



Center for Connected Multimodal Mobility (C²M²)

Semi-Annual Progress Report # 2

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Benedict College





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

1.1 What are the major goals of the program?

C²M²'s mission statement:

Our vision for the Center for Connected Multimodal Mobility (C²M²), a Tier 1 University Transportation Center, is to become a globally recognized multimodal mobility innovation center for moving people and goods, specializing in connectivity, data analytics, automation, and cybersecurity. To achieve this bold vision, our multidisciplinary research team from five leading higher education and research institutions in the state of South Carolina are working together to create and develop new initiatives and inventions by combining our complementary research strengths, our education and workforce development activities, our commitment to diversity, and our expertise in emerging communication and computing technologies.

C²M²'s main goals are to:

- Conduct interdisciplinary research and drive innovation through data science, data-driven computing, seamless vehicle, traveler and infrastructure connectivity, and automation
- Conduct education and workforce development/leadership activities
- Disseminate C²M² knowledge and technologies
- Support complementary collaborations with consortium members, private partners, and the public sector
- Broaden diversity by integrating consortium members' existing diversity programs with the C²M² activities

C²M² intends to meet these goals through the following means:

- Using data, connectivity, automation, and cybersecurity to promote access to opportunities and equity, and assist those with physical and cognitive disabilities, by fostering on-demand mobility services for those unable or unwilling to drive
- Creating strategies to improve the mobility of people and goods, and optimize passenger and freight movement through numerous techniques that will improve vehicle and system performance (e.g., by maximizing existing infrastructure capacity via vehicle-to-vehicle and vehicle-to-infrastructure connectivity)
- Contributing to Smart Cities that collect and process big data, often in real-time. To optimize the transportation system performance (including more intensive use of shared infrastructure)
- Developing innovations to improve multimodal planning and modeling for the movement of both people and goods, using connectivity and data to seamlessly guide transfers between vehicles, infrastructure, and modes
- Assisting regional planning and the setting of transportation priorities through innovations that leverage limited dollars to create large positive impacts (e.g., by using "Big Data" to aid in regional travel demand forecasting efforts)



1.2 What was accomplished under these goals?

In this reporting period, the following tasks were completed in order to meet the goals that were set for our center.

- C²M² Directors continued their bi-weekly conference calls to coordinate the Center's activities, and budget. (Ongoing)
- Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, Clemson University, meets 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, which is the result of a collaboration of researchers who are acquiring a connected and automated vehicle to further vehicle automation research in a transportation cyber-physical system environment. (Ongoing)
- Drs. Jennifer Ogle and Wayne Sarasua, C²M² affiliated researchers, Clemson University, in conjunction with the Clemson University Glenn Department of Civil Engineering NSF RED Grant worked to develop real-world project-based courses to supplement the existing curriculum with a focus on student success in attaining professional formation as engineers. (Ongoing)
- Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, Dr. Mizanur Rahman, C²M² Assistant Director, and Ms. Charlotte Ryggs, C²M² Program Coordinator, are part of the planning committee for the 7th Annual UTC Conference for the Southeastern Region to be held in Boca Raton, Florida on March 26 – 27, 2020. (Ongoing)
- In this reporting period, the Clemson branch of C²M² continued the Distinguished Speaker Series, where notable scholars from within the transportation community are invited to come to Clemson University, Clemson, South Carolina and speak to faculty and students on a range of transportation-related topics. These events are also broadcasted via webinar to the four other partner institutions within the C²M² consortium and any other interested participants. In this reporting period, Clemson University has hosted the following Distinguished Speakers:
 - Michael Hunter of Georgia Institute of Technology (Georgia Tech) presented his work on "Smart City Real-Time Data-Driven Transportation Simulation," (April 2, 2019) – this talk is available in our YouTube Channel
 - Bryant Walker Smith of University of South Carolina presented his work on "Discussing the Laws and Ethics of Autonomous Vehicles," (April 9, 2019)
 - Mac Devine of IBM presented his work on "The Perfect Storm," (July 23, 2019) – this talk is available in our YouTube Channel
- C²M² applied to host the 2021 CUTC Summer Meeting in Greenville, South Carolina. We worked with Shaun Gaines of the South Carolina Transportation Technology Transfer Service (T³S) to create a comprehensive proposal. (May 1, 2019)
- Mr. Bright Elijah, C²M² supported undergraduate student, Benedict College, graduated with a Bachelor of Science (B.Sc.) degree and was accepted into the MS program in Civil Engineering at the South Carolina State University. (May 2019)
- Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, Clemson University, hosted Amanda Ramage, project manager for Charleston County, for a day at Clemson University. She visited the Clemson Transportation Cyber-Physical Systems Laboratory, and Dr. Chowdhury demonstrated C²M²'s connected and automated vehicle technology at the Clemson



University - Connected Vehicles Testbed (CU-CVT). This visit was the beginning of C²M²'s working relationship with Charleston County with the goal of research collaboration on the deployment of smart city technology in Charleston county. (May 24, 2019)

- Md Mahfuzul Islam, a C²M² supported Clemson Ph.D. student in transportation, hosted a week-long summer program for four high school students from the South Carolina Governor's School for Mathematics and Science. The high school students worked on two connected and automated vehicle projects at the Clemson University Transportation Cyber-Physical Systems Laboratory. In addition, Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, Clemson University, presented his ongoing connected and automated vehicle research projects to the students. (June 10 -14, 2019)
- Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, Clemson University, hosted Benedict College's Cyber Security Summer Camp for the second year. 24 high school and middle school students traveled from Columbia, South Carolina to Clemson, South Carolina. Dr. Chowdhury presented his ongoing transportation cybersecurity-related research to the students. The students also visited C²M²'s Clemson University - Connected Vehicle Testbed (CU-CVT) and attended technology demonstrations of cybersecurity related to connected vehicles by Dr. Chowdhury and his research team. (June 12, 2019)
- Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, Clemson University, presented his ongoing research on connected and automated vehicles and its cybersecurity to the representatives from Ford Motor Company at the Clemson University International Center for Automotive Research (CU-ICAR) campus for future research collaboration. (June 13, 2019)
- Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, Clemson University, attended the International Transportation Innovation Center (ITIC) Smart Mobility Workshop Series with TalTech – ISEAUTO AV in Greenville, South Carolina, and presented his C²M² funded research work related to connected and automated vehicles. (June 20-21, 2019)
- Dr. Dimitra Michalaka, C²M² Associate Director, The Citadel, offered a 'Tour of Engineering' week-long (30 hrs) summer camp on engineering at the SC Governor's School of Science and Mathematics (SCGSSM) in Hartsville, South Carolina, to 16 rising 9th and 10th graders. Students learned about engineering and participated in hands-on projects. More specifically, topics covered including what engineers do, types of engineering, necessary skills to be successful as an engineer, in civil engineering, mechanical engineering, computer/software engineering, and sustainability. In civil engineering, the emphasis was given to bridge design and construction, complete streets, multimodal mobility, connected vehicles, and congestion mitigation. Along with the concepts, students were involved with many hands-on activities. They designed a bridge using Bridge Designer 2018 software package, and then they built a bridge and a section of a complete street using K'nex. After that, they built autonomous vehicles using Lego Mindstorm EV3 and program their vehicles to autonomously travel between complete street sections crossing the bridges. Additionally, students participated in a "Curb Your Congestion" challenge where they had to understand how design can meet the needs of different users, how to design a curb management plan, how to develop a financial strategy for supporting the curb space, and how to create a marketing campaign to make citizens aware of the new design. Furthermore, students played board games focused on transportation engineering like "Tokyo Highway" and "Railroad Ink." (June 23-29, 2019)



- Dr. Mizanur Rahman, C²M² Assistant Director, and Ms. Charlotte Ryggs, C²M² Program Coordinator, Clemson University, attended the CUTC Summer Meeting in Norman, Oklahoma. (June 24-26, 2019)
- Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, Clemson University, and two graduate students traveled to Orlando, Florida to attend the 2019 Automated Vehicles Symposium hosted by Southeastern Transportation Research, Innovation, Development & Education Center (STRIDE). While there, these two students presented two posters. (July 15-18, 2019)
- Dr. Gucan Comert, C²M² Associate Director, Benedict College, supervised nine undergraduate students from Benedict College (BC) as they participated in the BC Summer Research Program. In addition, participating students attended multiple workshops on computer programming, cybersecurity, ethics, and presentation preparation. This program culminated with the students presenting posters of their completed research and findings. (June – July 2019)
- Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, awarded the National Science Foundation Engineering Research Center Planning grant titled, “Engineering Research Center for Computer And Network Resiliency and Security for Transportation (CAN-RESIST).” This grant was submitted through C²M² and aligned with the center’s goals. (September 1, 2019)
- Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, and Dr. Mizanur Rahman, C²M² Assistant Director, met Jim Armstrong, Deputy County Administrator Transportation and Public Works of Charleston, and his team to discuss the possible pilot deployment strategy related to smart city technology in Charleston, South Carolina to improve traffic operation, safety and overall quality of life. The Charleston team included the following members: Kristen Hess, Deputy Clerk of Council (NASA team member); Doug Wurster, Project Officer for the CFO (NASA team member); Sunshine Trakas, Construction Project Manager II; Ryan Petersen, Planner III; and Kevin Limehouse, Innovation and Operation Officer. (August 28, 2019)
- Mac Devine of IBM joined our C²M² Advisory Board. (September 2, 2019)
- Drs. Dimitra Michalaka, C²M² Associate Director, William J. Davis, C²M² Co-Associate Director, and Kweku Brown, C²M² affiliated researcher, The Citadel, hosted prospective Citadel students (popularly known on campus as pre-knobs). The ongoing Pre-Knob Program is a unique enrichment and recruiting opportunity for high school students, 16-18 years old, to observe college student life at The Citadel through firsthand observation and engagement. Student recruits (pre-knobs) declare the academic major in which they are interested and spend time at that department when they come for an on-campus visit. Additionally, high school students shadow a civil engineering freshman student and spend the night in The Citadel dormitories (barracks), joining in family-style dining at the campus Mess Hall, and attending engineering classes. The Citadel Department of Civil, Environmental, and Construction Engineering opens its doors to host cohorts of pre-knobs introducing them to the civil engineering profession and allowing students to attend engineering classes. Pre-knobs learn about transportation engineering, see previous highway design projects, learn about research projects, and usually attend a transportation engineering course while visiting the Department. (September 20, 2019)



1.3 How have the results been disseminated?

- Dr. Paul Ziehl, C²M² affiliated researcher, University of South Carolina, presented his research at the “Structural Health Monitoring Workshop” in Columbia, South Carolina. (April 2, 2019)
- Dr. Paul Ziehl, C²M² affiliated researcher, University of South Carolina, along with Drs. Tommy Cousins, Brandon Ross, and Austin Downey, Clemson University, hosted the “Structural Evaluation and Monitoring Workshop,” South Carolina DOT Headquarters, Columbia, South Carolina. (April 2, 2019)
- Dr. Joseph Burgett, C²M² affiliated researcher, Clemson University, presented a paper at the 2019 Associated Schools of Construction Annual Conference. (April 10-13, 2019)
- Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, Clemson University, organized and presented in a session on Big Data Analytics at the EPSCoR/IDEA 2019 State Conference, held in Greenville, South Carolina. (April 12, 2019)
- Dr. Nathan Huynh, C²M² Associate Director, University of South Carolina, completed and published his 2017 funded project report, “Development of a Tool to Assess Effectiveness of Intermodal Facility Locations and Designs.” (April 19, 2019)
- Dr. Robert Mullen, C²M² affiliated researcher, University of South Carolina, completed and published his 2017 funded project report, “Real-Time Classification of Vehicle Types and Modes using Image Analysis and Data Fusion.” (April 22, 2019)
- Dr. Judith Mwakalonge, C²M² Associate Director, South Carolina State University (SCSU) and Md Mahmud H. Mamun, a C²M² sponsored graduate student, attended and presented three papers at the 60th Annual Transportation Research Forum Conference, Washington D.C. (May 2-4, 2019)
- Dr. Dimitris Rizos, C²M² affiliated researcher, University of South Carolina, completed and published his 2017 funded project report, “Railway Right of Way Monitoring and Early Warning System (RailMEWS) Based on Satellite and Aerial Imagery.” (May 3, 2019)
- Dr. Mizanur Rahman, C²M² Assistant Director, Clemson University, represented our center at the CUTC Spotlight Conference in Washington D.C. He presented a poster titled “Digital Multimodal Transportation Infrastructure for Roadway Crash and Congestion Elimination in a Cyber Secure Environment,” to members of Congress and their staff. This presentation detailed the center’s ongoing research and the products that we have been developing in the field of transportation cyber-physical systems for connected and automated vehicles. (May 14, 2019)
- Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, Clemson University, along with Clemson University International Center for Automotive Research (CU-ICAR) affiliates Drs. Pierluigi Pisu, Matthais Josef Al Schmid, and Yunyi Jia met with Heather Reichert, of AutonomousStuff; David Bruemmer, Adaptive Motion Group; and Mac Devine, IBM in Greenville to discuss the deployment of 5G and its relationship to smart infrastructure in Greenville. (May 23, 2019)
- Dr. Eric Morris, C²M² affiliated researcher, Clemson University, completed and published his 2017 funded project report, “Assessing the Experience of Providers and Users of Transportation Network Company Ridesharing Services.” (June 14, 2019)
- Dr. William J. Davis, C²M² Co-Associate Director, The Citadel, gave a keynote Address, “Construction Engineering at The Citadel,” at the Charleston Contractors Association Annual



Scholarship Award Ceremony. The Ceremony attended 40 participants including general contractors, engineers, business leaders, college students, and high school students. (July 1, 2019)

- Md Mahfuzul Islam and Md Zadid Kahn, C²M² supported Clemson Ph.D. students, and Ms. Charlotte Ryggs, C²M² Program Coordinator, traveled to Columbia, South Carolina to conduct a connected and automated vehicle (CAV) training workshop to 11 interested Benedict students and faculty. This workshop was entitled “Connected and Automated Vehicles (CAVs) in the Transportation Cyber-Physical Systems (TCPS).” This workshop was hosted by Dr. Gurcan Comert, C²M² Associate Director, Benedict College. (July 11, 2019)
- Md Mahfuzul Islam and Md Zadid Kahn, C²M² supported Clemson Ph.D. students, presented their research posters titled “Resilient End-to-End Autonomous Vehicle Driving System under Adversarial Attack,” and “In-Vehicle False Information Attack Detection and Mitigation Strategies for Connected and Autonomous Vehicles,” at the 2019 Automated Vehicles Symposium hosted by Southeastern Transportation Research, Innovation, Development & Education Center (STRIDE). (July 15-18, 2019)
- Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, Clemson University, gave a technology demonstration of our Clemson University – Connected Vehicle Testbed (CU-CVT) testbed to a representative from the Federal Highway Administration at Clemson University, South Carolina. (August 13, 2019)
- Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, Clemson University, developed and launched “CE 8930: Autonomous Vehicle Systems,” a Civil Engineering graduate course. This course will provide students with a comprehensive overview of concepts and hands-on experience in various Autonomous Vehicle Systems (AVS) component designs, operations principles, and evaluation tools related to different levels of vehicle automation. (Fall 2019)

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

- Clemson University’s C²M² affiliates will continue their Distinguished Speaker Series and will be sponsoring notable transportation researchers whose talks will be made available via webinar and announced on our social media platforms. (Ongoing)
- Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, Clemson University, is continuing to work with Clemson University Facilities on expanding his Clemson University - Connected Vehicle Testbed (CU-CVT) from Perimeter Road to the entire Clemson University campus, which includes real-time traffic monitoring, pedestrian safety warning and signal-vehicle coordination systems. (Ongoing)
- Dr. Eric Morris, C²M² affiliated researcher, Clemson University, will be appearing on the Rideshare Guy Podcast to discuss the findings of his C²M² supported research project.
- C²M² expects to see the remaining final reports from our 2017 round of funded projects listed below to be published in November and December of 2019.
 - “Impact of Transportation on Air Quality at Elementary and Middle Schools in South Carolina,” Gurcan Comert, P.I., Benedict College
 - “Assessment of Safety Benefits of Technologies to Reduce Pedestrian Crossing Fatalities at Midblock Locations,” Jennifer Ogle, P.I., Clemson University



- “Infrastructure and Policy Needs for Personal Electric Mobility Devices in a Connected Vehicle World, Judith Mwakalonge, P.I., South Carolina State University
- “Active Traffic Monitoring through Camera Networks with Automatic Camera Calibration for Pan-Tilt-Zoom Cameras,” Wayne Sarasua, P.I., Clemson University
- “Real-Time and Secure Analysis of Pedestrian Data for Connected Vehicles (CVs),” Amy Apon, P.I., Clemson University
- “Uncertainty Quantification of Cyber Attacks on Intelligent Traffic Signals,” Jim Martin, P.I., Clemson University
- “Adaptive Signal Control Algorithms for Connected Systems,” Gurcan Comert, P.I., Benedict College
- C²M² researchers who received funding approval in the 2018/2019 round of funded projects will begin to complete their research and begin publishing their final reports. (Ongoing - 2020)
- Dr. Gucan Comert, C²M² Associate Director, Benedict College is leading the effort to develop a connected and autonomous systems lab at Benedict College. (Ongoing - 2020)
- C²M²sponsored researchers and affiliated students will be attending the 2020 Transportation Research Board (TRB) conference in Washington D.C. presenting papers on their sponsored research. (January 2020)
- C²M² researchers are planning to demonstrate their cybersecurity-related technologies on behalf of the U.S. Department of Transportation (U.S. DOT) at the Consumer Electronics Show (CES) in Las Vegas, NV. (January 7 to 10, 2020)
- C²M² will release our third “Call for Proposals” soliciting research proposals for funding. (February 2020)

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

2.1 What organizations have been involved as partners?

The C²M² consortium is made up of five South Carolina schools; Clemson University, the lead institution; Benedict College; The Citadel; South Carolina State University; and the University of South Carolina. Benedict College and South Carolina State University are categorized as Historically Black Colleges/Universities. These five schools work together, collaborating on research projects, workshops, developing courses, and supporting C²M² with financial and in-kind support. Since the creation of this consortium, Clemson’s Board of Trustees approved the creation of the Center for Connected Multimodal Mobility at Clemson University and pledged their support of its ongoing programs.

The C²M² Advisory Board continues to be a vital asset to the success of our center. Our current board is made up of 16 members. To date, we have four industry members, seven members from academia, four members from government agencies, and one member from the local community. This diverse assortment of transportation professionals continues to evolve as we grow and is an integral part of our team. We are working closely with these individuals as we move forward, with the intention to increase collaboration with industry and local communities as well as to achieve technology transfer objectives and implement the center’s sustainability plan.



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

2.2 Have other collaborators or contacts been involved?

Along with the five institutions that make up the C²M² consortium partnership, C²M² has and is collaborating on projects with or received support from the followings:

- *College of Charleston, Charleston, South Carolina: research collaboration*
- *City of Columbia Bicycle and Pedestrian Advisory Committee (BPAC), Charleston, South Carolina: research collaboration*
- *Charleston County, Charleston, South Carolina: research collaboration*
- *SoftServe, Austin, Texas: research collaboration*
- *IBM, Charlotte, North Carolina: research collaboration*
- *Facility Solutions Group, Perth Amboy, New Jersey: research collaboration, in-kind support*
- *AutonomousStuff, Detroit, Michigan: research collaboration*
- *SC Governor's School of Science and Mathematics (SCGSSM), Hartsville, South Carolina: event organizer, in-kind support*
- *Charleston Contractors Association, Charleston, South Carolina: event organizer, facilities provider*
- *Holy Spokes, Charleston, South Carolina: data collection, research collaboration*
- *Girl Scouts of Eastern South Carolina, North Charleston, South Carolina: event collaborators*
- *Society of Women Engineers, Lowcountry, South Carolina: event collaborators*
- *Lowcountry STEM Collaborative, Lowcountry, South Carolina: event collaborators*
- *Richland County District, Columbia, South Carolina: event collaborators*
- *Clemson University International Center for Automotive Research (CU-ICAR), Greenville, South Carolina: in-kind support, facilities, collaborative research*
- *International Transportation Innovation Center (ITIC), Greenville, South Carolina: in-kind support*
- *University of Oregon, Eugene, Oregon: collaborative research, personnel exchange*
- *The Rideshare Guy Blog, Los Angeles, California: personnel exchange*
- *Qualtrics, Provo, UT: data collection*
- *TrafficVision, Clemson, South Carolina: equipment, research collaboration, in-kind support*
- *Carolinas Alliance 4 Innovation, Greenville, South Carolina: in-kind support, research collaboration*
- *Greenville County, Greenville, South Carolina: in-kind support, research collaboration*



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. We are pleased to note that we are on track to meet these goals that we set for our center in the T² Plan, which was created and accepted in the fall of 2018.

No.	Goals	Research Performance Measures	Target per year	Completed in this reporting period
Outputs				
Output #1	Disseminate C ² M ² 's research results to a large audience utilizing different research distribution media	Number of technical reports published	5	4
		Number of conference presentations	20	7
		Number of peer-reviewed papers published	10	8
		Number of conferences solely based on C ² M ² 's research	1	0
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	5
Output #3	Demonstrate developed technologies	Number of pilot demonstrations of technology	3	4

3.1 Output#1: C²M²'s research results dissemination

Technical Reports

1. Huynh, N., Ferrell, W., Padmanabhan, B., Badyal, V., (2019), “Development of a Tool to Assess Effectiveness of Intermodal Facility Locations and Designs,” Center for Connected Multimodal Mobility (C²M²) Final Report, 44 pages.



2. Huynh, N., Mullen, R., Mejia, Y., (2019), “Real-Time Classification of Vehicle Types and Modes using Image Analysis and Data Fusion,” Center for Connected Multimodal Mobility (C²M²) Final Report, 31 pages.
3. Rizos, D., Mullen, R., Byrraju, S., (2019), “Railway Right of Way Monitoring and Early Warning System (RailMEWS) Based on Satellite and Aerial Imagery,” Center for Connected Multimodal Mobility (C²M²) Final Report, 65 pages.
4. Morris, E. A., Pratt, A. N., Zhou, Y., Brown, A., Khan, S., Derochers, J., Campbell, H., Chowdhury, M., (2019), “Assessing the Experience of Providers and Users of Transportation Network Company Ridesharing Services.” Center for Connected Multimodal Mobility (C²M²) Final Report, 154 pages.

Conference Presentations

1. Dr. Paul Ziehl, C²M² affiliated researcher, University of South Carolina, presented his research at the “Structural Health Monitoring Workshop” in Columbia, SC. (April 2, 2019)
2. Dr. Joseph Burgett, C²M² affiliated researcher, Clemson University, presented a paper at the 2019 Associated Schools of Construction Annual Conference. (April 10-13, 2019)
3. Dr. Mashrur “Ronnie” Chowdhury, C²M² Director, Clemson University, organized and presented his research titled, “Big Data Analytics for Future Transportation Systems” at the EPSCoR/IDEA 2019 State Conference in Greenville, SC. (April 12, 2019)
4. Dr. Mizanur Rahman, C²M² Assistant Director, Clemson University, presented C²M²'s connected and automated vehicle-related research titled, “Development of transportation cyber-physical systems (CPS) for connected and automated vehicles (CAVs),” at the University Transportation Centers (UTC) Spotlight Conference in Washington D.C. (May 14, 2019).
5. Dr. William J. Davis, C²M² Co-Associate Director, The Citadel, gave a keynote Address, “Construction Engineering at The Citadel,” at the Charleston Contractors Association Annual Scholarship Award Ceremony. (July 1, 2019)
6. Md Mahfuzul Islam, Ph.D. student, Clemson University, presented his research titled, “Resilient End-To-End Autonomous Vehicle Driving System under Adversarial Attack” at the Autonomous Vehicle Symposium 2019 in Orlando, FL. (July 16, 2019)
7. Md Zadid Khan, Ph.D. student, Clemson University, presented his research titled, “In-Vehicle False Information Attack Detection and Mitigation Strategies for Connected and Autonomous Vehicles” at the Automated Vehicle Symposium in Orlando, FL. (July 16, 2019)

Peer-Reviewed Publications

1. Chowdhury, M., Islam, M. and Khan, Z., (2019), “Security of Connected and Automated Vehicles,” *The Bridge. National Academy of Engineering*, 49(3), pp. 46–56.
2. Islam, M., Chowdhury, M., Li, H., and Hu, H., (2019), “Vision-based Navigation of Autonomous Vehicle in Roadway Environments with Unexpected Hazards,” *Journal of Transportation Research Board: Transportation Research Record*, <https://doi.org/10.1177/0361198119855606>
3. Rahman, M., Islam, M., Calhoun, J., and Chowdhury, M., (2019), “Real-Time Pedestrian Detection Approach with an Efficient Data Communication Bandwidth Strategy,” *Journal of*



Transportation Research Board: Transportation Research Record,
<https://doi.org/10.1177/0361198119843255>.

4. Khan, S.M., Chowdhury, M., Ngo, L.B. and Apon, A., (2019). Multi-class twitter data categorization and geocoding with a novel computing framework. *Cities*, 96, <https://doi.org/10.1016/j.cities.2019.102410>.
5. Morris, E. A., Brown, A., Zhou, Y., Khan, S., Derochers, L., Pratt, A. N., Campbell, H., and Chowdhury, M., (accepted for publication), "Are drivers cool with Pool? Driver attitudes towards the shared TNC services UberPool and Lyft Shared," *Transport Policy*.
6. Mamun, M., Mwakalonge, J., and Siuhi, S., (2019), "Feasibility of Bone Conduction Headphone in Abating Pedestrian Distractions While Walking," 60th Annual Transportation Research Forum Conference, Washington D.C.
7. Adjidjonu, D., and Burgett, J., (2019), "Optimal UAS Parameters for Aerial Mapping and Modeling," 2019 Associated Schools of Construction Annual Conference, Denver, CO.
8. Zhao, X., D. Dawson, and W. Sarasua, (2019), "Multiple Hypothesis Tracking with Kinematics and Appearance Models on Traffic Flow for Wide Area Traffic Surveillance," *Journal of Computing in Civil Engineering*, American Society of Civil Engineers, 33(3), p.04019009.

3.2 Output#2: New methods and products

1. We have developed software-defined networking (SDN) based in-vehicle Ethernet networking system that provides security against false-information attacks on brake-related Electronic Control Units (ECUs) of connected and automated vehicles (CAVs) using machine learning models.
2. We have developed a software-defined networking (SDN)-based radio-access technology (RAT) selection and handover system for heterogeneous wireless networks. This system can ensure the connected vehicle application quality of service (QoS) while not overloading any of the wireless networking options, thus maintaining optimized network operations.
3. We have developed a strategy for monitoring of the right of way of the railroads and the surrounding area for the detection of large and small scale deformations and other triggering events that may lead to landslides and other infrastructure failures using satellite radar images. Radar images are superimposed to aerial images for ease of evaluation, comprehension, and dissemination of the information. The method could supplement or replace existing conventional monitoring techniques.
4. We have developed car and truck detection and classification method from real-time video streams. This method will allow transportation agencies to have their own in-house vehicle classification software.
5. We developed two mathematical programming models that can lead to improved efficiency of future freight transportation in South Carolina in the face of increasing demand and changes in the nature of the freight.



3.3 Output#3: Technology demonstrations

1. Chowdhury, M., Rahman, M., Islam, M. and Khan, Z., “Clemson University Connected Vehicles Testbed (CU-CVT) Technology Demonstration,” Demonstrated for Amanda Ramage of Charleston County, Clemson, SC, May 24, 2019
2. Chowdhury, M., “Clemson University Connected Vehicles Testbed (CU-CVT) Technology Demonstration,” Demonstrated for Benedict College Cyber Security Summer Camp students, Clemson, SC, June 12, 2019
3. Chowdhury, M., Rahman, M., Islam, M. and Khan, Z., “Clemson University Connected Vehicles Testbed (CU-CVT) Technology Demonstration,” Demonstrated for Mac Devine of IBM, Clemson, SC, July 23, 2019
4. Chowdhury, M., Rahman, M., Islam, M. and Khan, Z., “Clemson University Connected Vehicles Testbed (CU-CVT) Technology Demonstration,” Demonstrated for Federal Highway Administration Representative, Jim Garling, Clemson, SC, August 13, 2019

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

C²M²'s website was updated as needed by Ms. Charlotte Ryggs, C²M² Program Coordinator. The center's website address is (cecas.clemson.edu/c2m2). The website outlines the C²M²'s goal, participants, research in progress, and events, both upcoming and past.

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

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

www.youtube.com/channel/UCITo_BgCYEjjH_PTU3vPFOw

3.5 Technologies or techniques

- Researchers at Clemson University have developed software-defined networking (SDN) based in-vehicle Ethernet networking system that provides security against false-information attacks on brake-related Electronic Control Units (ECUs) of connected and automated vehicles (CAVs) using machine learning model. The SDN-based networking system can detect false information attacks in real-time, leading to opportunities in preventing incorrect braking in CAVs and reducing the number of crashes due to cyberattacks on CAVs.
- Researchers at Clemson University have developed software-defined networking (SDN)-based radio-access technology (RAT) selection and handover system for heterogeneous wireless networks. The system identifies the best wireless communication option (access point/base station/Dedicated Short Range Communication enabled Roadside Unit) and pushes handover requests as needed to each connected vehicle (CV) in real-time based on the CV application requirements, currently available network resources, and future traffic conditions. The



developed system can ensure the CV application quality of service (QoS) while not overloading any of the wireless networking options, thus maintaining optimized network operations.

3.6 Inventions, patent applications, and/or licenses

Nothing to report at this time.

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

Data related to Autonomous vehicles

An autonomous vehicle driving dataset was developed through simulation to conduct research on the autonomous vehicle end-to-end driving model. This dataset contains the images from three front cameras along with the data of vehicle location, speed, and steering angle. This dataset can be used in developing an end-to-end driving system of an autonomous vehicle. Using this dataset, we have developed an improved end-to-end driving system, and this research was published in the Transportation Research Record (TRR) journal. We will publish the generated data in the C²M² website for the researchers to do their own autonomous vehicle-related research.

Books chapters

- Physical Activity and Public Health Science, Editors Daniel Bornstein, Amy Eyler, Jay Maddock, Justin Moore, ISBN 9780826134585, Springer Publishing, New York, 2019, coauthored Chapter 14, Parks, Recreation and Physical Activity
- Physical Activity and Public Health Science, Editors Daniel Bornstein, Amy Eyler, Jay Maddock, Justin Moore, ISBN 9780826134585, Springer Publishing, New York, 2019, coauthored Chapter 18, Physical Activity in Urban Settings.

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

In this reporting period, we published four final reports from our 2017 round of funded projects. In the coming reporting period, the remainder of our 2017 funded research projects will be completed and their results will be disseminated. Thus, we will see the completion of our first and a portion of our second rounds of funded projects, as these projects start to wrap-up, and we expect to see a large increase in the production of journal publications, databases, workshops/training programs, and transportation engineering curriculum, and potentially ridesharing services. We also expect to see more adoption of our research results in the coming reporting period as our researchers will have had more time to market their research to potential stakeholders.

In our T² plan, we established three outcome goals for our center to strive towards each year. These goals are to create/host at least two training or workshop events a year; to develop at least four



techniques and practices and offer implementation/deployment guidance for the adoption of these techniques; and to develop at least four new technologies and/or processes each year.

No.	Goals	Research Performance Measures	Target per year	Completed in this reporting period
Outcomes				
Outcome #1	Train the current and future transportation workforce to operate in an increasingly high-tech environment	Number of training events and workshops	2	2
Outcome #2	Incorporate new technologies (software and/or hardware) and/or techniques and/or practices that are deployment ready	Number of new technologies, and/or techniques and/or practices that offer implementation or deployment guidance	4	2
Outcome #3	Improve technologies and/or processes in addressing transportation issues	Number of improved technologies and/or processes disseminated from C ² M ² funded research projects	4	0

4.1 Outcome #1: Training for workforce development

1. Dr. Paul Ziehl, C²M² affiliated researcher, University of South Carolina, along with Drs. Tommy Cousins, Brandon Ross, and Austin Downey, Clemson University, hosted the “Structural Evaluation and Monitoring Workshop,” related to bridge health monitoring at the South Carolina DOT Headquarters, Columbia, SC. (April 2, 2019)
2. Md Mahfuzul Islam and Md Zaidid Kahn, C²M² supported Clemson Ph.D. students, traveled to Columbia, South Carolina to conduct a connected and autonomous vehicle (CAV) training workshop to Benedict College students and faculty. A total of eleven students and faculty attended the workshop. This training workshop was entitled “Connected and Automated in the Transportation Cyber-Physical Systems (TCPS)” and was hosted by Dr. Gurcan Comert, C²M² Associate Director, Benedict College. (July 11, 2019)



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

1. Researchers at Clemson University have demonstrated their software-defined networking (SDN) based in-vehicle Ethernet networking system that provides security against false-information attacks on brake-related Electronic Control Units (ECUs) of connected and automated vehicles (CAVs) using machine learning models. This technology has been demonstrated to both industry members and FHWA representatives.
2. Researchers at Clemson University have demonstrated their software-defined networking (SDN)-based radio-access technology (RAT) selection and handover system for heterogeneous wireless networks. This system demonstration was presented to both multiple industry members.

4.3 Outcome #3: Improvement of technologies

Nothing to report.

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?

In this reporting period, four reports have been published in total. As many of our researchers are only just finishing their work we do not have many quantifiable impacts to report in this reporting period. With the completion of these projects, we intend to encourage and support our researchers in the creation and distribution of training programs and workshops to disseminate the results of their projects and to produce measurable improvements in the effectiveness of our current transportation system.

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
Impacts				
Impact #1	Increase the adoption of new technologies, methods or practices based on C ² M ² 's research	Number of cases of adoption by transportation agencies and/or commercialization of C ² M ² 's technologies, methods or practices	2	0



No.	Goals	Research Performance Measures	Target per year	Completed in this reporting period
Impact #2	Improve transportation system operations and/or transportation safety and/or quality of life	Number of cases of C ² M ² 's research that resulted in societal benefits, such as lives saved, congestion reduced, and fuel conserved through changing behavior, practices, decision making, policies (including regulatory policies), and/or social actions	2	0

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

At the time of reporting, all C²M²'s first round of funded research projects have not been completed, and we do not have any impacts to report. However, we expect to see an impact in the future with the completion of the final projects from our first round C²M² research. We are working towards disseminating the results of this research to develop new courses, workshops, and training programs for our consortium institutions, State DOTs, Technical Colleges, and transportation professionals as well.

With the completion of our “Impact of Transportation on Air Quality at Elementary and Middle Schools in South Carolina” project, we expect the adoption of its finding to impact the planning process for the placement of infrastructure in what is designated as a “sensitive zone.” Having air quality monitoring sensors in sensitive zones, such as work zones, schools, hospitals, and ports, would enable officials to make real-time decisions for the personnel with environmental sensitivities. Moreover, trends over decline or improvement in air quality can be monitored. Measuring such pollutants would also be very important for agricultural industries to monitor levels of pollutants in the air. Adjustments can then be made by State Departments of Transportation (DOTs) or Environmental Protection Agency (EPA) officials to improve trends in air quality. Our analysis results can guide such agencies to select air quality equipment that would meet the requirement of an application and maintain or improve existing air quality. Similar analyses can be used by various agencies, urban planners, and developers to identify suitable locations for K-12 schools and hospitals and to generate environmental policies. For instance, a framework could be designed for real-time school zone emission measurements from similar connected systems allowing the South Carolina DOT to make real-time traffic adjustments to improve air quality.

With the completion of our “Infrastructure and Policy Needs for Personal Electric Mobility Devices (PEMDs) in a Connected Vehicle World” project, we hope this research will improve safety knowledge for the public. We anticipate this research to have an impact on the developing policies related to PEMDs.

In a connected environment, the vehicle transmits data among pedestrians, other motorized vehicles, and infrastructure. As research on vehicle automation and connectivity continues to advance, results from our experiments will aid the design of multimodal connected infrastructure that considers the interaction between vehicles, infrastructure, PEMDs, and pedestrians.



5.2 What is the impact on the adoption of new practices, or instances where research outcomes have led to the initiation of a start-up company?

Nothing to report.

5.3 What is the impact on the body of scientific knowledge?

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

- “Assessing the Experience of Providers and Users of Transportation Network Company Ridesharing Services”
- “Infrastructure and Policy Needs for Personal Electric Mobility Devices in a Connected Vehicle World”

These two specific projects explored two relatively new modes of transportation that have developed in the last few years: ridesharing and personal electric mobility devices (PEMDs). Both are very new phenomena that have not yet been the subject of much academic study. We anticipate that the data collected from these two projects will be the basis for a new avenue of study and will impact the future of ridesharing and PEMDs as well as contributing to further study.

5.4 What is the impact on transportation workforce development?

In this reporting period, we continued to see that our biggest impact on the transportation workforce development comes from our supported students. To date, one of our previously sponsored students has completed his Ph.D. program, and two undergraduate students from one of our minority serving institutions have started graduate programs at other partner schools, utilizing the connections they made in our consortium as undergraduate students.

We have seen an increasing involvement of undergraduate student interest in “Transportation Engineering” through their involvement in sponsored research projects, and anticipate more growth in this area in the next reporting period. These undergraduate students are currently gaining valuable research experience that better prepares them for the demands of graduate programs. Our yearly conference also affords them the opportunity to network with researchers from our affiliated schools and builds a pipeline to graduate programs for them.

In addition, Benedict College is continuing the process of developing a “Connected and Automated Vehicles Systems Laboratory” to further support the research that is taking place there and to promote collaboration between engineering majors. We expect this new lab to increase undergraduate recruitment and involvement in ongoing funded research projects in the coming years.

Clemson University is currently working to refine its new undergraduate curriculum that incorporates professional development with traditional transportation engineering content. The very first Springer course was launched at the beginning of the spring 2019 semester, data collected from this course was then used to refine the second course that has been offered in the fall 2019 semester.



Clemson University is currently offering its “Connected and Autonomous Vehicle Technologies in the Transportation Cyber-Physical Systems” workshop to its partner institutions. We are working to create a workshop model that can then be shared with Technical Colleges, and industry partners as professional development. Once this program has been refined, it will be shared with any interested institutions planning to offer similar training and workshop. We are also closely working with Clemson University Center for Workforce Development (CUCWD) on developing online courses for workforce development.

Drs. Mashrur “Ronnie” Chowdhury, C²M² Director and Mizanur Rahman, C²M² Assistant Director, are currently partnering with both Greenville and Charleston counties, in South Carolina to help deploy smart city technology with the goal of easing congestion, and improving transportation safety.

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

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

In this reporting period, we are still seeing a delay in the completion of C²M² 2017 funded projects. It was anticipated that these projects would be completed by October of 2018 with final reports being submitted in November of 2018; however, their delayed start has continued to impact completion dates. We are continuing to work closely with our researchers and are confident that the remaining 2017 funded projects will be completed within the next reporting period.

PIs of our 2018 round of funded projects were asked to submit quarterly progress reports so that our Center can more closely monitor their progress, and intervene if necessary to keep projects on track to complete by their projected timeline. These quarterly reports have allowed us to better monitor the progress being made on these projects and to troubleshoot issues as they develop.

6.3 Changes that have a significant impact on expenditures

Nothing to report

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

Nothing to report



7. SPECIAL REPORTING REQUIREMENTS

7.1 Research Project Requirements

All funded projects for both our 2017 and 2018 rounds of funded projects have been submitted to Transportation Research Board's (TRB) Research in Progress (RiP) database and subsequently updated as required by OST-R and the Fast Act Grant Deliverables. Each project description includes the project title, brief abstract, project start and completion dates, project status, and funding amount. These submissions also include details of all the sponsoring organizations and research programs contributing to the project, including the Federal sponsor (OST-R) and all non-Federal sponsors as outlined in the Fast Act Grant Deliverables. This information is displayed on our Center website as well. In keeping with these requirements, PIs of all funded projects are also required to obtain an ORCID, which is reported on the TRB RiP database and included in all final reports.

7.2 Submission of Final Research Reports

In this reporting period, four final reports have been created and published on our Center website in its entirety along with the archived data as required by the Fast Act Grant Deliverables. TRB RiP updates and the final submission requirements will be completed within the USDOT established deadline.