Economic Analysis of Shared Autonomous Vehicles: Implications for Policy and Planning.*** Investigate public acceptance towards SAVs by assessing the intention to switch from public transportation in favor of ride-sharing services operated by autonomous vehicles (SAVs) using data from two cities in the Midwest (Indianapolis, IN and Chicago, IL) and conduct a socio-economic analysis, using the results of market segmentation analysis for the two study areas, to inform policy and planning decisions.
   PI: N. Gkritza
   Status: The project was started this period. A market segmentation analysis for Chicago was completed based on the data collected in the behavioral experiment approved by Purdue's IRB (Protocol# 1701018708). A market segmentation analysis for Indianapolis has been started based on the data collected in the behavioral experiment approved by Purdue's IRB (Protocol#1801020160). Identification of the significant factors influencing public acceptance of SAVs for Chicago and Indianapolis is now underway. The team also began to assess the transport of disadvantage and investigate socio-economic implication due to the emergence of SAVs.
10. ***Impacts of In-Vehicle Alert Systems on Situational Awareness and Driving Performance in SAE Level 3 Vehicle Automation.*** Evaluate impacts of in-vehicle alert systems (such as vibration- and voice-based) on driving performance for taking control under level 3 vehicle automation using interactive driving simulator-based experiments.
   PI: S. Peeta
   Status: Project approved. There will be five tasks associated with this project: (1) design and construct driving simulator environment; (2) design experiment protocol, pilot testing and prepare IRB application; (3) recruit participants and execute experiment; (4) data analysis; and (5) draft final reports.

11. ***Adapting Land Use and Infrastructure for Automated Driving.*** Establish quantitative modeling frameworks to analyze the transformation of urban form, its land use and mobility systems due to adoption of autonomous vehicles.
   PI: S. Peeta
   Status: Project approved but not started. There are six tasks associated with this project: (1) review literature; (2) develop monocentric city model with AVs; (3) develop polycentric city model with AVs; (4) time-invariant optimal deployment of AV facilities; (5) roadmap for evolving infrastructures toward automated mobility; and (6) draft and final reports.
12. ***Changes in Highway Agency Expenditures and Revenue in an Era of CAVs.*** Estimate: (i) The changes in highway expenditures in an era of CAV operations, (ii) The change in highway revenues that can be expected to arise from CAV operations, and (iii) The changes in highway cost allocation and revenue attribution among the highway users in the era of CAVs.
   PI: S. Labi
   Status: Started January 2018. During this reporting period, the research team started work on the literature review. Work has also started on estimating VMT changes due to CAVs, estimating expenditure changes due to CAVs, and estimating revenue changes due to CAVs.

<u>University of Illinois at Urbana-Champaign</u>

Operations of Connected and Autonomous Freight Trucks under Congestion and Infrastructure Cost Considerations. This proposal aims at developing an integrated connected and autonomous truck routing model that simultaneously considers interdependency between traffic lane/"track" use, platooning, and pavement deterioration and rehabilitation, such that the total life-cycle societal costs due to infrastructure investment, traffic delay, and pavement life-cycle costs are minimized.

PI: I. Al-Qadi, Y. Ouyang, J. Roesler, H. Ozer, H. Meidani

Status: Developed an efficient data collection scheme that selects and transmits only a small subset of data to alleviate data transmission burden. Using the Safety Pilot Model Deployment data set, it was demonstrated with this approach that the collection ratio can be as small as 0.05. Moreover, a simulation study was performed to evaluate the travel time estimation accuracy using the proposed data collection approach, where the results show that the proposed data collection approach can significantly improve travel time estimation accuracy. In order to facilitate the truck platooning and speed up the calculation of the drag forces for different configurations of trucks, we have started developing a novel deep learning approach, which is regularized by the fluid dynamics equations. Currently, the methodology has been validated on small problems and they are ready to be tested on the truck platooning problem. Efforts on developing an optimization framework for an autonomous and connected truck (ACT)-freight transportation/routing network have been initiated. The framework seeks to minimize the total cost as the summation of agency cost (pavement rehabilitation) and user cost (fuel consumption, vehicle maintenance and time loss) for a gross freight delivery throughput across a region. The network-level optimization model builds upon optimal platoon configuration on a corridor. Another optimization framework that minimizes the overall freight transportation cost (i.e., summation of user costs and maintenance and rehabilitation costs) has been developed and evaluated on a case study where optimum platoon skeletons (i.e., configuration of lateral position of trucks in a platoon) have been generated for any platoon sizes. Preliminary, the framework was evaluated on the platoon sizes of 5, 10 and 15 ACTs. The results showed that the overall cost can be reduced by 0.5 million $/mile in average over 45 years of analysis period assuming 100% ACT penetration. Completion of literature review of existing sensor technology used in autonomous vehicles was also completed this period. Lastly, progress was made in report write-up regarding modification of existing pavements and the design of new pavements to accommodate fully autonomous vehicles without compromising safety and use of expensive in-pavement sensor technology.

Central State University

1. ***CAV Systems Incorporating Air Pollution Information from Traffic Congestion.*** Through CCAT center, 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.
   PI: K. Nedunuri and R. Kandiah
   Status: This summer, the research team began to capture the typical contaminants from NAAQS and GHG emissions from two types of vehicles. Data capture will continue to get sampling from different seasons.
2. ***CAV Developed Vehicles as Real-Time Sensors for Assessing Greenhouse Gases.*** 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. MOVES will be used to generate several scenarios to determine emissions from vehicles in a simulated traffic congestion scenario. ODOT traffic

data will be used in these scenarios. 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 on freeways on radio channels approaching congested areas.

PI: K. Nedunuri and R. Kandiah
Status: An inventory of priority Pollutant and greenhouse gas emissions from On-Road Vehicles in Franklin County was conducted.

1. B Outreach, Education, Leadership Development, and Workforce Development

This period, CCAT continued the Distinguished Lecture Series. The University of Michigan hosted Dr. Hani S. Mahmassani from Northwestern University on April 11, 2018 and Dr. Maged M. Dessouky, University of Southern California on September 26, 2018. Dr. Mahmassani presented "Autonomous Vehicles and Connected Urban Mobility: Rethinking Public Transit." Dr. Dessouky presented "Research, Practice, and Future Directions of Dynamic Ridesharing." Both presentations can be accessed on the CCAT website (ccat.umtri.umich.edu)

Additionally, CCAT consortium members completed the following outreach, education, leadership development, and workforce development activities during this reporting period:

Washtenaw Community College

- WCC Regional Symposium, April 6, 2018, entitled "Smart Cities: A Connected Way Forward…The Future Is Here, Are You Ready?" providing participants with updates on the transformative changes from old-to-smart city infrastructure planning and development. Key speakers, presentations and panelists included many prominent members of government and industry. Symposium attendees included representatives of Business/Industry, Economic Developers, and City Planners representing Michigan, Ohio, and Indiana. The full agenda can be accessed at http://sites.wccnet.edu/smart-cities/.
- WCC participated in the ITS-America Annual Meeting, June 4-7, with a display of Mobility Programs in the Planet M exhibit area, and four speakers participated in two panel sessions.
- Continued professional development for WCC staff in ITS, Smart Cities, and Connected/Autonomous Vehicle conferences. A highlight was the Center for Automotive Research Management Briefing Seminars, July 29- August 2, 2018. Five WCC staff and two students participated.

- WCC provided a connected vehicle display at the Ann Arbor SPARK Tech Trek and Mobility Row event, June 15, 2018, on the streets of Ann Arbor. Both the public and businesses inquired about WCC's ATC programs.
- Continued supplying automotive students into UMTRI Internships during the 2018 Winter and Spring/Summer terms. The internships provided installation training and functional verification in connected vehicle equipment for the Ann Arbor Connected Vehicle Test Environment project.
- Integration of an introductory video module on Intelligent Transportation for every IT course.
- Cross collaboration between IT and Automotive instructors resulted in the integration of key IT, Networking and Communications content modules and materials in the Automotive curriculum Fall Term 2018, in support of an emerging Mobility Program.
- Developing a student advising guide and internal outreach effort to educate WCC advisors in counseling students to explore Mobility programs/careers. Implementation may be scheduled during upcoming faculty/staff In-Service activities in November 2018.
- Delivered new ITS Field Technician Introductory Online Training, April-July 2018.
- Completed Design of Augmented Reality Geo-Location MicroMapper Online Training, Aug. 2018.
- Continued development of 1) Mobility Analyst Online Training, 2) Vehicle Localization Introduction Online Training Module.
- Initiated development of a Robotic Operating System project applied to a scaled model vehicle [Donkey Car] to encourage robotic software development among K-12 and community enthusiast groups.
- Ann Arbor Scarlett Middle School Training in Computer Programming, April 2018.
- WCC participated with Square One Education Network Middle/High School annual competition events for 2018 Innovative Vehicle Design Mobility Challenge Competition at Mcity, May 19, 2019, including hosting vehicle evaluation meetings and providing mobile diagnostic/repair facilities for project teams.
- Connected Vehicle Training Youth Camp at Parkridge Community, Ypsilanti, MI, summer 2018.
- Hosted MDOT Youth Career Exploration Fair 2018, exhibiting various STEM technologies for transportation occupations, June 2018.
- Hosted Square One Education Network's "Masters of Mobility V2X Connected Vehicle" Lab School training September 26-27, 2018. Participants included regional K-12 students and teachers in the 2-day workshop. Eligible teachers were provided the opportunity to earn CEU's through WCC's registration process.

<u>University of Michigan</u>

- Continued to supported MiTSO (Michigan Transportation Student Organization)
- Maintained CCAT website (ccat.umtri.umich.edu)

- Published CCAT Newsletter May 2018 edition.
- In this reporting period, eighteen (18) outreach engagements occurred plus eleven (17) technical exchanges. Because of space limitations, full details of the engagements are not provided, but are available upon request.

Purdue

- Held discussions with personnel from Purdue University Hub for Connected and Autonomous Vehicles and Purdue Policy Research Institute.
- Dr. Souders presented a guest lecture Autonomous Vehicles: Benefits and Concerns to the retired community University Place in West Lafayette, IN. The lecture also served as a recruitment tool for older participants for the driving simulator studies.
- Established connections with Indiana University–Purdue University Indianapolis (IUPUI) researchers who have carried out a "naturalistic" study of pedestrians in crosswalks.
- Presentation on AV's Impacts on Energy Use and GHG Emissions at the Purdue ITE Student seminar.

Central State University

- Two environmental engineering majors Mr. Daniel Lee and Ms. Jasmine Walker have been selected as student research scholars in Transportation Research Board for 2017-2018. They are preparing papers on NAAQS and GHG pollutants for Transportation Engineering Conference for OTEC 2019.

University of Illinois at Urbana-Champaign

- A journal paper has been submitted based on the work on efficient collection of connected vehicle data.
- A paper has been submitted and accepted for presentation at the Transportation Research Board meeting regarding the optimization framework for an autonomous and connected truck (ACT)-freight transportation/routing network. The paper will also be submitted to a journal with a higher impact factor.
- Acceptance of an abstract named "Vehicle-Infrastructure communication to assist automated vehicle guidance" for paper and presentation at "ASCE-T&DI International Airfield & Highway Pavements Conference (Pavements 2019)".

1. C Deliverables

The main deliverables for this reporting period were:

- PPPR #2 for 6/1/17 through3/31/18
- Technology Transfer Plan
- All approved research projects' UTC forms were posted to the CCAT website and entered into RiP

Deliverables planned for next reporting period are:

- Continue to update the CCAT website to include planned outreach events, news research, etc.
- 3rd edition CCAT newsletter
- Conclude research project selection for year 3 funding
- Complete product submissions, as applicable
- Update all UTC forms to current status, post to CCAT website, and update RiP

1. Products

In this reporting period, the CCAT consortium created the following products:

University of Michigan

- Masoud, N. "Computationally Efficient Truthful Mechanisms for Large-scale P2P Ridesharing Systems" has been scheduled at the INFORMS conference, held in November 2018.
- Masoud, N. "Investigating the Role Assignment Stability in Large-scale Peer-to-Peer Ridesharing Markets" has been accepted to be presented at a poster session in the 2019 TRB annual meeting.
- Masoud, N. "High Quality Approximation Algorithms for Vehicle Synchronization in Transit Systems" has been accepted for presentation in the 2019 TRB annual meeting.
- Brewer, R. "Understanding the Power of Control in Autonomous Vehicles for People with Vision Impairments" presented at ASSETS conference.
- Brewer, R. "Facilitating discussion and shared meaning: Rethinking co-design sessions with people with vision impairments"
- Peng, H., Huang, X. & Zhang, S. "Developing Robot Driver Etiquette Based on Naturalistic Human Driving Behavior" submitted, not yet accepted.

Washtenaw Community College

- ITS Field Technician Online course April –July 2018.
- Augmented Reality Geo-location Micro Mapper Online Training course.
- Upgraded credit curriculum in Automotive and Computer Information Systems

Purdue University

- A cooperative adaptive cruise control (CACC) model considering dynamic Information Topology for the CAV platoon was established. The paper was submitted to the 21st IEEE International Conference on Intelligent Transportation Systems.
- Peeta, S., Agrawal, S., Benedyk, I. (2018). "Evaluating the Impacts of Driver Cognitive and Physiological State on Decision-Making Behavior under Real-Time Travel Information,"

9th International Conference on Applied Human Factors and Ergonomics, Orlando, FL, July 2018.

- Peeta, S., Agrawal, S., Benedyk, I. (2018). "Evaluating Driver Cognitive State under Real-Time Travel Information Provision Using Physiological Factors and its Impacts on Route Choice Behavior," 15th International Conference on Travel Behavior Research, Santa Barbara, CA, July 2018.
- Taxonomies and models that describe interactions between pedestrians and motorists at unsignalized crosswalks.
- Gkartzonikas, C. & K. Gkritza. "Factors Influencing the Behavioral Intention to Ride in Autonomous Vehicles", Presented at 2018 the Global Symposium for Connected and Automated Vehicles and Infrastructure on March 7-8, 2018 in Ann Arbor, MI.
- Gkartzonikas, C. & K, Gkritza. "Assessing the Behavioral Intention to Ride in Autonomous and Shared Autonomous Vehicles and Market Segmentation Analysis", Presented at the 15th International Conference on Travel Behavior Research on July 15-20, 2018 in Santa Barbara, CA.
- Gkartzonikas, C., and K. Gkritza, "Intention to Ride in Autonomous Vehicles: Relationships with Attitudes, Norms, and Perceived Behavioral Control", Transportation Research Part F: Traffic Psychology and Behaviour (under review).
- Gkartzonikas, C., and K. Gkritza, "What Have We Learned?: A Review of Stated Preference and Choice Studies on Autonomous Vehicles", Transportation Research Part C: Emerging Technologies, (under review).
- Gkartzonikas, C. & K, Gkritza. "Assessing the Behavioral Intention to Ride in Autonomous and Shared Autonomous Vehicles and Market Segmentation Analysis" Presented at 15th International Conference on Travel Behavior Research on July 15th-20th, 2018 in Santa Barbara, CA.

<u>Central State University</u>

- MOVES model customized to estimate NAAQS and GHG.

<u>University of Illinois at Urbana-Champaign</u>

- A new flexible pavement design framework for ACTs that can explicitly consider the lateral position of loading, axle width, and lane width has been developed. This framework will help transportation researchers and engineers to quantify the potential impacts of ACTs so that they can revise their budget and maintenance resources allocation strategies accordingly to be prepared for infrastructure-related challenges due to ACTs. For instance, it can be used for policy/fee development that compensates for the additional damage imparted by ACTs. Furthermore, this research has resulted in numerical modelling for truck aerodynamics that can be used to compute the amount of fuel efficiency of any platoon configuration with respect to the spacing and lateral offset between the trucks.

- The optimization framework for network freight transportation using ACT fleets integrates factors such as background traffic, route parameters (network layout, distance, O-D location, etc.) to jointly optimize the choice of route(s), steady-state platoon sizes, and platooning configuration (e.g., lateral displacements) on each route. The framework also consists of a subroutine model that optimizes the scheduling for pavement rehabilitation activities.
- A report summarizing current autonomous vehicle sensors and potential sensor/material technologies that would enable safe autonomous vehicle navigation on existing and new pavements.

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. In year 2 of the CCAT grant, the University of Michigan and Purdue University developed a joint research project "Adapting Land Use and Infrastructure for Automated Driving." Additionally, the following tables summarize the collaborations that occurred during this reporting period.

CCAT Org.	Org.	Location	Contribution
WCC	Automation Alley	Ann Arbor, MI	Participated in WCC's Smart Cities Event [April 6, '18] and Invited WCC exhibit CAV technologies at the "Tech Trek and Mobility Row" Event in Ann Arbor, June 15, '18
WCC	City of Seat Pleasant, MD	Seat Pleasant, MD	Participated in WCC's Smart Cities Event [April 6, '18]
WCC	DTE Energy	Detroit, MI	Participated in WCC's Smart Cities Event [April 6, '18]
WCC	Ford Motor Co.	Dearborn, MI.	Insights into Ford's development of vehicles to operate safely in SMART Cities.
WCC	GRIMM Company	Grand Rapids, MI	Cyber Security consultation and an Anti-Hacking Lab Workbench for laboratory exercises
WCC	Macomb Community College	Warren, MI	Curriculum Syllabi for Automotive Programs through the CAAT NSF Grant, and collaboration on training for the ACM
WCC	MAGNA International	Troy, MI	Toured WCC's ATC Laboratories and reviewed Automotive Service curricula for future Interns in CAV development.
WCC	MI Works Agency SE		Assisting WCC in promoting STEM education in Mobility to youth and career seekers.
WCC	Oakland County MI Works	Waterford, MI	Assisting WCC in promoting STEM education in Mobility to youth and career seekers.
WCC	SE MI Community Alliance	Taylor, MI	Assisting WCC in promoting STEM education in Mobility to youth and career seekers.
WCC	Univ. of MI Institute for Social Research	Ann Arbor, MI	Participated in WCC's Smart Cities Event [April 6, '18]

WCC	Workforce Intelligence Network [SE MI]	Detroit, MI	Assisting WCC in promoting STEM education in Mobility to youth and career seekers.
UM	Mcity	Ann Arbor, MI	Funding for additional projects including a pedestrian detection deployment and the transportation control room. Collaboration on joint project selection process.
Akron	City of Akron (Traffic Engineering Department)	Akron, OH	The Traffic Engineering Department of the city of Akron collaborates with the University of Akron in the project by providing test sites (intersections) and technical staff to facilitate field investigation and system testing
Akron	Pathmaster, Inc.	Aurora, OH	Pathmaster provides technical guidance in signal equipment adjustment and system integration.
Purdue	Purdue Policy Research Institute	West Lafayette, IN	Purdue Policy Research Institute has offered the assistance in data analysis and using research insights and results to develop CAV related policy recommendations.
Purdue	Texas A&M University	College Station, TX	Collaboration on the demand assessments
Purdue	Chongqing University of Posts and Telecommunications	Chongqing, China	Funding for projects on cooperative adaptive cruise control for CAV platoon. Collaboration on joint project selection process.
Purdue	University of Michigan Transportation Research Institute (UMTRI)	Ann Arbor, MI	Dr. James R. Sayer, Director of UMTRI, has offered the assistance from some of his staff to assist the PI in areas where they themselves have already performed pedestrian safety research and can offer guidance and share lessons learned.
CSU	Transportation Research Board (TRB) and FHWA	Washington, DC	Facilitates recognition of CCAT research by students through Minority Student Fellows Program

3. Impact

University of Michigan

The use of augmented reality for CAV testing will save automobile manufacturers millions of dollars in development and validation costs.

Washtenaw Community College

Participating in the UMTRI internship program has successfully launched our students into high-paying technical careers in the automated vehicle industry including jobs at May Mobility.

University of Illinois at Urbana-Champaign

- The research team is in contact with the Ford Company to investigate the implementation challenges of the data compression technique in actual vehicles and intelligent transportation infrastructure.
- The optimization framework for network freight transportation using ACT fleets may serve as a decision-support tool to freight carriers to plan a shipment routing strategy

on a daily basis. Given the massive quantity of freight-distance usually involved in the industry and the large impact of truck traffic on pavement deterioration, there is a great potential for savings on freight shipping costs and pavement life-cycle costs. Traffic engineers or urban planners to predict the impact of platooned ACT fleets on freeway traffic flow and level of service can also utilize the model. Such information can further be used by policy makers to develop regulations and/or engineering guidelines on rehabilitation of infrastructure, construction of new routes, or pricing for heavy vehicle permits.

- The flexible pavement design framework for ACTs has demonstrated how enabling communication technologies embedded in autonomous and connected trucks can be leveraged to improve the freight transportation economy. Furthermore, this study has introduced two methodological contributions (i.e., pavement design framework for ACTs and numerical modelling for simulating truck aerodynamics) to the literature that can be used to quantify the impact of platooning on transportation network.
- Proposed several ideas in report that can be used for potential improvement of safety in large-scale autonomous vehicle deployment through pavement and vehicle interaction. New ideas will be proposed in next year funding and tested in the laboratory and then inserted into experimental test sections to check the performance in adverse weather conditions.

4. CHANGES/PROBLEMS

Financially, the most significant problem to report is that the year 3 contract has not been issued. This is causing delays in awarding year 3 projects and procuring needed items for year three education and workforce development.

Technically, the most significant problem to report was in the developed flexible pavement design framework for ACTs by the University of Illinois at Urbana-Champaign, objective function was solved using metaheuristic algorithms such as genetic algorithm or particle swarm optimization. Although these algorithms were able to solve the objective functions in lower dimension accurately and efficiently (e.g., the platoon sizes up to 8-10 trucks), their computational cost and instabilities were increased significantly for higher dimensions. Therefore, there is a need for more robust and computationally efficient optimization approach for the future studies.