



Center for Connected Multimodal Mobility (C²M²)

Semi-Annual Progress Report # 7

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

Federal Grant number: 69A3551747117

Project Title: Center for Connected Multimodal Mobility (C²M²)

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Submission Date: April 30th, 2022

DUNS#: 0426298

EIN#: 57-6000254

Recipient Organization: Clemson University, Clemson, South Carolina 29634

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

Grant Period: November 30, 2016 – September 30, 2023

Reporting Period: October 01, 2021 – March 31, 2022

Report Term: Semi-annual

Signature of Submitting Official: _____



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?

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 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.

- C²M² Directors from five partner institutions continued their bi-weekly conference calls to coordinate the Center's activities and budget. (Ongoing)
- Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, Dr. Sakib Khan, C²M² Assistant Director, and Ms. Charlotte Ryggs, C²M² Program Coordinator, met with Clemson University students daily to coordinate Center-related activities. (Ongoing)
- Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, Dr. Sakib Mahmud Khan, C²M² Assistant Director, continue to coordinate with Minsik Lee, IBM, on Quantum Artificial Intelligence (Q-AI) Lab activities and possible IBM support for future Quantum Artificial Intelligence (Q-AI) activities for improving mobility of people and goods. (Ongoing)
- A collaborative team of researchers and students are currently using the C²M² Q-AI lab facilities to work on three collaborative transportation cyber-physical systems projects and meet bi-weekly to discuss progress. (Ongoing)
- Dr. Nathan Hyunh, C²M² Associate Director, University of South Carolina, held weekly meetings with two C²M² funded Ph.D. students to track research progress of C²M² 2020 funded project "Improving Freight Transport Mobility and Efficiency via Synchronization." (Ongoing)
- Dr. Gurcan Comert, C²M² Associate Director, Benedict College, held regular meetings with his team who is working on the "Modeling Impact of Weather Conditions on 5G Communication and Mitigation Measures on Control of Automated Intersections" project. (Ongoing)
- Judith Mwakalonge, C²M² Associate Director, South Carolina State University, and her research team members held weekly research meetings every Friday for the C²M² 2020 funded project "Smart Monitoring and Warning System for Road/Lane(s) Closure for Connected and Non-connected Vehicles." (Ongoing)
- Dr. Chin-Tser Huang, C²M² affiliated researcher, University of South Carolina, held regular weekly team meetings for the C²M² funded project "A Machine Learning-Assisted Framework for Determination of Performance Degradation Causes and Selection of Channel Switching Strategy in Vehicular Networks." (Ongoing)
- In this reporting period, C²M² 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 C²M² 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:



- Paul Ziehl, University of South Carolina, presented his work on “Sensors Working with Humans: A Case for Bridges,” on October 28, 2021
- Yunyi Jia, Clemson University – International Center for Automotive Research (CU-ICAR), presented his work on “Cloud-based Collaborative Road Condition Monitoring using In-Vehicle Smartphones,” on December 10, 2021
- Taimi Olsen, Clemson University, presented “Inclusive Teaching for Today’s Engineering and Science Students,” on January 26, 2022
- Elham “Ellie” Masoomkhah, Harvard University, presented her work on “Racist Highways,” on March 11, 2022
- Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, Dr. Sakib Khan, C²M² Assistant Director, and Ms. Charlotte Ryggs, C²M² Program Coordinator, hosted our Annual Advisory Board Meeting to update our board on center progress and to discuss future activities. This meeting was held virtually. (October 14, 2021)
- Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, Dr. Sakib Khan, C²M² Assistant Director, and Ms. Charlotte Ryggs, C²M² Program Coordinator, 5th 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. This year’s conference was Co-Chaired and Co-hosted by Dr. Vareva Harris of Benedict College, who is also our C²M² Diversity, Equity & Inclusion Chair. (October 15, 2021)
- C²M² along with Dr. Vareva Harris, C²M² Diversity, Equity & Inclusion Chair, presented Ms. Pamela Foster with a “Life Long Achievement Award,” for her 36 years spent advocating for civil rights in transportation. This award was presented at our 5th Annual Fall Conference. (October 15, 2021)
- Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, Dr. Sakib Khan, C²M² Assistant Director, worked with Clemson University’s CECAS PROMO group to develop a short video explaining C²M²’s work with Quantum Artificial Intelligence. This video is developed for the inaugural UTC video webinar series hosted by USDOT, and it will be presented to a congressional committee in partnership with the US DOT. (October – December 2021)
- Dr. Davis, C²M² affiliated researcher, The Citadel, has hosted several academic sessions to recruit students, promote degree programs, and provide tour of civil, transportation, environmental, construction engineering labs, classrooms, and computer labs. (October 2021-March 2022).
- C²M² was featured in the ASCE AI Committee in Transportation October 2021 Newsletter. (November 1, 2021)
- C²M² partnered with the South Carolina Research Authority and the Office of Small & Disadvantaged Business Utilization to hold a webinar, “Path to Entrepreneurship for HBCU Students.” This panel discussion featured a welcome from Shelby M. Scales, Director of the Office of Small and Disadvantaged Business Utilization, talks from Hebrew Dixon, Mid South Atlantic Region, Small Business Transportation Resource Center, and Matt Bell, SCLaunch Director, and a panel discussion moderated by Will Cruz, SCLaunch Investment Manager, as well as Minority and Female business owners from around the United States. (November 3, 2021)



- Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, Dr. Sakib Khan, C²M² Assistant Director, and Ms. Charlotte Ryggs, C²M² Program Coordinator participated in the US DOT Public Meeting on Justice40. November 9 & 16, 2021)
- Dr. Sakib Khan, C²M² Assistant Director, and Ms. Charlotte Ryggs, C²M² Program Coordinator, worked with Kimberly Williams from Clemson University’s CECAS PROMO group to re-design our C²M² website. (November – December, 2021)
- Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, Dr. Sakib Khan, C²M² Assistant Director, and Ms. Charlotte Ryggs, C²M² Program Coordinator took a group of Clemson IEEE ITS students to tour Clemson University International Center for Automotive Research and to see the OPEN CAV CU-ICAR project autonomous car that C²M² co-sponsors. This tour was led by Dr. Matthias Schmid, one of our sponsored researchers. (December 1, 2021)
- Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, Dr. Sakib Khan, C²M² Assistant Director, and Ms. Charlotte Ryggs, C²M² Program Coordinator hosted a meeting with representatives from Innova EV, and Clemson University Parking & Transportation Services to discuss a potential collaborative electric shuttle project at Clemson University. (December 16, 2021)
- Mr. Matthew Stanley, Clemson, was selected as our C²M² UTC Student of the Year for his work with Dr. Wayne Sarasua. Matthew was recognized at the CUTC 2022 Winter Awards Banquet. (January 8, 2022)
- Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, and his work on Smart Cities was featured in Clemson University’s IDEAS Monthly. <https://cecas.clemson.edu/ideas/creating-smart-cities-of-the-future/> (January 25, 2022)
- The Citadel hosted the "Introduce a Girl to Engineering" K-12 Outreach event with Girl Scouts of Eastern SC and Society of Women Engineers (SWE). This year's program theme was on Space Exploration, including 3 hands-on design and construction exercises involving 44 Citadel volunteers (36 students, 8 faculty/staff) and 110 Girl Scout participants who received engineering merit badges after the event. (Feb. 27, 2022)
- Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, Dr. Sakib Khan, C²M² Assistant Director, worked with students from Benedict College to compete in the 2022 AT&T HBCU Innovation Challenge. (February 2022)
- C²M² partnered with Dr. Patricia Carbajales and Clemson’s Center for Geospatial Technologies to offer our students at our partner institutions a three week-long GIS Fundamentals Workshop Series. (March – April 2022)
- Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, Clemson University, Co-chaired the planning of and presided over the IEEE ICCVE 2022 Conference. (March 7-9, 2022)
- Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, Dr. Sakib Khan, C²M² Assistant Director, and several sponsored students gave a technology demonstration to students from Ms. Jackson’s Hickory Tavern Middle School class. These students learned about our Pedestrian Safety Message (PSM) generation and our South Carolina-Connected Vehicle Testbed. (March 17, 2022)
- In this reporting period, the Clemson branch of C²M² continued the C²M² 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 C²M² 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:

- Mhafuzul Islam, General Motors, presented his work on “Hybrid Quantum-Classical Machine Learning for Cloud-supported In-Vehicle Cyberattack Detection,” on March 18, 2022
- Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, and Ms. Charlotte Ryggs, C²M² Program Coordinator, took part in the planning committee for the 7th Annual UTC Conference for the Southeastern Region that was held in Boca Raton, Florida. Dr. Sakib Khan, C²M² Assistant Director, and sponsored students participated in the conference. The team demonstrated multiple connected and automated vehicle applications to conference attendees including government officials, faculty members, and students from non-C²M² universities. (March 24-25, 2022)
- C²M² partnered with the South Carolina Research Authority to hold a webinar, “Path to Entrepreneurship for HBCU Students – Business Pitching Contest” as a continuation of our “Path to” webinar series. This contest provided HBCU students to give a three-minute business pitch to a panel of entrepreneurs, with the top three proposals receiving prizes. (March 30, 2022)

1.3 How have the results been disseminated?

- Dr. Gurcan Comert, C²M² Associate Director, Benedict College, presented the findings from his summer 2021 research “The Effect of Dust and Sand on the 5G Terrestrial Links” at the IEEE WiSEE 2021 Conference, Cleveland, Ohio. (October 12 to 14, 2021)
- Dr. Nathan Huynh's, C²M² Associate Director, University of South Carolina, student Vishal Badyal, Clemson University, presented the research poster at the C²M² 5th Annual Fall Conference, Clemson, SC (October 14, 2021).
- Dr. Nathan Huynh's, C²M² Associate Director, University of South Carolina, student Fahim Ahmed, University of South Carolina, presented the research poster at the C²M² 5th Annual Fall Conference, Clemson, SC (October 14, 2021).
- Dr. Nathan Huynh, C²M² Associate Director, USC, completed and published his 2018 funded project report, “Tool to Assess Effectiveness of Intermodal Facility Location and Carrier Collaboration.” (October 18, 2021)
- Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, gave a talk for Florida International University’s Institute of Transportation Engineers and Women’s Transportation Seminar’s student chapters. His talk was titled “*Cyberattack Detection Model Resiliency for AI-Enabled Connected Mobility in Smart Cities.*” (October 29, 2021)
- Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, demonstrated his work on Pedestrian Collision Avoidance technology, our Pedestrian Safety Message (PSM) generation and our South Carolina-Connected Vehicle Testbed for representatives from the US Army and the Clemson VIPR group. (November 2, 2021)
- Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, was invited to present his research titled “Cyberattack Detection Model Resiliency for AI-Enabled Connected Mobility in Smart Cities” in the ASCE workshop “*Artificial Intelligence Enabled Next Generation Transportation Systems,*” as part of the ASCE AI in Transportation Event. (November 4, 2021)



- Dr. Judith Mwakalonge, C²M² Associate Director, SCSU, completed and published her 2018 funded project report, “Attribution Theory and Collisions at Intersections.” (December 12, 2021)
- C²M² sent multiple students from each of our partner institutions to present this year at the 101st 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)
- Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, gave a talk for the NC-CAV Center of Excellence on Connected Autonomous Vehicle Technology Seminar Series. His talk was titled, “*Security and Resiliency of Cyber-Physical Systems for Connected and Automated Transportation Systems.*” (January 28, 2022)
- Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, was a guest speaker for the Clemson University CURI Spring Seminar Series. Dr. Chowdhury discussed his work with Cyber-physical Systems. (March 8, 2022)
- Dr. Gurcan Comert, C²M² Associate Director, Benedict College, Dr. Chin-Tser Huang, C²M² Affiliated Researcher, University of South Carolina, published the following work based on the C²M² 2020 funded project “Modeling Impact of Weather Conditions on 5G Communication and Mitigation Measures on Control of Automated Intersections.”
 - E. M. Abuhdima et al., "Impact of Dust and Sand on 5G Communications for Connected Vehicles Applications," in IEEE Journal of Radio Frequency Identification, doi: 10.1109/JRFID.2022.3161391.
 - E. M. Abuhdima et al., "The effect of Dust and Sand on the 5G Millimeter-Wave links," 2021 IEEE International Conference on Wireless for Space and Extreme Environments (WiSEE), 2021, pp. 60-65, doi: 10.1109/WiSEE50203.2021.9613843.
 - Abuhdima, E.M., Comert, G., Pisu, P., Huang, C.T., Qaouaq, A.E., Zhao, C., Alston, S., Ambrose, K. and Liu, J., 2021. The Effect of Dust and Sand on the 5G Terrestrial Links. arXiv preprint arXiv:2108.09226.
- Dr. Chin-Tser Huang, C²M² Affiliated Researcher, University of South Carolina, and M. Krishnamurthy, presented their work on “Safety Assessment of CACC Vehicles with Faulty Sensors Using SUMO Simulations,” at IEEE SoutheastCon 2022, March 2022, based on C²M² funded project “Modeling Impact of Weather Conditions on 5G Communication and Mitigation Measures on Control of Automated Intersections”

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 C²M² 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)
 - Anton Bezuglov, Valassis, will present his work on “Tuning Personalized Recommendations with the Multi-Armed Bandit Approach,” on April 7th, 2022
 - Zaid Khan, Walmart, Inc. will present his work on "Cybersecurity of connected automated vehicles in transportation cyber-physical systems with artificial intelligence" in a C²M² CPS Frontier Series on April 21st, 2022



- Manveen Kaur, Ph.D. candidate in School of Computing at Clemson University, is scheduled to present her work on "The Design and Validation of an ICN-Enabled Hybrid Unmanned Aerial System" as a C²M² CPS Frontier Series speaker on April 28th, 2022.
- Dr. Mashrur "Ronnie" Chowdhury, C²M² 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, C²M² 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 - 2022)
- Dr. Nathan Huynh, C²M² Associate Director, USC, and Dr. William Ferrell, C²M² 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 – 2020-2022)
- Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, Clemson University, will be speaking on the "Historically Black Colleges and Universities in Transportation Research" panel to discuss our successful partnership with HBCUs. (April 12, 2022)
- Dr. Richard Brooks, C²M² Associate Director, Clemson University, will submit the final report of C²M² funded project "Enhanced DSRC Security".
- Dr. Judith Mwakalonge, C²M² Associate Director, SCSU, will submit the final report of C²M² funded project " Evaluation of Before and After Measures to Curb Distracted Walking".
- Dr. Gurcan Comert, C²M² Associate Director, Benedict College, will submit the final report of C²M² funded project "Modeling Impact of Weather Conditions on 5G Communication and Mitigation Measures on Control of Automated Intersections"
- Dr. Chin-Tser Huang, C²M² Affiliated Researcher, University of South Carolina are preparing a manuscript based on their C²M² funded project "A Machine Learning-Assisted Framework for Determination of Performance Degradation Causes and Selection of Channel Switching Strategy in Vehicular Networks" to be submitted to a journal.
- Dr. Qian Yu, C²M² Affiliated Researcher, University of South Carolina, have submitted the following manuscript to *Expert Systems with Applications*.
 - Liu, Y., Qian, Y.*, Comert, G., and Begashaw, N. (2022). "Mobility Support for Disadvantaged and Disabled Travelers during Pandemic or Similar Situations" *Expert Systems with Applications*. IF=6.954 (Under Review)
- Dr. Bing Li, C²M² affiliated researcher, Clemson University International Center for Automated Research (CU-ICAR), has the following publications under review based on his 2020 C²M² 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, C²M² 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 - 2020-2022)
- Dr. Pamela Murray-Tuite, C²M² affiliated researcher, Clemson University, is currently developing two journal manuscripts based on her 2018 C²M² funded project, "Assessment of Autonomous Vehicle Sharing for Evacuation and Disaster Relief." (Ongoing – 2020 -2022)

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

2.1 What organizations have been involved as key 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 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, Armonk, New York*: 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 C²M² 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, Department of Health & Human Performance, Charleston, SC, collaborative research*
- *Cooper River Center for Advanced Studies, Charleston, South Carolina*
- *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 (October 01, 2021 – March 31, 2022)
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	2
		Number of conference presentations	20	12
		Number of peer-reviewed journal and magazine papers published	10	4
		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	7
Output #3	Demonstrate developed technologies	Number of pilot demonstrations of technology	3	3

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

Technical Reports

1. Huynh, N., Ferrell, W., Padmanabhan, B., and Badyal, V. Tool to Assess Effectiveness of Intermodal Facility Location and Carrier Collaboration C²M² Final Report. (October 18, 2021)
2. Mwakalonge, J., Comert, G., Akter, S., and Siuhi, S. Attribution Theory and Collisions at Intersections C²M² Final Report. (December 10, 2021)



Conference Presentations

1. J. Ogle, "Roadway Contextual Risk Assessment Using Dynamic Traffic Conditions Data Obtained from Autonomous Vehicles." Presentation, ASCE 2021 International Conference on Computing in Civil Engineering (i3CE 2021) (September 12-14, 2021)
2. G. Comert, "The Effect of Dust and Sand on the 5G Terrestrial Links," IEEE WiSEE 2021 Conference, Cleveland, Ohio. (October 12-14, 2021)
3. E. M. Abuhdima G. Comert, P. Pisu, C.T. Huang, A. Elqaoouaq, C. Zhao, S. Alston, K. Ambrose, and J. Liu, "The effect of Dust and Sand on the 5G Millimeter-Wave links," 2021 IEEE International Conference on Wireless for Space and Extreme Environments (WiSEE), pp. 60-65, doi: 10.1109/WiSEE50203.2021.9613843. (October 12-14, 2021)
4. V. Badyal, and N. Huynh, "Real-Time Cross Dock Scheduling Under Uncertain Inbound Trailer Arrival Times", C²M² 5th Annual Fall Conference, Clemson, SC (October 14, 2021).
5. F. Ahmed, and N. Huynh, "Real-Time Vehicle Re-Routing Under Disruption in Cross-Dock Network with Time Constraints", C²M² 5th Annual Fall Conference, Clemson, SC (October 14, 2021).
6. P. Zielh, "An Autonomous Framework Using Digital Twin," ASNT 2021: The Annual Conference, Towards Intelligent Bridge Evaluation, Phoenix, AZ (November 15-18, 2021)
7. R. Majumder, S.M. Khan, F. Ahmed, M.Z. Khan, F. Ngeni, G. Comert, J. Mwakalonge, D. Michalaka, and M. Chowdhury, "Hybrid Classical-Quantum Deep Learning Models for Autonomous Vehicle Traffic Image Classification Under Adversarial Attack," 101st Transportation Research Board Annual Meeting, Washington, D.C. (January 9-13, 2022)
8. M.Z. Khan, S. M. Khan, J. M. Tine, A.T. Comert, D. Rice, G. Comert, D. Michalaka, J. Mwakalonge, R. Majumdar, and M. Chowdhury, "Hybrid Quantum-Classical Neural Network for Incident Detection," 101st Transportation Research Board Annual Meeting, Washington, D.C. (January 9-13, 2022)
9. B. Davis, D. Michalaka, W. Sarasua, P. Murray-Tuite, J. Ogle, F. Zou, M. Stanley, J. Lloyd, and L. Wade, "Site Characterization for Fatal Crashes in South Carolina," Presentation, 101st Transportation Research Board Annual Meeting, Washington, D.C. (January 10, 2022)
10. M. Krishnamurthy, and C.T. Huang, "Safety Assessment of CACC Vehicles with Faulty Sensors Using SUMO Simulations," Proceedings of IEEE SoutheastCon 2022, (March 2022)
11. Y. Jia, and L. Hu, "Multimodal-AI based Roadway Hazard Identification and Warning using Onboard Smartphones with Cloud-based Fusion," 7th Annual UTC Conference for the Southeastern Region, Boca Raton, Florida. (March 24, 2022)
12. Y. Jia, and L. Guo, "Cloud-based Collaborative Road Condition Monitoring using In-Vehicle Smartphone Data," Podium presentation, 7th Annual UTC Conference for the Southeastern Region, Boca Raton, Florida. (March 24, 2022)

Peer-Reviewed Journal and Magazine Publications

1. T. Shirley, B. Padmanabha, P. Murray-Tuite, N. Huynh, G. Comert, and J. Shen, "Exploring the Potential of Using Privately-Owned, Self-Driving Autonomous Vehicles for Evacuation Assistance," *Journal of Advanced Transportation*, vol 2021, Article ID 2156964, doi:10.1155/2021/2156964 (September 25, 2021)
2. M. Islam, M. Chowdhury, Z. Khan and S. M. Khan, "Hybrid Quantum-Classical Neural Network for Cloud-Supported In-Vehicle Cyberattack Detection," in *IEEE Sensors Letters*, vol. 6, no. 4, pp. 1-4, February 2022, Art no. 6001204, doi: 10.1109/LENS.2022.3153931.



3. E. M. Abuhdima, J. Liu, C. Zhao, A. Elqaouaq, G. Comert, C.T. Huang, P. Pisu, and A.H. Nazeri, "Impact of Dust and Sand on 5G Communications for Connected Vehicles Applications," in *IEEE Journal of Radio Frequency Identification*, doi: 10.1109/JRFID.2022.3161391. (March 22,2022)
4. Z. Khan, S. M. Khan, M. Chowdhury, M. Rahman and M. Islam, "Performance Evaluation of 5G Millimeter-Wave-Based Vehicular Communication for Connected Vehicles," in *IEEE Access*, vol. 10, pp. 31031-31042, 2022, doi: 10.1109/ACCESS.2022.3158669. (March 24, 2022)

C²M² Sponsored Research Conferences

- C²M² Fifth Annual Fall Conference held virtually on October 15, 2021

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

3.2.1 New or improved methods

1. Dr. Mashrur "Ronnie" Chowdhury and his team have developed hybrid quantum-classical machine learning models for traffic sign classification. The hybrid quantum-classical machine learning models are found to be resilient against adversarial attacks on the machine learning models compared to the classical-only machine learning model.
2. Dr. Mashrur "Ronnie" Chowdhury and his team have developed hybrid quantum-classical machine learning models to classify freeway incidents using connected vehicle data.
3. Dr. Nathan Huynh and his team have developed a real-time model and heuristics for cross-dock scheduling problem (CDSP) for multiple dock doors and scheduling both inbound and outbound trailers. They have also developed a real-time model vehicle routing problem with cross-dock (VRPCD) under disruption and heuristics for rerouting vehicles after a disruption event. They have synchronized CDSP and VRPCD under disruption by developing a real-time model and heuristics for reoptimizing the truck routing plan and cross-dock unloading/loading plan. A real-time communication interface will allow trucks to communicate with their dispatchers and the cross-dock operator. A cross-dock repair strategy has been introduced, which will help adjust unloading/loading plan to accommodate changes to inbound trucks' arrival times.
4. Dr. Gurcan Comert and his team have created a new link margin model (including path loss for dust and sand) to simulate the effect of dust and sand on the 5G communication channel.
5. Dr. Qian Yu have developed a model to better allocate a fleet to serve disabled and disadvantaged people with transportation need in challenging situations, such as a pandemic. The model can help the government or public agency maximize positive social impact with limited budget.

3.2.2 New or improved products

1. Dr. Chin-Tser Huang and his team created a simulation testbed for measuring the impact of weather on the performance of 5G and LTE channels. The team developed NS3 simulations to collect data about the impact of dust, sand, humidity, visibility, distance, and height of



the installation, on the receive power and throughput of 5G and LTE communication channels. They have installed and configured Mini Link equipment for conducting experiments.

2. Dr. Paul Zielh and his team developed a real-sized finite element (FE) model of single and multiple slabs through ABAQUS finite element software that was validated by the laboratory test results. He and his team also implemented machine learning techniques to classify crack extension on the slabs and load steps.

3.3 Output#3: Technology demonstrations in this reporting period

1. Dr. Mashrur Chowdhury, C²M² Director, and C²M² researchers from Clemson University demonstrated technology for our Pedestrian Safety Message (PSM) generation and our South Carolina-Connected Vehicle Testbed to representatives from the US Army and the Clemson VIPR group. (November 2, 2021)
2. Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, Dr. Sakib Khan, C²M² Assistant Director, and several sponsored students gave a technology demonstration to students from Ms. Jackson’s Hickory Tavern Middle School class. These students learned about our Pedestrian Safety Message (PSM) generation and our South Carolina-Connected Vehicle Testbed. (March 17, 2022)
3. Dr. Sakib Khan, C²M² Assistant Director, and several C²M² students gave a connected vehicle technology demonstration at the 7th Annual UTC Conference for the Southeastern Region that was held in Boca Raton, Florida. (March 24-25, 2022)

3.4 Additional Outputs

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

C²M²'s website was redesigned by Dr. Sakib Khan, C²M² Assistant Director, Ms. Charlotte Ryggs, C²M² Program Coordinator and Ms. Kimberly Williams and re-launched in December. 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.

C²M² launched a new website to showcase the evolution of our HBCU partnerships. This new site can be found at <https://storymaps.arcgis.com/stories/4cd34c0186214825a669dc1c5b38e07c>.

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 by Ms. Charlotte Ryggs, C²M² Program Coordinator. Three new videos were added during this reporting period. Our YouTube channel can be found at www.youtube.com/channel/UCITo_BgCYEjjH_PTU3vPFOw

Our LinkedIn organization page is updated weekly by Ms. Charlotte Ryggs, C²M² 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



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 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 (Oct 01, 2021 – Mar 31, 2022)
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	3
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	1



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

1. Our C²M² Distinguished Speaker Series and our C²M² Cyber-Physical Systems Frontiers Series have continued to draw a large audience of researcher, students, and industry members, allowing C²M² to share our ongoing research efforts with 84 people in this reporting period.
2. Dr. Dimitri Michalaka and The Citadel Civil Engineering Capstone Design have created a 2-semester course sequence "Engineering Infrastructure Required for Electric Vertical Take Off & Landing Vehicles (eVTOLS) at Rock Hill-York County Airport." Team of 4-5 students works collaboratively to learn and apply their skills and knowledge about an exciting and emerging transportation trend called AAM (Advanced Air Mobility). Students engage with practicing professionals throughout the project and present their work to the Capstone Panel at the end of the project.
3. C²M² partnered with Dr. Patricia Carbajales and Clemson's Center for Geospatial Technologies to offer students at our partner institutions a three week-long GIS Fundamentals Workshop Series. Students and faculty members from Benedict College and South Carolina State University participated in the course (March – April 2022)

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

1. Dr. Dimitra Michalaka, The Citadel, and her team have been investigating bike share networks and active transportation modes in South Carolina. They have studied the bike road network around Charleston for developing a method to identify suitable bike roads for the benefit of vulnerable road users.

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

1. Dr. Jenniger Ogle, C²M² affiliated researcher, Clemson University, with her research team, utilized LiDAR technology for building an unsupervised clustering model to estimate roadway environment's complexity. The team also built a 3D visualization model, all based on the C²M² funded project "Assessment of Contextual Complexity and Risk Using Unsupervised Clustering Approaches with Dynamic Traffic Condition Data Obtained from Autonomous Vehicles."



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 C²M² funded reports with an additional three reports under external 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 diligently to facilitate the adoption of and subsequent impacts from our sponsored research on community and state policies. 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 T² plan, we set two goals for the impact that we would like to see as a result of our center’s yearly activities. These goals are to see at least two of our Center’s developed technologies, methods, or practices adopted per year and to track at least two cases where these technologies, techniques/methods, and practices quantifiably improved transportation.

No.	Goals	Research Performance Measures	Target per year	Completed in this reporting period (Oct 01, 2021 – Mar 31, 2022)
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	1
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	2



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

1. Dr. Dimitri Michalaka and The Citadel research team have engaged multiple stakeholders in Charleston area, including Gotcha, City of Charleston, Charleston Moves, SCDOT, local leaders, etc., for the purpose of informing public policy and identifying network improvements, safety concerns/enhancements, and stakeholder communication/empowerment.

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

1. Using our C²M² Quantum Artificial Intelligence Lab at Benedict College, students and researchers from all partner institutions are accessing cloud-based computing resources for Quantum AI research. Both Benedict College and South Carolina State University have continued to adopt the Clemson Smart City Testbed to enhance their in-house research and teaching capacity.
2. In continuation of the collaboration between C²M² and HBCU, we conducted a "Path to Entrepreneurship for HBCU Students - Business Pitching Contest" as a part of the "Path to" webinar series on March 30, 2022. Six participants from Morgan state university, Benedict college, and South Carolina State University presented their business ideas within a three-minute pitching time. We invited three guests as judges who were successful Founders and CEOs of their respective businesses. The Director of the Office of Small and Disadvantaged Business Utilization (OSDBU), Shelby Scales, SC launch director of The South Carolina Research Authority (SCRA), and Matt bell were also present in the webinar. The webinar was attended by a total of 20 audiences. The contestants were judged based on their business idea, approach to the solution, and the identification of the target market. The judges provided insightful feedback from their personal experiences to the participants, which the students found helpful.

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. 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, the completed 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.