



Center for Connected Multimodal Mobility (C²M²)

Semi-Annual Progress Report # 3

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Benedict College





***Residual Impacts of COVID-19 on Transportation and Transportation Research as anticipated by C²M²**

COVID-19 could have a significant influence on transportation policies, investments and behavior, and it will also impact the data, information, and research priorities that support transportation decision-making going forward. It could change passenger travel demand, passenger travel supply, freight transportation demand, freight transportation supply, the economics of the transportation industry, land use patterns, social, cultural and political factors, and the environment. On the other hand, many possible impacts may not come to be, given the tremendous uncertainty about the crisis's potential length and impacts. In the short term, there will be dramatic impacts as a result of COVID-19-related lockdown. Beyond this, the likely steep recession will also influence transportation dramatically. And even after the virus is controlled and the economy recovers, some people and firms who changed their travel behavior during the crisis will adopt these new patterns as the result of trying new ways of getting around (or getting around less) during the crisis.

Some of the possible changes include:

Passenger travel demand and Passenger travel supply

- Travel of all sorts is likely to drop dramatically, first because of COVID-19-related social distancing, and later because economic recession will involve lower employment, shopping, etc.
- Because it is a private form of transportation that involves little contact with others, car ownership and travel may increase, relative to other modes, especially during the crisis.
- Because they also need not result in much human contact or potential for the disease to spread, walking and cycling may increase, at least in relative terms.
- The use of personal electronic mobility devices (PEMDs) may also increase due to their relative safety from contagion.
- The use of public transportation services, including ride-hailing services, such as Uber and Lyft is likely to fall as travelers eschew communal modes for health reasons.
- The demand for car-rental services, air travel, and other commercial travel will decrease as travel is reduced.

Freight transportation demand and freight transportation supply

- During the crisis, demand for delivered items will skyrocket. This will work to the benefit of online shopping, particularly giants like Amazon and Walmart. After the first wave of COVID-19 is beyond us, many people will continue to shop this way. This may mean great challenges for brick-and-mortar retail, which was already seeing hard times. In terms of transportation, trips by individual shoppers to stores may be replaced with deliveries by firms like UPS, Fedex, and the USPS. This may be a positive development, since deliveries promise to be more efficient.
- Due to strains on the logistics system, and particularly the demand being placed on firms like Amazon, the pace of automation in this sector may be accelerated.

Challenges for transportation firms and agencies

- Declines in travel during and after the crisis will pose dramatic and possibly existential challenges to transit agencies, airlines, cruise ship companies, automakers, etc. There are plans



to provide bailout funds to these entities but it remains to be seen whether and when these firms return to financial health.

- Unemployment in the transportation sector may increase dramatically as a result of this.

Changes to transportation infrastructure

As we write this, there is talk that the government may enact a huge infrastructure funding package as a means of jumpstarting the economy once COVID-19 is controlled. This may bring great benefits in terms of improved roads, transit and rail systems, airports, and broadband service. It may also offset some of the unemployment in the transportation sector. However, if this money is disbursed too hastily and without proper analysis, there is the potential for much wasteful spending.

Social, cultural or political changes

- The use of telemedicine will increase, which will reduce travel.
- As has been noted, online shopping will increase during and quite probably after the crisis, reducing passenger vehicle travel.
- Business travel will decrease in the short term and possibly the long term as firms realize that videoconferencing and other ICT (Information and Communications Technology) solutions are acceptable substitutes.
- Widespread telecommuting is currently taking place, and some firms will discover it is an acceptable substitute for in-office work. This would save firms money. In terms of transportation, this may lead to less commuting, which would be particularly beneficial for congestion in that it would remove vehicles from the morning and evening peaks.
- School bus travel will decrease in the short term but ultimately will be the same as before when the condition becomes normal.

Changes in land use

- With increasing online shopping, over the long-term, there may be a reduced demand for parking at retailers. This may open the opportunity for infill development in some parking lots.
- Retail districts will be hit hard during the crisis, and potentially far beyond. America's malls, shopping strips and central business districts may see widespread vacancies. This may increase the availability and reduce the cost of parking, as well as congestion.

Environmental impacts

- During the crisis, we are seeing reductions in greenhouse gas emissions. This may or may not sustain depending on the other changes outlined above.
- COVID-19 has resulted in a major drop in air and roadway travel, and even when the crisis will be over it may change travel behavior patterns permanently. Using data available from the U.S. and other countries, research may focus on how changing travel behavior now and in the future affects the generation of greenhouse gases and other transportation-related pollutants.

**Special commentary in response to the ongoing COVID-19 situation.*



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

1.1 What are the major goals 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, automation, and cybersecurity. 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 and 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, automation, and cybersecurity 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 Board of Directors continued their bi-weekly conference calls to coordinate the Center's activities, and budget. (Ongoing)
- Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, Clemson University, and his research team meets bi-weekly with a team led by the Clemson University International Center for Automotive Research (CU-ICAR) to work on the OpenCAV CU-ICAR project, which is the result of a collaboration of researchers at Clemson University who are acquiring a connected and automated vehicle to further vehicle automation research in a transportation cyber-physical system environment. C²M² is a primary stakeholder in the OpenCAV project. (Ongoing)
- Drs. Jennifer Ogle and Wayne Sarasua, C²M² affiliated researchers, Clemson University, as a part of 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)
- Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, Dr. Mizanur Rahman, C²M² Assistant Director, and Ms. Charlotte Ryggs, C²M² Program Coordinator, are part of the planning committee for the 7th Annual UTC Conference for the Southeastern Region scheduled to be held in Boca Raton, Florida on March 26 – 27, 2020 (postponed until 2021 due to COVID-19). (Ongoing)
- In this reporting period, the Clemson branch of C²M² continued the Distinguished Speaker Series, where notable scholars from within the transportation community are invited to come to Clemson University, Clemson, South Carolina, 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 and any other interested participants. In this reporting period, Clemson University has hosted the following Distinguished Speakers:
 - Long Chen of Clemson University presented his work on "Securing Automotive Cyber-Physical Systems," (October 10, 2019) – this talk is available in our YouTube Channel: https://www.youtube.com/channel/UCITo_BgCYEjjH_PTU3vPFOW
 - Bhavani Thuraisingham of the University of Texas at Dallas presented her work on "SecAI: Integrating Cyber Security and Artificial Intelligence (AI) with Applications in Internet of Transportation and Infrastructures," (October 18, 2019) – this talk is available in our YouTube Channel: https://www.youtube.com/channel/UCITo_BgCYEjjH_PTU3vPFOW
 - Bing Li of Clemson University International Center for Automotive Research (CU-ICAR) presented his work on "Assistive Navigation for Disabled Travelers in the Transportation Chains," (March 5, 2020) – this talk is available in our YouTube Channel: https://www.youtube.com/channel/UCITo_BgCYEjjH_PTU3vPFOW
 - Eric Morris of Clemson University presented his work on "Good Trips: The Connection Between Travel and Quality of Life," (March 6, 2020) – this talk is available in our YouTube Channel: https://www.youtube.com/channel/UCITo_BgCYEjjH_PTU3vPFOW



- C²M² Advisory Board members convened for our annual advisory board meeting during the 3rd Annual C²M² Fall Conference with Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, Dr. Mizanur Rahman, C²M² Assistant Director. Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, gave a presentation related to the Center’s activities for the year, and the board discussed and proposed our course of action for the coming year. (October 17, 2019)
- C²M² organized and hosted the 3rd Annual C²M² Fall Conference at the Madren Conference Center in Clemson, South Carolina. This conference featured, Dr. Bhavani Thuraisingham as a keynote speaker, Jennifer Oswald Rhoades, P.E. as a featured speaker from the South Carolina Department of Transportation (SCDOT), research poster presentations by students with prizes awarded for the top three student posters, and a Connected and Automated Vehicle Technology Demonstration. Approximately 70 participants attended from throughout South Carolina during the day-long conference. (October 18, 2019)
- Mr. Mhafuzul Islam, C²M² affiliated Clemson doctoral student’s poster titled “Evaluation of Adversarial attack on Autonomous Vehicle” was rewarded as the 1st place in the 3rd Annual C²M² Student Poster Presentation. (October 18, 2020)
- Dr. Dimitra Michalaka, C²M² Associate Director, The Citadel, organized and hosted the East Cooper Montessori Charter School, Bridge Competition, which is an academic competition with 7-8 Graders where students constructed model bridges using popsicle sticks that concluded with a load-testing event. This competition was hosted in conjunction with Science, Technology, Engineering and Mathematics (STEM), and Gifted & Talented Program. (October 21, 2019)
- Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, and Dr. Mizanur Rahman, C²M² Assistant Director, met Doug Webster, Chairman of the Board for Carolinas Alliance 4 Innovation (CA4I), Fred Payne, Board Member of CA4I and Brad Van Meter to discuss the possible industry involvement and pilot deployment strategy related to smart city technology in Greenville to improve traffic operation, safety and overall quality of life. Several areas of interest for the pilot smart city technology deployment were discussed including autonomous transit network deployment, smart infrastructure improvements, and pedestrian safety. (October 23, 2019)
- Dr. Dimitra Michalaka, C²M² Associate Director, and an additional faculty member from The Citadel met with the FIRST Lego League Club of James Island (elementary school-aged homeschooled children and their parents), to discuss the club's innovation project addressing needs in their local community with a specific focus on providing alternative transportation options to solve traffic congestion on roads leading to Folly Beach during summer months. Later, students presented their plan at the FIRST LEGO League competition in Summerville on November 23, 2019. (October 24, 2019)
- Dr. Mashrur “Ronnie” Chowdhury, C²M² Director and Dr. Mizanur Rahman, C²M² Assistant Director, met with representatives from Sprint and CU-ICAR in Greenville, South Carolina to discuss potential research collaboration related to connected and automated vehicles deployment. (November 5, 2019)
- Dr. Dimitra Michalaka, C²M² Associate Director, The Citadel, attended the Society of Women Engineers 2019 Conference in Anaheim, California (CA). (November 7-9, 2019)
- Dr. Mashrur “Ronnie” Chowdhury, C²M² Director and Dr. Mizanur Rahman, C²M² Assistant Director, hosted a one-day planning workshop in Greenville, SC for the “Engineering Research Center for Computer And Network Resiliency and Security for Transportation



- (CAN-RESIST),” as part of our National Science Foundation (NSF)-Engineering Research Center (ERC) Planning grant. This grant aligns with the center’s vision and goals. (November 7, 2019)
- Dr. Mashrur “Ronnie” Chowdhury, C²M² Director and Dr. Mizanur Rahman, C²M² Assistant Director, hosted David Bruemmer from the Adaptive Motion Group in our Transportation Cyber-Physical Systems lab in Clemson, South Carolina to install micro positioning devices, which will provide accurate location information for connected and automated vehicles. (November 15, 2019)
 - C²M², in collaboration with Clemson Universities College of Engineering, Computing, and Applied Sciences, created a short introductory video outlining the Center’s vision and highlighting Center’s research. This video has been posted to all of our social media platforms. (December 16, 2019)
 - Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, Dr. Mizanur Rahman, C²M² Assistant Director, and Ms. Charlotte Ryggs, C²M² Program Coordinator, Clemson University, held a preliminary conference call with Kevin Limehouse, of the Charleston County Council to discuss future collaboration on a smart city initiative in Charleston. (December 18, 2020)
 - Mr. Isa Musa, C²M² supported South Carolina State University (SCSU) Master’s student, was selected as our 2019 University Transportation Center Student of the Year. Isa was nominated by his advisor Dr. Judith Mwakalonge, C²M² Associate Director, SCSU. (January 6, 2020)
 - Dr. Mizanur Rahman, C²M² Assistant Director, and Ms. Charlotte Ryggs, C²M² Program Coordinator, Clemson University, participated in a conference call with Kevin Limehouse and Kristen Hess of the Charleston County Council to discuss our participation and demonstration of connected and automated vehicle technologies at the 2020 Countdown to Success - NASA STEM Fair March 25, 2020 (postponed due to COVID-19). 1500 high school students from Dorchester, Berkeley, and Charleston counties in SC were invited to participate in a day of STEM demonstrations. (January 9, 2020)
 - C²M² hosted our very first “Breakfast and Conversations” networking event at the 99th Annual TRB Conference. (January 13, 2020)
 - Mr. Weimin Jin, C²M² affiliated Clemson doctoral student’s poster titled “Evaluation of Project Development Process at State Transportation Agencies” was rewarded as the 3rd place in the 99th TRB Poster Session: Research Topics in Construction Management. (January 16, 2020)
 - Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, Clemson University, was invited to present on a smart city/smart mobility panel as part of the ITS Carolinas Conference March 24, 2020 (postponed due to COVID-19). (January 27, 2020)
 - Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, met with representatives from both AT&T and Clemson University to discuss collaborative research utilizing AT&T’s 5G technology and its deployment opportunity in the South Carolina Connected Vehicle Testbed (SC-CVT) at Clemson as a potential use case. (January 30, 2020)
 - Clemson University IDEAS magazine featured Dr. Mashrur “Ronnie” Chowdhury’s, C²M² Director, research in cybersecurity in both a print article and affiliated video, which were posted on our Center’s website. (February 6, 2020)
 - Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, Dr. Mizanur Rahman, C²M² Assistant Director, and Ms. Charlotte Ryggs, C²M² Program Coordinator, Clemson University, hosted



- representatives from CU-ICAR, Michelin, and Charleston County Council at Clemson University for a half-day tour of our Transportation Cyber-Physical Systems Lab which included an overview of our work at C²M² and a demonstration of our South Carolina - Connected Vehicle Testbed (SC-CVT). The purpose of this visit was to discuss potential future research collaborations related to mobility in smart cities. (February 4, 2020)
- Dr. Dimitra Michalaka, C²M² Associate Director, The Citadel, hosted Storm The Citadel, where civil engineering student volunteered and faculty hosted a bridge and transportation competition event focused on K-12 outreach and workforce development. 200 bridge event participants, Citadel students, teachers and parents took part; while a total of 500 Storm The Citadel attendees participated in Robotics, Water Bottle Rockets and Trebuchet activities. Charleston Mayor, John Tecklenburg, attended as a dignitary. The event involved students from public and private schools across the Lowcountry Region in South Carolina. (February 8, 2020)
 - Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, Dr. Mizanur Rahman, C²M² Assistant Director, and Ms. Charlotte Ryggs, C²M² Program Coordinator, Clemson University, held a preliminary planning call with representatives from the Palmetto Clean Fuels Coalition, a US Department of Energy sponsored coalition in South Carolina, to discuss co-hosting a summit on Energy Efficient Mobility Systems. (February 11, 2020)
 - Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, and Dr. Mizanur Rahman, C²M² Assistant Director, met in Greenville, South Carolina to participate in the Technology & Innovation Task Force of the Upstate Mobility Alliance meeting. Dr. Chowdhury gave an hour long presentation and joined representatives from CU-ICAR, Greenville County, BMW, Carolinas Alliance 4 Innovation, Greenville city, and Zipit Wireless at this meeting of the Upstate Mobility Alliance to discuss congestion management via emerging connected and automated vehicle technology. (February 12, 2020)
 - Dr. Dimitra Michalaka, C²M² Associate Director, The Citadel, hosted Introduce a Girl to Engineering, a Girl Scouts Merit Badge Event. At this event, The Citadel’s Civil, Environmental and Construction Engineering, School of Engineering (SOE), and Society of Women Engineers (SWE) student chapter collaborated with Girl Scouts of Eastern South Carolina, and Lowcountry SWE professional chapter to plan, organize and host “Introduce a Girl to Engineering Day,” a three-hour outreach event designed to motivate middle-school-aged female students about engineering through fast-paced and hands-on learning activities. This year, 36 girl scouts participated in the event along with 26 engineering students and professional volunteers. Educational activities included constructing a castle, building a crane, designing and building a road, and programming an Ozobot (a coding robot) to navigate the road. All learning activities and engineering design challenges were introduced to girl scout participants using the theme “Disney Princesses.” (February 16, 2020)
 - C²M² announced our 2020 Call for Proposals. Invitations to apply were sent out to our five partner institutions and posted on our C²M² website. Proposals are due by May 1, 2020. (February 26, 2020)
 - C²M² launched an eight-week program titled C²M² Future Leaders Program. This program is led by Clemson University and offered to our partner institutions via webinar. Each session will feature a speaker and group discussion and will focus on practical skills, such as how to be an effective writer/speaker and what makes an effective leader. In addition, this program



will showcase real-world examples from leaders in the private industry and academia. (February 28 – April 24, 2020)

- Dr. Dimitra Michalaka, C²M² Associate Director, The Citadel, and Dr. Wayne Sarasua, C²M² affiliated researcher, Clemson, took Citadel and Clemson students to participate in the Southern District 2020 ITE Student Leadership Summit in Atlanta, Georgia. (February 28 – March 1, 2020)
- Dr. Mizanur Rahman, C²M² Assistant Director, and two center-supported Clemson doctoral students traveled to the C²M² partner institutions, South Carolina State University (SCSU), in Orangeburg, South Carolina, to present a half-day workshop titled, “Connected and Automated Vehicles (CAVs) in the Transportation Cyber-Physical Systems.” SCSU faculty and students participated in this half-day program sponsored by Dr. Judith Mwakalonge, C²M² Associate Director, SCSU. (March 2, 2020)
- Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, and Dr. Mizanur Rahman, C²M² Assistant Director, Clemson University, attended the 2020 Men of Color National Summit. C²M² was also represented at the Clemson University Programs for Educational Enrichment (PEER)/Women in Science and Engineering (WISE) table at the summit. (March 3-4, 2020)
- Dr. Dimitra Michalaka, C²M² Associate Director, The Citadel, participated in the Charleston Science, Technology, Engineering & Math (STEM) Festival. During the 5-hour event, approximately 200 students participated in the program and were introduced to foundational principles of civil engineering. The annual STEM festival celebration attracts over 10,000 K-12 students, and their families, from South Carolina (SC) counties (i.e., Berkeley, Charleston, and Dorchester Counties) extending across the SC Coastal Lowcountry. This event received strong support from industry, manufacturing, trade professions, business, and educational institutions, with over 80 exhibitors, hands-on activities, live performances, interactive demonstrations, and family-oriented STEM engagement. (March 9, 2020)
- Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, Dr. Mizanur Rahman, C²M² Assistant Director, and Ms. Charlotte Ryggs, C²M² Program Coordinator, Clemson University, met to finalize COVID-19 plan of action for all center related events and daily activities to minimize disruption as much as possible. This plan was then presented to the Associate Directors in our bi-weekly conference call. (March 10, 2020)
- Drs. Dimitra Michalaka, C²M² Associate Director, William J. Davis, C²M² Co-Associate Director, and Kweku Brown, C²M² affiliated researcher, The Citadel, hosted prospective Citadel students (popularly known on campus as pre-knobs). The ongoing Pre-Knob Program is a unique enrichment and recruiting opportunity for high school students, 16-18 years old, to observe college student life at The Citadel through firsthand observation and engagement. Student recruits (pre-knobs) declare the academic major in which they are interested and spend time at that department when they come for an on-campus visit. Additionally, high school students shadow a civil engineering freshman student and spend the night at The Citadel dormitories (barracks), joining in family-style dining at the campus Mess Hall, and attending engineering classes. The Citadel Department of Civil, Environmental, and Construction Engineering opened its doors to host cohorts of pre-knobs, introducing them to the civil engineering profession and allowing students to attend engineering classes. Pre-knobs learn about transportation engineering, see previous highway design projects, learn about research projects, and usually attend a transportation engineering course while visiting the Department. (October 10-11, 2019; October 31-



November 1, 2019; November 14-15, 2019; December 5-6, 2019; January 23-24, 2020; February 6-7, 2020; February 20-21, 2020; and February 27-28, 2020)

1.3 How have the results been disseminated?

- Dr. Paul Ziehl, C²M² affiliated researcher, University of South Carolina, presented his research at the ACI Fall Convention, at the Duke Energy Convention Center and Hyatt Regency Cincinnati, Ohio. His presentation was held at the ACI 437 Committee Session for Strength Evaluation of Existing Concrete Structures. (October 20-24, 2019)
- Dr. Paul Ziehl, C²M² affiliated researcher, University of South Carolina, along with his Ph.D. student published the following journal article based on their 2017 C²M² funded project.
Anay, R., Lane, A., Jáuregui, D., Weldon, B., Soltangharai, V., and Ziehl, P., "On-Site Acoustic-Emission Monitoring for Assessment of a Prestressed Concrete BT-54 AASHTO Girder Bridge," *Journal of Performance of Constructed Facilities*, 34(3), 04020034.
- Dr. Jennifer Ogle, C²M² affiliated researcher, Clemson University, developed a course module to showcase the use of safety data for defining problems related to non-motorized transportation users for Clemson's Master of Transportation Safety Administration program core curriculum based on her C²M² sponsored project. (Fall 2019)
- Dr. Judith Mwakalonge, C²M² Associate Director, SCSU, completed and published her 2017 funded project report, "Infrastructure and Policy Needs for Personal Electric Mobility Devices in a Connected Vehicle World." (November 15, 2019)
- Dr. Gurcan Comert, C²M² Associate Director, Benedict College, completed and published his 2017 funded project report, "Impact of Transportation on Air Quality at Elementary and Middle Schools in South Carolina." (November 18, 2019)
- Dr. Mashrur "Ronnie" Chowdhury, Director of C²M², gave an invited talk on his ongoing research on cybersecurity of connected and automated vehicles to the Alabama Transportation Institute via webinar. (November 18, 2019)
- Former C²M² supported student, Dr. Sakib Mahmud Khan, in collaboration with Drs. Mashrur "Ronnie" Chowdhury, C²M² Director, Eric Morris, and Lipika Deka, authored paper "Synergizing Roadway Infrastructure Investment with Digital Infrastructure for Infrastructure-based Connected Vehicle Applications: Review of Current Status and Future Directions" was selected to be featured in the Editor's Choice section of the *Journal of Infrastructure Systems* page in the ASCE Library. (December 4, 2019)
- Dr. Joseph Burgett, C²M² affiliated researcher, Clemson University, completed and published his 2018 funded project report, "Unmanned Aircraft Systems (UAS) Impact on Operational Efficiency and Connectivity." (December 19, 2019)
- Dr. Mizanur Rahman, C²M² Assistant Director, and two C²M² supported graduate students represented our Center and demonstrated our ongoing research related to cybersecurity, and connected and automated vehicles at the U.S. Department of Transportation's (USDOT) booth at the Consumer Electronics Show (CES) in Las Vegas, NV. (January 7-9, 2020)
- More than 30 C²M² sponsored researchers and affiliated students attended the 2020 99th Annual Transportation Research Board (TRB) Conference in Washington D.C. and presented papers and posters on their C²M² sponsored research, as well as presiding over committee meetings and sessions. (January 12-16, 2020)



- Dr. Dimitra Michalaka, C²M² Associate Director, The Citadel, presented at the ASCE South Carolina (SC) section, Eastern Branch luncheon meeting. Her presentation covered The Citadel transportation and mobility research in SC and beyond, and the findings of the C²M² project "Assessing the potential of bike share networks and active transportation to improve urban mobility, physical activity and public health outcomes in South Carolina." (January 10, 2020)
- Dr. Yu Qian, C²M² affiliated researcher, University of South Carolina, partnered with Operational Lifesaver, Inc. to advocate for railroad safety at the USC Engineering Open House (EOH). (February 15, 2020)
- Dr. Morgan Hughey, C²M² affiliated researcher, College of Charleston has completed the following presentations related to her C²M² sponsored project: Hughey, S.M., Leen, K., Bornstein, D., Brown, K., Davis, J. Quantifying physical activity levels and patterns for the bike share system in Charleston, SC in 2018. This presentation was given at the Active Living Conference, Orlando, Florida. (February 2-5, 2020)
- Dr. Jennifer Ogle, C²M² affiliated researcher, Clemson University, presented a research brief with the South Carolina Department of Transportation (SCDOT) Research Office to share the results of her research and to impress the need for focused countermeasures at urban/suburban midblock crossings and along rural two-lane roads. SCDOT requested the preparation of a self-paced training media to share the information. (February 2020)
- Dr. Nathan Huynh, C²M² Associate Director, University of South Carolina, and his co-authors have published a paper (accepted for publication) in the Transportation Research Record (TRR) journal.
Badyal, V., Ferrell, W., Huynh, N., Padmanabhan, B. A Multi-Period Optimization Model for Siting Capacitated Intermodal Facilities (Accepted March 2020).
- Dr. Dimitris Rizos, C²M² affiliated researcher, University of South Carolina, published the following paper in the Transportation Research Record (TRR) journal.
Byraju, S., Rizos, D.C., and Qian, Y.; "Satellite Radar Imagery for Detection and Monitoring of Geohazards" Transportation Research Record, <https://doi.org/10.1177/0361198120910746> (First Published March 5, 2020)
- Dr. Wayne Sarasua, C²M² affiliated researcher, Clemson University, completed and published his 2017 funded project report titled, "Active Traffic Monitoring Through Large Scale Processing of Aerial Camera Array Networks." (March 6, 2020)
- Dr. Gucan Comert, C²M² Associate Director, Benedict College, completed and published his 2017 funded project report titled, "Adaptive Signal Control Algorithms for Connected Vehicles." (March 31, 2020)

1.4 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 notable transportation researchers whose talks will be made available via webinar and announced on our social media platforms. Currently, we have scheduled the following webinars (Ongoing).
 - Ivan Lichtenstein, of Georgia Department of Transportation, scheduled to speak on April 2, 2020.



- Dimitra Michalaka, of The Citadel, scheduled to speak on April 3, 2020.
- Gurcan Comert, of Benedict College, scheduled to speak on April 3, 2020.
- Mac Devine, of IBM, scheduled to speak on April 10, 2020.
- Carla Bailo, of the Center for Automotive Research (CAR), scheduled to speak on April 17, 2020.
- Brian Smith, of the University of Virginia, scheduled to speak on May 1, 2020. (Rescheduled due to COVID-19 for TBD, Fall 2020)
- Lily Elefteriadou, of the University of Florida, scheduled to speak on May 27, 2020.
- Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, Clemson University, is continuing to work with Clemson University Facilities on expanding his South Carolina - Connected Vehicles Testbed (SC-CVT) from Perimeter Road to the entire Clemson University campus, which includes real-time traffic monitoring, pedestrian safety warning, and signal-vehicle coordination systems. (Ongoing)
- C²M² will participate in the 2021 Countdown to Success - NASA STEM Fair (postponed due to COVID-19). 1500 high school students from Dorchester, Berkeley, and Charleston counties in South Carolina have been invited to participate in a day of STEM demonstrations. (March 3, 2021)
- Dr. Nathan Huynh, C²M² Associate Director, University of South Carolina, proposed and organized a panel titled "Autonomous Vehicle Platooning and Security" for the 2020 SC EPSCoR State Conference on April 3, 2020 (postponed due to COVID-19).
- C²M² will send research proposals from our Spring 2020 Call for Proposals out for blind review, and then meet to select projects for funding in this round. (May – June 2020)
- C²M² is launching a six-week-long, online computer programming course titled, “C²M² Coders.” This pilot program is aimed at female students enrolled in South Carolina colleges. It will be led by Clemson University and offered to our partner institutions via webinar. (May 11, 2020)
- C²M² supported students and researchers (Samia Akter, Md Mahmud Hasan Mamun, Judith Mwakalonge, Saidi Siuhi, Gurcan Comert) poster “Application of Attribution Theory to Predict Drivers’ Cognitive Behavior at Highway Intersection” was selected for presentation at the ASCE International Conference on Transportation & Development (ICTD 2020), Seattle, Washington (postponed due to COVID-19). (May 26 – 29, 2020)
- Dr. Yuche Chen, C²M² affiliated researcher, University of South Carolina, was invited to present his findings from his C²M² funded project “Data-Driven Multimodal Transportation Energy Consumption Prediction and Analysis Framework for Sustainable Transit and Transportation Planning” at the TRB Transportation Health Symposium (postponed due to COVID-19). (Summer, 2020)
- C²M² expects to see the remaining final reports from our 2017 round of funded projects listed below to be published in April and May of 2020.
 - “Assessment of Safety Benefits of Technologies to Reduce Pedestrian Crossing Fatalities at Midblock Locations,” Jennifer Ogle, P.I., Clemson University
 - “Real-Time and Secure Analysis of Pedestrian Data for Connected Vehicles (CVs),” Amy Apon, P.I., Clemson University
 - “Uncertainty Quantification of Cyber Attacks on Intelligent Traffic Signals,” Jim Martin, P.I., Clemson University



- The remaining C²M² researchers who received funding approval in the 2018/2019 round of funded projects will begin to complete their research and begin publishing their final reports. (Ongoing -2020)
- Dr. Gurcan Comert, C²M² Associate Director, Benedict College, is leading the effort to develop a connected and autonomous systems laboratory at Benedict College. They are in the process of obtaining sensors, computers, and other equipment for the laboratory. (Ongoing - 2020)
- Dr. Gurcan Comert, C²M² Associate Director, Benedict College, will present “Prediction Model for Energy Consumption in Heavy-Duty Vehicle Formations,” in the 2020 IISE Annual Conference, New Orleans, LA” (canceled due to COVID-19). (May 30-June 01, 2020)
- Dr. Gurcan Comert, C²M² Associate Director, Benedict College, is presenting “Simulation-Optimization Platooning Model for a Fleet of Commercial Autonomous Trucks, Proceedings of the 2020 IISE Annual Conference, New Orleans, LA” (canceled due to COVID-19). (May 30-June 01, 2020)
- Two papers related to Dr. Burak Eksioglu’s, C²M² affiliated researcher, Arkansas University, research project, “Framework for Accommodating Emerging Autonomous Vehicles,” were accepted for publication.
 - Liu, D., Eksioglu, B., Schmid, M., Huynh, N., Comert, G.; “Simulation-Optimization Platooning Model for of a Fleet of Autonomous Trucks”, Proceedings of the 2020 IISE Annual Conference.
 - Schmid, M., Liu, D., Eksioglu, B., Huynh, N., Comert, G.; “Prediction Model for Energy Consumption in Heavy-Duty Vehicle Formations”, Proceedings of the 2020 IISE Annual Conference.

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

2.1 What organizations have been involved as partners?

The C²M² consortium is made up of five South Carolina schools; Clemson University, the lead institution; Benedict College; The Citadel; South Carolina State University; and the University of South Carolina. Benedict College and South Carolina State University are categorized as Historically Black Colleges/Universities. These five schools work together, collaborating on research projects, workshops, developing courses, and supporting 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 C²M² Advisory Board continues to be a vital asset to the success of our center. Our current board is made up of 16 members. To date, we have four industry members, seven members from academia, four members from government agencies, and one member from the local community. This diverse assortment of transportation professionals continues to evolve as we grow and is an integral part of our team. We are working closely with these individuals as we move forward, to increase collaboration with industry and local communities as well as to achieve technology transfer objectives and implement the center’s sustainability plan.



The center also continues to partner with the South Carolina Department of Transportation (SCDOT), which provides data, research collaboration, and in-kind support. In this reporting period, we have begun to work closely with industry partners, i.e., IBM and SoftServe. We have also closely work with Carolinas Alliance 4 Innovation (CA4I), Upstate Mobility Alliance, Greenville County and Charleston County on the pilot deployment of smart city technology developed by our center.

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 followings:

- *College of Charleston, Charleston, South Carolina: research collaboration*
- *City of Columbia Bicycle and Pedestrian Advisory Committee (BPAC), Charleston, South Carolina: research collaboration*
- *Charleston County, Charleston, South Carolina: research collaboration*
- *Charleston Moves, Charleston, South Carolina: research collaboration*
- *SoftServe, Austin, Texas: research collaboration*
- *IBM, Charlotte, North Carolina: research collaboration*
- *Facility Solutions Group (FSG), Perth Amboy, New Jersey: research collaboration, in-kind support*
- *AutonomousStuff, Detroit, Michigan: research collaboration*
- *Holy Spokes, Charleston, South Carolina: data collection, research collaboration*
- *Girl Scouts of Eastern South Carolina, North Charleston, South Carolina: event collaborators*
- *Society of Women Engineers, Lowcountry, South Carolina: event collaborators*
- *Lowcountry STEM Collaborative, Lowcountry, South Carolina: event collaborators*
- *Richland County District, Columbia, South Carolina: event collaborators*
- *Clemson University International Center for Automotive Research (CU-ICAR), Greenville, South Carolina: in-kind support, facilities, collaborative research*
- *Qualtrics, Provo, UT: data collection*
- *TrafficVision, Clemson, South Carolina: equipment, research collaboration, in-kind support*
- *Carolinas Alliance 4 Innovation, Greenville, South Carolina: in-kind support, research collaboration*
- *Greenville County, Greenville, South Carolina: in-kind support, research collaboration*
- *Palmetto Clean Fuels, Columbia, South Carolina: in-kind support, event collaboration*
- *Michelin, Greenville, South Carolina: research collaboration*
- *AT&T, Greenville, South Carolina: research collaboration*
- *Facilities Solutions Group, Austin, Texas: research collaboration, conference support*
- *Carolinas Alliance 4 Innovation, Greenville, South Carolina: conference support, research collaboration*
- *Upstate Mobility Alliance Greenville, South Carolina: research collaboration*



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

The Outputs listed in this Section of our Semi-Annual Progress Report fall solidly into the categories as outlined in our Technology Transfer (T²) plan and are listed in the following table and described in the subsections after the table.

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. Output #3 looks at the demonstrations of technology developed by our Center. We set the goal of hosting at least three demonstrations per year. We are pleased to note that we are on track to meet our output goals that we set for our center in the T² Plan, which was created and accepted in the fall of 2018.

No.	Goals	Research Performance Measures	Target per year	Completed in this reporting period
Outputs				
Output #1	Disseminate C ² M ² 's research results to a large audience utilizing different research distribution media	Number of technical reports published	5	5
		Number of conference presentations	20	19
		Number of peer-reviewed papers published	10	5
		Number of conferences solely based on C ² M ² 's research	1	1
Output #2	Develop new methods or products based on C ² M ² 's research	Number of new and/or improved research methods or products	10	4
Output #3	Demonstrate developed technologies	Number of pilot demonstrations of technology	3	5



3.1 Output#1: C²M²'s research results dissemination

Technical Reports

1. Mwakalonge, J., Mamun, M. M. H., Hong, J.D., Chowdhury, M., (2019), "Infrastructure and Policy Needs for Personal Electric Mobility Devices in a Connected Vehicle World." Center for Connected Multimodal Mobility (C²M²) Final Report, 66 pages.
2. Comert, G., Darko, S., Huynh, N., Mwakalonge, J., Elijah, B., Eloise, Q., (2019), "Impact of Transportation on Air Quality at Elementary and Middle Schools in South Carolina." Center for Connected Multimodal Mobility (C²M²) Final Report, 34 pages.
3. Burgett, J. M., Bausman, D. C., Comert, G., (2019), "Unmanned Aircraft Systems (UAS) Impact on Operational Efficiency and Connectivity." Center for Connected Multimodal Mobility (C²M²) Final Report, 86 pages.
4. Sarasua, W., Zhao, X., Davis, W. J., (2020), "Active Traffic Monitoring through Large Scale Processing of Aerial Camera Array Networks." Center for Connected Multimodal Mobility (C²M²) Final Report, 33 pages.
5. Comert, G., Chowdhury, M., Rahman, M., Khan, Md., Z., (2020), "Adaptive Signal Control Algorithms for Connected Vehicles." Center for Connected Multimodal Mobility (C²M²) Final Report, 30 pages.

Conference Presentations

1. Chowdhury, M.; Security of Connected and Automated Vehicles in a Cyber-physical System Environment. Lecturn presentation at the 3rd Annual C²M² Fall Conference. (Clemson, SC) October 18, 2019
2. Michalaka, D.; Assessing the Potential of Bike Share Networks and Active Transportation to Improve Urban Mobility, Physical Activity and Public Health Outcomes in SC. Lecturn presentation at the 3rd Annual C²M² Fall Conference. (Clemson, SC) October 18, 2019
3. Huynh, N.; Tool to Access Effectiveness of Intermodal Facility Location and Carrier Collaboration," Lecturn presentation at the 3rd Annual C²M² Fall Conference. (Clemson, SC) October 18, 2019
4. Mwakalonge, J.; Infrastructure and Policy Needs for Personal Electric Mobility Devices in the Connected Vehicle World," Lecturn presentation at the 3rd Annual C²M² Fall Conference. (Clemson, SC) October 18, 2019
5. Islam, M. and Chowdhury, M.; Evaluation of Adversarial attack on Autonomous Vehicle. Poster presentation at the 3rd Annual C²M² Meeting, Clemson, SC. October 18, 2020
6. Ziehl, P.; Presentation at ACI 437 Committee Session for Strength Evaluation of Existing Concrete Structures. Lecturn presentation at the ACI Fall Convention. (Cincinnati, OH) October 20-24, 2019
7. Badyal, V., Ferrell, W., Huynh, N., Padmanabhan, B.; A Multi-Period Optimization Model for Siting Capacitated Intermodal Facilities. Lecturn presentation at Transportation Research Board meeting (Washington, DC). January 2020



8. Jin, W., Haidary, T., Bausman, D., Chowdhury, M.; Evaluation of Project Development Process at State Transportation Agencies. Poster presentation at Transportation Research Board meeting (Washington, DC). January 2020
9. Khan, S., Chowdhury, M.; Situation Aware, Left Turning Connected and Automated Vehicle Operation at Signalized Intersections. Poster presentation at Transportation Research Board meeting (Washington, DC). January 2020
10. Comert, G., Khan, Z., Rahman, M., Chowdhury, M.; Grey Systems-Based Traffic Queue Length Prediction Models for Adaptive Traffic Signal Control Systems. Poster presentation at Transportation Research Board meeting (Washington, DC). January 2020
11. Islam, M., Rahman, M., Khan, S., Chowdhury, M., Deka, L.; Development and Performance Evaluation of a Connected Vehicle Application Development Platform. Lectern presentation at Transportation Research Board meeting (Washington, DC). January 2020
12. Guo, F., Qian, Y., Wang, Y., Rizos, D., Wang, S., Yu, .; Real-Time Traffic Congestion Assessment and Decongestion Time Prediction at Grade Crossing for the First Responders. Lectern presentation at Transportation Research Board meeting (Washington, DC). January 2020
13. Huynh, N.; Intermodal Freight Terminal Design and Operations Committee. Lectern presiding presentation at Transportation Research Board meeting (Washington, DC). January 2020
14. Byrraju, S., Rizos, D., Qian, Y.; Satellite Radar Imagery for Detection and Monitoring of Geohazards: Three Case Studies. Lectern presentation at Transportation Research Board meeting (Washington, DC). January 2020
15. Huynh, N.; Impact of Tariffs and Supply Chain Realignment on Intermodal Terminals. Lectern presiding presentation at Transportation Research Board meeting (Washington, DC). January 2020
16. Chen, Y., Nelson, C.; Environmental Analysis Research Topics Subcommittee, ADA10(2). Committee presiding at Transportation Research Board meeting (Washington, DC). January 2020
17. Uddin, M., Huynh, N.; Model for Collaboration Among Carriers in Domestic Intermodal Freight Transport. Poster presentation at Transportation Research Board meeting (Washington, DC). January 2020
18. Huynh, N.; Contemporary Issues in Intermodal Freight Terminal Design and Operations. Presiding over poster presentation at Transportation Research Board meeting (Washington, DC). January 2020
19. Hughey, M.; Quantifying Physical Activity Levels and Patterns for the Bike Share System in Charleston, SC in 2018. Lectern presentation at the Active Living Conference. (Orlando, Florida) February 2-5, 2020



Peer-Reviewed Publications

1. Islam, M., Rahman, M., Khan, S. M., Chowdhury, M., Deka, L.; Connected Vehicle Application Development Platform (CVDeP) for Edge-centric Cyber-Physical Systems. *Accepted for publication in the Journal of Transportation Research Record (TRR)*.
2. Islam, M., Rahman, M., Chowdhury, M., Comert, G., Sood E. D., and Apon, A.; Vision-based Personal Safety Messages (PSMs) Generation for Connected Vehicles. *IEEE Transactions on Vehicular Technology*. DOI: 10.1109/TVT.2020.2982189
3. Anay, R., Lane, A., Jáuregui, D., Weldon, B., Soltangharaei, V., and Ziehl, P.; On-Site Acoustic-Emission Monitoring for Assessment of a Prestressed Concrete BT-54 AASHTO Girder Bridge, *Journal of Performance of Constructed Facilities*, 34(3), 04020034.
4. Badyal, V., Ferrell, W., Huynh, N., Padmanabhan, B.; A Multi-Period Optimization Model for Siting Capacitated Intermodal Facilities Accepted for publication in the journal, *Transportation Research Record (TRR)*. (Accepted March 2020).
5. Byraju, S., Rizos, D.C., and Qian, Y.; Satellite Radar Imagery for Detection and Monitoring of Geohazards *Transportation Research Record*, <https://doi.org/10.1177/0361198120910746> (First Published March 5, 2020)

3.2 Output#2: New methods and products

1. Connected Vehicle Application Development Platform (CVDeP): Researchers at Clemson University (Led by Dr. Mashrur “Ronnie” Chowdhury) have developed software packages for a scalable and secure connected vehicle (CV) application development platform (CVDeP) that enables CV application developers to build, debug, and test CV applications in real-time. One can develop their connected vehicle applications and deploy the applications directly in the edge-centric CPS, which is South Carolina Connected Vehicle Testbed (SC-CVT), via the Graphical User Interface (GUI) of our application development interface. We have published the source code of the CVDeP in the “GitHub” open-source platform so that it can be used by any external users (GitHub link: <https://github.com/mahfuz195/CVDEP>). We have also performed usability testing internally through user feedback. Currently, C²M² partner institutions are also using CVDeP for their C²M² funded project. As the software is open to use for external organization, feedback from the external organization is expected through the GitHub maintenance page. Furthermore, as the authors published the source code of the CVDeP in the GitHub, any external users can use it and contribute to expanding the utility of CVDeP by adding more modules.
2. Pedestrian detection under varying lighting conditions: Researchers at Clemson University (Led by Dr. Jennifer Ogle) have developed a method for comparing pedestrian detection technologies under varying lighting conditions at distances from 25’ to 300’. An infrared camera and a night vision camera were tested without streetlights in low moonlight conditions. Pedestrians were dressed in a variety of clothing from bio-motion suits (most detectable) to full black clothing (least detectable). Image analysis comparisons are provided for two camera types.



3. Integrated Two-stage Model for Intermodal Terminal Location and Operational Decisions: Researchers at the University of South Carolina and Clemson University (Led by Dr. Nathan Huynh) have developed a two-stage model and application framework for strategic decisions of intermodal terminal location and operational decisions of carrier collaborations. The two above-mentioned processes are physically separated in the real-world. Therefore, this problem can be modeled as a two-stage model.
4. Strategic Model for Intermodal Terminal Location Problem: Researchers at the University of South Carolina and Clemson University (Led by Dr. Nathan Huynh) have developed a model to determine the number and location of intermodal terminals (IMTs) that minimize the total relevant transportation and operational costs, given a set of constraints like ensuring all pickup/delivery demands to/from customers are met, budget, and a limited set of candidate IMT locations.

3.3 Output#3: Technology demonstrations

1. Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, and his research team (Dr. Mizanur Rahman, Mr. Mhafuzul Islam, and Mr. Zadid Khan) demonstrated “Connected and Automated Vehicle Technology Demonstration,” at the 3rd Annual C²M² Fall Conference, Clemson, SC, on October 18, 2019
2. Dr. Joseph Michael Burgett, C²M² affiliated researcher, demonstrated “Unmanned Aircraft Systems for Bridge Inspection,” at the 3rd Annual C²M² Fall Conference, Clemson, SC, on October 18, 2019
3. Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, and his research team (Dr. Mizanur Rahman, Mr. Mhafuzul Islam, and Mr. Zadid Khan) “South Carolina Connected Vehicles Testbed (SC-CVT) Technology Demonstration,” Demonstrated for David Bruemmer of the Adaptive Motion group, Clemson, SC, November 15, 2019
4. Dr. Mashrur “Ronnie” Chowdhury’s, C²M² Director, research team (Dr. Mizanur Rahman, Mr. Zadid Khan and Mr. Hsien-Wen Deng) demonstrated “Security Technologies for Connected and Automated Vehicles,” at the 2020 Consumer Electronic Show (CES), Las Vegas, NV, on January 7, 2020
5. Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, and his research team (Dr. Mizanur Rahman, Mr. Mhafuzul Islam, Mr. Zadid Khan, Mr. Sabbir Salek, and Mr. Hsien-Wen Deng) demonstrated “Connected and Automated Vehicle Technology and South Carolina Connected Vehicles Testbed (SC-CVT) Technology Demonstration,” to the Michelin, CU-ICAR, and Charleston County Council representatives, Clemson, SC, February 4, 2020

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

C²M²'s website was updated 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.



The C²M² YouTube account was updated as needed by Ms. Charlotte Ryggs, C²M² Program Coordinator. Two new distinguished speaker videos were added and Ms. Ryggs is currently editing six additional videos to be added in the next reporting period. Our YouTube channel can be found at www.youtube.com/channel/UCITo_BgCYEijH_PTU3vPFOw

3.5 Technologies or techniques

1. Dr. Richard Brooks developed software-defined networking (SDN) based real-time communication system as part of his ongoing sponsored project. This allows communications between processes on different onboard units (OBUs).
2. Drs. Nathan Huynh and Robert Mullen have developed a Convolutional Neural Network (CNN) using MATLABR2019b to count and classify six different classes of vehicles. Also, a background subtraction algorithm was developed based on a Gaussian Mixture Model to separate the moving objects from the background. The developed CNN has been trained and validated using over half of millions of images extracted from SCDOT traffic video recordings.

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

1. C²M² Future Leaders Program was developed and launched in February, 2020. Each session of the eight-week program students learned from various industry professionals the skills it takes to become a leader, focusing on the different aspects that it takes to move forward in their education and career to make an impact on the future of transportation. Sessions focused on practical skills such as how to be an effective writer/speaker, what makes a good leader, real-world examples from professionals in the transportation industry, and opportunities for students to improve their presentation skills.
2. Dr. Jennifer Ogle developed a course module to showcase the use of safety data for defining problems related to non-motorized transportation users for Clemson's Master of Transportation Safety Administration program core curriculum.
3. Drs. Nathan Huynh and Robert Mullen have developed a vehicle image database for model training and validation by other researchers. This database will be published on the C²M² website and made available for researchers upon request.



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

In this reporting period, we published four final reports from our 2017 round of funded projects and one from our 2018 round of funded projects. In the coming reporting period, the remainder of our 2017 funded research projects will be completed and their results will be disseminated. We also expect to see the majority of our 2018 round of funded projects complete their research and submit their final reports in the coming reporting period. As we see the majority of our projects have completed, we expect to be able to report multiple journal publications, databases, workshops/training programs, and transportation engineering curriculum to disseminate their results. We also expect to see a larger adoption of our research results in the coming reporting period as our researchers will have had more time to market their research to potential stakeholders.

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 to develop at least four new technologies and/or processes each year.

No.	Goals	Research Performance Measures	Target per year	Completed in this reporting period
Outcomes				
Outcome #1	Train the current and future transportation workforce to operate in an increasingly high-tech environment	Number of training events and workshops	2	2
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	4	2
Outcome #3	Improve technologies and/or processes in addressing transportation issues	Number of improved technologies and/or processes disseminated from C ² M ² funded research projects	4	2



4.1 Outcome #1: Training for workforce development

1. Dr. Mashrur “Ronnie” Chowdhury, Director of C²M² and Dr. Mizanur Rahman, Assistant Director of C²M², hosted a one-day planning workshop in Greenville, SC for the “Engineering Research Center for Computer And Network Resiliency and Security for Transportation (CAN-RESIST),” as part of our National Science Foundation Engineering Research Center Planning grant. This grant was submitted through C²M² and aligned with the center’s goals. (November 7, 2019).
2. Dr. Mizanur Rahman, C²M² Assistant Director, along with Md Mhafuzul Islam and Md Zadid Kahn, C²M² supported Clemson Ph.D. students, traveled to Orangeburg, South Carolina to conduct a connected and autonomous vehicle (CAV) training workshop to South Carolina State University (SCSU) students and faculty. A total of nine students and faculty attended the workshop. This training workshop was entitled “Connected and Automated in the Transportation Cyber-Physical Systems” and was hosted by Dr. Judith Mwakalonge, C²M² Associate Director, SCSU. (March 2, 2020).

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

1. Dr. Mashrur “Ronnie” Chowdhury and his research team have developed a unique risk-predictive on-ramp merging using the Bayes’ theorem merging strategy for autonomous vehicles merging from on-ramp to the freeway. Compared to the existing gap acceptance models, the risk-based model produces higher safety benefits in the majority of comparison scenarios since it has higher time-to-collision (TTC) and lower Time Exposed Time-to-Collision (TET). Also, this risk-based model has better efficacy in most of the comparison scenarios since it has a relatively lower merging-decision time.
2. Dr. William Ferrell and his research team developed an operational model using a Mixed Integer Linear Program (MILP) for the Less than Truckload (LTL) carrier collaboration under centralized planning. It will optimally allocate jobs in the common pool to each carrier in the alliance by determining the optimal vehicle routes for each carrier to serve both retained and allocated jobs (model is referred to as carrier collaboration vehicle routing problem with pickup and delivery or CCVRPPD). To solve the CCVRPPD, a new insertion algorithm was developed for a large neighborhood search (LNS) heuristic.

4.3 Outcome #3: Improvement of technologies

1. Dr. Mashrur “Ronnie” Chowdhury and his research team have developed a strategy for dynamically changing the video compression level, using the error-bounded lossy compression (EBLC) technique, depending on different environmental conditions (such as rain, dark and cloudy) in order to maintain a high pedestrian detection accuracy. This EBLC-based strategy can reduce the communication bandwidth usage of a video feed, which allows more video streaming through a fixed bandwidth. Furthermore, dynamic EBLC significantly reduces the storage requirements to archive videos for offline analysis.
2. Dr. Mashrur “Ronnie” Chowdhury and his research team have developed a software that improves cyberattack detection for in-vehicle network. This software can detect the presence



of an attack by analyzing the in-vehicle network data frames in real-time. The software shows an overall improvement of 3% in accuracy over baseline detection models.

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

At the time of this reporting period, ten C²M² funded reports have been published in total. It is still too early to see quantifiable impacts as the result of our sponsored research. Now that we are reaching the completion of our first and second round of funded projects, we hope to see broader adoption of our research and a measurable impact of our research on the effectiveness of the current transportation system.

In our Technology Transfer 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	Target per year	Completed in this reporting period
Impacts				
Impact #1	Increase the adoption of new technologies, methods or practices based on C ² M ² 's research	Number of cases of adoption by transportation agencies and/or commercialization of C ² M ² 's technologies, methods or practices	2	0
Impact #2	Improve transportation system operations and/or transportation safety and/or quality of life	Number of cases of C ² M ² '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	2	0

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

At the time of reporting, we are nearing the completion of our first and second round of funded research projects, however, at this time we do not have any impacts to report. We expect to see future impacts as these two rounds wrap up and our researchers can develop workshops, courses, and training



modules based on their results for our consortium institutions, State DOTs, Technical Colleges, and transportation professionals as well.

Currently, Dr. Nathan Huynh is utilizing the models and experimental data generated from his project “Tool to Access Effectiveness of Intermodal Facility Location and Carrier Collaboration,” for the course ECIV 790, Intermodal Freight Transport, at the University of South Carolina. This course will be taught in the fall of 2020. It will be covered under the topic “freight network design and analysis.” Dr. Huynh has also secured additional funding from the SCDOT to develop a tool that the agency can use to process videos and provide a summary report of the number of types of vehicles observed over 24 hours based on his “Data Fusion to Improve the Accuracy of Multi-Modal Traffic Counts,” project.

Dr. Joseph Burgett is working with the SCDOT to develop a training module on the use of unmanned aircraft systems for bridge inspection based on his completed 2018 C²M² project.

We expect to see a tangible impact from the development of these two projects and the adoption of their results.

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?

At this time, we have two completed projects that we believe will create an impact on the body of scientific knowledge, they are:

1. “Unmanned Aircraft Systems (UAS) Impact on Operational Efficiency and Connectivity”
2. “Adaptive Signal Control Algorithms for Connected Vehicles”

The first project explored a new ways of land surveying and bridge inspection using UAS and explored the benefits of UAS technology when deployed at the SCDOT, specifically focused on the areas land surveying and bridge inspection. The second project explored grey systems for developing short-term queue length prediction models for adaptive signal control systems in a connected vehicle environment. Both are very new techniques that have not yet been the subject of much academic study.

5.4 What is the impact on transportation workforce development?

As with previous reporting periods, our biggest impact on workforce development comes from our supported students. We currently have several students preparing to defend their doctoral dissertations based on the research they completed under C²M² funded projects. One former student has accepted a post-doctoral research position at the University of California, Berkeley, California and another has accepted a faculty position at the University of Alabama, Tuscaloosa, Alabama. Our minority-serving partner affiliates are supporting 11 students through C²M² funded projects and expanding their laboratories and course offerings. For example, Benedict College has continued to develop its “Connected and Automated Vehicles Systems Laboratory” to further support the research that is taking



place there and to promote collaboration between engineering majors. This lab is being used in collaboration with their Computer Science and Mathematics departments.

C²M² launched a “Future Leaders Program” aimed at helping our students to develop real-world leadership skills and plan to offer this program again in the fall 2020. We are currently developing a six-week-long computer programming course, called C²M² Coders, which will start on May 11, 2020.

Clemson University has continued to offer its “Connected and Automated Vehicle Technologies in the Transportation Cyber-Physical Systems” workshop to its partner institutions, providing a half day workshop for SCSU students and faculty.

Drs. Mashrur “Ronnie” Chowdhury, C²M² Director, and Mizanur Rahman, C²M² Assistant Director, have continued partnering with both Greenville and Charleston counties, in South Carolina, to help deploy smart city technology to ease congestion, and improving transportation safety.

Drs. Dimitra Michalaka, C²M² Associate Director and William J. Davis, C²M² Co-Associate Director, are working with the City of Charleston in South Carolina, the South Carolina Department of Transportation (SCDOT) and several bike rental companies to improve mixed-use road safety in Charleston, South Carolina.

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

Due to the currently evolving COVID-19 situation, all C²M² affiliated partner institutions have closed their campuses and moved all courses, programs, events and research meetings online when possible, and postponed or canceled activities that cannot be conducted online. At this time, it is still too early to know how long these actions will be necessary, and to what extent they will affect our ongoing work and future goals. However, the C²M² leadership team is holding bi-weekly check-in calls to monitor progress, and each Associate Director is coordinating with their institution and research team to maintain our Center’s forward progress.

6.3 Changes that have a significant impact on expenditures

Nothing to report

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

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

In this reporting period, five final reports have been created and published on 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 USDOT established deadline.