Center for Connected Multimodal Mobility (C²M²)

Semi-Annual Progress Report # 1

Submitted to: United States Department of Transportation (USDOT), Office of the Assistant Secretary for Research and Technology (OST-R)

Federal Grant number: 69A3551747117

Project Title: Center for Connected Multimodal Mobility (C²M²)

Center Director:
Mashrur "Ronnie" Chowdhury, Ph.D., P.E., F. ASCE
Eugene Douglas Mays Professor of Transportation
Director, USDOT Center for Connected Multimodal Mobility (C²M²)
Clemson University, SC 29634
Phone: (864)-656-3313, Email: mac@clemson.edu

Submission Date: April 30, 2019
DUNS#: 0426298
EIN#: 57-6000254

Recipient Organization: Clemson University, Clemson, South Carolina 29634

Recipient Identifying Number or Account Number, if any: 69A3551747117

Grant Period: November 30, 2016 – September 30, 2022

Reporting Period: October 01, 2018 – March 31, 2019

Report Term or Frequency: Semi-annual

Signature of Submitting Official: _____

1. ACCOMPLISHMENTS - What was done? What was learned?

1.1 What are the major goals of the program?

C^{2}M^2's mission statement:

Our vision for the Center for Connected Multimodal Mobility (C^{2}M^2), a Tier 1 University Transportation Center, is to become a globally recognized multimodal mobility innovation center for moving people and goods, specializing in connectivity, data analytics and automation. To achieve this bold vision, our multidisciplinary research team from five leading higher education and research institutions in the state of South Carolina are working together to create and develop new initiatives and inventions by combining our complementary research strengths, our education and workforce development activities, our commitment to diversity, and our expertise in emerging communication and computing technologies.

C^{2}M^2's main goals are to:

- Conduct interdisciplinary research and drive innovation through data science, data-driven computing, seamless vehicle, traveler and infrastructure connectivity, and automation
- Conduct education and workforce development/leadership activities
- Disseminate C^{2}M^2 knowledge and technologies
- Support complementary collaborations with consortium members, private partners, and the public sector
- Broaden diversity by integrating consortium members' existing diversity programs with the C^{2}M^2 activities

C^{2}M^2 intends to meet these goals through the following means:

- Using data, connectivity, and automation to promote access to opportunities and equity, and assist those with physical and cognitive disabilities, by fostering on demand mobility services for those unable or unwilling to drive
- Creating strategies to improve the mobility of people and goods, and optimize passenger and freight movement, through numerous techniques that will improve vehicle and system performance (e.g., by maximizing existing infrastructure capacity via vehicle-to-vehicle and vehicle-to-infrastructure connectivity)
- Contributing to Smart Cities that collect and process big data, often in real-time. To optimize the transportation system performance (including more intensive use of shared infrastructure)
- Developing innovations to improve multimodal planning and modeling for the movement of both people and goods, using connectivity and data to seamlessly guide transfers between vehicles, infrastructure and modes
- Assisting regional planning and the setting of transportation priorities through innovations that leverage limited dollars to create large positive impacts (e.g., by using "Big Data" to aid in regional travel demand forecasting efforts)

1.2 What was accomplished under these goals?

In this reporting period, the following tasks were completed in order to meet the goals that were set for our Center.

- C²M² Directors continued their bi-weekly conference calls to coordinate the Center's activities, and budget. (Ongoing)
- Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, Clemson University, meets weekly with a team from the Clemson University International Center for Automotive Research (CU-ICAR) to collaborate on the OPEN CAV CU-ICAR project, which is a collaboration of researchers who are purchasing a connected and automated vehicle to further vehicle automation research in a cyber-physical system environment. (Ongoing)
- Drs. Jennifer Ogle and Wayne Sarasua, C²M² affiliated researchers, Clemson University, in conjunction with the Clemson University Glenn Department of Civil Engineering NSF RED Grant worked to develop real-world project-based courses to supplement the existing curriculum with a focus on student success in attaining professional formation as engineers. (Ongoing)
- C²M² hosted the 6th Annual University Transportation Centers Conference for the Southeastern Region, at the Madren Conference Center in Clemson, SC. This conference featured, Carla Bailo of the Center for Automated Research as a keynote speaker, a State DOT Panel, research presentations by students and faculty with prizes awarded for the top three student posters and presenters, and a Connected and Automated Vehicle Technology Demonstration. Approximately 200 participants attended from throughout the Southeastern Region during the two-day conference. (October 24-25, 2018)
- Drs. Dimitra Michalaka, C²M² Associate Director, William J. Davis, C²M² Co-Associate Director, and Kweku Brown, C²M² affiliated researcher, The Citadel, gave tours to prospective Citadel students interested in pursuing an engineering degree as part of The Citadel's Pre-Knob program. These students were given an overview of The Citadel's ongoing sponsored research projects and the opportunity to participate in this research as undergraduate students. (October, 2018 – March, 2019)
- Drs. Dimitra Michalaka, C²M² Associate Director, William J. Davis, C²M² Co-Associate Director, and Kweku Brown, an affiliated researcher, at The Citadel hosted 28 groups of 5th graders from Richland Country Schools at the civil engineering department at The Citadel to be introduced to civil engineering. The different civil engineering disciplines, including transportation engineering, were explained through presentation, discussions, and hands-on activities by Dr. Kweku Brown, Dr. William J. Davis, Dr. Dimitra Michalaka and other faculty. (Fall 2018)
- C²M² Advisory Board members convened for our annual meeting during the 6th Annual UTC Conference for the Southeastern Region, where Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, Clemson and available Associate Directors gave a presentation of the Center's activities for the year and begin proposing action for the coming year. Dr. Nadim Aziz was elected as the Advisory Board President in this meeting. (October 24, 2018)
- C²M² researchers who received funding approval in the 2018/2019 round of funded projects all began their research. (November, 2018 – January, 2019)

- Drs. Jennifer Ogle and Wayne Sarasua, C^{2}M^2 affiliated researchers, Clemson, and Clemson's student ITE chapter co-sponsored National GIS Day activities held at Clemson's Center for Geospatial Technologies (CCGT). Several ITE members attended the event. GIS Day 2018 events included talks from researchers and professionals across the Southeast, contests and prizes, a map gallery, food and beverages, games for all ages, a poster competition and exhibitors from NASA, ESRI, Clemson Geopaths, and Clemson Mappers. Faculty Advisors Dr. Wayne Sarasua and Dr. Jennifer Ogle were speakers, while Clemson ITE student members Adika Iqbal and Afshin Famili each submitted maps to the map gallery contest, which won first and second places, respectively. (November 14, 2018)
- Dr. Gurcan Comert, C^{2}M^2 Associate Director, Benedict College, hosted Dr. Mashrur "Ronnie" Chowdhury, C^{2}M^2 Director, Clemson, to speak about his ongoing research on connected and automated vehicles in front of 40 interested Benedict College faculty and students. (February 15, 2019)
- Drs. Dimitra Michalaka, C^{2}M^2 Associate Director and William J. Davis, C^{2}M^2 Co-Associate Director, The Citadel, hosted the 2019 Introduce a Girl to Engineering event in Charleston, SC, where 72 Girl Scouts in grades 4th-10th participated in engineering and transportation engineering activities. (February 17, 2019)
- C^{2}M^2 co-sponsored the Southern District 2019 Institute of Transportation Engineers (ITE) Student Leadership Summit at Clemson University and Dr. Mashrur "Ronnie" Chowdhury, C^{2}M^2 Director, gave the closing presentation. C^{2}M^2 Associate Directors, Drs. Dimitra Michalaka and William J. Davis, The Citadel, and affiliated researchers Drs. Jennifer Ogle and Wayne Sarasua, Clemson University, helped the Clemson ITE student chapter organize this summit and gave presentations. (February 22-24, 2019)
- C^{2}M^2 researchers who received funding in the 2017/2018 round of funded projects have begun submitting their final research reports, wrapping up C^{2}M^2's first round of funded projects. The titles of these reports will be listed in section (3). (March, 2019)
- Dr. William J. Davis, C^{2}M^2 Co-Associate Director, The Citadel, led activities at the Charleston STEM (Science, Technology, Engineering and Math) Festival, a STEM celebration in Charleston, SC. More than 500 kids were introduced to civil and transportation engineering with hands-on activities, which included testing and making bridges using K'nex pieces. (March 9, 2019)
- Ms. Amy Tang McElwain, Program Delivery Manager, Office of Strategic Innovations Virginia Department of Transportation joined the C^{2}M^2 Advisory Board, replacing Dr. Andre Luckow. (March 14, 2019)
- Mr. Sakib Mahmud Khan, Clemson PhD student in transportation, was awarded the College of Engineering, Computing and Applied Sciences Outstanding Graduate Research Assistant Award from Clemson University. (March 20, 2019)
- In this reporting period, the Clemson branch of C^{2}M^2 continued our Distinguished Speaker Series, where notable scholars from within the transportation community are invited to come to Clemson University, Clemson, SC and speak to faculty and students on a range of transportation related topics. These events are also broadcasted via webinar to the four other partner institutions within the C^{2}M^2 consortium and any other interested participants. In this reporting period, Clemson University has hosted the following Distinguished Speaker Series:

    Dr. Ardalan Vahidi, of Clemson University presented his work on "Coordinating Cars and Signals in Smart Cities" (March 28, 2019) – this talk will be added to our YouTube channel in the next reporting period.

- In this reporting period, the Clemson branch of C²M² partnered with Clemson's branch of ITE to host the following Guest Speakers for their Friday luncheons:
  - Stephen Fry, Engineer at Georgia Department of Transportation. Mr. Stephen Fry, recent Clemson ITE alumnus, spoke about the roadway design projects he has been working on during his time with the Georgia Department of Transportation and the challenges his team has overcome on those projects. (Oct 12, 2018)
  - Dr. Ali Reza Fayazi, Post-Doctoral Fellow, Clemson University. Dr. Ali Reza Fayazi gave a presentation entitled "Eco-driving with Connected and Autonomous Vehicles under V2X Environment." (October 19, 2018)
  - Katerina Moreland, Senior Associate Director of Parking and Transportation Services, Clemson University. Ms. Moreland presented on the ongoing and upcoming projects for parking and transportation around the Clemson University campus. She also showed students some of the latest technology that Parking and Transportation Services uses to evaluate these projects, and explained the decision-making process for these and other important transportation-related plans for the university. (October 26, 2018)
  - Drew Stokes, Traffic Engineer, South Carolina Department of Transportation. Mr. Drew Stokes from SCDOT spoke about his work in the safety division of SCDOT. He presented crash and safety statistics for the state of South Carolina and explained the Target Zero initiative that SCDOT has for pursuing zero vehicle fatalities in the state in the future. (November 2, 2018)
  - Bryan Webb, P.E., PTOE, Ramey Kemp and Associates. Mr. Bryan Webb presented updates on some of the ongoing projects that he was working on at Ramey Kemp and Associates, including a congestion improvement project for US 17 in Charleston County, SC. (November 9, 2018)
  - Stuart Day, P.E., PTOE, IMSA TS II, and Joshua Mitchell, Transportation Engineers at Stantec, Inc. Mr. Stuart Day and Mr. Joshua Mitchell from Stantec gave a presentation entitled "Campus Transportation Planning at Clemson University" This presentation was about their work with Stantec on the Clemson University 10-Year Master Plan. (November 16, 2018)
  - Sreekanth Nandagiri P.E., PMP, Associate Vice President at AECOM. Mr. Sreekanth (Sunny) Nandagiri, Associate Vice President at AECOM, spoke about some of the past and ongoing transportation projects that AECOM is a part of across the Southeast, including traffic congestion management, corridor management, and innovative intersection improvement projects. (November 30, 2018)

1.3 How have the results been disseminated?

C²M² Research Initiatives:

- Dr. Jae Dong Hong, C²M² affiliated researcher, South Carolina State University, presented his research at the 2018 SEINFORMS Annual Meeting, Myrtle Beach, SC. (October 4-5, 2018)
- Dr. Joseph Burgett, C²M² affiliated researcher, Clemson, presented his work related to Unmanned Aerial Systems and their use cases within state DOTs at the SC Information Technology Directors Association 2018 Conference. (October 22-23, 2018)

- Dr. Gurcan Comert, C^{2}M^2 Associate Director, Benedict College, hosted Dr. Mashrur "Ronnie" Chowdhury, C^{2}M^2 Director, Clemson, as a speaker at the Benedict College Cybersecurity Symposium attended by Benedict College faculty and students. (November 9, 2018)
- Dr. Mashrur "Ronnie" Chowdhury, C^{2}M^2 Director, Clemson, hosted two representatives from the South Carolina Department of Transportation (SCDOT) for a demonstration of the unique autonomous vehicle hazard detection and maneuvering approach, which can safely navigate autonomous vehicles during any unexpected roadway events, caused either by deliberate action (e.g., roadblock) or unintentionally (e.g., debris), thus improving the safety of autonomous vehicles. It is a computer vision-based software, developed by C^{2}M^2, which detects unexpected events and helps CAVs to maneuver safely. (December 17, 2019)
- Approximately 30 C^{2}M^2 sponsored researchers and affiliated students attended the 2019 TRB conference in Washington D.C. presenting papers and posters on their sponsored research, presided over committee meetings and sessions. (January 13-17, 2019)
- C^{2}M^2 and Dr. Mashrur "Ronnie" Chowdhury, C^{2}M^2 Director, Clemson, hosted Dr. Chin-ya Huang from the National Taiwan University Science and Technology. Dr. Huang, met with C^{2}M^2 sponsored students, toured our Transportation Cyber-Physical Systems laboratory and the Clemson University International Center for Automotive Research (CUICAR). (February 1, 2019)
- Drs. William J. Davis and Kweku Brown, C^{2}M^2 affiliated researchers, The Citadel, presented their progress on their ongoing bike share program research at the 2019 Active Living Conference in Charleston, SC. (February 17, 2019)
- Dr. Judith Mwakalonge, C^{2}M^2 Associate Director, South Carolina State University (SCSU), along with her three graduate students, presented their research at the SCSU STEM Research Showcase. (February 21, 2019)
- Dr. Joseph Burgett, C^{2}M^2 affiliated researcher, Clemson, accompanied by two Clemson graduate students, and one Benedict College undergraduate student conducted two training/data collection session with SCDOT bridge inspection engineers as part of his ongoing research. (January 23, and March 14, 2019)
- Dr. Joseph Burgett, C^{2}M^2 affiliated researcher, Clemson, presented on his work with Unmanned Aerial Systems and how they can be leveraged to support SCDOT bridge inspections and surveyors at the 2019 SC Highway Engineers Conference. (March 26-27 2019)
- Mr. Jerodi Hill and Mr. Treylon Wofford, C^{2}M^2 affiliated undergraduate students, Benedict College, presented posters detailing their research at Benedict College's Research Symposium. (March 28, 2019)
- Dr. Paul Ziehl, C^{2}M^2 affiliated researcher, USC, completed and published his 2017 funded project report, "Improved Resiliency of Transportation Networks through Connected Mobility." (March 29, 2019)

1.4 What do you plan to do during the next reporting period to accomplish the goals?

- Clemson University's C^{2}M^2 affiliates will continue their Distinguished Speaker Series, and will continue sponsoring notable transportation researchers, whose talks are made available via webinar and announced on our social media platforms. Currently we have:

- - Dr. Michael Hunter, of Georgia Institute of Technology (Georgia Tech) scheduled to speak on April 2, 2019
  - Bryant Walker Smith, of the University of South Carolina, scheduled to speak on April 9, 2019
- Dr. Mashrur "Ronnie" Chowdhury, C^{2}M^2 Director, Clemson is continuing to work with Clemson University Facilities on expanding the functionalities of the Clemson connected and automated vehicle test bed on Perimeter Road. (Ongoing)
- C^{2}M^2 has applied for the research credits to use the Google Cloud Platform (GCP) that will act as the permanent server for our connected and automated vehicles related projects. If accepted, use of GCP will allow our researchers to stream, process, and store data for collaborative projects in real-time. (Ongoing)
- Dr. Mashrur "Ronnie" Chowdhury, C^{2}M^2 Director, Clemson, is working with Dr. Kapil Chalil Madathil, and the Clemson University Center for Workforce Development (CUCWD) to develop an online course focused on workforce development for transportation engineers. (Ongoing)
- C^{2}M^2 has four final reports from our 2017 round of funded project that will be published in April:
  - "Development of a Tool to Assess the Effectiveness of Intermodal Facility Locations and Designs," Nathan Huynh, P.I., USC
  - "Real Time Classification of Vehicle Types and Modes using Image Analysis and Data Fusion," Robert Mullen, P.I., USC
  - "Assessing the Experience of Providers and Users of Transportation Network Company Ridersharing Services," Eric Morris, P.I., Clemson
  - "Railway Right of Way Monitoring and Early Warning System (RailMEWS) Based on Satellite and Aerial Imagery," Dimitris Rizos, P.I., USC
- Dr. Paul Ziehl, C^{2}M^2 affiliated researcher, USC, will present his research at the "Structural Health Monitoring Workshop" in Columbia, SC. (April 2, 2019)
- Drs. Paul Ziehl, Tommy Cousins, Brandon Ross, and student Austin Downey will participate in the "Structural Evaluation and Monitoring Workshop" at the SCDOT Headquarter, Columbia, SC. (April 2, 2019)
- Dr. Joseph Burgett, C^{2}M^2 affiliated researcher, Clemson, will be presenting a paper at the 2019 Associated Schools of Construction Annual Conference. (April 10-13, 2019)
- Dr. Mashrur "Ronnie" Chowdhury, C^{2}M^2 Director, and Dr. Mizanur Rahman, C^{2}M^2 Post-doctoral research fellow, Clemson, will be participating on/moderating a session titled "Big Data Analytics" as part of the SC EPSCoR State Conference 2019. (April 12, 2019)
- Dr. Eric Morris, C^{2}M^2 affiliated researcher, Clemson, will be speaking on *The Rideshare Guy* podcast, to discuss his research on UberPool and Lyft Shared ridesharing services. (April or May 2019)
- Dr. Mizanur Rahman, C^{2}M^2 Post-doctoral research fellow, Clemson, will be presenting "Development of transportation cyber-physical systems (CPS) for connected and automated vehicles (CAVs)," at the University Transportation Centers Spotlight Conference, U.S. House of Representatives, Washington D.C. (May 14, 2019)
- Dr. Judith Mwakalonge, C^{2}M^2 Associate Director, SCSU, and two students from SCSU will be traveling to Clemson University to perform testings on Clemson's CAVT Testbed along with Clemson students. (May 21-22, 2019)

- Dr. Mashrur "Ronnie" Chowdhury, C^{2}M^2 Director and Dr. Mizanur Rahman, C^{2}M^2 Post-doctoral research fellow, Clemson, will be meeting with Ms. Amanda Ramage, Project Officer, Charleston County Government, to discuss collaborating on smart cities technology. Charleston County is interested in finding an opportunity to incorporate smart technology into their current and new road projects/infrastructure and county fleet vehicles, etc. (May 24, 2019)

- Drs. Dimitra Michalaka, C^{2}M^2 Associate Director and William J. Davis, C^{2}M^2 Co-Associate Director, and Kweku Brown, C^{2}M^2 affiliated researcher, The Citadel, will conduct spring tours to prospective Citadel students interested in pursuing an engineering degree as part of the Citadel's Pre-Knob program. (Ongoing)

- C^{2}M^2 will host, in Clemson, a week-long STEM focused summer program for four high school students from the South Carolina Governor's School for Mathematics and Science. This week-long program will include supervised time in C^{2}M^2's Transportation Cyber-Physical Systems Laboratory, as well as a presentation by Dr. Mashrur "Ronnie" Chowdhury, C^{2}M^2 Director, Clemson, on his ongoing Connected and Automated Vehicle Research projects. (June, 2019)

- Dr. Mashrur "Ronnie" Chowdhury, C^{2}M^2 Director, Clemson University, will be giving a presentation to middle and high school student participants of Benedict College's Cybersecurity Summer Program at Benedict College. (June 12, 2019)

- Dr. Mashrur "Ronnie" Chowdhury, C^{2}M^2 Director, Clemson University, and other Clemson C^{2}M^2 affiliated students and researchers will be participating in the Benedict College Summer Transportation Institute for the third year. (June 2019)

- Dr. Mashrur "Ronnie" Chowdhury, C^{2}M^2 Director, Dr. Mizanur Rahman, C^{2}M^2 Post-doctoral research fellow, and Ms. Charlotte Ryggs, Program Coordinator, Clemson, will be attending the 2019 CUTC Conference hosted by the Southern Plains Transportation Center in Norman, OK. (June 24-26, 2019)

2. PARTICIPANTS AND COLLABORATING ORGANIZATIONS: who has been involved?

2.1 What organizations have been involved as partners?

The C^{2}M^2 consortium is made up of five South Carolina schools; Clemson University, the lead institution; the University of South Carolina; The Citadel; South Carolina State University; and Benedict College; the last two of which are Historically Black Colleges/Universities. These five schools work together, collaborating on research projects, workshops, developing courses, and supporting the C^{2}M^2 with financial and in-kind support. Since the creation of this consortium, Clemson's Board of Trustees approved the creation of the Center for Connected Multimodal Mobility at Clemson University and pledged their support of its ongoing programs.

The Center also continues to partner with the South Carolina Department of Transportation (SCDOT), which provides data, technical support and in-kind support on research projects.

2.2 Have other collaborators or contacts been involved?

Along with the five institutions that make up the C²M² consortium partnership, C²M² has and is collaborating on projects with or received support from the following:

- *College of Charleston, Charleston, SC*: research collaboration
- *Holy Spokes, Charleston, SC*: data collection and research collaboration
- *Girl Scouts of Eastern SC, N. Charleston, SC*: event collaborators
- *Society of Women Engineers, Lowcountry, SC*: event collaborators
- *Lowcountry STEM Collaborative, Lowcountry, SC*: event collaborators
- *Richland County District, Columbia, SC*: event collaborators
- C*lemson University International Center for Automotive Research, Greenville, SC*: in-kind support, facilities and collaborative research
- *Kaspersky Labs, Moscow, Russia*: in-kind support
- *International Transportation Innovation Center, Greenville, SC*: in-kind support
- *University of Oregon, Eugene, OR*: collaborative research and personnel exchange
- *The Rideshare Guy Blog, Los Angeles, CA*: personnel exchange
- *Qualtrics, Provo, UT*: data collection
- *TrafficVision, Clemson, SC*: equipment, research collaboration and in-kind support
- *Charleston County Government, Charleston, SC*: research collaboration
- *Clemson University Center for Workforce Development, Clemson, SC*: in-kind support
- *Clemson University Cybersecurity Center, Clemson, SC*: in-kind support
- *EPSCoR, Columbia, SC:* Advisory Board support
- *Carolinas Alliance 4 Innovation, Greenville, SC:* in-kind support, data collection and research collaboration
- *Kimley-Horn, Columbia, SC:* data collection and research collaboration
- *Trafficware, Inc., Sugar Land, TX*: data collection and research collaboration

3. OUTPUTS – What new research, technology or process has the program produced?

The Outputs listed in this Section 3 of our Semi-Annual Progress Report fall solidly into the following categories, as outlined in our Technology Transfer (T²) plan and are listed below, first numerically in table format, and then in depth below. In our T² plan, we identified three areas of 'Output' that we would focus on. Output #1 identifies the goals that C²M² set for the dissemination of our research results. We expected to see at least five technical reports published, 20 conference presentations, ten peer reviewed papers, and one conference held by C²M² annually. Output #2 focuses on new or improved methods created by our researchers. We would like to see at least ten new/improved methods developed by our researchers each year. Our final Output #3, looks at the demonstrations of technology developed by our Center. We set the goal of hosting at least three demonstrations a year. We are pleased to note that we are on track to meet these goals that we set for our Center in the Technology Transfer Plan, which was created and accepted last fall.

No.	Goals	Research Performance Measures	Completed
Outputs			
Output #1	Disseminate C²M²'s research results to a large audience utilizing different research distribution media	Number of technical reports published	2
		Number of conference presentations	22
		Number of peer-reviewed papers published	3
		Number of conferences solely based on C²M²'s research	1
Output #2	Develop new methods or products based on C²M²'s research	Number of new and/or improved research methods or products	2
Output #3	Demonstrate developed technologies	Number of pilot demonstrations of technology	4

3.1 Output#1: C²M²'s research results dissemination

Technical Reports
- Ziehl, P., Huynh, N., Anay, R., Abduljabbar, R., Padmanabhan, B., and Soltangharaei, V., (2019), "Feasibility Study for Rapid Evaluation of Bridge Decks", South Carolina DOT Research Project SPR724 Final Report, 107 pp.
- Ziehl, P., Pang, W., Mullen, R., Anay, R., Wonoto, N., (2019), "Improved Resiliency of Transportation Networks through Connected Mobility", Center for Connected Multimodal Mobility (C²M²) Final Report, 102 pp.

Conference Presentations
- "Improving Wireless Network Performance under MPTCP based Multipath Access," Chen, K., Xing, X., Palash, M.R., Liu, J., and Martin, J., Proc. of the 43nd IEEE Conference on Local Computer Networks, October 2018
- "What do people tweet about the people that they meet? Analyzing online commentary about UberPool and Lyft Line." Presented by Pratt, A. N., 6th Annual University Transportation Center Conference for the Southeastern Region, Clemson, SC, October 24, 2018
- "The Impact of Traffic on Air Quality with Environmental Eggs: Calibration and Microsimulations," Bright, E., Presented at 6th Annual UTC Conference for the Southeastern Region, Clemson, SC October 24-25, 2018
- "Quantification of Uncertainty from Cyber-Attacks in Connected and Autonomous Vehicles Applications," Wofford, T., Benedict College. Presented at 6th Annual UTC Conference for the Southeastern Region, Clemson, SC October 24-25, 2018

- "Evaluation of Error in Queue Length Estimation at Traffic Signals: Using Data from Probe Vehicles with Range Measurement Sensors," Hill, J. Presented at 6th Annual UTC Conference for the Southeastern Region, Clemson, SC October 24-25, 2018
- "The Impact of Transportation on Air Quality Around Schools in the State of South Carolina," Eloise, Q., Bright, E., Comert, G., Darko, S., Huynh, N., Mwakalonge, J. Presented at 6th Annual UTC Conference for the Southeastern Region, Clemson, SC October 24-25, 2018
- "Statistical Change Point Models for Cyber Attack Detection in a Connected Vehicle Environment," Hernandez, S.J., Comert, G., Rahman, M., Islam, M., Chowdhury, M., Presented at 6th Annual UTC Conference for the Southeastern Region, Clemson, SC October 24-25, 2018
- "A Deep Learning Based Approach for Compensating Failed Sensor Data in a Platoon of Cooperative Adaptive Cruise Control (CACC) for Connected Autonomous Vehicles (CAVs)," Islam, M., Chowdhury, M., Presented at 6th Annual UTC Conference for the Southeastern Region, Clemson, SC October 24-25, 2018
- "Assessment of Safety Benefits of Technologies to Reduce Pedestrian Crossing Fatalities," Islam, S., Ogle, J., Presented at 6th Annual UTC Conference for the Southeastern Region, Clemson, SC October 24-25, 2018
- "Strategies for Mitigating Congestion in Small Urban and Rural Areas," Brown, K., Michalaka, D., Presented at 6th Annual UTC Conference for the Southeastern Region, Clemson, SC October 24-25, 2018
- "Change Point Models for Real-time V2I Cyber Attack Detection in a Connected Vehicle Environment," Comert, G., M. Rahman, M. Islam, and M. Chowdhury, Presented at the 98th Annual Meeting of the Transportation Research Board, Washington D.C., January 2019
- "Short Segment Statewide Screening of Mid-Block Crashes in South Carolina," Famili, A., Sarasua, W., Iqbal, A., Kumar, D., Ogle, J. Presented at the 98th Annual Meeting of the Transportation Research Board, Washington D.C., January, 2019
- "Towards Secure Infrastructure – Based Cooperative Adaptive Cruise Control," Kaur, M., Rayamajhi, A., Rahman, M., Martin, J., Comert, G., Chowdhury, M., Presented at 6th Annual UTC Conference for the Southeastern Region, Clemson, SC October 24-25, 2018
- "Freight Network Design and Routing Under Horizontal Collaboration." Badyal. V, Padmanabhan, B. Ferrell, B and Huynh N., 6th Annual University Transportation Center Conference for the Southeastern Region, Clemson SC, October 24 - 25, 2018
- "Vehicle Detection and Classification using Cascade Classifiers and Convolutional Neural Networks", Mejia. Y, Mullen R. Huynh N., 6th Annual University Transportation Center Conference for the Southeastern Region, Clemson SC, October 24 - 25, 2018
- "Active Traffic Monitoring through Large-scale Camera Networks", Sarasua, W., Zhao X., 6th Annual University Transportation Center Conference for the Southeastern Region, Clemson SC, October 24 - 25, 2018
- "Developing Analysis System for Improving Highway Network Resiliency Under Seismic Hazards: A Case Study of Charleston, SC", Wonoto, N., Pang, W., Anay, R., Zeil, P., 6th Annual University Transportation Center Conference for the Southeastern Region, Clemson SC, October 24 - 25, 2018
- "Satellite and Aerial Imagery in Railway Infrastructure Monitoring", Rizos, D., Byraju, S., 6th Annual University Transportation Center Conference for the Southeastern Region, Clemson SC, October 24 - 25, 2018
- "Contemporary Issues in Intermodal Freight Terminal Design and Operations." Huynh, N., Presented at Transportation Research Board meeting, Washington, DC. January 2019

- "The Impact of Traffic on Air Quality with Environmental Eggs: Calibration and Microsimulations," Bright, E., Eisenhower Fellow, Presented at the 98th Annual Meeting of the Transportation Research Board, Washington D.C., January, 2019
- "Change Point Models for Real-time V2I Cyber Attack Detection in a Connected Vehicle Environment," Comert, G., M. Rahman, M. Islam, and M. Chowdhury, Presented at the 98th Annual Meeting of the Transportation Research Board, Washington D.C.
- "2019 Holy Spokes bike share: Exploring the patterns of use, associations with built environment features, and implications for city planning and transportation in Charleston, South Carolina," Hughey, S.M., Mcnamara, M., Bornstein, D., Brown, K., Davis, W.J., Lindsey, J., Presented at 2019 Active Living Conference 2019, Charleston, SC. Presented on February 17, 2019

Peer Reviewed Publications
- Sarker, A., Shen, H., Rahman, M., Chowdhury, M., Dey, K., Li, F., Wang, Y., and Narman, H., A Review of Intelligent Controller, Sensing and Communication, and Human Factors Aspects for Information-Aware Connected Autonomous Vehicles. IEEE Transaction on Intelligent Transportation Systems (IEEE T-ITS), DOI**:** 10.1109/TITS.2019.2892399 March., 2019.
- Pratt, Angela N., Morris, E.A., Khan, S., Zhou, Y., and Chowdhury, M., (2019). What do people tweet about the people that they meet? Analyzing online commentary about UberPool and Lyft Line. Transportation Research Part F: Psychology and Behaviour 62, 459-427. Federal support was acknowledged.
- Comert, G., S. Darko, N. Huynh, E. Bright, and Q. Eloise, "Evaluating the Impact of Traffic Volume on Air Quality in South Carolina" was accepted to be published on International Journal of Transportation Science and Technology, March 25, 2019.

Conference (in which all C²M² partner institutions participated and C²M² hosted)
6th Annual University Transportation Centers Conference for the Southeastern Region, Clemson, SC, October 24-25, 2018

3.2 Output#2: New methods and products

- We have developed a computer vision-based approach that processes information from video camera at intersections to generate Pedestrian Safety Messages (PSMs) in real-time to generate pedestrian warning to alert connected vehicles and pedestrians, and ultimately improve safety while reducing pedestrian-vehicle conflicts;
- We have developed a unique autonomous vehicle hazard detection and maneuvering approach, which can safely navigate autonomous vehicles during any unexpected roadway events, caused either by deliberate action (e.g., roadblock) or unintentionally (e.g., debris), thus improving the safety of autonomous vehicles. The final product is a computer vision-based software that detects unexpected events and helps CAVs to maneuver safely.

3.3 Output#3: Technology demonstrations

- Chowdhury, M., "Vision-Based Navigation of Autonomous Vehicles (AVs) in Roadway Environments with Unexpected Hazards" Demonstrated for 6th Annual UTC Conference for the Southeastern Region, Clemson, SC, October 24-25 and for SC DOT representatives, Clemson, SC, December 17, 2019

- Apon, A., Chowdhury, M., Rahman, M., Islam, M., Khan, S., Khan, Z., "Real-Time and Secure Analysis of Pedestrian Data for Connected Vehicles CVs, Demonstrated for 6th Annual UTC Conference for the Southeastern Region, Clemson, SC, October 24-25 and for SC DOT representatives, Clemson, SC, December 17, 2019
- Burgett, J., Comert, G., Wofford, T., "Unmanned Aircraft Systems Impact on Operational Efficiency and Connectivity," Demonstrated for SC DOT District 7 Bridge Inspection Team, Aiken, SC, January 23, 2019
- Burgett, J., Comert, G., Wofford, T., "Unmanned Aircraft Systems Impact on Operational Efficiency and Connectivity," Demonstrated for SCDOT District 7 Bridge Inspection Team, Aiken, SC, March 14, 2019

3.4 Websites(s) or other Internet site(s)

C²M²'s website was completely overhauled and redesigned in December by Dr. Mizanur Rahman, C²M² postdoctoral research fellow, Ms. Charlotte Ryggs, C²M² Program Coordinator, and Mr. Ashvit Shetty, a Clemson student. This upgrade allowed C²M² to add twice as much content, and improved the user interface. The website was then updated weekly as needed by Ms. Charlotte Ryggs, C²M² Program Coordinator. The Center's website address is (cecas.clemson.edu/c2m2). The website outlines the C²M²'s goal, participants, research in progress, and events, both upcoming and past.

The C²M² twitter was expanded with user engagement increasing again in this reporting period and can be found at twitter.com/SC_UTC.

A C²M² YouTube account was created, and linked to the C²M² website. This account features videos from our Distinguished Speaker Series, Recorded Technology Demonstrations, Video Training/Research Project Updates, and Invited Talks given by Center Directors and Researchers. To date eight videos have been created and uploaded, and Ms. Charlotte Ryggs, C²M² Program Coordinator, is currently editing three additional videos to be added in the next reporting period. Our channel can be found at www.youtube.com/channel/UCITo_BgCYEjjH_PTU3vPFOw

3.5 Technologies or techniques

- Researchers at Clemson University have developed and demonstrated a unique Autonomous Vehicle (AV) hazard detection and maneuvering technique, which can improve safety by navigating AV during unexpected roadway events such as, roadblocks, pedestrians, or debris.
- Researchers at the University of South Carolina created technology that processes satellite radar images for monitoring of the right of way of the railroads and the surrounding areas for the detection of large and small scale deformations and other triggering events that may lead to landslides and other infrastructure failures. Radar images are superimposed to aerial images for ease of evaluation, comprehension and dissemination of the information.

3.6 Inventions, patent applications, and/or licenses

Nothing to report at this time.

3.7 Other products, such as data or databases, physical collections, audio or video products, software or NetWare, models, educational aids or curricula, instruments, or equipment

- Dr. Paul Ziehl and his team as part of "Improved Resiliency of Transportation Networks through Connected Mobility" project developed a Graphical User Interface (GUI) in Matlab. The GUI was designed as a multi-window GUI that allows the user to work progressively while having a clear picture regarding how the program works based on the guideline attached in each GUI.
- "Development of a Tool to Assess the Effectiveness of Intermodal Facility Locations and Designs" project lead by Dr. Nathan Huynh of USC, developed algorithms that implement the strategic intermodal terminal location model and the operational vehicle scheduling with horizontal collaboration model, which were developed to assist South Carolina transportation agencies with freight planning. The codes for algorithms are shared via the Center's website.
- "Real Time Classification of Vehicle Types and Modes using Image Analysis and Data Fusion" project conducted by Dr. Robert Mullen and his team from USC, created a database containing images of cars and trucks using recordings from the South Carolina Department of Transportation (SCDOT) and Python codes that implement vehicle detection and classification. These Python codes and data are shared via the Center's website.
- "Real-time and Secure Analysis of Pedestrian Data for Connected Vehicles CVs" project conducted by Dr. Amy Apon and her team at Clemson, developed PSMGen software. This software processes information from video camera at intersections to generate Pedestrian Safety Messages (PSMs) in real-time to alert connected vehicles and pedestrians, and ultimately improve safety while reducing pedestrian-vehicle conflicts.

4. OUTCOMES – What outcomes has the program produced? How are the research outputs described in section (3) above being used to create outcomes?

As our very first round of funded research projects have begun to wrap up in this reporting period, and one final report has been published we have a few outcomes to report at this time. In the coming reporting period the remainder of our 2017 funded research projects will be completed and their results will be disseminated, producing a myriad of journal publications, data bases, workshops/training programs, and transportation engineering curriculum. As these results are disseminated, we expect to see techniques developed from this research adopted by state DOTs and ideally the transportation community as a whole.

In our T² plan, we established three outcome goals for our Center to strive towards each year. These goals are to create/host at least two training or workshop events a year; to develop, at least four techniques and practices and offer implementation/deployment guidance for the adoption of these techniques; and for our researchers, to develop at least four new technologies and or processes each year.

No.	Goals	Research Performance Measures	Completed
Outcomes			
Outcome #1	Train the current and future transportation workforce to operate in an increasingly high-tech environment	Number of training events and workshops	1
Outcome #2	Incorporate new technologies (software and/or hardware) and/or techniques and/or practices that are deployment ready	Number of new technologies, and/or techniques and/or practices that offer implementation or deployment guidance	3
Outcome #3	Improve technologies and/or processes in addressing transportation issues	Number of improved technologies and/or processes disseminated from C²M² funded research projects	2

4.1 Outcome #1: Training for workforce development

The "Railway Right of Way Monitoring and Early Warning System (RailMEWS) based on Satallite and Aerial Imagery" project has been completed and the researchers is in the process of completing their final report, but they have already presented their findings and RailMEWS system to industry members. This technology has been presented in the REES 2018 event as part of activities to train new faculty in railway infrastructure monitoring. The technology has been presented as an example of the state of the art infrastructure monitoring that was developed by Dr. Rizos's and his research team.

4.2 Outcome #2: New technologies, techniques, and practices

- The "Real-Time and Secure Analysis of Pedestrian Data for Connected Vehicles CVs" project developed software that processes information from video cameras at intersections to generate Pedestrian Safety Messages (PSMs) in real-time to generate pedestrian warning to warn other vehicles, and ultimately improve safety while reducing pedestrian-vehicle conflicts.
- Our "Vision-based Navigation of Autonomous vehicle in Roadway Environments with Unexpected Hazards," a part of the foundational research project, has developed a unique autonomous vehicle hazard detection and maneuvering approach, which can safely navigate autonomous vehicles during any unexpected roadway events, caused either by deliberate action (e.g., roadblock) or unintentionally (e.g., debris), thus improving the safety of autonomous vehicles. This is a computer vision-based software that detects unexpected events and helps CAVs to maneuver safely.
- The "Improved Resiliency of Transportation Networks through Connected Mobility" project led to the creation of a Graphical User Interface (GUI), which can be used to optimize the performance of a transportation network under seismic demand, allowing users to detect bridges most vulnerable to damage during an extreme event. We expect that the adoption of this program will facilitate a new technique to identify the most critical bridges in the network for purposes of instrumentation, meaning which bridges should be monitored and for those

bridges, which specific regions should be monitored to rapidly assess damage after a seismic event. This information can then be utilized for routing of traffic and for the assessment of potential retrofitting strategies, thereby improving reliability of the transportation system. This process can be approached by employing acoustic emission as a structural health monitoring technique during and after an extreme event.

4.3 Outcome #3: Improvement to technologies

- "Development of a Tool to Assess Effectiveness of Intermodal Facility Locations and Designs," which is on the cusp of completion, led to the development of two mathematical programing models that once adopted can lead to the improved efficiency of the future freight transportation. These developed models can be used by South Carolina transportation agencies to plan for freight expansion and determine the impact of various freight scenarios. Specifically, they can be used to determine how demands and supplies can be dynamically aggregated and disaggregated using horizontal collaboration in a way that minimizes costs, gives insight into the capacities required for the network over a long planning horizon, and supports decision making on infrastructure.
- "Real Time Classification of Vehicle Types and Modes using Image Analysis and Data Fusion," has led to the creation of a database of vehicle types and modes, and Python codes to implement vehicle detection and classification, both this database and these codes will be available to the public via our C²M² website. With these tools, transportation agencies will be able to do their own traffic data collection using videos, and thereby improve safety and lower traffic data collection cost. Moreover, the adoption of vehicle classification software is a workforce development opportunity to provide department of transportation staff with the necessary skills to be successful in an increasingly technology-driven world.

5. IMPACTS – What is the impact of the program? How has it contributed to improve the transportation system: safety, reliability, durability, etc.; transportation education; and the workforce?

At the time of this report three of our total funded projects have completed and one report has been published, which means that at this time we do not have many quantifiable impacts to report. We anticipate that with the completion of our remaining 2017 funded projects, and the dissemination of their results, we will see an increase in the impact of our Center on the greater transportation community as a whole. With the completion of these projects, we intend to encourage and support our researchers in the creation and distribution of training programs and workshops to disseminate the results of their projects and to produce measurable improvements in the effectiveness of our current transportation system. In our T² plan, we set two goals for the impact that we would like to see as a result of our Center's yearly activities. These goals are to see at least two of our Center's developed technologies, methods, or practices adopted per year, and to track at least two cases where these technologies, techniques/methods, and practices quantifiably improved transportation.

No.	Goals	Research Performance Measures	Completed
Impacts			
Impact #1	Increase adoption of new technologies, methods or practices based on C²M²'s research	Number of cases of adoption by transportation agencies and/or commercialization of C²M²'s technologies, methods or practices	0
Impact #2	Improve transportation system operations and/or transportation safety and/or quality of life	Number of cases of C²M²'s research that resulted in societal benefits, such as lives saved, congestion reduced, and fuel conserved through changing behavior, practices, decision making, policies (including regulatory policies), and/or social actions	0

5.1 What is the impact on the effectiveness of the transportation system?

While it is still too early to see quantifiable results from our sponsored projects we anticipate impacts to result from the following projects in the coming reporting period.

- "Development of a Tool to Assess Effectiveness of Intermodal Facility Locations and Designs," which is near completion is focused on the improved efficiency of freight movements, and with the anticipated adoption of these results, we expect to see a quantifiable change in the movement of freight in the state of South Carolina.
- "Assessing the Experience of Providers and Users of Transportation Network Company Ridersharing Services," that will be completed and disseminated in the next reporting period, has the potential to improve ride sharing apps. As it is still in the process of completing and disseminating this work, its impacts are not fully developed. However, we anticipate that as our findings get rolled out, we will contribute to improvements in shared ride service, which will be important to improve the lives of drivers and travelers. It may aid workforce development as it ultimately brings new workers into the transportation system. Further, society as a whole will benefit if our work leads to more sharing of rides, since this may mean less congestion, pollution, crashes, fuel use, etc.
- Our "Railway Right of Way Monitoring and Early Warning System (RailMEWS) based on Satellite and Aerial Imagery" team at USC is currently in discussions with two Class I railroad companies on the adoption of the proposed technology on an experimental basis. We are looking into the possibility to monitor regions of the railroad network susceptible to landslides and other geohazards.
- In our "Real-Time and Secure Analysis of Pedestrian Data for Connected Vehicles (CVs)" project, the research team developed a novel approach using vision-based sensor fusion and deep learning that can generate Pedestrian Safety Messages (PSMs) to improve the intersection pedestrian safety. The team also validated its method of generating PSMs using field experiments in a Connected Vehicle environment. Our method can significantly improve pedestrian safety at a signalized intersection. We have developed software packages for this pedestrian safety application to improve pedestrian safety.

5.2 What is the impact on the adoption of new practices, or instances where research outcomes have led to the initiation of a start-up company?

Nothing to Report

5.3 What is the impact on the body of scientific knowledge?

We expect to see several of our funded projects impact the body of scientific knowledge in the coming reporting period, such as the two projects that are focused on new areas of transportation like ride sharing and personal electronic mobility devices. For instance the ridersharing project is in the process of advancing scientific knowledge about the ridesharing phenomenon, since we have already begun publishing this work in academic journals and presenting at scholarly conferences. Ridesharing is a very new phenomenon which has not yet been the subject of much academic study. More major impacts lie ahead as we proceed with disseminating our results.

In our "Real-Time and Secure Analysis of Pedestrian Data for Connected Vehicles (CVs)" project, the research team has developed a novel approach using vision-based sensor fusion and deep learning that can generate Pedestrian Safety Messages (PSMs) to improve the intersection pedestrian safety. The team has validated its method of generating PSMs using a field experiments in a Connected Vehicle environment. Our method can significantly improve pedestrian safety at a signalized intersection. We have developed software packages for this pedestrian safety application to improve pedestrian safety and expect to see a quantifiable safety improvement with its adoption.

5.4 What is the impact on transportation workforce development?

One of the broad impacts on transportation workforce development that C²M² has seen in this reporting period is the growth and advancement of supported students, as they work with researchers from within our consortium. In this reporting period, ten new graduate students and three new undergraduate students were hired to work on funded projects. One of our previously sponsored student's completed his PhD program, and two undergraduate students from one of our Minority Serving Institutions have been accepted into graduate programs. We have seen an increase in undergraduate student interest in Transportation Engineering through our co-sponsoring of Clemson's ITE Student Chapter Speakers and our Distinguished Speaker events, and the Glenn Department of Civil Engineering is working to expand the number of transportation engineering classes and faculty due to this increase. We expect to begin to see results from our K-12 endeavors in the coming reporting periods.

Benedict College has created a new major combining industrial and systems engineering based upon the interest that our Center activities have raised at their institution and are enrolling students now for their inaugural fall semester. Benedict College is also in the process of developing a Connected and Automated Vehicles Systems lab to further support the research that is taking place there and to promote collaboration between engineering majors. Faculty at Benedict College are also collaborating on creating courses that combine physics, computer science, and engineering.

Clemson University is in the midst of creating a new undergraduate curriculum that incorporates professional development with traditional transportation engineering content. The very first Springer

course was launched at the beginning of the spring 2019 semester, data collected from this course will be used to refine the second course to be offered in the fall 2019 semester.

As for professional development, Clemson University is still reaching out to technical colleges within South Carolina to offer either a one or two-day training and workshop program that teaches participants "Connected and Autonomous Vehicle Technologies in Transportation Cyber-Physical Systems." Once this program has been refined, it will be shared with any interested institutions planning to offer a similar training and workshop. Once our "Assessing the Experience of Providers and Users of Transportation Network Company Ridersharing Services," report is completed, the results will be shared via *The Rideshare Guy's* blog and podcast, which are the current go to venues for ridesharing discussion, exposing a large audience to our research results.

6. CHANGES/PROBLEMS

6.1 Changes in approach and reasons for change

Nothing to report

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

In this reporting period, C²M² funded researchers have experienced delays in the completion of their 2017 funded projects. It was anticipated that these projects would be completed by October of 2018, with final reports being submitted in November of 2018; however, due to funding delays related to the establishment of mini-project budget lines, six of these 12 funded projects did not officially begin until January of 2018 or later, which has led to multiple no-cost extensions being granted. This late start has since pushed their completion dates back by several months, and subsequently, we are only just now seeing the first few projects submit final reports for publication. We have also encountered delays in the editing process of report submissions. This process has taken longer than we originally anticipated, although we have refined the process with each submitted final report and have improved the timing reducing delays in future reporting.

We believe that these delays were a part of the learning process, as this was our very first round of funded projects. We had to start from scratch to establish the publication protocols and have already taken steps to improve efficiency for our 2018 round of funded projects. PIs of our 2018 round of funded projects have already experienced a much smoother start to their projects, and have been asked to submit quarterly progress reports, so that our Center can more closely monitor their progress, and intervene if necessary to keep projects on track to finish by their projected timeline.

6.3 Changes that have a significant impact on expenditures

Nothing to report

6.4 Significant changes in use or care of human subjects, vertebrate animals, and/or biohazards

Nothing to report

6.5 Change of primary performance site location from that originally proposed

Nothing to report

7. SPECIAL REPORTING REQUIREMENTS

7.1 Research Project Requirements

All funded projects for both our 2017 and 2018 rounds of funded projects have been submitted to Transportation Research Board's (TRB) Research in Progress (RiP) database and subsequently updated as required by OST-R and the Fast Act Grant Deliverables. Each project description includes the project title, brief abstract, project start and completion dates, project status, and funding amount. These submissions also include details of all the sponsoring organizations and research programs contributing to the project, including the Federal sponsor (OST-R) and all non-Federal sponsors as outlined in the Fast Act Grant Deliverables. This information is displayed on our Center website as well. In keeping with these requirements, PIs of all funded projects are also required to obtain an ORCID, which is reported on the TRB RiP database and included in all final reports.

7.2 Submission of Final Research Reports

At the time of this reporting period, one project has been completed and a corresponding final report has been published. To date, this report has been created and published to our Center website in its entirety along with the archived data as required by the Fast Act Grant Deliverables. TRB RiP updates and the final submission requirements will be completed within the deadline of May 30, 2019.