



# Center for Connected Multimodal Mobility (C<sup>2</sup>M<sup>2</sup>)

## Program Progress Performance Report # 3

**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 (C<sup>2</sup>M<sup>2</sup>)

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**Recipient Organization:** Clemson University, Clemson, South Carolina 29634

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

**Reporting Period:** April 01, 2018 – September 30, 2018

**Report Term:** Semi-annual

**Signature of Submitting Official:** \_\_\_\_\_



Benedict College





## 1. Accomplishments

### 1.1 What are the major goals and objectives of the program?

C<sup>2</sup>M<sup>2</sup>'s mission statement:

Our vision for the Center for Connected Multimodal Mobility (C<sup>2</sup>M<sup>2</sup>), 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<sup>2</sup>M<sup>2</sup>'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<sup>2</sup>M<sup>2</sup> knowledge and technologies
- Support complementary collaborations with consortium members, industry partners, and the public and private agencies
- Broaden diversity by integrating consortium members' existing diversity programs with the C<sup>2</sup>M<sup>2</sup> activities

C<sup>2</sup>M<sup>2</sup> 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.

- Ms. Charlotte Ryggs, C<sup>2</sup>M<sup>2</sup> Program Coordinator, Clemson, attended the 2018 Men of Color Summit in Greenville, SC to represent the Center and participate in outreach activities. (April 12, 2018)
- C<sup>2</sup>M<sup>2</sup> applied for, and was granted membership into the Council of University Transportation Centers (CUTC). (April 25, 2018)
- Dr. Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, Ms. Karen Lantgios, Grant Manager, and Ms. Charlotte Ryggs, C<sup>2</sup>M<sup>2</sup> Program Coordinator, Clemson, traveled to Minneapolis, Minnesota to attend the CUTC Summer Meeting 2018. (June 4-6, 2018)
- Dr. Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, and Ms. Charlotte Ryggs, Program Coordinator, Clemson University, led the planning committee for the 6<sup>th</sup> Annual UTC Conference for the Southeastern Region, which will be hosted by C<sup>2</sup>M<sup>2</sup> on October 24 and 25, 2018 at Clemson University. The planning committee was made up of UTC directors from the Southeastern Region, with representatives from Southeastern Transportation Research, Innovation, Development and Education (STRIDE), University of Florida Transportation Institute (UFTI), Center for Urban Transportation Research (CURT), and other partnering schools. This planning committee held monthly calls, culminating in the fall conference. (from January 2018 to September 2018)
- C<sup>2</sup>M<sup>2</sup> Directors, Drs. Chowdhury (Clemson University), Huynh (University of South Carolina), Comert (Benedict College), Mwakalonge (South Carolina State University), and Davis (the Citadel) met at Benedict College, Columbia, SC to evaluate research proposals for our 2018/2019 round of funded research. At this time, 12 proposals out of the 14 submitted proposals were selected for funding based on their reviews, and will begin in early November of 2018. (September 28, 2018)
- C<sup>2</sup>M<sup>2</sup> directors continued their bi-weekly conference calls to coordinate the center’s activities, and budget. (Ongoing)
- C<sup>2</sup>M<sup>2</sup> Directors continued quarterly conference calls with our Advisory Board members, to update them on the Center’s ongoing activities, and to involve them in



6<sup>th</sup> Annual UTC Conference for the Southeastern Region planning process. Our Advisory Board members also were consulted on the development of C<sup>2</sup>M<sup>2</sup>'s Technology Transfer Plan, which was drafted over the spring, and submitted to the USDOT in July. (Ongoing)

Academically, the center has accomplished the following:

- In this reporting period, C<sup>2</sup>M<sup>2</sup> saw the first of its supported students graduate. The following students were granted a Master of Science degree, Md Zadid Khan, from Clemson University, Sumanth Byraju, from University of South Carolina. Both of these students will continue to work with C<sup>2</sup>M<sup>2</sup> as they pursue their doctorate degrees. Md Mizanur Rahman, from Clemson University, became the first of our Center supported students to receive his doctorate degree.
- Drs. Michalaka, C<sup>2</sup>M<sup>2</sup> Associate Director and Davis, C<sup>2</sup>M<sup>2</sup> Co-Associate Directors, the Citadel, gave tours to prospective Citadel students interested in pursuing an engineering degree. 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. (April – May 2018)
- Dr. Michalaka, C<sup>2</sup>M<sup>2</sup> Associate Director, the Citadel, took 37 Citadel engineering students to tour the ongoing Port Access Road Construction site in North Charleston, South Carolina, to give them a chance to see a project in progress. (April 18, 2018)
- Dr. Mwakalonge, C<sup>2</sup>M<sup>2</sup> Associate Director, South Carolina State University, and her sponsored students presented posters outlining their research on distracted walking as part of South Carolina State University's STEM Expo, in conjunction with West Point's LEADS Workshop, this activity also acted as a recruiting opportunity. (April 27, 2018)
- Dr. Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, Clemson, hosted two doctoral students from Wingate University to discuss our Center's outreach activities, and research dissemination, and gave them a tour of our Transportation Cyber-Physical Systems Lab. (June 8, 2018)
- Md Mizanur Rahman, C<sup>2</sup>M<sup>2</sup> supported doctoral student, Clemson, hosted a week-long summer program for four high school students from the South Carolina Governor's School for Mathematics and Science. This week-long program included supervised time in C<sup>2</sup>M<sup>2</sup>'s Transportation Cyber-Physical Systems Laboratory, as well as a presentation by Dr. Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, Clemson, on his ongoing Connected and Autonomous Vehicle Research projects. (June 11 -15, 2018)
- Dr. Michalaka, C<sup>2</sup>M<sup>2</sup> Associate Director, the Citadel, hosted a week-long summer program in conjunction with the South Carolina Governor's School for Mathematics and Science, South Carolina Department of Transportation, and STRIDE, titled "Tour of Engineering." In this program, she spent a week with 18 rising 9<sup>th</sup> and 10<sup>th</sup> graders exploring what engineers do, and diving deep into some of her ongoing research



- projects, covering bridge design and connected and autonomous vehicle research. (June 17-23, 2018)
- Drs. Comert, C<sup>2</sup>M<sup>2</sup> Associate Director, and Geter of Benedict College, hosted a Cyber-Security summer program affiliated with the Summer Transportation Institute (STI) at Benedict College, in which 75 students participated. These students made two trips to Clemson University to participate in Connected and Autonomous Vehicle demonstrations/presentations hosted by Dr. Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, Clemson University, and C<sup>2</sup>M<sup>2</sup> supported students. The students also visited Dr. Huynh, C<sup>2</sup>M<sup>2</sup> Associate Director, University of South Carolina, to learn about the importance of ports, and freight transit, and took a tour of the Inland Port located in Greer, South Carolina. (June 18 & 25, 2018)
  - Dr. Comert, C<sup>2</sup>M<sup>2</sup> Associate Director, Benedict College, mentored seven undergraduate students as a part of Benedict College's Summer Undergraduate Research Institute (SURI), with assistance from Dr. Huynh, C<sup>2</sup>M<sup>2</sup> Associate Director, University of South Carolina. During this eight-week program, students were paired with a faculty mentor and supervised as they participate in ongoing research being conducted at Benedict College, the program culminates with a research expo where the students present posters outlining the research that they conducted. (June-July, 2018)
  - Dr. Comert, C<sup>2</sup>M<sup>2</sup> Associate Director, Benedict College, supervised five undergraduate students who participated in workshops given by Dr. Martin, C<sup>2</sup>M<sup>2</sup> affiliated researcher, Clemson University. This workshop series covered Drs. Comert and Martin's ongoing cyber-security research being funded by our Center. (July, 2018)
  - Dr. Mwakalonge, C<sup>2</sup>M<sup>2</sup> Associate Director, South Carolina State University, hosted students from the Michigan Department of Transportation's Summer Transportation Institute, showcasing her work on distracted walking, and personal mobility devices. (July 2018)
  - Drs. Comert, C<sup>2</sup>M<sup>2</sup> Associate Director, and Iyangar of Benedict College, brought four Benedict College students to Clemson University to participate in a national Hackathon event, competing against students from across the nation in a hacking competition, utilizing the skills that they have been developing while working on Dr. Comert's cyber-security research project. (August 8, 2018)

### C<sup>2</sup>M<sup>2</sup> Research Initiatives:

- Drs. Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, Bausman, C<sup>2</sup>M<sup>2</sup> affiliated researcher, and Ms. Charlotte Ryggs, C<sup>2</sup>M<sup>2</sup> Program Coordinator, Clemson University, held a conference call with David Jared, Assistant Research Engineer of the Georgia Department of Transportation (GDOT), to discuss GDOT's needs for a training program being



- developed by C<sup>2</sup>M<sup>2</sup> to GDOT engineers regarding transportation construction projects. (April 6, 2018)
- Dr. Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, Ms. Charlotte Ryggs, C<sup>2</sup>M<sup>2</sup> Program Coordinator, and five students, Clemson University, met with three representatives from Samsung to discuss future collaboration on Connected and Autonomous Vehicle research. (April 18, 2018)
  - Dr. Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, Clemson, with Fred Payne of Carolinas Alliance 4 Innovation, met with Cheryl Hayes and Dan Hoffman of Clemson Parking Services to discuss partnering together on a project to bring connected and autonomous transportation options to Clemson University. (April 26, 2018)
  - Dr. Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, and Ms. Charlotte Ryggs, C<sup>2</sup>M<sup>2</sup> Program Coordinator, and five students, Clemson University, met with representatives from Kimley-Horn, Trafficware, and Clemson Facilities to begin planning the expansion of Clemson University's Connected and Autonomous Vehicle Testbed (CU-CAVT). (May 15, 2018)
  - Drs. Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, Apon and Calhoun, C<sup>2</sup>M<sup>2</sup> affiliated researchers, Clemson University, held a planning call with representatives from Toyota to discuss partnering together on a project that would work to improve freight mobility in ports utilizing Connected and Autonomous Vehicles. (May 22, 2018)
  - C<sup>2</sup>M<sup>2</sup> sent out a Call for Proposals to 21 researchers at our five affiliated schools, launching our 2018/2019 round of funded projects. This call for proposals was also announced on our website, and twitter feed, inviting affiliated researchers to apply for funding. (June 29, 2018)
  - Dr. Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, and Ms. Charlotte Ryggs, C<sup>2</sup>M<sup>2</sup> Program Coordinator, and two students, Clemson University, met with Medi Jaafari from Cisco to collaborate on the expansion of the Clemson University Connected and Autonomous Vehicle Testbed (CU-CAVT). Mr. Jaafari will continue to advise and collaborate on the expansion of the testbed. (July 23 and 26, 2018)
  - 14 research Proposals were submitted to C<sup>2</sup>M<sup>2</sup> for potential funding, with six new principal investigators (PIs) submitting, and eight returning PIs, covering a myriad of new topics. Proposals were then sent out for blind review by industry professionals from academia, and public and private agencies. Each proposal received at least three reviews, which were then used to select projects for funding. (August 2018)
  - 12 research projects were selected for funding from the 14 proposals submitted during the summer 2018 Call for Proposals. Of these 12 selected projects, five are led by Clemson University, two are led by SCSU, four are led by USC, and the Citadel will lead one of the 12 selected projects. Benedict College will collaborate on 10 of the selected projects. Collaboration between consortium members was strongly encouraged and several new PIs received funding to increase the breadth of research topics funded by our Center. The following projects were selected:



**Table: Selected Projects from 2018 Call for Proposals**

Proposal Title	Lead Principal Investigators (PIs)	Co PI's
Assessing Potential of Bike Share Networks and Active Transportation to Improve Urban Mobility, Physical Activity and Public Health Outcomes in South Carolina	William J. Davis, TC	Kweku Brown, TC; Daniel Bornstein, TC; Morgan Hughey, CoC; Dimitra Michalaka, TC; Nathan Huynh, USC; Andrew Kaczynski, USC
Enhanced DSRC Security	Richard R. Brooks, CU	Gurcan Comert, BC
Framework for Accommodating Emerging Autonomous Vehicles	Burak Eksioglu, CU	Matthias Josef Al Schmid, CU; Gurcan Comert, BC; Nathan Huynh, USC
Unmanned Aircraft Systems Impact on Operational Efficiency and Connectivity	Joseph M. Burgett, CU	Dennis Bausman, CU; Gurcan Comert, BC
Assessment of Autonomous Vehicle Sharing for Evacuation and Disaster Relief	Pamela Murray-Tuite, CU	Nathan Huynh, USC; Gurcan Comert, BC
Security of Connected Vehicles via Sandboxing against False Data Injection Attack	Pierluigi Pisu, CU	Gurcan Comert, BC
Data-driven Multimodal Transportation Energy Consumption Prediction and Analysis Framework for Sustainable Transit and Transportation Planning	Yuche Chen, USC	Gurcan Comert, BC; Nathan Huynh, USC
Tool to Access Effectiveness of Intermodal Facility Location and Carrier Collaboration	Nathan Huynh, USC	William Ferrell, CU
Data Fusion to Improve the Accuracy of Multi-Modal Traffic Counts	Robert L. Mullen, USC	Nathan Huynh, USC; Gurcan Comert, BC; Balaji Iyengar, BC
Intelligent Camera Aided Railway Emergency System (i-CARES)	Yu Qian, USC	Yi Wang, USC; Dimitris Rizos, USC
Attribution Theory and Collisions at Intersections	Judith L. Mwakalongo, SCSU	Gurcan Comert, BC
Evaluation of Before and After Measures to Curb Distracted Walking	Judith L. Mwakalongo, SCSU	Jae Dong Hong, SCSU; Gurcan Comert, BC

**Note:** BC- Benedict College; TC- The Citadel; CU- Clemson University; CoC- College of Charleston; SCSU- South Carolina State University; and USC- University of South Carolina.



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

- In this reporting period, the Clemson branch of C<sup>2</sup>M<sup>2</sup> 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<sup>2</sup>M<sup>2</sup> consortium. In this reporting period, Clemson University has hosted the following Distinguished Speaker Series:
  - Dr. G.G. Md. Nawaz Ali, of CU-ICAR presented his work on “Mobility for Tomorrow: A Large Scale Smart Mobility Test Bed (SMTB) in Singapore” (April 13, 2018) (this event was not broadcasted to C<sup>2</sup>M<sup>2</sup> partner institutions)
  - Dr. Patricia Mokhtarian of Georgia Technical Institute spoke on “It’s Not All Fun and Games: An Investigation of the Reported Benefits and Disadvantages of Conducting Activities while Commuting.” (April 27, 2018)
- Drs. Michalaka, C<sup>2</sup>M<sup>2</sup> Associate Director and Davis, C<sup>2</sup>M<sup>2</sup> Co-Associate Directors, the Citadel, both presented their ongoing C<sup>2</sup>M<sup>2</sup> research at the Statewide ITE Section Meeting held in Charleston, SC. (April 20, 2018)
- Dr. Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, Clemson, with Fred Payne of Carolinas Alliance 4 Innovation, held a call to discuss setting up a workshop to provide training on the use of Connected and Autonomous Vehicle simulation software to Greenville County engineers, and Greenville Technical College Faculty. (April 20, 2018)
- Dr. Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, and five students from Clemson University, gave a demonstration of our Connected and Autonomous Vehicle Technology at the SAE Automated and Connected Vehicle Systems Testing Symposium, held at the CU-ICAR campus in Greenville, SC. (June 20-21, 2018)
- Dr. Michalaka, C<sup>2</sup>M<sup>2</sup> Associate Director, the Citadel, organized a Connected Vehicle Workshop in Greenville, SC, where Dr. Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, Clemson was a featured speaker. This workshop was attended by South Carolina Department of Transportation engineers, and private industry members, and attendees received professional development hours. (June 26, 2018)
- Dr. Michalaka, C<sup>2</sup>M<sup>2</sup> Associate Director, the Citadel, helped coordinate and led the Summer ITE/ASCE Summer Meeting in Greenville, SC. (June 26, 2018)

## **1.4 How have the results been disseminated?**

- Clemson University C<sup>2</sup>M<sup>2</sup> students, Md Mizanur Rahman and Md Mahfuzul Islam along with Ms. Charlotte Ryggs, C<sup>2</sup>M<sup>2</sup> Program Coordinator, represented the Center and presented some of our ongoing research initiatives and Center activities at the





Clemson Research Symposium, held by the Office of Sponsored Programs at Clemson University at the Watt Family Innovation Center. This gathering presented an opportunity to discuss potential collaborations with other Clemson researchers and industry members. (May 9, 2018)

- Dr. Paul Zeihl, C<sup>2</sup>M<sup>2</sup> sponsored researcher, University of South Carolina (USC), co-sponsored the Acoustic Emission Working Group (AEWG) 60 Meeting in Charleston. It was the 60<sup>th</sup> Anniversary of the AEWG. This event was co-chaired by Dr. Paul Zheil of USC, and our Center sponsored several students, enabling them to present their research and competed for AEWG Student Award. This event featured attendees from around the world, including forty presentations. (June 19-20, 2018)
- Dr. Dimitris Rizos, C<sup>2</sup>M<sup>2</sup> sponsored researcher, USC, organized and co-chaired the American Railway Engineering and Maintenance-of-Way Association (AREMA) Railway Engineering Education Symposium 2018, in Columbia, SC. This was a gathering of 113 professors from 70 different universities and featured some of C<sup>2</sup>M<sup>2</sup>'s railway related research. (June 26-27, 2018)
- Dr. Mwakalonge, C<sup>2</sup>M<sup>2</sup> Associate Director, South Carolina State University presented her research at the University of Toronto, as an invited speaker. (July 9, 2018)
- Dr. Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, Clemson University and five students in conjunction with South Carolina Transportation Technology Transfer Services (T<sup>3</sup>S) gave a technology demonstration to Department of Transportation engineers from Kansas, Maryland, South Carolina, Tennessee, and Kentucky at Clemson University as a part of T<sup>3</sup>S's Peer Exchange. (August 28, 2018)
- C<sup>2</sup>M<sup>2</sup> students from Clemson University, Md Mahfuzul Islam, Md Zadid Khan, and Sakib Mahmud Khan, presented ongoing C<sup>2</sup>M<sup>2</sup>'s research at the Civil Engineering Fall Cookout Expo, to undergraduate Civil Engineering students as a recruiting event. (September 21, 2018)
- Dr. Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, Clemson and four students gave a connected and autonomous technology demonstration to potential engineering students at Engineering Discovery Night at Clemson University. (September 25, 2018)
- Dr. Md Mizanur Rahman was hired as a Postdoctoral Fellow for implementing Technology Transfer plan. He will be responsible for overseeing C<sup>2</sup>M<sup>2</sup>'s technology transfer activities and monitoring the progress of our Center funded research projects. (September 28, 2018)

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

Upcoming Academic Endeavors:

- C<sup>2</sup>M<sup>2</sup> and Dr. Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, Clemson University, will host the 6<sup>th</sup> Annual University Transportation Centers Conference for the Southeastern Region, at the Madren Conference Center in Clemson, SC. This conference will feature, Carla Bailo of



- the Center for Automotive Research as a keynote speaker, a State DOT Panel, research presentations by students and faculty with prizes for the top three student poster presentations and top three student oral presentations, and a Connected and Autonomous Vehicle Technology Demonstration. (October 24-25, 2018)
- C<sup>2</sup>M<sup>2</sup> Advisory Board members will convene for our annual meeting during the 6<sup>th</sup> Annual UTC Conference for the Southeastern Region, where Dr. Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, Clemson and available Associate Directors will give a presentation of the Center's activities for the year and begin proposing action for the coming year. (October 24, 2018)
  - Dr. Michalaka, C<sup>2</sup>M<sup>2</sup> Associate Director, Dr. Davis, C<sup>2</sup>M<sup>2</sup> Co-Associate Director and affiliated researcher, and Dr. Brown an affiliated researcher at the Citadel will host 28 groups of 5<sup>th</sup> graders from Richland Country Schools in the civil engineering department at the Citadel to be introduced to civil engineering. The different civil engineering disciplines, including transportation engineering, will be explained through the presentation, discussions, and hands-on activities by Dr. Brown, Dr. Davis, Dr. Michalaka and other faculty. (Fall 2018)
  - Clemson University's C<sup>2</sup>M<sup>2</sup> affiliates will continue their Distinguished Speaker Series, and will be sponsoring notable transportation researchers whose talks will be made available via webinar and announced on our social media platforms. (Ongoing)

## Upcoming Research Initiatives:

- C<sup>2</sup>M<sup>2</sup> researchers who received funding approval in the 2018/2019 round of funded projects will begin their research. (November 2018)
- C<sup>2</sup>M<sup>2</sup> researchers who received funding in the 2017/2018 round of funded projects will begin submitting their final research reports, wrapping up C<sup>2</sup>M<sup>2</sup>'s first round of funded projects. (November 2018)
- C<sup>2</sup>M<sup>2</sup> sponsored researchers and affiliated students will be attending the 2019 Transportation Research Board (TRB) conference in Washington DC presenting papers on their sponsored research. (January 2019)
- Dr. Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, Clemson is continuing to work with Clemson University Facilities on expanding Clemson University- Connected and Autonomous Vehicle Testbed from Perimeter Road to throughout Clemson University's campus. (Ongoing)

## 2. Products

### 2.1 Publications, conference papers, and presentations

C<sup>2</sup>M<sup>2</sup> affiliated researchers and supported students are currently revising papers and presentations that will be presented at the 6<sup>th</sup> Annual UTC Conference for the Southeastern



Region and the 2019 TRB Meeting, below is a table presenting our publications, conference papers and presentations for this reporting period.

**Table: List of publications, conference papers and presentations**

Title	Author(s)	C <sup>2</sup> M <sup>2</sup> affiliation (Project name funded by C <sup>2</sup> M <sup>2</sup> )	Product Type
Modeling Cyber Attacks at Intelligent Traffic Signals	Gurcan Comert, Jacquan Pollard, David M. Nicol, Kartik Palani, Babu Vignesh	Uncertainty Quantification of Cyber Attacks at Intelligent	Journal paper
Change Point Models for Real-time V2I Cyber Attack Detection	Gurcan Comert, Mizanur Rahman, Mhafuzul Islam, Mashrur Chowdhury	Uncertainty Quantification of Cyber Attacks at Intelligent	Conference paper
The Impact of Transportation on Air Quality Around Schools in The State Of South Carolina	Quentin Y. Eloise, Alexis Ward, Samuel Darko, Gurcan Comert	Impact of Transportation on Air Quality in South Carolina	Presentation
Simulating Connected Autonomous Vehicles	Jerodi Hill, Cristian Palacios, Malcolm Peterson, Gurcan Comert	Adaptive Signal Control Models from Connected Vehicles	Presentation
Modeling and Quantifying Cyber Attacks on Signalized Traffic Networks	Rajae Ouzir, Meriem Abdi, Treyton Wofford, and Gurcan Comert	Uncertainty Quantification of Cyber Attacks at Intelligent	Presentation
Lessons Learned from the Real-World Deployment of a Connected Vehicle Testbed	Mashrur Chowdhury, Mizanur Rahman, Anjan Rayamajhi, Sakib Khan, Mhafuzul Islam, Zaid Khan, and Jim Martin	Development of Cyber-Physical Systems for Connected and Autonomous Vehicle Research	Journal paper
Cybersecurity Attacks in Vehicle-to-Infrastructure (V2I) Applications and their Prevention	Mhafuzul Islam, Mashrur Chowdhury, Hongda Li, and Hongxin Hu	Development of Cyber-Physical Systems for Connected and Autonomous Vehicle Research	Journal paper
Biofuel Logistics Network Design Using Two-Stage Network Data Envelopment Analysis	Jae Dong Hong	Infrastructure and Policy Needs for Personal Electric Mobility Devices in the Connected Vehicle World	Conference paper



## **2.2 Websites(s) or other Internet site(s)**

C<sup>2</sup>M<sup>2</sup>'s website was updated weekly as needed by Ms. Charlotte Ryggs, C<sup>2</sup>M<sup>2</sup> Program Coordinator, Md Mhafuzul Islam, Clemson Ph.D. student. The center's website address is ([cecas.clemson.edu/c2m2](https://cecas.clemson.edu/c2m2)). The website outlines the C<sup>2</sup>M<sup>2</sup>'s goal, participants, research in progress, and events, both upcoming and past.

A C<sup>2</sup>M<sup>2</sup> twitter was expanded with user engagement increasing again in this reporting period and can be found at [twitter.com/SC.UTC](https://twitter.com/SC.UTC).

A C<sup>2</sup>M<sup>2</sup> LinkedIn page was created, and content is currently being developed to be shared via this medium and to expand our social media reach. The center's profile can be found at: [www.linkedin.com/in/center-for-connected-multimodal-mobility-304527163/](https://www.linkedin.com/in/center-for-connected-multimodal-mobility-304527163/)

Links of our Center's website and other internet sites at a glance.

C<sup>2</sup>M<sup>2</sup>'s website: <https://cecas.clemson.edu/C2M2/>

C<sup>2</sup>M<sup>2</sup> twitter page: <https://twitter.com/SC.UTC>

C<sup>2</sup>M<sup>2</sup> LinkedIn page: <https://www.linkedin.com/in/center-for-connected-multimodal-mobility-304527163/>

## **2.3 Technologies or techniques**

One of the foundational projects, that is in the process of final review, by our Center Director, Dr. Chowdhury of Clemson, will change the way that researchers access real-time data. Our research focus is to develop a scalable and secure connected vehicle application development platform (CVDeP) that enables connected and autonomous vehicle (CAV) application developers to build, debug, and test CAV applications in real time. In addition, our research is focused on developing CAV applications that coordinate the exchange of data between traffic signals, vehicles, and pedestrians in real time so that vehicles can maneuver in a safe, efficient and environment-friendly manner at signalized intersections, with the aim of reducing crashes, travel time, fuel consumption, and greenhouse gas emissions. We are also developing techniques on improving the safety of autonomous vehicles through the development of a hazard detection and maneuvering approach, which can help autonomous vehicles to navigate safely during unexpected roadway events, whether caused by a deliberate action (e.g., roadblock) or unintentionally (e.g., debris).

## **2.4 Inventions, patent applications, and/or licenses**

Nothing to report at this time.



## **2.5 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, C<sup>2</sup>M<sup>2</sup> students at Clemson University are 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;
- 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:

- Enable to collect, process and distribute data, and run computation functions of CV applications at different edge layers of the CU-CVT testbed;
- Ensure security of the applications while considering the scalability of the applications;
- Provide an abstraction layer that can hide the underlying low-level software, hardware, and associated details from the developers; and
- Provide secured access to all the researchers of associated institutions of C<sup>2</sup>M<sup>2</sup> into the CU-CAVT testbed. CVDeP will be released using code-sharing platforms, such as *GitHub*, to all of the associated institutions of C<sup>2</sup>M<sup>2</sup> by Spring, 2019.

In addition, we will release a software package that processes information from traffic signals, pedestrians and vehicles to coordinate vehicle flow at intersections, and ultimately improve safety and mobility while reducing fuel consumption. We are also developing computer vision-based software that detects unexpected events and helps CAVs to maneuver safely. This software is focused on improving the safety of autonomous vehicles in a CPS environment through the development of a hazard detection and maneuvering approach, which can help autonomous vehicles to navigate safely during unexpected roadway events, whether caused by a deliberate action (e.g., roadblock) or unintentionally (e.g., debris).



## 3. Participants and Collaborating Organizations

### 3.1 What organizations have been involved as partners?

The C<sup>2</sup>M<sup>2</sup> 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<sup>2</sup>M<sup>2</sup> 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.

### 3.2 Have other collaborators or contacts been involved?

Along with the five institutions that make up the C<sup>2</sup>M<sup>2</sup> consortium partnership, C<sup>2</sup>M<sup>2</sup> has and is collaborating on projects with or received support from the following:

- *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
- *Carolinas Alliance 4 Innovation, Greenville, SC:* in-kind support, data collection, research collaboration
- *Kimley-Horn, Columbia, SC:* data collection, research collaboration
- *International Transportation Innovation Center, Greenville, SC:* data collection, research collaboration
- *Trafficware, Inc., Sugar Land, TX:* data collection, research collaboration
- *College of Charleston, Charleston, SC:* data collection, research collaboration



- *South Carolina Council on Competitiveness, Columbia, SC:* in-kind support, data collection, research collaboration
- *Amazon Web Services, Seattle, WA:* data collection, research collaboration

## 4. Impact

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

As the C<sup>2</sup>M<sup>2</sup> 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 C<sup>2</sup>M<sup>2</sup> 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. This process will be the responsibility of our brand new Postdoctoral Fellow for Technology Transfer, Dr. Md Mizanur Rahman, will assist our researchers in the dissemination of their research results.

C<sup>2</sup>M<sup>2</sup> also expects to see an impact on the diversity of upcoming 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.

### **4.2 What is the impact on other disciplines?**

- Dr. Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, Clemson University, is working with Dr. Jim Martin, an associate professor of School of Computing, Clemson University to extend Clemson University- Connected and Autonomous Vehicle Testbed, and is working with students from both departments.
- Dr. Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, Clemson University, is collaborating with Dr. John Wagner, a professor of Mechanical Engineering at Clemson University to build information aware connected autonomous vehicle, and is working with students from both departments to achieve this goal.



### **4.3 What is the impact on the development of transportation workforce development?**

Currently, Clemson University is 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 the 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.

All five of our consortium schools have impacted the development of transportation workforce development through our outreach activities with students as well. Benedict College hosts Summer Transportation Institute (STI) each year, which recruits high school students with an interest in transportation engineering. In this reporting period, STI students visited University of South Carolina and Clemson University for technology demonstrations and we anticipate continuing to work with this program. The Citadel has an established series of recruiting activities that involve K-12 students from the greater Charleston area, giving them opportunities to participate in hands-on engineering projects and simulations. C<sup>2</sup>M<sup>2</sup> affiliates at Clemson University continue to offer both their Distinguished Speaker Series, bringing transportation experts to Clemson to share their research and broadcasting these talks to our partner schools offering our students an opportunity to learn about areas of transportation research being conducted outside of our consortium of schools, and an opportunity to build connections to new researchers. This speaker series also gives undergraduate students at our partner institutions an opportunity to see how our graduate students are involved in ongoing research projects.

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

C<sup>2</sup>M<sup>2</sup> 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 including data processing unit and two traffic monitoring cameras.

In addition, we are working on multiple field tests on connected transportation technology at C<sup>2</sup>M<sup>2</sup>'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 a significant enhancement of the capability of consortium member researchers for developing the connected vehicle applications using real-time data with the completion of Connected Vehicle Application Development Platform (CVDeP).





## **4.5 What is the impact on technology transfer?**

We have created and submitted a technology transfer plan, and are currently revising it. This plan, once approved will be posted on our center's website. We have also hire Dr. Md Mizanur Rahman as a Postdoctoral Fellow of Technology Transfer, to facilitate and oversee our center's technology transfer activities. The Connected Vehicle Application Development Platform (CVDeP) is directly contributing to realizing these benefits by helping to move connected vehicle technology from the lab to the road.

## **4.6 What is the impact on society beyond science and technology?**

Our developed technologies related to multimodal transportation systems will significantly reduce crashes, save fuel, reduce congestion delays, and increase roadway efficiency and cost-effectiveness. In addition, our connected autonomous vehicle research will improve the public's trust in driverless vehicles while improving passengers' safety and comfort.

## **5. Changes/Problems**

### **5.1 Changes in approach and reason for change?**

Nothing to report at this time.

### **5.2 Actual or anticipated problems or delays and actions or plans to resolve them.**

Nothing to report at this time.

### **5.3 Changes that have a significant impact on expenditures.**

Nothing to report at this time.

### **5.4 Significant changes in use or care of animals, human subjects and/or biohazards.**

Nothing to report at this time.

### **5.5 Change of primary performance site location from that originally proposed.**

Nothing to report at this time.

### **5.6 Additional information regarding products or impacts.**

Nothing to report at this time.



## 6. Special Reporting Requirements

There is nothing to report at this time.