



Center for Connected Multimodal Mobility (C²M²)

Semi-Annual Progress Report # 12

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

● 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 systems' 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).



- **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 the five partner institutions continued their bi-weekly conference calls to coordinate the center's activities and budget.
- Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, and Ahmad Zaki Ghafari, C²M² Assistant Director, met with Clemson University (Clemson) C²M² students daily to coordinate center-related activities.
- Dr. Nathan Hyunh, a C²M² affiliated researcher at the University of South Carolina (USC), submitted the final report of the project "Improving Freight Transport Mobility and Efficiency via Synchronization." The report will be published after review.
- Dr. Mashrur "Ronnie" Chowdhury submitted the final report of the project "A Cloud-based Quantum Artificial Intelligence-supported Truck Platooning Strategy for Safety and Operational Performance." The report is under review and will be published soon.
- Dr. Christopher Post, C²M² affiliated researcher at Clemson, submitted the final report of the project, "Intelligent River® Bridge Flood Monitoring System to Improve Transportation Mobility." The report will be published after review.
- Dr. William G. Ferrell, C²M² affiliated researcher at Clemson, submitted the final report of the project, "A Web-Based Tool for Cross Dock Trailer Scheduling." The report will be published after review.
- Dr. Chin Tser Huang, C²M² affiliated researcher at the University of South Carolina (USC), submitted the final report of the project, "Transfer of Technologies for Performance Degradation Prediction and Channel Switching in Vehicular Networks under Harsh Weather Conditions and Integration with State-of-the-Art Products." The report will be published after review.
- Dr. Dimitra Michalaka, C²M² Associate Director at the Citadel, submitted the final report of the project, "Assessing Transportation Infrastructure Segments for Bike Suitability." The report will be published after review.
- C²M² participated in the inaugural Future of Transportation (FoT) Summit hosted by USDOT at its headquarters in Washington, D.C., from August 13-15, 2024. The event focused on transformative research in mobility, safety, infrastructure, sustainability, and cybersecurity conducted at the University Transportation Centers, with funding from the FAST Act and the Bipartisan Infrastructure Law. C²M² personnel were closely involved in the planning and execution of the event. In addition, Dr. Ronnie Chowdhury, C²M² Director, spoke on "Cybersecurity and Resiliency of Transportation Systems and Infrastructure" during one of the two cybersecurity sessions and moderated the other cybersecurity session. In addition, C²M² contributed to outdoor demonstrations and poster sessions. The demonstrations included: 1) Real-time Collision Warning Application Using Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) communication, 2) Vision-based Pedestrian Safety Alert and 3) Low-Cost Flood Monitoring for Bridges. Also, Jian Liu (USC) presented a poster on Performance Degradation Prediction and Channel Switching in a Vehicular Network Under Harsh Weather.



- C²M² hosted its 8th Annual Fall Conference, on August 22nd, 2024, in Columbia, SC. This year's conference was opened by Mashrur "Ronnie" Chowdhury as he provided an overview of the center over the years and its achievements. Dr. Chowdhury's presentation was followed by presentations by each of the C²M² Associate Directors. The highlight of the conference was the keynote speaker, Dr. Michael Hunter, Professor in the School of Civil and Environmental Engineering at Georgia Institute of Technology. Dr. Hunter's research interests are in transportation operations and design, specializing in adaptive signal control, traffic simulation, freeway geometric design, and arterial corridor operations. The afternoon session kicked off with a keynote talk by Dr. Hunter on the uncertain role of emerging technology in transportation. Following the keynote was a technology demonstration session led by C²M² students and researchers, followed by poster presentations. These technology demonstrations and presentations were rated by a panel of judges, and the following students received recognition for best post awards: Ostonya Thomas, Clemson (1st Place), Methusela Sulle, South Carolina State University (SCSU) (2nd Place), and Araf Rahman, Clemson and Joshua Wetmore, the Citadel (3rd Place). The results of the technology demonstration were as follows: Joshua Wetmore, the Citadel (1st Place); Li Ai, USC (2nd Place); and Sefatun-Noor Puspa, Clemson (3rd Place).
- C²M² organized a session entitled "Cybersecurity: Threats and Opportunities" at the annual South Carolina (SC) Established Program to Stimulate Competitive Research (EPSCoR) State Conference on April 9th, 2024, in Columbia, SC. The primary objective of the conference is to unite South Carolina faculty, postdoctoral fellows, graduate and undergraduate students, and STEM professionals, fostering networking and encouraging collaborative efforts.
- Abyad Enan, a Clemson Ph.D. student, won second place in the poster competition at the SC EPSCoR Conference on April 9th, 2024, in Columbia, SC. The conference brought together senior researchers, graduate students, and STEM professionals to facilitate networking and promote collaboration in South Carolina. Abyad had the opportunity to present his work at this prestigious platform, learn from diverse perspectives, and showcase his contributions to the academic community.
- Mr. Paul Omulokoli and Ms. Juliana Chengula, graduate students at SCSU, funded by C²M², completed their graduate school studies on May 15th, 2024.
- Mr. Nabeyou Tadessa, a C²M² student from Benedict College (Benedict), has been selected to participate in the TechWise program, supported by Google. Mr. Tadessa successfully navigated a rigorous four-stage selection process earlier this year and is now part of an elite community of 125 students from across the US chosen for TechWise. This opportunity showcases the exceptional talent at Benedict and the remarkable opportunities available to our students.
- Dr. Dimitra Michalaka was appointed as a member of the ASCE Workforce Development Council.
- Dr. Dimitra Michalaka co-authored the paper "Framework for the Development of a Diverse Transportation Workforce in the Southeast Region," which was selected as the winner of the Charley V. Wootan Award by the Transportation Research Board. This award is given each year for the best paper in transportation policy and organization.



- Undergraduate student Joshua Wetmore won two awards for his presentation on “Connected and Automated Vehicle Technologies and Related Legislation” during the Academic Excellence Day on Friday, April 5th, 2024, at The Citadel:
 - 1st Place in Engineering
 - Best Veteran/Active Duty Student Award
- Dr. Michalaka collaborated with the South Carolina Governor’s School of Science and Mathematics (SCGSSM) and offered two one-week-long summer camps to rising 8th, 9th, and 10th graders. The camp topics and description are presented below:
 - Engineering Adventures at Home*
 - *Instructor:* Dr. Dimitra Michalaka
 - *Grade Level:* Rising 8th, 9th, & 10th
 - *Dates:* June 17-21, 2024
 - *Description:* Does the idea of creating something new excite you? Do you dream of making a positive impact on the world? Unleash your inner engineer by using online software, engaging in hands-on projects, and exploring various engineering disciplines. Whether you want to design amazing structures, invent cool gadgets, or solve problems to help your community, this camp is right for you. Embark on a journey into the exciting world of engineering and become a superhero of change! Participating students will need a computer capable of running the Bridge Designer software.
 - Transportation Engineering Explorers*
 - *Instructor:* Dr. Dimitra Michalaka
 - *Grade Level:* Rising 8th, 9th, & 10th
 - *Dates:* June 24-28, 2024
 - *Description:* Have you ever wanted to look behind the curtain at how our roads and transportation systems are managed? Who or what decides when the traffic signal turns green? Why do some places have bike lanes and nice sidewalks while others don’t? And are we really ready for self-driving cars? Get ready to discover what it means to be a transportation engineer! Throughout the week, we will complete plenty of hands-on activities and group projects while exploring the world of transportation engineering. Join us and dive into the future of how society moves!
- Dr. Dimitra Michalaka, C²M² Associate Director at the Citadel, is collaborating with individuals from the Southern District Institute of Transportation Engineers (SDITE) and South Carolina Section ITE to create a K-12 plan for students in the southeast (SCSITE).
- The Citadel hosted around 800 Richland 2 ALERT students (4th/5th Gifted and Talented students) during the Fall 2024. The students, their teachers, and their chaperones enjoy coming to campus, learning a little about The Citadel, and engaging in hands-on STEM activities. Drs. Michalaka and Doeffinger led three sessions, where students learned about civil engineering and engaged in two hands-on projects using Sphero Indi, and a screenless vehicle robot.



- **How have the results been disseminated?**

- Dr. Jennifer Ogle, C²M² affiliated researcher at Clemson, has completed and published the final report of the project, "A Statistical and Machine Learning Approach to Assess Contextual Complexity of the Driving Environment Using Autonomous Vehicle Data."
- Dr. Dimitra Michalaka presented on "Potential Reduction of Fatal Crashes in South Carolina due to Automated Vehicles" at the Southern District Institute of Transportation Engineers (SDITE) Annual meeting in Wilmington, NC, on April 8th, 2024.
- Dr. Michalaka presented on "Potential Fatal Crash Reduction in South Carolina due to Different Levels of Automated Driving" at the 2024 International Conference on Transportation & Development in Atlanta, GA, on June 17th, 2024.
- Dr. Dimitra Michalaka presented on "Safety and Health Impacts of Mobility Alternatives" at the 2024 International Conference on Transportation & Development in Atlanta, GA, on June 17th, 2024. The presentation focused on three individual projects that fall under the overarching theme of safety and health impact of mobility alternatives. The projects were:
 - Evaluation of Transportation Network Infrastructure, Safety, and Travel Route Characteristics of Bike Share, Electric-Powered Pedal-Assist Bike Share, and Electric Scooter System Operation (STRIDE funded)
 - Assessing Transportation Infrastructure Segments for Bike Suitability (C²M² funded)
 - Potential Reduction of Fatal Crashes in South Carolina due to Automated Vehicles (C²M² funded)
- Dr. Michalaka presented on "Smart Cyber-Physical-Social-Systems (CPSS) to improve safety and mobility of people and goods" at the 2024 International Conference on Transportation & Development in Atlanta, GA, on June 17th, 2024.
- Undergraduate student Joshua Wetmore demonstrated live at the AIMSUN Next simulation used on the research project "Assessing the Safety Impact of Connected and Automated Vehicles in Mixed Traffic Environments using AIMSUN Microsimulation Model".
- Dr. Michalaka presented her sabbatical assignment, which was inspired by C²M² projects, to The Citadel faculty on September 24th, 2024. Her sabbatical theme was "Sustainable Cutting-Edge Transportation Engineering at The Citadel through Research and Education."
- Colin Dees, C²M² student, defended his Ph.D. in the Construction Development and Planning Department at Clemson University. The dissertation is titled "The Development of a Convenient and Consistent Methodology for Flight Proficiency to Certify Multi-rotor UAS Pilots for State Departments of Transportation."

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

- Dr. William Davis, C²M² affiliated researcher at The Citadel, will submit the final report of the project "Assessing Potential of Bike Share Networks and Active Transportation to Improve Urban Mobility, Physical Activity and Public Health Outcomes in South Carolina." The report will be published after review.
- Dr. Joseph Burgett, C²M² affiliated researcher at Clemson, will submit the final report of the project, "Transfer of Unmanned Aircraft Systems Technology to SCDOT for Enhanced



- Bridge Inspections.” (Ongoing)
- Dr. Pierluigi Pisu, a C²M² affiliated researcher at Clemson, will submit the final report of the project, “A Software Tool for Securing Deep Learning against Adversarial Attacks for CAVs.” The report will be published after review. (Ongoing)
 - Dr. Yuche Chen, a C²M² affiliated researcher at USC, will submit the final report of the project, “Development of Transportation Air Quality Planning Tool for Transportation Agencies.” The report will be published after review. (Ongoing)
 - Dr. Paul Ziehl, C²M² affiliated researcher at USC, will submit the final report of the project, “Intelligent Asset Management for Improved Mobility: Technology Transfer for South Carolina.” The report will be published after review. (Ongoing)
 - Dr. Yu Qian, a C²M² affiliated researcher at USC, will submit the final report of the project “Developing a Portable Railroad Crossing Monitoring System based on Artificial Intelligence and Image Processing Technology.” The report will be published after review. (Ongoing)
 - Dr. Yuche Chen, C²M² affiliated researcher at USC, will submit the final report of the project, “Strategic Development of GUI Tools for Enhancing Transportation Mobility Among Vulnerable Groups During Pandemics.” The report will be published after review. (Ongoing)
 - Dr. Dimitra Michalaka, C²M² Associate Director at the Citadel, will submit the final report of the project, “Safety and Health Impacts of Mobility Alternatives Technology Transfer.” The report will be published after review. (Ongoing)
 - Dr. Judith Mwakalongo, C²M² Associate Director at SCSU, will submit the final report of the project, “Computer-Vision Model for Estimation of Road Sign Retro-Reflectivity Based on Deep Learning Algorithm and Vehicle Built-in Cameras.” The report will be published after review. (Ongoing)
 - Dr. Dimitra Michalaka will present "Smart Cyber-Physical-Social-Systems (CPSS) to Improve Safety and Mobility of People and Goods" at the TPM-GS Seminar Series at TUDelft, Delft, Netherlands on October 10th, 2024.
 - Dr. Dimitra Michalaka will organize two summer camps in June 2025 to build connections and synergies among K-12 and college institutions. The camps will be on introducing Engineering/ Transportation engineering to rising 8th, 9th, and 10th graders, through the camps organized by the South Carolina Governor’s School for Science and Mathematics (GSSM).
 - Dr. Dimitra Michalaka is scheduled to present on “Analysis of potential safety benefits resulting from different automation levels and penetration rates of automated vehicles: a case study in the Netherlands.” on October 30th, 2024, at the 2024 Road Safety and Simulation Conference in Lexington, KY.
 - Dr. Michalaka is scheduled to present the article “Assessing Bike Suitability of Transportation Infrastructure Segments” at the 104th Transportation Research Board Annual Meeting, on January 7th, 2025 in Washington, D.C. Co-authors include: Chun-Hsing (Jun) Ho, Kewei Ren, Yuche Chen, Xiwen Hao, Kweku Brown, Nathan Huynh, William J. Davis.
 - Dr. Michalaka is scheduled to present the article “Evaluating Safety Benefits of Various Automation Levels and Penetration Rates of Automated Vehicles: A Case Study from the



Netherlands” at the 104th Transportation Research Board Annual Meeting on January 8th, 2025, in Washington, D.C. Co-authors include: Eleonora Papadimitriou, Amna Chaudhry, Joshua Wetmore.

- Dr. Christopher Post, a C²M² affiliated researcher at Clemson, will present “Bridge-Based Water Monitoring Using the Intelligent River[®] System” at the South Carolina Water Resources Conference to be held in Columbia Metropolitan Conference Center, Columbia, SC, on October 16-17th, 2024.
- The following presentations are accepted for presentation at IEEE conferences to be held in Daytona Beach, FL, in December 2024.:
 - Abuhdima, E.M.M., Comert, G., Huang, C.-T., Pisu, P., Liu, J., Nazeri, A., Mrebit, A., Barr, R., Basden, A., Development of Predictive Mathematical Model for Millimeter Wave Degradation in Sandstorm Regions, accepted for presentation at 12th IEEE International Conference on Wireless for Space and Extreme Environments (WiSEE'24).
 - Abuhdima, E.M.M., Mrebit, A., Naomi, R., Laing, J., Tadessa, N., Liu, J., Nazeri, A., Comert, G., Huang, C.-T., Pisu, P., Switching Millimeter Wave Channels Using Fuzzy Controller System, accepted for presentation at IEEE RFID-TA 2024.
- The following presentations are accepted for presentation at the 104th annual TRB meeting in Washington, D.C., in January 2025:
 - Ruganuzza, D., Sulle, M., Mwakalonge, J., Comert, G., Siuhi, S., Application of Deep Learning Models in Predicting Traffic Sign Degradation.
 - Michalaka, D., Papadimitriou, E., Chaudhry, A., Wetmore, J., Evaluating Safety Benefits of Various Automation Levels and Penetration Rates of Automated Vehicles: A Case Study from the Netherlands.
 - Michalaka, D., Ho, C.-H., Ren, K., Chen, Y., Hao, X., Brown, K., Huynh, N., Davis, W.J., Assessing Bike Suitability of Transportation Infrastructure Segments.

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

● 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 (HBCUs). 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 C²M² 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 12 members. To date, we have four industry members, three members from academia, two retired from academia, one member from the non-profit agency, one member from state



department of transportation and one member from the local community. This diverse assortment of transportation professionals continues to evolve as we grow and is an integral part of our team. We are working closely with these individuals as we move forward, to increase collaboration with industry and local communities as well as to achieve technology transfer objectives and implement the center's sustainability plan.

The Center also continues to partner with the South Carolina Department of Transportation (SCDOT), which provides data, research collaboration, and in-kind support. We have also closely worked with the South Carolina Research Authority (SCRA) and Innova EV 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 several HBCUs to organize and host multiple webinars aimed at connecting HBCU students with academic and industry partners. For the project "Intelligent Asset Management for Improved Mobility: Technology Transfer for South Carolina," C²M² partner institution, USC is working closely with IBM, Verizon, and Luna Innovations to expand on the results of the project. The following is a list of all collaborators:

- *SCRA, Columbia, South Carolina*
 - *Innova EV, Burr Ridge, Illinois*
 - *SCDOT, Columbia, South Carolina*
 - *IBM*
 - *Verizon*
 - *Luna Innovations*
 - *North Carolina Agricultural and Technical State University*
 - *FMCSA - Federal Motor Carrier Safety Administration*
 - *University of Nebraska*
 - *University of Alabama at Birmingham*
- **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 collaborators:

- *Charleston Moves, Bicycle and Pedestrian Advocacy Organization*
- *City of Columbia Bicycle and Pedestrian Advisory Committee (BPAC)*
- *Gotcha Group, Charleston, South Carolina*
- *Delft University of Technology, The Netherlands*
- *Cooper River Center for Advanced Studies*
- *South Carolina Governor's School for Science and Mathematics*
- *Engineering Project Lead The Way (Dorchester Co., Charleston, Co.)*
- *Classical Conversation Groups Downtown and Mount Pleasant Campuses – Homeschool Curriculum*
- *Southern District Institute of Transportation Engineers (SDITE)*
- *South Carolina Section ITE*



- *Richland School District 2, ALERT – Gifted and Talented program*
- *University of Nebraska, College of Engineering*
- *Habitat for Humanity, Greenville, South Carolina*
- *Goodwill, Greenville, South Carolina,*
- *Microtik*

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

The Outputs listed in 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 after the table.

In our T² plan, we identified three areas of 'Output' that we would focus on. Output #1 identifies the goals that C²M² set for the dissemination of our research results. We expected to see at least five technical reports published, 20 conference presentations, ten peer-reviewed papers, and one conference held by C²M² annually. Output #2 focuses on new or improved methods created by our researchers. We would like to see at least ten new/improved methods developed by our researchers each year. 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.

No.	Goals	Research Performance Measures	Target per year	Completed in this reporting period (April 1, 2024 – September 30, 2024)
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	1
		Number of conference presentations	20	12
		Number of peer-reviewed journal and magazine papers published	10	5
		Number of conferences solely based on C ² M ² 's research	1	1
Output #2	Develop new methods or products based on C ² M ² 's research	Number of new and/or improved research methods or products	10	2
Output #3	Demonstrate developed technologies	Number of pilot demonstrations of technology	3	5



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

Technical Reports

1. Ogle, J., Comert, G., Bendigeri, V., Zou, F., Ghafari, A.Z., "A Statistical and Machine Learning Approach to Assess Contextual Complexity of the Driving Environment Using Autonomous Vehicle Data."

Conference Presentations

1. Guscott, O., Gauthier, P., Mackey, B., Development of Scaled Autonomous Vehicles, Presented at Summer Undergraduate Research Institute, Benedict College, Columbia SC, July 2024.
2. Sweeting, D., Iyengar, B., Comert, G., Begashaw N., Traffic Incident Detection Using Sumo Simulation With TraCI Interface, Presented at Summer Undergraduate Research Institute, Benedict College, Columbia SC, July 2024.
3. Omulokoli, P. O., Mwakalonge, J.L., Comert, G., Siuhi, S., Spatiotemporal Modeling for Enhanced Road Safety: Bayesian Hierarchical Approach with INLA-SPDE in Analyzing Large Truck Crashes, Texas (2016-2021), presented at the 65th International Meeting of the Transportation Research Forum in Arlington, Virginia, April 2024.
4. Ruganuz, D., Omulokoli, P. O., Mwakalonge, J.L., Comert, G., Siuhi, S., Enhancing Road Safety: Investigating Animal-Autonomous Vehicle Collision Avoidance Using F1/10 Vehicles to Warn Human Drivers and Nearby Traffic, presented at the 65th International Meeting of the Transportation Research Forum in Arlington, Virginia, April 2024.
5. Sulle, M., Mwakalonge, J.L., Comert, G., Siuhi, S., Roberts, J., Analysis of Distracted Pedestrians Crossing Behavior: An Immersive Virtual Reality Application, presented at the 65th International Meeting of the Transportation Research Forum in Arlington, Virginia, April 2024.
6. Osei, E., Mwakalonge, J.L., Comert, G., Siuhi, S., Developing Computer Vision and Sensor Models for Parking Facilities Using Machine Learning Techniques: Optimizing Parking Space Allocation, presented at the 65th International Meeting of the Transportation Research Forum in Arlington, Virginia, April 2024.
7. Sulle, M., Mwakalonge, J.L., Comert, G., Siuhi, S., Roberts, J., Evaluating the Environmental Impact of Connected Autonomous Vehicles: Combustion Engine vs Electric Vehicles, presented at the Southern District of ITE Annual Meeting in Wilmington, NC, April 2024.
8. Omulokoli, P. O., Mwakalonge, J.L., Comert, G., Siuhi, S., Spatiotemporal Modeling for Enhanced Road Safety: Explanatory analysis of spatiotemporal distribution trends of electric vehicle charging stations in two cities in South Carolina, presented at the Southern District of ITE Annual Meeting in Wilmington, NC, April 2024.
9. Sulle, M., Mwakalonge, J.L., Comert, G., Siuhi, S., Roberts, J., Cybersecurity Threats in Autonomous Vehicle Technologies: Perceptions and Preparedness, A Case Study, presented at the South Carolina EPSCoR State Conference, Columbia, SC, April 2024.



10. Musau, H. M., Mwakalonge, J., Comert, G., Sulle, M., & Siuhi, S., Evaluating Factors Influencing School Travel Mode Choice in the United States Using Explainable Artificial Intelligence, presented at the South Carolina EPSCoR State Conference, Columbia, SC, April 2024.
11. Ruganuza, D., Omulokoli, P. O., Sulle, M., Mwakalonge, J.L., Comert, G., Siuhi, S., Creating a Comprehensive Dataset to Explore Retroreflectivity Degradation in Traffic Signs: Incorporating Environmental Factors, presented at the South Carolina EPSCoR State Conference, Columbia, SC, April 2024.
12. Indah, D. A., Mwakalonge, J.L., Comert, G., Siuhi, S., Conditional Density Estimation for CMV Crash Severity Analysis and uncertainty Quantification in Work Zones, presented at the South Carolina EPSCoR State Conference, Columbia, SC, April 2024.

Peer-Reviewed Journal and Magazine Publications

1. Deng, H-W., Salek, M.S., Rahman, M., Chowdhury, M., Shue, M., Apon, A.W., 2024. Leveraging public cloud infrastructure for real-time connected vehicle speed advisory at a signalized corridor. *International Journal of Transportation Science and Technology*, in press.
2. Chengula, T.J., Mwakalonge, J., Comert, G., Sulle, M., Siuhi, S., Osei, E., 2024. Enhancing advanced driver assistance systems through explainable artificial intelligence for driver anomaly detection. *Machine Learning with Applications*, 17, p.100580.
3. Comert, G., Amdeberhan, T., Begashaw, N., Medhin, N.G., Chowdhury, M., 2024. Simple analytical models for estimating the queue lengths from probe vehicles at traffic signals: A combinatorial approach for nonparametric models. *Expert Systems with Applications*, 252, p.124076.
4. Liu, D., Eksioğlu, B., Schmid, M., Huynh, N., Comert, G., 2024. Decentralized platoon formation for a fleet of connected and autonomous trucks. *Expert Systems with Applications*, 249, p.123650.
5. Ruseruka, C., Mwakalonge, J., Comert, G., Siuhi, S., Indah, D., Kasomi, S., Chengula, T.J., 2024. An Investigation of factors Influencing electric vehicles charging Needs: Machine learning approach. *Transportation Research Interdisciplinary Perspectives*, 27, p.101211.

C²M² Sponsored Research Conferences

The eighth Annual Fall Conference of C²M² was held in Columbia, SC, on August 22nd, 2024.

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

New or improved methods

1. Dr. Yuche Chen's team at USC, through their project, "Development of Transportation Air Quality Planning Tool for Transportation Agencies," developed a new Excel-based air quality planning tool using the latest MOVES model advancements. The tool is user-friendly for non-specialists, with specific calculators for projects like electronic tolling,



telework, and transit upgrades, enabling precise emissions assessments.

2. Dr. Joseph Burgett and his team at Clemson developed several outputs from their project titled “Transfer of Unmanned Aircraft Systems Technology to SCDOT for Enhanced Bridge Inspections”, as highlighted below:
 - *Flight Proficiency Assessment Tool*: To address the FAA Part 107’s focus on theory, a practical assessment tool was developed to evaluate mission planning, flight control, and scenario-based skills, ensuring operators are field-ready.
 - *Basic UAS Reference Guide and Manual (B.U.R.G. Manual)*: This manual standardizes operational procedures with pre-flight checklists, tutorials, and protocols, providing inspectors with structured guidance from planning to post-flight checks of Unmanned Aircraft Systems (UAS).
 - *Blended Training Program*: The program included six weeks of online coursework, covering FAA exam prep and simulator practice, paired with weekly Zoom calls. This allowed participants to build foundational knowledge and practice remotely.
 - *Flight Simulator*: A simulator was incorporated into the online training to help participants develop basic drone control skills, allowing them to gain muscle memory and confidence before flying in real-world conditions. This allowed for the In-Person UAS Bootcamp to focus on more advanced flight training.
 - *In-Person UAS Bootcamps*: The project provides intensive, two-day boot camps at Clemson University, providing hands-on training in mission planning and drone operation, including mock bridge inspections to apply skills in realistic scenarios.
 - *BPERP Certification Option*: Participants could pursue the APFA’s Basic Proficiency Evaluation for Remote Pilots (BPERP), which is a certification by a third party attesting to their flight proficiency.

New or improved products

Nothing to report at this time.

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

Dr. Mashrur "Ronnie" Chowdhury and C²M² students and researchers hosted several technology demonstrations as listed:

1. On May 4th, 2024, C²M² participated in the Habitat Tech Fair organized by Habitat for Humanity of Greenville, SC.
2. C²M² students led several demonstrations at the TraCR Annual Conference, Greenville, SC, on May 6-7, 2024.
3. C²M² students demonstrated their technologies to the leaders from SCDOT and the Federal Motor Carrier Safety Administration (FMCSA) on May 9th, 2024, in Greenville, SC.
4. C²M² participated in the inaugural Future of Transportation (FoT) Summit hosted by USDOT at its headquarters in Washington, D.C., from August 13-15, 2024. C²M² contributed to outdoor demonstrations: 1) Real-time Collision Warning Application Using



V2V and V2I, 2) Vision-based Pedestrian Safety Alert and 3) Low-Cost Flood Monitoring for Bridges.

5. C²M² hosted its 8th Annual Fall Conference on August 22nd, 2024, in Columbia, SC, and the students and researchers from Clemson and its consortium showcased their technology. The conference featured a total of 16 demonstrations.

- **Additional Outputs**

Websites(s) or other Internet site(s)

C²M²'s website address is <http://cecas.clemson.edu/c2m2>. The website outlines the C²M²'s goal, participants, research in progress, and past events.

The C²M² Twitter handle is used to announce updates as well as events hosted by C²M². An archive of all C²M² Twitter posts is available at http://twitter.com/SC_UTC.

The C²M² YouTube channel features videos from all webinars over the course of the center. The channel can be accessed at: www.youtube.com/channel/UCITo_BgCYEjjH_PTU3vPFOW.

The C²M² LinkedIn organization page has been our primary platform to disseminate center outcomes to transportation professionals. The page saw consistent growth in engagement throughout the center duration. It can be found at: www.linkedin.com/in/center-for-connected-multimodal-mobility-304527163.

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 one final report from our funded projects. We also have six final reports under review from our funded projects, with nine more reports to be submitted within the next month. Once all reports are reviewed, we will disseminate the results. 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 (April 1, 2024 – September 30, 2024)
Outcome #1	Train the current and future transportation workforce to operate in an increasingly high-tech environment	Number of trainings events and workshops	2	6
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	1

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

Dr. Joseph Burgett and his team at Clemson had several outcomes from their project titled “Transfer of Unmanned Aircraft Systems Technology to SCDOT for Enhanced Bridge Inspections” related to training for workforce development, as highlighted below:

1. FAA Part 107 Exam Preparation: The training program prepared SCDOT personnel for the FAA Part 107 exam through a structured online course, enabling them to gain remote pilot certification essential for UAS operations.



2. *Flight Simulator Training:* Participants used a flight simulator to build basic drone handling skills, aiding in muscle memory development and enhancing confidence in flight control before live operations.
 3. *Hands-On Bootcamps:* The program included two-day in-person bootcamps at Clemson University's Experiential Learning Lab. These sessions offered practical training in mission planning, equipment handling, and real-time drone operation, reinforcing hands-on skills.
 4. *APSA BPERP Certification Option:* Participants could opt for the Basic Proficiency in Evaluation for Remote Pilots (BPERP) certification, which involved rigorous testing in emergency response capabilities and further advanced their operational readiness.
 5. *Bridge-Specific Mock Missions:* Participants conducted simulated bridge inspections in field settings, allowing them to apply learned skills directly in realistic scenarios and practice mission planning and execution in a safe environment.
 6. *Provision of Commercial-Grade UAS Equipment:* SCDOT teams across seven districts were provided with UAS equipment and field guides, enabling immediate practical application of their skills and standardizing equipment use and procedures statewide.
- **Outcome #2: New deployment-ready technologies, techniques, and practices in this reporting period**
 1. Dr. Yuche Chen's team at USC, through their project, "Strategic Development of GUI Tools for Enhancing Transportation Mobility Among Vulnerable Groups During Pandemics", addresses critical transportation access needs for vulnerable populations, offering a user-friendly GUI to support decision-making in car-sharing operations, especially for essential services during emergencies. A new user-friendly Python-based GUI tool, simplifying complex car-sharing algorithms into an accessible format with automated data processing and interactive input, making it practical for non-specialist use in urban mobility planning.
 2. The project "A Software Tool for Securing Deep Learning against Adversarial Attacks for CAVs," led by Dr. Pierluigi Pisu at Clemson, addressed the problem of improving the resilience of image classification models to the possibility of adversarial attacks aimed at affecting the performance of the perception module of CAVs, therefore improving vehicle reliability and functional safety beyond currently adopted practices. The results of this project will have broad applicability not only to the transportation sector but also to many other engineering fields utilizing machine learning for classification, including robotics and biometric identification. The output of the project was a GUI to generate, train and test intrinsically robust image classifiers to make adversarial attacks less effective, which means to obtain correct recognition results even in the presence of adversarial attacks. In the project, the team uses a deep Bayesian regression model as an enhancement to prior work on robust generative classification models. Limited performance was observed on the COCO dataset with 90 classes due to the limitation of Bayesian inference.



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

1. Dr. Christopher Post and his team have developed the adhesive bridge mounting system, which has been tested to allow non-destructive deployments on bridges, which enables wide-scale deployment. The system has been deployed and tested to assist with monitoring critical dam infrastructure (there are over 600 critical dams in SC). The BridgeBox™ will enable dam monitoring, which is critical to build infrastructure because of the risk of flooding of roads and houses when dam failure occurs. This project has resulted in new embedded software that lowered overall power consumption while improving radar accuracy. A disclosure has been made to the Clemson University Research Foundation regarding the BridgeBox™ and the team has begun discussions on commercialization.

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 37 C²M²-funded reports, with an additional six reports under review and nine more expected to be submitted within the next month. We continue to see the biggest impact of 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 (April 1, 2024 – September 30, 2024)
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	2
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

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

1. The impacts from Dr. Joseph Burgett and his team at Clemson’s project, “Transfer of Unmanned Aircraft Systems Technology to SCDOT for Enhanced Bridge Inspections,” include:
 - *Skill Development and Workforce Enhancement:* The project developed a flight proficiency assessment tool, filling a critical gap in UAS operator training. While the FAA’s Part 107 test certifies theoretical knowledge, the project’s proficiency tool adds practical evaluations, assessing participants on scenario-based tasks and aircraft control skills. Alongside this tool, the training program, which included both online coursework and intensive in-person bootcamps, effectively prepared SCDOT personnel to operate drones proficiently. The impact of this training was clear, as 20 out of the 21 participants passed the Part 107 exam, gaining not only certification but also a practical understanding of UAS applications in real-world settings.
 - *Immediate Operational Deployment:* By supplying SCDOT’s seven districts with commercial-grade UAS equipment, along with the Basic UAS Reference Guide and



Manual, this project allowed for rapid deployment of drone technology in bridge inspection workflows. The equipment provided was purposefully selected for its advanced imaging and operational capabilities, enabling inspectors to collect detailed visual data from previously challenging angles and perspectives. With tools and training now standardized, SCDOT can implement UAS technology across regions, improving consistency and reliability in inspections. This early adoption also supports long-term scalability, as SCDOT now has a foundation to integrate additional UAS advancements as they emerge, paving the way for future research and technology transfers within the transportation sector.

- **Enhanced Safety:** The use of UAS technology in bridge inspections allows for remote assessment, significantly reducing the need for inspectors to physically access dangerous areas. Traditionally, inspectors are required to work at elevated heights or in close proximity to traffic, which carries considerable risks of falls, collisions, and other accidents. With drones, these risks are minimized as inspections can now be conducted from safe distances.
 - **Increased Efficiency:** Drones enable more rapid and detailed data collection, thereby accelerating the entire inspection process. Unlike traditional methods that can be time-intensive and logistically complex, drones streamline tasks like capturing imagery and inspecting hard-to-reach areas. With fewer interruptions to traffic flow and reduced equipment needs, SCDOT can conduct more inspections in less time, contributing to cost savings.
2. Dr. Christopher Post and his team have tested and refined the bridge water level monitoring system, the BridgeBox™, to the point where it is ready for large-scale deployments. During the recent Hurricane Helene-related extreme weather events in the Upstate of SC, the deployed systems continued to function and report flood events that overtopped roads at multiple locations. At one location in Greenville, SC, the BridgeBox™ has been deployed alongside a USGS water level gauge. The BridgeBox™ data closely matched the USGS gauge, which is 40 times more expensive. There is now a realization within South Carolina and beyond that bridges over streams and rivers need real-time monitoring, given the increased frequency of extreme weather events. The team is in discussions with the SC Office of Resilience (SCOR), in collaboration with the SCDOT, to do a dense deployment pilot of as many as 300 systems, with a vision of the future of thousands to tens of thousands of deployed BridgeBox™ systems.
- **Impact #2: Improve transportation system operations and/or transportation safety and/or quality of life in this reporting period**

Nothing to report.



6. CHANGES/PROBLEMS

- **Changes in approach and reasons for change**

Nothing to report.

- **Actual or anticipated problems or delays and actions or plans to resolve them**

Nothing to report.

- **Changes that have a significant impact on expenditures**

Nothing to report.

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

Nothing to report.

7. SPECIAL REPORTING REQUIREMENTS

- **Research Project Requirements**

In keeping with reporting requirements, we plan to publish all of the final reports for the remaining projects in the next month. We will also post these reports on our website and submit them to the Transportation Research Board's (TRB) Research in Progress (RiP) database. These project entries will also be subsequently updated as required by OST-R and the Fast Act Grant Deliverables.

- **Submission of Final Research Reports**

In this reporting period, one final report was created and published on our Center website in its entirety, along with the archived data as required by the Fast Act Grant Deliverables.