



Center for Connected Multimodal Mobility (C²M²)

Program Progress Performance Report # 2

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
Clemson University, SC 29634
Phone: (864)-656-3313, Email: mac@clermson.edu

Submission Date: April 30th, 2018

DUNS#: 0426298

EIN#: 57-6000254

Recipient Organization: Clemson University, Clemson, South Carolina 29634

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

Reporting Period: June 1, 2017 – March 31, 2018

Report Term: Semi-annual

Signature of Submitting Official: _____



Benedict College





1. Accomplishments

What are the major goals and objectives of the program?

C²M²'s mission statement:

Our vision for the Center for Connected Multimodal Mobility (C²M²), 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.

C²M²'s main goals are to:

- Conduct interdisciplinary research and drive innovation through data science, data-driven computing, seamless vehicle, traveler, infrastructure connectivity, and automation
- Conduct education and workforce development/leadership activities
- Disseminate C²M² 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 C²M² activities

C²M² 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)

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.

- Expansion of our Advisory Board made up of industry and academic members from the transportation community which included:
 - Dr. Essam Radwan, formerly of University of Central Florida
 - Dr. Anthony Saka, Morgan State University
 - Dr. Kakan Dey, West Virginia University
 - Fred Payne, Carolinas Alliance 4 Innovation and Greenville County Council
 - Dr. Andre Luckow, BMW IT Research Center
 - Dr. Elise Miller-Hooks, George Mason University
 - Dr. Patricia Mokhtarian, Georgia Institute of Technology
 - David Jared, Georgia Department of Transportation
 - Jennifer Johnson, Kimley-Horn
 - Carla Bailo, Center for Automotive Research
 - Art Shulman, Global Autonomous Vehicle Partnership
 - Mandy Orzechowski, Tri County Technical College

In this reporting period our advisory board held its very first meeting on November 2, 2017, in Clemson, South Carolina with our Director and Associate directors. Those unable to attend in person called in via a conference line. At this meeting our C²M² Director, Dr. Ronnie Chowdhury, laid out our goals for our center and how our Advisory board would help us achieve these goals. Our board was also asked to elect a board president, they selected Jennifer Johnson of Kimley-Horn to serve as our very first Advisory Board president. Since this initial meeting we have held monthly calls with our Advisory board.

- C²M² directors continued their bi-weekly conference calls to coordinate the center’s activities, and budget.
- C²M² Directors, Drs. Chowdhury (Clemson), Huynh (USC), Comert (Benedict), Mwakalonge (SCSU), and Davis (Citadel) met at Benedict College, Columbia, SC to evaluate research proposals for our 2017/2018 round of funded research. (September 1, 2017)
- Ms. Charlotte Ryggs, C²M² Program Coordinator, and Mr. Vishnuprabhu Thirugnanasambandam, Computer Science Graduate student, Clemson, worked together to update C²M²’s website, adding the center’s funded research projects and improving the user interface. (December, 2017)
- Dr. Chowdhury, C²M² Director, Clemson, served on the planning committee for the 5th Annual UTC Conference for the Southeastern Region. (Summer 2017)



- Drs. Chowdhury, C²M² Director, Clemson, Michalaka, C²M² Associate Director, the Citadel, Davis, C²M² Co-Associate Director, the Citadel, welcomed members of our Advisory Board to Clemson, SC for our very first Advisory Board meeting. Our remaining Associate Directors and those Advisory Board members unable to travel at the time joined via Adobe Connect, allowing them to participate in the meeting. (November 2, 2017)

Academically, the center has accomplished the following:

- Dr. Comert, C²M² Associate Director, and his student Mr. Jacquan Pollard, Junior, Electrical Engineering, Benedict College, participated on the Summer Research Team for Minority Serving Institutions of the Department of Homeland Security, through the Critical Infrastructure Resilience Institute, under the Information Trust Institute at the University of Illinois, Urbana- Champaign. (May 30, 2017-August 7, 2017)
- Katherine Brunk, Graduate Student, Clemson, received the U.S. DOT Dwight E. Eisenhower Transportation Fellowship. (January 2018)
- Clemson C²M² affiliated researchers taught fifteen transportation related courses at the graduate and undergraduate level in this reporting period and sponsored 22 undergraduate students and 19 graduate students.
- Benedict College C²M² affiliated researchers taught seven transportation related courses at the undergraduate level in this reporting period and sponsored 10 undergraduate students.
- USC C²M² affiliated researchers taught eight transportation related courses at the graduate and undergraduate level in this reporting period and sponsored four graduate students.
- SCSU C²M² affiliated researchers taught four transportation related courses at the undergraduate level in this reporting period and sponsored three graduate students.
- The Citadel C²M² affiliated researchers taught four transportation related courses at the undergraduate level in this reporting period.

C²M² Research Initiatives:

- Dr. Chowdhury, C²M² Director, and Ms. Charlotte Ryggs, C²M² Program Coordinator, Clemson, met with Dr. Tanju Karanfil, Vice President for Research at Clemson University to discuss using Clemson's Division of Research resources to further C²M² goal to become a nationally recognized transportation center. (November 22, 2017)
- Dr. Chowdhury, C²M² Director, Clemson, consulted with Fred Payne and Frederick Cartwright of Carolinas Alliance 4 Innovation, on creating a presentation for a ITS Joint Program Office Roundtable on Data for Automated Vehicle Safety (held December 7, 2017 in Washington DC) discussion on the future of connected and autonomous vehicles in the United States. (December 5, 2017)
- Dr. Paul Zeihl, C²M² sponsored researcher, USC, was awarded a SC DOT project titled "Assessment of Structural Degradation for Bridges and Culverts" (January 1, 2018)
- Dr. Chowdhury, C²M² Director, and Ms. Charlotte Ryggs, C²M² Program Coordinator, Clemson, traveled to Columbia SC to meet with the SC DOT Research and Development Executive Committee to propose future project collaboration between SC DOT and C²M². (January 25, 2018)



- Dr. Chowdhury, C²M² Director, Clemson, held a meeting with Fred Payne, Carolinas Alliance 4 Innovation to discuss combining C²M²'s ongoing connected and autonomous vehicle technology research with Greenville SC's Autonomous Taxi program. (February 5, 2018)
- Dr. Chowdhury, C²M² Director, Ms. Charlotte Ryggs, C²M² Program Coordinator, and Mhafuzul Islam, PhD student, all from Clemson, met with Fred Payne, Carolinas Alliance 4 Innovation and Edward Motten, Robotics Research, in Greenville SC, to discuss including C²M² developed connected and autonomous vehicle technology and software in Greenville's autonomous taxis. (February 13, 2018)
- Dr. Chowdhury, C²M² Director, Ms. Charlotte Ryggs, C²M² Program Coordinator, and five Clemson students met with 15 representatives from SCDOT to discuss giving C²M² access to traffic signals within the South Carolina Upstate area, specifically in Greenville and Clemson SC, to install C²M² technology and software for data collection and research purposes. (February 28, 2018)
- Dr. Chowdhury, C²M² Director, Clemson, and five Clemson students met with representatives from SGS and ITIC in Clemson SC, to discuss partnering on Smart City research applications in Clemson, SC. (March 6, 2018)
- Dr. Chowdhury, C²M² Director, and Ms. Charlotte Ryggs, C²M² Program Coordinator, Clemson, traveled to Atlanta, GA, for a day of meetings with GDOT representatives to discuss the potential for combining C²M²'s ongoing connected and autonomous vehicle technology research with Atlanta's downtown smart corridor. (March 23, 2018)
- Twelve research projects were selected for funding from the 15 proposals submitted during the Spring, 2017 Request for Proposals. Of these 12 selected projects, two were led by Benedict College, five were led by Clemson University, one was led by SCSU, and four were led by USC. The Citadel co-sponsored two of the 12 selected projects. Collaboration between consortium members was strongly encouraged. The following projects were selected:

Proposal Title	Principal Investigator	Co PI's
Adaptive Signal Control Algorithms For Connected Vehicles	Gurcan Comert, Benedict College	Ronnie Chowdhury, Clemson
Impact of Transportation Air Quality at Elementary and Middle Schools in SC	Gurcan Comert, Benedict College	Samuel Darko, Benedict College; Nathan Huynh, USC
Real-Time and Secure Analysis of Data for Connected Vehicles	Amy Apon, Clemson Univ	Mashrur "Ronnie" Chowdhury, Clemson Univ; Gurcan Comert, Benedict College
Uncertainty Quantification of Cyber Attacks at Intelligent Traffic Signals	Jim Martin, Clemson	Gurcan Comert, Benedict College



Proposal Title	Principal Investigator	Co PI's
Assessing the Experience of Providers and Users of Transportation Network Company Ridesharing Services	Eric Morris, Clemson	Judith Mwakalonge, SCSU; Sakib Khan, Clemson; Ronnie Chowdhury, Clemson
Assessment of Safety Benefits of Technologies to Reduce Pedestrian Crossing Fatalities at Midblock Location	Jennifer Ogle, Clemson	Judith Mwakalonge, SCSU; Ronnie Chowdhury, Clemson; Kweku Brown, The Citadel
Active Traffic Monitoring through Camera Networks with Automatic Camera Calibration for Pan-Tilt-Zoom Cameras	Wayne Sarasua, Clemson	Kweku Brown, The Citadel; William J. Davis, The Citadel; Dimitra Michalaka, The Citadel
Infrastructure and Policy Needs for Personal Electric Mobility Devices in the Connected Vehicle World	Judith Mwakalonge, SCSU	Jae Dong Hong, SCSU; Ronnie Chowdhury, Clemson
Development of Tool to Assess Effectiveness of Intermodal Facility Locations and Designs	Nathan Huynh, USC	William Ferrell, Clemson
Real Time Classification of Vehicle Types and Modes using Image Analysis and Data Fusion	Robert Mullen, USC	Nathan Huynh, USC
Railway Right of Way Monitoring and Early Warning System (RailMEWS) Based on Satellite and Aerial Imagery	Dimitris Rizos, USC	Robert Mullen, USC
Improved Resiliency of Transportation Networks through Connect Mobility	Paul Ziehl, USC	Robert Mullen, USC; Weichang Pang, Clemson

What opportunities for training and professional development has the program provided?

- In this reporting period, the Clemson branch of C²M² launched a 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 C²M² consortium. To date, Clemson University has hosted the following Distinguished Speaker Series:



- Dr. Essam Radwan, formerly of University of Central Florida spoke on “Simulation of Vehicular-Pedestrian Conflicts” (September 8th, 2017)
- Dr. Chris Hendrickson, Carnegie Mellon University spoke on “Transformational Transportation Technologies” (November 3rd, 2017)
- Dr. Yan (Joann) Zhou, Argonne National Laboratory spoke on “National Inter-City Freight Energy Analysis of Smart Technologies and Mode Shift” (February 23rd, 2017)
- Dr. Mohan Venigalla, George Mason University spoke on “Price Discovery in Shared Mobility: Lessons from Capital Bikeshare” (March 15th, 2018)
- Dr. Chris Gerdes, Stanford University spoke about his research with autonomous vehicles at the Center for Automotive Research (Co-Sponsored by Clemson University Division of Research) (March 28, 2018)
- Drs. Michalaka, C²M² Associate Director and Davis, C²M² Co-Associate Directors, the Citadel, hosted the Citadel Success Institute Civil Engineering Outreach Day, introducing 70 Citadel students to the concepts of civil and transportation engineering and the research being conducted at the Citadel, Charleston, SC. (July 8, 2017)
- Dr. Chowdhury, C²M² Director, and Ms. Charlotte Ryggs, C²M² Program Coordinator, Clemson, began consulting with the Glenn Department of Civil Engineering on their National Science Foundation (NSF) Revolutionizing Engineering and Computer Science Departments (Red) Grant, attending their kick-off meeting and subsequent meetings. (September 18, 2017 – ongoing)
- Dr. Chowdhury, C²M² Director, Clemson and three students gave a technology demonstration to potential engineering students at Engineering Discovery Night at Clemson University. (September 26, 2017)
- Dr. Davis, C²M² Co-Associate Director, the Citadel took 27 students to the Palmetto Commerce Park/Interchange I-26 Public Meeting, in North Charleston, SC to learn about interchange design and alternative analysis, public engagement, and interaction with design engineers. (October 17, 2017)
- Dr. Michalaka, C²M² Associate Director, Dr. Davis, C²M² Co-Associate Director, and five Citadel students participated in the City of Charleston Transportation Planning Workshop alongside Charleston’s Mayor, City Council, State Senate, and City staff as part of a public design charrette. (October 17, 2017)
- Dr. Michalaka, C²M² Associate Director, Dr. Davis, C²M² Co-Associate Director and an affiliated researcher, and Dr. Brown, an affiliated researcher at the Citadel, gave tours to over 80 potential Citadel students interested in Civil Engineering. During the eight scheduled events throughout the fall and spring semesters high school students with an interest in civil engineering including transportation engineering are given demonstrations of the highway engineering design project taking place at the Citadel. (Fall 2017)
- Dr. Chowdhury, C²M² Director, and Ms. Charlotte Ryggs, C²M² Program Coordinator, Clemson, met with Dr. Ronnie Booth, President, Tri-County Technical College, Mr. Galen DeHay, Senior Vice President, Tri-County Technical College, and Ms. Mandy Orzechowski, Dean of Engineering and Industrial Technology, Tri-County Technical College to discuss



- partnering with them to develop and disseminate a workshop and training program for technical colleges based on the research that our center is conducting. (December 11, 2017)
- C²M² Directors, sponsored researchers and affiliated students attended the annual TRB conference in Washington D.C. where a total of 39 papers were presented by researchers from the C²M² partner institutions. (January 7-11, 2018)
 - Dr. Chowdhury, C²M² Director, Clemson, and six students participated in Engineer Week at Clemson University by hosting a laboratory demo titled “Demonstration of Future Transportation Systems with Connected Autonomous Vehicle Technologies” at the Transportation Cyber-Physical Systems Lab, Clemson University. (February 22, 2018)
 - Dr. Michalaka, C²M² Associate Director, the Citadel, the Citadel student chapter of the Society of Women Engineers (SWE), the Lowcountry Branch of SWE, the Girl Scouts of Eastern South Carolina, and the Charleston County, Office of the Deputy County Administrator of Transportation and Public Works coordinated to plan the “Introduce a Girl to Engineering Day,” a three-hour outreach event designed to excite middle-school-aged females about engineering. More than 100 girl scouts and 40 student and professional volunteers attended this year’s event. (February, 25, 2018)
 - Dr. Chowdhury, C²M² Director, Clemson held a two-day workshop and training program titled “Connected and Autonomous Vehicle Technologies in Transportation Cyber-Physical Systems” where 11 faculty members from Tri-County Technical College learned how to work with a complete development environment to model, program and simulate connected autonomous vehicles. (March 29-30, 2018)

How have the results been disseminated?

- Dr. Davis, C²M² Co-Associate Director, the Citadel, attended a proposal meeting at SC EPSCOR in Columbia to discuss partnering on autonomous vehicle research. (July 25, 2017)
- C²M² Directors hosted, and presented at the first annual C²M² Fall Conference in Clemson, SC. The conference was opened with a brief overview of the center funded research projects being led by each C²M² Director’s institutions. This conference also featured Dr. Chris Hendrickson, Carnegie Mellon University, Fred Payne, Carolinas Alliance 4 Innovation, Dr. Mashrur “Ronnie” Chowdhury, Clemson University, and Jim Feda, SCDOT as speakers. The conference also featured four connected vehicle application demonstrations, which is showcasing the research that C²M² has been developing. (November 3rd, 2017)
- Dr. Huynh, C²M² Associate Director, USC, organized and spoke at a conference co-sponsored by the Sultan Qaboos Cultural Center, titled “The Importance of Tourism and Ports in Economic Development: Best Practices in Oman and the USA.” (November 8, 2017)
- Dr. Comert, C²M² Associate Director, Benedict College, accompanied five C²M² sponsored students from Clemson University to the 5th Annual UTC Conference for the Southeastern Region in Gainesville, FL, where they presented a demonstration of our connected and autonomous vehicle technology. Two of our students also presented posters on their ongoing research. (November 15 – 16, 2017)



- Dr. Michalaka, C²M² Associate Director, Dr. Davis, C²M² Co-Associate Director and affiliated researcher, and Dr. Brown an affiliated researcher at the Citadel took four students from the Citadel to the 5th Annual UTC Conference for the Southeastern Region in Gainesville, FL. Mr. Terry Swygert of the SCDOT and a member of our Advisory Board, was a panel speaker at the conference. (November 15-16, 2017)
- Dr. Chowdhury, C²M² Director, Clemson was asked by the planning committee to host the 6th Annual UTC Conference for the Southeastern Region in Clemson, SC. (November 20, 2017)
- Dr. Robert Mullen, C²M² sponsored researcher, USC, planned and co-hosted the Models and Simulations 8 Conference at USC. (March 15-16, 2018)

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

- Clemson University's C²M² affiliates will continue their Distinguished Speaker Series, and will be sponsoring Dr. Patricia Mokhtarian of Georgia Technical Institute to speak on "It's Not All Fun and Games: An Investigation of the Reported Benefits and Disadvantages of Conducting Activities while Commuting." (April 27, 2018)
- Dr. Chowdhury, C²M² Director, Clemson, will be conducting a one-day version of his "Connected and Autonomous Vehicle Technologies in Transportation Cyber-Physical Systems" workshop and training program for faculty of Greenville Technical College and interested SCDOT engineers in Greenville, SC. (May 10, 2018)
- Dr. Chowdhury, C²M² Director, Clemson, has hired a Tri-County Technical College student as a summer intern, and will begin involving him in on-going center research projects. This student was recruited through our inaugural workshop session with the Tri-County Technical College. (May 2018)
- C²M² Directors will finalize and send out a Request for Proposals for the 2018, year-two round of funded research. (May, 2018)
- Dr. Chowdhury, C²M² Director, Ms. Charlotte Ryggs, C²M² Program Coordinator, and Ms. Karen Lantgios, Clemson C²M² Grant Administrator, will be attending the 2018 CUTC Conference in Minneapolis, MN. (June 4-6, 2018)
- Mr. Mizanur Rahman, a C²M² PhD student, Clemson, will be hosting four high school students from the South Carolina Governor School as part of the South Carolina's Governor School for Science and Mathematics Accelerate Program. These students will work in the Transportation Cyber-Physical Systems Lab on C²M² related research projects and be mentored by Mr. Rahman. (June 11-15, 2018)
- Ms. Katherine Brunk, Graduate student, Clemson, will be traveling to Stanford, CA to work with Dr. Chris Gerdes of Stanford University's Center for Automotive Research on a research project studying the ethics related to autonomous vehicles. Ms. Brunk's summer will be co-sponsored by C²M² and Clemson's Glenn Department of Civil Engineering. (June 2018)
- Dr. Huynh, C²M² Associate Director, and Dr. Paul Ziehl, USC, C²M² sponsored researcher, are co-planning and sponsoring the Acoustic Emissions Working Group 60th Meeting in Charleston, SC. (June 19-20, 2018)



- Dr. Huynh, C²M² Associate Director, and Dr. Dimitris Rizos, USC, C²M² sponsored researcher, are co-planning the American Railway Engineering and Maintenance-of-way Association (AREMA) Railway Engineering Education Symposium 2018, in Columbia, SC. (June 26-27, 2018)
- Dr. Chowdhury, C²M² Director, Clemson is working with Clemson University Facilities for expanding his Clemson connected and autonomous vehicle test bed from Perimeter Road throughout Clemson University’s campus. (Summer 2018)
- Ms. Ryggs, C²M² Program Coordinator, Clemson, will begin coordinating with Clemson’s branches of PEER and WISE to increase our diversity initiatives and prioritize recruitment into transportation engineering.

2. Products

Publications, conference papers, and presentations

Title	Author(s)	C ² M ² Affiliation	Product Type
Data infrastructure-Enabled Connected-Autonomous Vehicle Operations in Mixed Traffic	Sakib Khan	Clemson University	Conference Poster
Development of Eco-Approach & Departure at Signalized Intersections: Application in a Real-World Connected Vehicle Environment	Mizanur Rahman	Clemson University	Conference Poster
Lessons Learned from the Real-World Deployment of a Connected Vehicle Testbed	Dr. Mashrur “Ronnie” Chowdhury, Mizanur Rahman, Sakib Khan, Mhafuzul Islam, MD Zadid Khan, Dr. James Martin	Clemson University	Conference Paper
Human-Centered Time Headway Controller for Cooperative Adaptive Cruise Control (CACC)	Dr. Mashrur “Ronnie” Chowdhury, Mhafuzul Islam, Mizanur Rahman, Fangjian Li, Sababa Islam, Yue Wang	Clemson University	Conference Paper
Adaptive Queue Prediction Algorithm Using Edge Centric Cyber-Physical System Platform in a Connected Vehicle Environment	Dr. Mashrur “Ronnie” Chowdhury, Dr. James Martin, Dr. Kakan Dey, Anjan Rayamajhi, Mizanur Rahman	Clemson University, West Virginia University	Conference Paper
Impacts of State Specific Policy and Legislation on Safety Advancement by Departments of Transportation	Dr. Jennifer Ogle, Sababa Islam, Dr. Kweku Brown, Dr. William Davis, Dr. Wayne Sarasua	Clemson University, The Citadel	Conference Paper and Presentation



Title	Author(s)	C ² M ² Affiliation	Product Type
Cybersecurity Attacks in Vehicle-to-Infrastructure (V2I) Applications and Their Prevention	Dr. Mashrur “Ronnie” Chowdhury, Mhafuzul Islam, Hongda Li, Honxin Hu	Clemson University	Conference Paper
Operational and Economic Impacts of Access Management: Recent Perspectives of State DOTs	Dr. Mashrur “Ronnie” Chowdhury, Dr. Nathan Huynh, Sakib Khan, Katherine Brunk, Samaneh Shiri, Joshua Mitchell	Clemson University, USC	Conference Paper
Augmenting Safety and Economic Considerations with Operational Impacts in Access Management Policy Development: A South Carolina Case Study	Dr. Mashrur “Ronnie” Chowdhury, Dr. Nathan Huynh, Dr. Kakan Dey, Sakib Khan, Samaneh Shiri, MD Zadid Khan	Clemson University, USC, West Virginia University	Conference Paper
Evaluation of Expected Traffic Sign Life in South Carolina	Dr. Nathan Huynh, Dr. Robert Mullen, Zane Pulver	USC	Conference Paper
Development of Statewide AADT Estimation Model from Short-Term Counts: A Comparative Study for South Carolina	Dr. Nathan Huynh, Dr. Mashrur “Ronnie” Chowdhury, Dr. Kakan Dey, Sakib Kahn, Sababa Islam, MD Zadid Khan	USC, Clemson University, West Virginia University	Conference Paper
Probability of Delay in Transportation Construction Projects	Dr. Nathan Huynh, Dr. Robert Mullen, Fahim Ahmed	USC	Conference Paper
Reliable Routing of Road-Rail Intermodal Freight Under Uncertainty	Dr. Nathan Huynh, M. Majbah Uddin	USC	Conference Paper
Emergence and Impacts of Second-Tier Container Port Facilities	Dr. Nathan Huynh, Samaneh Shiri, Daniel Smith, Frank Harder	USC	Conference Paper
Truck Appointment Systems Considering Impact to Drayage Truck Tours	Dr. Nathan Huynh, Samaneh Shiri, Mohammad Torkjazi	USC	Conference Paper
Advances in Intermodal Freight Terminal Design and Operations	Dr. Nathan Huynh	USC	Conference Presentation



Title	Author(s)	C ² M ² Affiliation	Product Type
A Reliable Multi-Period Intermodal Freight Network Expansion Problem	Dr. Nathan Huynh	USC	Journal Publication
Assessment of U.S. Chassis Supply Models on Drayage Productivity and Air Emissions	Dr. Nathan Huynh	USC	Journal Publication
Modeling Cyberattacks at Intelligent Traffic Signals	Dr. Gurcan Comert, Jacquan Pollard, Dr. David M Nicol, Palani Kartik, Babu Vignesh	Benedict College, University of Illinois Urbana-Champaign	Conference Paper, Journal Publication
Transportation Engineering Activities at the Citadel	Dr. Dimitra Michalaka, Dr. Kweku Brown	The Citadel	Conference Presentation
LeadershipITE	Dr. Dimitra Michalaka	The Citadel	Conference Presentation
Leadership at The Citadel	Dr. Dimitra Michalaka	The Citadel	Conference Presentation

Websites(s) or other Internet site(s)

C²M²'s website was updated weekly as needed by Ms. Charlotte Ryggs, C²M² Program Coordinator, Mhafuzul Islam, Clemson PhD student, and Vishnuprabhu Thirugnanasambandam, Clemson Computer Science Graduate student. 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.

A C²M² twitter was expanded with user engagement doubling in this reporting period and can be found at twitter.com/SC.UTC.

A C²M² YouTube channel was created, and content is currently being developed to be shared via this medium. The center's channel can be found at youtube.com/channel/UC14CcKnUvNMRQI5ETNYmo8A

Technologies or techniques

Nothing to report at this time.

Inventions, patent applications, and/or licenses



Nothing to report at this time.

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

Currently, C²M² students at Clemson University are conducting research on software-based security architecture to create a security platform designed to protect connected vehicles in a vehicle to infrastructure network.

C²M² students at Clemson University are also conducting research for developing Connected Vehicle Application Development Platform (CVDeP). Any connected vehicle application developer can use this platform to develop, debug and test CV applications in Clemson University's Connected and Autonomous Vehicle Testbed (CU-CAVT). CVDeP is comprised of the following elements: 1) application management platform; and 2) application development interface. Application management platform is a layer that resides between the user-end and CV edge devices, and is dedicated to control access to the edge devices and stored data, and enables heterogeneous wireless network services of the platform. One can develop their connected vehicle applications and deploy the applications directly in the edge-centric CPS via the Graphical User Interface (GUI) of our application development interface. The CVDeP will (a) enable to collect, process and distribute data, and run computation functions of CV applications at different edge layers of the CU-CAVT testbed; (b) ensure security of the applications while considering the scalability of the applications; (c) provide an abstraction layer that can hide the underlying low-level software, hardware, and associated details from the developers; and (d) provide a secured access to all the researchers of associated institutions of C²M² into the CU-CAVT testbed. CVDeP will be released using code sharing platforms, such as *GitHub*, to all of the associated institutions of C²M² by summer, 2018.

A promotional video, showcasing C²M² facilities, testbeds, and promoting our center's goals for future research is currently in development. At the time of this report the video is in the conception stage, but is slated to begin filming this summer.

3. Participants and Collaborating Organizations

What organizations have been involved as partners?

The C²M² 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 C²M² 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 partners with the South Carolina Department of Transportation, which provides data, and research support.

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:

- *BMW, Munich, Germany/ Greenville, SC:* facilities, data collection, research collaboration, in-kind support
- *Bureau of Transportation Statistics, Washington, D.C.:* data collection, research collaboration
- *City Council of Beaufort, South Carolina:* data collection, research collaboration, facilities
- *Norfolk Southern Corporation, Atlanta, GA:* data collection, research collaboration
- *CSX Corporation, Jacksonville, FL:* data collection, research collaboration
- *Mermec Inc., Columbia, SC:* data collection, research collaboration
- *National Science Foundation, Arlington, VA:* financial support
- *EPSCoR, Columbia, SC:* Advisory Board support
- *Traffic Technology Services, Inc., Beaverton, OR:* data collection, research collaboration
- *Robotic Research, Gaithersburg, MD:* data collection, research collaboration
- *Carolinas Alliance 4 Innovation, Greenville, SC:* in-kind support, data collection, research collaboration
- *Kimley-Horn, Columbia, SC:* data collection, research collaboration
- *Stanford University Center for Automotive Research, Stanford, CA:* data collection, research collaboration
- *International Transportation Innovation Center, Greenville, SC:* data collection, research collaboration

4. Impact

What is the impact on the development of the principal discipline(s) of the program?

As the C²M² first round of funded research has not been completed yet there is no significant impact from the research to report at this time. However, we expect to see significant impact in the future with the completion of the first round C²M² research. With the current scope of research, we expect to see an impact on the security of connected vehicle software, accessibility of real-time data, improvements in the mobility of people and goods, as well as connected infrastructure throughout South Carolina. We are working towards using this research to develop new courses, and workshop and training programs for our consortium institutions, State DOTs, Technical Colleges, and transportation professionals as well. C²M² also expects to see an impact on the diversity of up coming engineering students directly related to its outreach activities to minority students, from underserved communities and partnership with two of



South Carolina's historically black colleges and universities (HBCUs). The center will also have an impact on Clemson University's Civil Engineering program with our involvement in their NSF RED grant, and their effort to re-imagine civil engineering.

C²M² has shown their impact within the transportation discipline as evidenced by the following awards:

- Dr. Michalaka, C²M² Associate Director, the Citadel, was selected to participate at the 2018 LeadershipITE, ITE's premier leadership development program. More info at: <http://library.ite.org/pub/5b7a9775-b6d2-17c3-8dd2-f2d35f11c95c>
- Dr. Michalaka, C²M² Associate Director, the Citadel, was the recipient of the ITE "Legacy Fund Scholarship." This scholarship supports one or two individuals a year to participate at the LeadershipITE program. More info: library.ite.org/pub/eab1123d-f5e8-9de5-cba7-9ee246c74a24
- Dr. Michalaka, C²M² Associate Director, the Citadel, was nominated as the chair of the Engineering graphics division and secretary of the Civil Engineering and Professional Skills divisions during the American Society for Engineering Education (ASEE) Southeast Section (SE) in Daytona Beach, FL.
- Dr. Brown, C²M² sponsored researcher, the Citadel, was nominated as the Vice Chair for the Engineering Graphics division.
- Dr. Robert Mullen, C²M² sponsored researcher, USC, will serve as the honorary Chair at the Reliable Engineering Computing Meeting in Liverpool, UK. (July 16 - 18, 2018)

What is the impact on other disciplines?

- Drs. Chowdhury, C²M² Director, and Amy Apon, chair and a professor of the School of Computing at Clemson University, developed and taught a Computer Science graduate course at Clemson University, titled "Data Analytics in ITS," during the fall 2017 semester, partially based on one of the center's foundational projects.
- Dr. Chowdhury, C²M² Director, Clemson, is planning to develop a training program with Dr. Dennis Bausman, a Construction Science and Management professor at Clemson University for state DOTs.
- Drs. Comert, Darko, Iyengar, and Abuhdima, C²M² Associate Director and affiliate researchers at Benedict College have been developing course materials involving Connected Autonomous Vehicles in their transportation, introduction to engineering, environmental engineering, computer science, and electrical engineering courses.

What is the impact on the development of transportation workforce development?

Currently, Clemson is reaching out to technical colleges within South Carolina to offer a 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.



What is the impact on physical, institutional, and information resources at the university or other partner institutions?

C²M² is expanding the current Clemson University Connected and Autonomous Vehicle Testbed (CU-CAVT) to support research and development. The extended testbed will include 11 signalized intersections, four roadside infrastructures and two video cameras.

In addition, we are working to realize multiple field tests on connected transportation technology at C²M²'s institutions throughout the state of South Carolina with the goal of supporting their current research projects and the expanding Clemson University's Connected and Autonomous Vehicle Testbed. The center also expects to see improved data sharing between consortium members with the completion of Connected Vehicle Application Development Platform (CVDeP).

What is the impact on technology transfer?

Nothing to report at this time.

What is the impact on society beyond science and technology?

Nothing to report at this time.

5. Changes/Problems

Nothing to report at this time.

6. Special Reporting Requirements

N/A