



# Center for Connected Multimodal Mobility (C²M²)

## Semi-Annual Progress Report # 6

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**Center Director:**

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Benedict College





## 1. Goals and Accomplishments - What was done? What was learned? What is next?

### 1.1 What are the major goals 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, 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.

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, private partners, and the public sector
- 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, 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 for different systems in a smart city)
- Developing innovations to improve the 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 to meet the goals that were set for our center.

- C<sup>2</sup>M<sup>2</sup> Directors continued their bi-weekly conference calls to coordinate the Center’s activities and budget. (Ongoing)
- Dr. Mashrur “Ronnie” Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, Dr. Sakib Khan, C<sup>2</sup>M<sup>2</sup> Assistant Director, and Ms. Charlotte Ryggs, C<sup>2</sup>M<sup>2</sup> Program Coordinator, and Center met with Clemson University students daily to coordinate Center-related activities. (Ongoing)
- Dr. Mashrur “Ronnie” Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, and Dr. Sakib Khan, C<sup>2</sup>M<sup>2</sup> Assistant Director meet weekly with a team led by the Clemson University International Center for Automotive Research (CU-ICAR) to work on the OPEN CAV CU-ICAR project. This OPEN CAV project is the result of a collaboration of researchers who acquired a connected and automated vehicle and associated simulation software with the support from Clemson University to further vehicle automation research in a transportation cyber-physical system environment. C<sup>2</sup>M<sup>2</sup> is a founding partner of OPEN CAV. (Ongoing)
- Dr. Mashrur “Ronnie” Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, and Ms. Charlotte Ryggs, C<sup>2</sup>M<sup>2</sup> Program Coordinator, continued to take part in the planning committee for the 7th Annual UTC Conference for the Southeastern Region to be held in Boca Raton, Florida, planned for Spring 2022 (postponed until March 24-25, 2022, due to COVID-19). (Ongoing)
- Dr. Mashrur “Ronnie” Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, Dr. Sakib Mahmud Khan, C<sup>2</sup>M<sup>2</sup> Assistant Director, and Ms. Charlotte Ryggs, C<sup>2</sup>M<sup>2</sup> Program Coordinator, continue to coordinate with Minsik Lee, IBM, on Quantum Artificial Intelligence (Q-AI) Lab activities and possible IBM support for future Q-AI activities. (Ongoing)
- Dr. Sakib Mahmud Khan, C<sup>2</sup>M<sup>2</sup> Assistant Director, is taking part in the organization of the 2021 ASCE T&DI Series titled, “AI Enabled Next Generation Transportation Systems” (Virtual). (Ongoing)
- A collaborative team of researchers and students are currently using the C<sup>2</sup>M<sup>2</sup> Q-AI lab facilities to work on three collaborative transportation cyber-physical systems projects and meet bi-weekly to discuss progress. (Ongoing)
- In this reporting period, C<sup>2</sup>M<sup>2</sup> continued the Distinguished Speaker Series, where notable scholars from within the transportation community are invited to speak to faculty and students on a range of multimodal transportation-related topics. These events are broadcast as webinars to all partner institutions within the C<sup>2</sup>M<sup>2</sup> consortium and any other interested participants. These talks are recorded and then posted to our Youtube channel and website. In this reporting period, Clemson University has hosted the following Distinguished Speakers:
  - William Ferrell, Clemson University, and Nathan Huynh, University of South Carolina, presented their work on “Freight Logistics and Intermodal Network Design,” on April 2, 2021



- Bing Li, Clemson University International Center for Automotive Research, presented his work on “Computer Vision and AI-Based Wayfinding for Blind or Visually Impaired Travelers,” on June 4, 2021.
- Jesus M. de la Garza, Clemson University, presented “Keys to Successful NSF Proposals,” on August 31, 2021
- Haiying “Helen” Shen, University of Virginia, presented her work on “Black-box Adversarial Attacks for Deep Driving Maneuver Classification Model,” on September 3, 2021
- Mohammed Atiquzzaman, University of Oklahoma, presented his work on “Connected and Autonomous Vehicles,” on September 10, 2021
- In this reporting period, the Clemson branch of C<sup>2</sup>M<sup>2</sup> launched the C<sup>2</sup>M<sup>2</sup> Cyber-Physical Systems (CPS) Frontier Series, to showcase emerging scholars from within the transportation community, inviting them to speak to faculty and students on a range of multimodal transportation-related topics. Like our Distinguished Speaker series, these events are broadcast via webinar to all partner institutions within the C<sup>2</sup>M<sup>2</sup> consortium and any other interested audience. These talks are recorded and then posted to our Youtube channel and website. In this reporting period, Clemson University has hosted the following CPS Frontier Speakers:
  - Mizanur Rahman, University of Alabama, presented his work on “A Physics-based Longitudinal Control Model for Automated Vehicles in a Mixed Traffic Environment,” on May 28, 2021
  - Kweku Brown, The Citadel, presented his work on “Assessing Potential of Bike Share Networks and Active Transportation to Improve Urban Mobility, Physical Activity and Public Health Outcomes in South Carolina,” on June 18, 2021
- C<sup>2</sup>M<sup>2</sup> continued the second C<sup>2</sup>M<sup>2</sup> Coders Course. This year the three-week course was led by Dr. Mashrur “Ronnie” Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, and Dr. Sakib Mahmud Khan, C<sup>2</sup>M<sup>2</sup> Assistant Director, with support from two C<sup>2</sup>M<sup>2</sup>-supported Ph.D. students. Twenty students from our five partner institutions signed up to participate in this year's course. As with last year's offering in this three-week-long course, each participant had a hands-on learning experience with the Python programming language. (April 2021)
- Dr. Mashrur “Ronnie” Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, Dr. Sakib Mahmud Khan, C<sup>2</sup>M<sup>2</sup> Assistant Director, worked with the IEEE ITS Clemson University Chapter to host a “3 Minute Thesis” Competition. A total of 13 students from Clemson University, Benedict College, and South Carolina State University presented their research and competed for cash prizes. (April 16, 2021)
- Dr. Dimitra Michalaka, C<sup>2</sup>M<sup>2</sup> Associate Director, The Citadel, has joined the Cooper River Center for Advanced Studies (CAS) (<https://www.ccsdschools.com/domain/2971>) as a business partner. She has participated in two Engineering Business Partners meetings. The goal of these meetings is to learn more about the mission of the Cooper River Center for Advanced Studies, the Project Lead the Way (PLTW) curriculum (adopted and implemented in the Charleston County School District at the district level), the course offerings, facilities and equipment, certifications, and business partnerships. The role of a Business Partner is (1) to advise and assess specific areas of the pre-engineering program, and make suggestions and recommendations to improve the program, (2) to assist students, instructors, and administrators to carry out the mission of the program, and (3) to advocate



- and promote the pre-engineering program throughout the community. (April 4 -June 15, 2021)
- Dr. Kweku Brown C<sup>2</sup>M<sup>2</sup> Affiliated Researcher, The Citadel, received the 2021 New Faculty Award by The Citadel Faculty Excellence Committee and The Citadel Provost. (April 18, 2021)
  - Dr. Dimitra Michalaka, C<sup>2</sup>M<sup>2</sup> Associate Director, The Citadel, received the 2021 Service Award from The Citadel Faculty Excellence Committee and The Citadel Provost. (April 18, 2021)
  - Dr. Rebekah Burke, Ms. Stephanie Fye, and Dr. William J. Davis, C<sup>2</sup>M<sup>2</sup> Affiliated Researcher, The Citadel, held a student recruiting meeting with Tim Fulford, Dean of Engineering and Construction, Trident Technical College, to improve student support and academic progression in the CTP (2+2) degree programs at The Citadel. (May 6, 2021)
  - Dr. Mashrur “Ronnie” Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, and Dr. Sakib Mahmud Khan, C<sup>2</sup>M<sup>2</sup> Assistant Director, met with Dr. Joachim Taiber, International Transportation Innovation Center, to discuss a collaborative Connected and Automated Vehicle research project. (May 7, 2021)
  - Ms. Charlotte Ryggs, C<sup>2</sup>M<sup>2</sup> Program Coordinator, and Dr. Richard Brooks, C<sup>2</sup>M<sup>2</sup> affiliated researcher, attended and participated in the *South Carolina Small Business Cyber-Security Summit*. Dr. Brooks spoke on the Cyber-Security Panel on his C<sup>2</sup>M<sup>2</sup> funded research. (May 12, 2021)
  - Mr. Frank Ngeni, C<sup>2</sup>M<sup>2</sup> sponsored graduate student, SCSU, attended a virtual GIS Workshop at Clemson Centre for Geospatial Technologies (CCGT), receiving a certificate for completion. (May 18, 2021)
  - Mr. Frank Ngeni, C<sup>2</sup>M<sup>2</sup> sponsored graduate student, SCSU, attended a Data Visualization Workshop at Clemson Centre for Geospatial Technologies (CCGT). (May 26, 2021)
  - Dr. Mashrur “Ronnie” Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, and Dr. Sakib Mahmud Khan, Assistant Director, met with Paul Alongi, Clemson PROMO Group, to create an in-depth multimedia project featuring C<sup>2</sup>M<sup>2</sup>’s Personal Safety Message (PSM) Generation project. This project is one of C<sup>2</sup>M<sup>2</sup>’s foundational projects. (May-August, 2021)
  - Dr. Mashrur “Ronnie” Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, Dr. Sakib Mahmud Khan, C<sup>2</sup>M<sup>2</sup> Assistant Director, and Ms. Charlotte Ryggs, C<sup>2</sup>M<sup>2</sup> Program Coordinator, and our C<sup>2</sup>M<sup>2</sup> Associate Directors held a virtual meeting for our C<sup>2</sup>M<sup>2</sup> Advisory Board. This meeting was held to provide an update on our Center’s overall progress and to discuss future events. (June 2, 2021)
  - Dr. Mashrur “Ronnie” Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, was featured in the *IEEE Spectrum* article, “How Software is Eating the Car” sharing his insight into the need for cybersecurity advancement with the development of connected and automated vehicles. (June 8, 2021)
  - Dr. Mashrur “Ronnie” Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, Dr. Sakib Mahmud Khan, C<sup>2</sup>M<sup>2</sup> Assistant Director, and Ms. Charlotte Ryggs, C<sup>2</sup>M<sup>2</sup> Program Coordinator, attended all sessions of the 2021 CUTC Virtual Summer Meeting. (June 15 & 16, 2021)
  - Dr. Kweku Brown and Cadet John Baker, The Citadel, held a 1-hr Zoom meeting session with High School Students interested in Civil, Environmental & Construction Engineering, focusing on engineering curriculum, enrichment activities, career opportunities, and student leadership. (June 21, 2021)
  - Dr. Dimitra Michalaka, C<sup>2</sup>M<sup>2</sup> Associate Director, The Citadel, Dr. Simon Ghanat, and Cadet Josh Gibson held a 1-hr Zoom meeting session with High School Students interested in Civil,



Environmental & Construction Engineering, focusing on engineering curriculum, enrichment activities, career opportunities, and student leadership. (June 22, 2021)

- Dr. Gurcan Comert, C²M² Associate Director, and Drs. Negash Begashaw, Samuel Darko, and Balaji Iyengar, C²M² affiliated researchers, Benedict College, participated in the Benedict College Summer 2021 “Virtual” Research Institute (SURI). This team mentored a group of 19 students as they researched various topics related to quantum artificial intelligence, cybersecurity, and connected infrastructure. In addition to meeting regularly with their team of advisors to discuss the progress of their research, there were guest lectures from transportation experts, and there was time allocated for students to conduct experiments at the McNair Aerospace Center at the University of South Carolina. (June - July 2021)
- Citadel student Dixon Flowers, a C²M² supported student, received the HARRY McCULLOUGH MIMS, SR. Scholarship. Recipients are chosen based on ability, character, temperament, and personality per traditionally high standards of The Citadel. Preference is given to a rising senior cadet with an average academic record, demonstrating an enthusiastic interest in Civil Engineering as a profession and an interest in highways or transportation and participating in departmental activities. This was first awarded in 1995. (July 2021)
- Dr. Dimitra Michalaka, C²M² Associate Director, The Citadel, taught two virtual week-long summer camps to 8th, 9th, and 10th-grade students. The camps’ theme was “Engineering Around Town” and covered the basics of several engineering majors including civil, mechanical, electrical, computer and software, through lectures, videos, hands-on activities, and use of online software. (July 12-16 and 19-23, 2021)
- Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, Dr. Sakib Mahmud Khan, C²M² Assistant Director, and Ms. Charlotte Ryggs, C²M² Program Coordinator, presented four sessions on C²M²’s research on Connected and Automated Vehicles, Quantum Computing, Artificial Intelligence, and future career opportunities to students participating in Benedict College’s Summer Transportation Institute. (July 13 & 20, 2021)
- Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, Dr. Sakib Mahmud Khan, C²M² Assistant Director, and Ms. Charlotte Ryggs, C²M² Program Coordinator, met with Dr. Vareva Harris, Benedict College, in Clemson, SC, to discuss her role as Conference Chair for our 5<sup>th</sup> Annual Fall Conference, and as part of our C²M² Diversity Council. We also gave Dr. Harris a tour of our lab and SC-CVT Testbed and discussed potential future research collaboration with Benedict College. (July 14 & 15, 2021)
- Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, gave the keynote address for the 2021 SURI Research Symposium. His talk, “Leading the Futures with Breakthrough Research” kicked off this year’s symposium for Benedict College’s SURI program this year. (July 15, 2021)
- Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, worked with Clemson University Facilities to expand his South Carolina - Connected Vehicle Testbed (SC-CVT) to six additional intersections on Perimeter Road and Clemson University campus. This expansion will enable real-time traffic monitoring, pedestrian safety warning, and signal-vehicle coordination systems. (July 16, 2021)
- Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, Dr. Sakib Mahmud Khan, C²M² Assistant Director, and Ms. Charlotte Ryggs, C²M² Program Coordinator, met with Dr. Kenneth Knapp, Director, Center for Cybersecurity, Anderson University to discuss future C²M² collaborative





- training for Anderson University students on the use of cyber-physical systems, and quantum computing. (July 19, 2021)
- Dr. Mashrur “Ronnie” Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, Dr. Sakib Mahmud Khan, C<sup>2</sup>M<sup>2</sup> Assistant Director, and Ms. Charlotte Ryggs, C<sup>2</sup>M<sup>2</sup> Program Coordinator, met with representatives from Leidos and CARMA to discuss collaborating on a future Quantum AI research project. (July 28, 2021)
  - C<sup>2</sup>M<sup>2</sup> Associate Directors met virtually with Dr. Mashrur “Ronnie” Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, Dr. Sakib Mahmud Khan, C<sup>2</sup>M<sup>2</sup> Assistant Director, and Ms. Charlotte Ryggs, C<sup>2</sup>M<sup>2</sup> Program Coordinator, to discuss and select projects for funding from our 2021 Call for Proposals. Of the 13 projects submitted, seven were selected for funding in this round. (August 4, 2021)
  - The following seven research projects were selected by our Board of Directors for funding in this round. Projects began in August or early September of 2021. Of these seven selected projects, four are led by Clemson University, and three are led by USC. Benedict College, the Citadel, and South Carolina State University are collaborating on multiple selected projects. After selection PIs were asked to revise their projects based on their reviews before starting. Projects were approved to start after revisions had been approved by the Center Director. (August – September 2021)

2021 Accepted Proposals		
Project Title	Lead PI	Co-PIs
Building Smarter Cities via Intelligent Asset Management: South Carolina Case Study using IBM Maximo Application	Paul Zielh	Nathan Huynh, Gurcan Comert
Assessment of Contextual Complexity and Risk Using Unsupervised Clustering Approaches with Dynamic Traffic Condition Data Obtained from Autonomous Vehicles	Jennifer Ogle	Hudson Smith, Vijay Bendigeri, Gurcan Comert
Real-time Decentralized Framework for Technology-Enabled Intermodal Freight Transport	Nathan Huynh	William Ferrell, Negash Begashaw, Gurcan Comert
Securing Deep Learning against Adversarial Attacks for Connected and Autonomous Vehicles	Pierluigi Pisu	Gurcan Comert, Negash Begashaw



Multimodal-AI based Roadway Hazard Identification and Warning using Onboard Smartphones with Cloud-based Fusion	Yunyi Jia	Gurcan Comert
A Machine Learning-Assisted Framework for Determination of Performance Degradation Causes and Selection of Channel Switching Strategy in Vehicular Networks	Chin Tser Huang	Pierluigi Pisu, Esmail Abuhdima, Gurcan Comert
A Cloud-based Quantum Artificial Intelligence-supported Truck Platooning Strategy for Safety and Operational	Mashrur Chowdhury	Gurcan Comert, Dimitra Michalaka, Jeff Davis, Kweku Brown, Judith Mwakalonge, Nathan Huynh

- C²M² presented Ms. Fengjiao Zou, C²M² sponsored student, with the C²M² Outstanding Student Leadership Award for her exemplary work as the IEEE ITS Student Chapter President and her involvement in our center-related events. (August 25, 2021)
- C²M² partnered with Dr. Mansoureh Jeihani, Morgan State University, to organize and host a webinar, “Path to Academic Careers for HBCU Students – Panel Discussion.” This webinar featured panel members from five schools and one national lab (Morgan State University, Clemson University, Benedict College, Indiana University – Purdue University – Indianapolis, South Carolina State University, and Argonne National Laboratory), where panel members discussed their experiences attending/working with HBCUs and how they progressed into their careers. The panel discussion was followed by a question-and-answer session and this recording has been posted to our center website and YouTube channel. (August 26, 2021)
- Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, Dr. Sakib Mahmud Khan, C²M² Assistant Director, and Ms. Charlotte Ryggs, C²M² Program Coordinator, met with representatives from the Office of Small Disadvantaged & Business Utilization, and the South Carolina Department of Transportation Minority and Small Business Affairs to discuss the organization of a panel discussion aimed at HBCU students interested in technology startups and launching a business. (September 16, 2021)
- Todd Anderson, C²M² Advisory Board Member, retired from the SC DOT and stepped down from our Advisory Board. (September 24, 2021)
- Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, Dr. Sakib Mahmud Khan, C²M² Assistant Director, and Ms. Charlotte Ryggs, C²M² Program Coordinator, along with Dr. Vareva Harris, and Gurcan Comert, Benedict College, met with representatives from the Center for Connected and Automated Transportation at the University of Michigan to discuss how to improve HBCU engagement and support. (September 30, 2021)

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

- Dr. Dimitris Rizos, and Sumanth Varma Byrraju, C²M² affiliated researchers, University of South Carolina, presented “Conditions Influencing Mudslides as Seen Through Radar





Coherence Images,” at the Joint Rail Conference (JRC 2021). This presentation was based on Dr. Rizos’s completed 2017 C<sup>2</sup>M<sup>2</sup> funded project. (April 20, 2021)

- Ms. Samia Akter, a C<sup>2</sup>M<sup>2</sup> supported graduate student, Benedict College, presented a paper at the ASCE International Conference on Transportation and Development. (June 8 -10, 2021)
  - Akter, S., Mamun, M. Md. H., Mwakalonge, J., Siuhi, S., Comert, G., “Application of Attribution Theory to Predict Drivers’ Cognitive Behavior at Highway Intersection.”
- Dr. Pierluigi Pisu, C<sup>2</sup>M<sup>2</sup> affiliated researcher, Clemson University, completed and published his 2018 funded project report, “Detection of False Data Injection Attack in Connected Vehicles via Cloud-based Sandboxing.” (May 21, 2021)
- Dr. Dimitra Michalaka, C<sup>2</sup>M<sup>2</sup> Associate Director, The Citadel, presented the C<sup>2</sup>M<sup>2</sup> project “Assessing Potential of Bike Share Networks and Active Transportation to Improve Urban Mobility, Physical Activity and Public Health Outcomes” at the 7<sup>th</sup> Annual International Conference on Transportation/ 11<sup>th</sup> Annual International Conference on Urban Studies & Planning in Athens, Greece. (May 31, 2021)
- Dr. Pamela Murray-Tuite, C<sup>2</sup>M<sup>2</sup> affiliated researcher, Clemson University, completed and published her 2018 funded project report, “Assessment of Autonomous Vehicle Sharing for Evacuation and Disaster Relief.” (June 22, 2021)
- Dr. Nathan Huynh, C<sup>2</sup>M<sup>2</sup> Associate Director, USC, and Dr. Judith Mwakalonge, C<sup>2</sup>M<sup>2</sup> Associate Director, SCSU, Dr. Richard Brooks, C<sup>2</sup>M<sup>2</sup> affiliated researcher, Clemson University, completed their 2018 funded project reports. These final reports are under review and will be published in the next reporting period. (October 2021)
- Dr. Gurcan Comert C<sup>2</sup>M<sup>2</sup> Associate Director, Benedict College, is currently working on revisions to “Part Two” of the final report for his completed 2017 funded project (Uncertainty Quantification of Cyber Attacks on Connected Vehicles and Infrastructure). This report will be reviewed one more time and then published in the next reporting period. (November 2021)

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

- Clemson University’s C<sup>2</sup>M<sup>2</sup> affiliates will continue their Distinguished Speaker Series and C<sup>2</sup>M<sup>2</sup> Cyber-Physical Systems (CPS) Frontier Series. They will be sponsoring notable transportation researchers whose talks will be made available via webinars and announced on our social media platforms. Currently, we have scheduled the following speakers. (Ongoing)
  - Paul Ziehl, University of South Carolina, is scheduled to speak on October 29, 2021.
  - Mhafuzul Islam, General Motors Co., is scheduled to speak TBD, 2022.
  - Chunzhao Guo, Toyota Research Institute, is scheduled to speak TBD 2022.
- Dr. Mashrur “Ronnie” Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, Clemson University, is continuing to work with Clemson University Facilities on expanding his South Carolina - Connected Vehicle Testbed (SC-CVT) from Perimeter Road to the entire Clemson University campus, which will enable real-time traffic monitoring, pedestrian safety warning, and signal-vehicle coordination systems. (Ongoing)



- Dr. Mashrur “Ronnie” Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, Clemson University, is continuing the effort to develop a Quantum-Artificial Intelligence or Q-AI lab at each of our consortium institutions. (Ongoing – 2020 - 2021)
- Dr. Bing Li, C<sup>2</sup>M<sup>2</sup> affiliated researcher, Clemson University International Center for Automated Research (CU-ICAR), has the following publications under review based on his 2020 C<sup>2</sup>M<sup>2</sup> funded project, “Safe and Efficient E-Wayfinding (SeeWay) Guidance for the Transition to Autonomous Vehicles for the Visually Impaired.”
  - J. Brooks, B. Li, C. Jenkins, L. Dylgjeri, Sarathkrishna, A. Ajayan, M. Ghodekar, S. Nikhal, A. Rana, and Z. Yang. "Transportation Preferences, Challenges & Opportunities for Visually Impaired Users." Journal of Visual Impairment & Blindness (JVIB), 2021. (Under-Review)
  - Z. Yang, L. Yang, L. Kong, A. Wei, J. Brooks and B. Li. "SeeWay: Vision-Language Assistive Navigation for the Visually Impaired". IEEE International Conference on Robotics and Automation (ICRA), 2021. (Under-Review)
- Dr. Gurcan Comert, C<sup>2</sup>M<sup>2</sup> Associate Director, Benedict College, has a manuscript under review in conjunction with his 2020 funded project, “Modeling Impact of Weather Conditions on 5G Communication and Mitigation Measures on Control of Automated Intersections.” (Ongoing - 2020-2021)
- Dr. Pamela Murray-Tuite, C<sup>2</sup>M<sup>2</sup> affiliated researcher, Clemson University, is currently developing two journal manuscripts based on her 2018 C<sup>2</sup>M<sup>2</sup> funded project, “Assessment of Autonomous Vehicle Sharing for Evacuation and Disaster Relief.” (Ongoing – 2020 -2021)
- Dr. Nathan Huynh, C<sup>2</sup>M<sup>2</sup> Associate Director, USC, and Dr. William Ferrell, C<sup>2</sup>M<sup>2</sup> affiliated researcher, Clemson University, are currently preparing two manuscripts for publication based on their 2020 funded project, “Improving Freight Transport Mobility and Efficiency via Synchronization.” (Ongoing – 2020-2021)
- Dr. Gurcan Comert, C<sup>2</sup>M<sup>2</sup> Associate Director, Benedict College, had a manuscript with materials from his summer 2021 research “The Effect of Dust and Sand on the 5G Terrestrial Links” accepted to be presented at IEEE WiSEE 2021, Cleveland, Ohio, USA. (October 12 to 14, 2021)
- C<sup>2</sup>M<sup>2</sup> will be holding our Annual Advisory Board Meeting to update our board on center progress, and to discuss future activities. (October 14, 2021)
- C<sup>2</sup>M<sup>2</sup> will be hosting our 5<sup>th</sup> Annual Fall Conference, featuring keynote speaker, Dr. Firas Ibrahim, Director of the USDOT Office of Research Development and Technology, along with an HBCU panel discussion as part of our morning session, and an afternoon of student research presentations and research briefs from our various funded research partners. (October 15, 2021)
- C<sup>2</sup>M<sup>2</sup> will be partnering with the South Carolina Research Authority and Office of Small Disadvantaged & Business Utilization to hold a webinar, “Path to Entrepreneurship for HBCU Students.” This panel discussion will feature minority and female small business owners as they discuss their journey to launch a small business. (November 3, 2021)
- C<sup>2</sup>M<sup>2</sup> will be sending multiple students from each of our partner institutions to present this year at the 101<sup>st</sup> Transportation Research Board Annual Meeting. The presentations include two research from the Q-AI lab where faculty members and students from all five universities have collaborated (January 2022)



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

### 2.1 What organizations have been involved as key partners?

The C<sup>2</sup>M<sup>2</sup> 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 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 C<sup>2</sup>M<sup>2</sup> Advisory Board is a vital asset to the success of our center. Our current board is made up of 15 members. To date, we have four industry members, seven members from academia, three members from government agencies, and one member from the local community. In this reporting period, one board member stepped down, but we are working to recruit a replacement board member to cover this vacancy. 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 continued working with our industry partners, i.e., IBM and BMW, on connected vehicle technology to improve movements of people and goods. We have also closely worked with the South Carolina Research Authority (SCRA), and Leidos on the pilot deployment of smart city technology developed by our Center and in the pursuit of sustainable, external funding for our Center. We have also partnered with SCRA and several HBCUs to organize and host multiple webinars aimed at connecting HBCU students with academic and industry partners. The following information shows the location and collaboration type of these partners.

- *IBM, Charlotte, North Carolina*: in-kind support, research collaboration
- *SCRA, Columbia, South Carolina*: research collaboration, event collaborator
- *Leidos/CARMA, Reston, Virginia*: research collaboration, in-kind support

### 2.2 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, our Center has partnered with the following:

- *College of Charleston, Charleston, South Carolina*: research collaboration
- *City of Columbia Bicycle and Pedestrian Advisory Committee (BPAC), Charleston, South Carolina*: research collaboration



- *City of Columbia Planning and Development Department, Columbia, South Carolina:* research collaboration
- *The Citadel STEM Center of Excellence, Charleston, South Carolina:* K-12 event collaboration
- *The Citadel Office of Admissions, Charleston, South Carolina:* K-12 event collaboration
- *Zucker Family School of Education, Charleston, South Carolina:* K-12 event collaboration
- *Swain Family School of Science and Mathematics, Charleston, South Carolina:* K-12 event collaboration, workforce development
- *Engineering Project Lead the Way, Charleston, South Carolina:* event collaboration
- *Holy Spokes, Charleston, South Carolina:* data collection, research collaboration
- *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
- *Gotcha Group, Charleston, South Carolina:* research collaboration, data collection, implementation of research findings
- *As We See It, Greenville, South Carolina:* research collaboration
- *South Carolina School for the Deaf and Blind, Spartanburg, South Carolina:* research collaboration
- *South Carolina Governor's School for Science and Mathematics, Columbia, South Carolina:* K-12 event collaboration, workforce development
- *Visibility Metrics LLC, Chappaqua, New York:* research collaboration, in-kind support
- *Charleston Moves Bicycle and Pedestrian Advocacy Group, Charleston, South Carolina:* research collaboration
- *NVIDIA, Santa Clara, California:* research collaboration
- *Innova EV, Burr Ridge, Illinois:* research collaboration, in-kind support

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

The Outputs listed in this Section 3 of our Semi-Annual Progress Report fall solidly into the categories as outlined in our Technology Transfer (T²) plan and are listed below, first numerically in a table format, and then in-depth below.

In our T² plan, we identified three areas of 'Output' that we would focus on. Output #1 identifies the goals that C²M² set for the dissemination of our research results. We expected to see at least five technical reports published, 20 conference presentations, ten peer-reviewed papers, and one conference held by C²M² annually. Output #2 focuses on new or improved methods created by our researchers. We would like to see at least ten new/improved methods developed by our researchers each year. Our final Output #3 looks at the demonstrations of technology developed by our Center. We set the goal of hosting at least three demonstrations per year. With the release of the Covid-19 vaccine and the loosening of related restrictions, we are starting to plan in-person events again and slowly working to return to pre-Covid levels of activity all while maintaining our increased activities in webinars, workshops, and virtual events to increase our online engagement.



No.	Goals	Research Performance Measures	Target per year	Completed in this reporting period (April 01, 2021 – Sep 30, 2021)	Completed this year (including the Oct 01, 2020 – Mar 31, 2021)
<b>Outputs</b>					
<b>Output #1</b>	Disseminate C²M²'s research results to a large audience utilizing different research distribution media	Number of technical reports published	5	3	4
		Number of conference presentations	20	3	13
		Number of peer-reviewed journal and magazine papers published	10	9	14
		Number of conferences solely based on C²M²'s research	1	0	1
<b>Output #2</b>	Develop new methods or products based on C²M²'s research	Number of new and/or improved research methods or products	10	8	16
<b>Output #3</b>	Demonstrate developed technologies	Number of pilot demonstrations of technology	3	3	4

## 3.1 Output#1: C²M²'s research results dissemination in this reporting period

### *Technical Reports*

1. Pisu, P., Comert, G., Zhao, C.; Detection of False Data Injection Attack in Connected Vehicles via Cloud-based Sandboxing C²M² Final Report. (May 21, 2021)
2. Murray – Tuite, P., Shirley, T., Padmanabhan, B., Huynh, N., Comert, G., Shen, J., Tadesse, H., Wofford, T. Assessment of Autonomous Vehicle Sharing for Evacuation and Disaster Relief C²M² Final Report. (June 22, 2021)
3. Ramesh, A. (2021). Cloud Based Collaborative Road Surface Monitoring Using Deep Learning and Smartphones. MS Thesis, Clemson University.

### *Conference Presentations*



1. Michalaka, D.; "Assessing Potential of Bike Share Networks and Active Transportation to Improve Urban Mobility, Physical Activity, and Public Health Outcomes." 7th Annual International Conference on Transportation/ 11th Annual International Conference on Urban Studies & Planning. (May 31, 2021)
2. Rizos, D., Byrraju, S.V.; "Conditions Influencing Mudslides as Seen Through Radar Coherence Images." Joint Rail Conference (JRC 2021). Virtual presentation (April 20, 2021)
3. Akter, S., Mamun, M. Md. H., Mwakalonge, J., Siuhi, S., Comert, G.; "Application of Attribution Theory to Predict Drivers' Cognitive Behavior at Highway Intersection." ASCE International Conference on Transportation and Development. (June 8-10, 2021)

## **Peer-Reviewed Journal and Magazine Publications**

1. Comert, G., Khan, Z., Rahman, M. and Chowdhury, M. "Grey models for short-term queue length predictions for adaptive traffic signal control." *Expert Systems with Applications*, 185, p.115618. (published online: July 2021)
2. Comert, G., Rahman, M., Islam, M. and Chowdhury, M. "Change point models for real-time cyber attack detection in connected vehicle environment." *IEEE Transactions on Intelligent Transportation Systems*, doi: 10.1109/TITS.2021.3113675, 2021.
3. Rahman, M., Islam, M., Holt, C., Calhoun, J. and Chowdhury, M., 2021. Dynamic error-bounded lossy compression to reduce the bandwidth requirement for real-time vision-based pedestrian safety applications. *Journal of Real-Time Image Processing*, pp.1-15, 2021.
4. Shirley, T., Padmanabha, B., Murray-Tuite, P., Huynh, N., Comert, G. and Shen, J. "Exploring the Potential of Using Privately-Owned, Self-Driving Autonomous Vehicles for Evacuation Assistance." *Journal of Advanced Transportation*, 2021.
5. Zhao, C., Gill, J.S., Pisu, P. and Comert, G. "Detection of False Data Injection Attack in Connected and Automated Vehicles via Cloud-Based Sandboxing." *IEEE Transactions on Intelligent Transportation Systems*, doi: 10.1109/TITS.2021.3090361.
6. Yin, P., Xu, L., Feng, Z., Egorov, A., and Li, B. "PSE-Match: A Viewpoint-Free Place Recognition Method with Parallel Semantic Embedding." *IEEE Transactions on Intelligent Transportation Systems*, 2021.
7. Comert, G., Begashaw, N., and Huynh, N. "Improved grey system models for predicting traffic parameters." *Expert Systems with Applications* 177 (2021): 114972.
8. Comert, G., and Cetin, M. "Queue length estimation from connected vehicles with range measurement sensors at traffic signals." *Applied Mathematical Modelling* 99 (2021): 418-434.
9. Comert, G., and Begashaw, N. "Cycle-to-cycle queue length estimation from connected vehicles with filtering on primary parameters." *International Journal of Transportation Science and Technology* (2021).

## **C<sup>2</sup>M<sup>2</sup> Sponsored Research Conferences**

Nothing to report.





## **3.2 Output#2: New or improved methods and products in this reporting period**

### ***3.2.1 New or improved methods***

1. Dr. Nathan Huynh and his team have developed a trailer-to-door scheduling optimization model at a cross-dock under uncertain inbound trailer arrival times to minimize the tardiness of outbound trailers and make-span. Specifically, it is a mixed-integer programming model which considers features such as soft departure deadlines, scattered inbound trailer arrivals, multiple dock doors, the non-linear penalty for tardiness, and product substitution. To solve this model, they have developed a constructive heuristic to produce good quality starting solutions and then use the population-based simulated annealing (PBSA) metaheuristic to improve the solution quality.
2. Dr. Nathan Huynh and his team have developed a real-time vehicle re-routing model for trucks making pickups and deliveries to/from a cross-dock. The model considers unexpected events that immobilize a pickup vehicle where other trucks need to change their plans and a backup truck needs to be dispatched. To solve the mixed-integer linear program, a modified Golden Ball algorithm (mGB) has been developed.
3. Dr. Gurcan Comert and his team have developed a model that shows the impact of environmental and geometric factors (dust, sand, humidity, visibility, distance), and 5G tower's height, and signal frequency on communication.
4. Dr. Gurcan Comert and his team have developed trigonometric Grey system models that better predict (compared to classic Grey or time series models) short-term (1-5 minute) traffic parameters such as speed, travel time, occupancy, and flow. In model validation, the team used publicly available data from California, Virginia, and Washington.
5. Dr. Gurcan Comert and his team have developed queue length estimation models at traffic signals from probe vehicles with range sensors. If probe vehicles are equipped with range sensors, they will be able to tell if there is another vehicle ahead of them or after which significantly improved the accuracy of the cycle-by-cycle queue length estimations at low market penetration levels.
6. Dr. Gurcan Comert and his team revised the CUSUM algorithm that produces fewer false positives and does not require nonattack data standard deviation to be known. This study showed the efficacy of change point models detecting denial of service, false information, and impersonation attacks.

### ***3.2.2 New or improved products***

1. Dr. Bing Li and his team have developed a software prototype for mobile devices. This is a new methodology of using visual-language artificial intelligence (AI) models in assistive navigation for the visually impaired; it bridges the gaps between language and navigation using visual-language navigation (VLN) models. This is part of Dr. Li's "Safe and Efficient E-Wayfinding" project.



2. Dr. Nathan Huynh and his team have developed a real-time communication interface that allows trucks to communicate with their dispatchers and the cross-dock operator.

### **3.3 Output#3: Technology demonstrations in this reporting period**

1. Dr. Mashrur Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, and C<sup>2</sup>M<sup>2</sup> supported graduate students from Clemson University gave a demonstration on the concepts of machine learning, and the applications of machine learning in autonomous vehicles to the student participants enrolled in the Summer Transportation Institute at Benedict College. (July 13 & 20, 2021)
2. Dr. Mashrur Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, and C<sup>2</sup>M<sup>2</sup> researchers from Clemson University demonstrated technology for our Pedestrian Safety Message (PSM) generation and our South Carolina-Connected Vehicle Testbed for the Clemson CECAS PROMO group. (August 11, 2021)
3. Dr. Mashrur Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, Dr. Sakib Mahmoud Khan, C<sup>2</sup>M<sup>2</sup> Assistant Director, and C<sup>2</sup>M<sup>2</sup> researchers from Clemson University demonstrated our South Carolina-Connected Vehicle Testbed for representatives of Innova EV. (September 21, 2021)

### **3.4 Additional Outputs**

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

C<sup>2</sup>M<sup>2</sup>'s website was updated as needed by Ms. Charlotte Ryggs, C<sup>2</sup>M<sup>2</sup> Program Coordinator. The center's website address is ([cecas.clemson.edu/c2m2](http://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.

The 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).

The C<sup>2</sup>M<sup>2</sup> YouTube account was updated as needed by Ms. Charlotte Ryggs, C<sup>2</sup>M<sup>2</sup> Program Coordinator. Eight new videos were added during this reporting period. Our YouTube channel can be found at [www.youtube.com/channel/UCITo\\_BgCYEjjH\\_PTU3vPFOw](https://www.youtube.com/channel/UCITo_BgCYEjjH_PTU3vPFOw)

Our LinkedIn organization page is updated weekly by Ms. Charlotte Ryggs, C<sup>2</sup>M<sup>2</sup> Program Coordinator, and has seen consistent growth in engagement during this reporting period. It 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)

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

Nothing to report at this time.



## 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 two final reports from our 2018 round of funded projects, and we currently have two more of our 2018 projects with reports in the final review process by the Center staff. We expect to see these reports published in the coming reporting period. The remainder of our 2018 funded research projects should be completed within the next reporting period, and their results will be disseminated at that time. We also expect to see the 2020 round of funded projects start to wrap up and publish their findings in the coming reporting period. We are currently working with our funded researchers to help facilitate the dissemination of multiple journal publications, databases, workshops/training programs, and transportation engineering curriculum to our stakeholders based on their completed projects.

In our T<sup>2</sup> 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 (April 01, 2021 – Sep 30, 2021)	Completed this year (including the Oct 01, 2020 – Mar 31, 2021)
<b>Outcomes</b>					
<b>Outcome #1</b>	Train the current and future transportation workforce to operate in an increasingly high-tech environment	Number of training events and workshops	2	4	12
<b>Outcome #2</b>	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	1	3
<b>Outcome #3</b>	Improve technologies and/or processes in addressing transportation issues	Number of improved technologies and/or processes disseminated from C <sup>2</sup> M <sup>2</sup> funded research projects	4	1	2



## **4.1 Outcome #1: Training for workforce development in this reporting period**

1. Dr. Dimitra Michalaka, C<sup>2</sup>M<sup>2</sup> Associate Director, developed curriculum for a two-week introduction to engineering summer program for students in 8<sup>th</sup> – 10<sup>th</sup> grades in partnership with the South Carolina Governor’s School for Science and Mathematics. (July 2021)
2. Dr. Dimitra Michalaka, C<sup>2</sup>M<sup>2</sup> Associate Director, worked with the South Carolina Governor’s School for Science and Mathematics to develop lessons aimed to introduce K-12 students to transportation engineering. (Summer 2021)
3. Dr. Mashrur “Ronnie” Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, and Dr. Sakib Khan, C<sup>2</sup>M<sup>2</sup> Assistant Director, launched a three-week online computer programming course titled C<sup>2</sup>M<sup>2</sup> Coders. This is the second time that we have offered this course. It was led by Clemson University and offered to our partner institutions via webinar. Participants in this course each had a hands-on learning experience with the Python programming language for developing an automated vehicle application. (March 30- April 13, 2021)
4. Our C<sup>2</sup>M<sup>2</sup> Distinguished Speaker Series and our C<sup>2</sup>M<sup>2</sup> Cyber-Physical Systems Frontiers Series have continued to draw a large audience of researcher, students, and industry members, allowing C<sup>2</sup>M<sup>2</sup> to share our ongoing research efforts with 172 people in this reporting period.

## **4.2 Outcome #2: New deployment-ready technologies, techniques, and practices in this reporting period**

1. Dr. Mashrur “Ronnie” Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, and his team has developed a real-time error-bounded lossy compression (EBLC) strategy to dynamically change the video compression level depending on different environmental conditions to maintain a high pedestrian detection accuracy. This developed technology dynamically selects the lossy compression error tolerances that maintain a high detection accuracy across a representative set of environmental conditions. Analyses reveal that for adverse environmental conditions, the dynamic EBLC technology increases pedestrian detection accuracy up to 14% and reduces the communication bandwidth up to 14 × compared to the state-of-the-practice.

## **4.3 Outcome #3: Improvement of technologies in addressing transportation issues in this reporting period**

1. Dr. Bing Li and his team have developed new visual feature learning for 3D visual recognition, and the state-of-the-art 3D depth prediction learning models as part of a cloud-aided mobile app solution that they are building. This project has revealed significant concerns for the challenges that visually impaired individuals encounter when accessing transportation and identifies the independent traveling concerns of the visually impaired individuals. Dr. Li’s “Safe and Efficient E-Wayfinding” project outputs are working to help mitigate some of these concerns for visually impaired individuals.



## 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?

To date, we have published 17 C<sup>2</sup>M<sup>2</sup> funded reports with an additional three reports under outside review. We continue to see the biggest impact from our Center's investment in our relationship between partner institutions and their surrounding communities through our workshops, webinar series, course development, and collaborative research efforts. We are working hard to facilitate the adoption of and subsequent impacts from our sponsored research on community and state policies soon. Our researchers continue to work to disseminate the results of their sponsored research, working with individuals from industry, city planners, and departments of transportation to improve transportation infrastructure, safety, and legislation at the local, state, and national levels.

In our T<sup>2</sup> 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 (April 01, 2021 – Sep 30, 2021)	Completed this year (including the Oct 01, 2020 – Mar 31, 2021)
Impacts					
Impact #1	Increase the adoption of new technologies, methods or practices based on C <sup>2</sup> M <sup>2</sup> 's research	Number of cases of adoption by transportation and other agencies and/or commercialization of C <sup>2</sup> M <sup>2</sup> 's technologies, methods or practices	2	1	2
Impact #2	Improve transportation system operations and/or transportation safety and/or quality of life	Number of cases of C <sup>2</sup> M <sup>2</sup> '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	3	3



## **5.1 Impact #1: Increase the adoption of new technologies, methods, or practices based on C²M²'s research in this reporting period**

1. Dr. Dimitra Michalaka, C²M² Associate Director, The Citadel, has joined the Cooper River Center for Advanced Studies (CAS) (<https://www.ccsdschools.com/domain/2971>) as a business partner. She has participated in two Engineering Business Partners meetings. The goal of these meetings is to learn more about the mission of the Cooper River Center for Advanced Studies, the Project Lead the Way (PLTW) curriculum (adopted and implemented in the Charleston County School District at the district level), the course offerings, facilities and equipment, certifications, and business partnerships. The role of a Business Partner is (1) to advise and assess specific areas of the pre-engineering program, and make suggestions and recommendations to improve the program, (2) to assist students, instructors, and administrators to carry out the mission of the program, and (3) to advocate and promote the pre-engineering program throughout the community.

## **5.2 Impact #2: Improve transportation system operations and/or transportation safety and/or quality of life in this reporting period**

1. In this reporting period Dr. Dimitra Michalaka, The Citadel, has worked closely with a broad audience of K-12 educators and students (specifically females and minority groups) on a curriculum focusing on transportation engineering concepts, technology applications, educational pathways, and career development opportunities. These activities have built connections and synergies among K-12 and college institutions affiliated with C²M² and our Center works diligently to build upon these relationships to help create a path to engineering for students from K-12 through graduate school and beyond. The student message below, sent after a K-12 program held this summer summarizes the impact that these K-12 programs can have on children:

*"Hi Ms. Michalaka*

*I wanted to Thank you. At first I didn't really think of going this class as a big deal, but after this week I really felt like I had learned so much. You have helped change the way I see engineering. I now realize just how important it is. I definitely have a lot of respect for you and those who are engineers. Before this class, engineering wasn't really a career I wanted to pursue, but after this class I am definitely considering pursuing it. The chances of me pursuing a job in the engineering field has increased drastically. I would most likely pursue Civil Engineering. I really am grateful. This class has been one of the best experiences of my life. You were so nice which encouraged me even more. You are very inspiring. I hope you know that you have inspired us (the class) very much."*

2. Based on the successful launch of our C²M² Quantum Artificial Intelligence Lab at Benedict College, we have begun meeting with individuals at South Carolina State University to discuss a future Quantum AI Lab on their campus. In the interim, students and researchers from all partner institutions are accessing cloud-based computing resources for Quantum AI research.
3. With the support of the USDOT Office of the Assistant Secretary for Research and Technology C²M² has conducted one "Path to Academic Careers for HBCU Students" webinar, a





collaborative effort between C²M² and HBCU representatives around the nation. This webinar was organized in conjunction with the National Transportation Center at Morgan State University and aimed to expose HBCU students to academic opportunities and potential career paths. 56 people participated in our live webinar and the video has been posted to both our website and YouTube channel as a further resource for future students. This collaboration was so successful, that we are currently working with the South Carolina Research Authority on a second “Path to” webinar that will focus on launching a tech startup or business.

## **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**

C²M² is continuing to navigate ever-changing Covid guidelines and restrictions, which have impacted some of our planned in-person events and necessitated adaptability to all planning efforts for this reporting period. At this time most of our in-person gatherings are still postponed or held virtually and travel is not allowed by our partner institutions. To mitigate these challenges the best that we can, C²M² leadership continues to hold bi-weekly check-in calls to monitor progress, and each Associate Director is coordinating with their institution and team to maintain as much forward progress as possible. In this reporting period, we continued to see a decrease in conferences and symposiums where our students and researchers would normally present their research findings.

### **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**

In keeping with reporting requirements, all selected projects for our 2017, 2018, and 2020 rounds of funded projects have been posted on our website and submitted to Transportation Research Board’s (TRB) Research in Progress (RiP) database. These project entries have also been 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, two final reports were 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.