



Center for Connected Multimodal Mobility (C²M²)

Semi-Annual Progress Report # 11

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

Federal Grant number: 69A3551747117

Project Title: Center for Connected Multimodal Mobility (C²M²)

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Submission Date: April 30th, 2024

DUNS#: 0426298

EIN#: 57-6000254

Recipient Organization: Clemson University, Clemson, South Carolina 29634

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

Grant Period: November 30, 2016 – September 30, 2024

Reporting Period: October 01, 2023 – March 31, 2024

Report Term: Semi-annual

Signature of Submitting Official: _____



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

1.1 What are the major goals of the program?

C²M²'s mission statement:

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

C²M²'s main goals are to:

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

C²M² intends to meet these goals through the following means:

1. 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.
2. 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)
3. Contributing to Smart Cities that collect and process big data, often in real-time, to optimize the transportation system performance (including more intensive use of shared infrastructure for different systems in a smart city)
4. 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.



5. Assisting regional planning and the setting of transportation priorities through innovations that leverage limited dollars to create large positive impacts (e.g., by using "Big Data" to aid in regional travel demand forecasting efforts)

1.2 What was accomplished under these goals?

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

- C²M² Directors from five partner institutions continued their bi-weekly conference calls to coordinate the Center's activities and budget. (Ongoing)
- Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, Ahmad Zaki Ghafari, C²M² Assistant Director, met with Clemson C²M² students daily to coordinate Center-related activities. (Ongoing)
- Dr. Judith Mwakalonge, C²M² Associate Director, South Carolina State University, and her research team members held virtual research meetings every Friday and Monday to continue working on C²M² funded research project "Computer-Vision Model for Estimation of Road Sign Retro-Reflectivity Based on Deep Learning Algorithm and Vehicle Built-in Cameras". (Ongoing)
- Dr. Juan Caicedo, C²M² Associate Director, University of South Carolina, and Dr. Nathan Hyunh, University of South Carolina held weekly meetings with two C²M²-funded Ph.D. students to track research progress of C²M² funded project "Improving Freight Transport Mobility and Efficiency via Synchronization". (Ongoing)
- Dr. Dimitra Michalaka, C²M² Associate Director, The Citadel, and her research team members held meetings weekly to continue working on C²M² funded research project "Assessing Transportation Infrastructure Segments for Bike Suitability". (Ongoing)
- Dr. Dimitra Michalaka, C²M² Associate Director, The Citadel, and her research team members held meetings weekly to continue working on C²M² funded research project "Safety and Health Impacts of Mobility Alternatives Technology Transfer". (Ongoing)
- Dr. Joseph M. Burgett, Clemson University, and his team started working on the new research project funded by C²M² "Transfer of Unmanned Aircraft Systems Technology to SCDOT for Enhanced Bridge Inspections". (Ongoing)
- Dr. Pierluigi Pisu, Clemson University, and his team started working on the new research project funded by C²M² "A software Tool for Securing Deep Learning against Adversarial Attacks for CAVs". (Ongoing)
- Dr. William G. Ferrell, Clemson University, and his team started working on the new research project funded by C²M² "A Web-Based Tool for Cross Dock Trailer Scheduling". (Ongoing)
- Dr. Christopher Post, Clemson University, and his team started working on the new research project funded by C²M² "Intelligent River® Bridge Flood Monitoring System to Improve Transportation Mobility". (Ongoing)
- Dr. Chin Tser Huang, University of South Carolina, and his team started working on the new research project funded by C²M² "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”. (Ongoing)

- Dr. Yuche Chen, University of South Carolina, and his team started working on the new research project funded by C²M² “Development of Transportation Air Quality Planning Tool for transportation agencies”. (Ongoing)
- Dr. Paul Ziehl, University of South Carolina, and his team started working on the new research project funded by C²M² “Intelligent Asset Management for Improved Mobility: Technology Transfer for South Carolina”. (Ongoing)
- Dr. Yu Qian, University of South Carolina, and his team started working on the new research project funded by C²M² “Developing a portable railroad crossing monitoring system based on artificial intelligence and image processing technology”. (Ongoing)
- Dr. Yuche Chen, University of South Carolina, and his team started working on the new research project funded by C²M² “Strategic Development of GUI Tools for Enhancing Transportation Mobility Among Vulnerable Groups During Pandemics”. (Ongoing)
- Dr. Dimitra Michalaka, C²M² Associate Director, The Citadel, presented about "Smart Cyber-Physical-Social-Systems (CPSS) to improve safety and mobility of people and goods," at the TPM-GS Seminar Series at TU Delft, Delft, Netherlands. (October 10th, 2023)
- Dr. Dimitra Michalaka, C²M² Associate Director, The Citadel, collaborated with individuals from Southern District Institute of Transportation Engineers (SDITE) and South Carolina Section ITE to create a K-12 plan for students in the southeast (SCSITE).
- Dr. Dimitra Michalaka, C²M² Associate Director, joined the panel discussing the possibility of teaching day camps, organized by GSSM for 6th-8th graders, in Charleston.
- In this reporting period, C²M² continued the Distinguished Speaker Series, where notable scholars from within the transportation community are invited to speak to faculty and students on a range of multimodal transportation-related topics. These events are broadcast as webinars to all partner institutions within the C²M² consortium and any other interested participants. These talks are recorded and then posted to our YouTube channel and website. In this reporting period, Clemson University has hosted the following Distinguished Speakers:
 - Dr. Gurcan Comert, Associate Director, Benedict College presented his work on "Simple Analytical Models for Estimating the Queue Lengths from Probe Vehicles at Traffic Signals: A Combinatorial Approach of Nonparametric Model" in a C²M² Distinguished Speaker Series. (October 26th, 2023)
 - Dr. Joseph Burgett, Ph.D., Associate Professor, Clemson University presented his work on “Developing and Pilot Testing a Comprehensive UAS Flight Proficiency Exam” in a C²M² Distinguished Speaker Series. (December 5th, 2024)
- Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, Ahmad Zaki Ghafari, C²M² Assistant Director, and students from IEEE ITSS and COMTO Clemson University Chapters attended a presentation from Dr. Mizanur Rahman, Assistant Professor, The University of Alabama, on the "transportation cyber-physical systems for smart cities".
- Mr. Cuthbert Ruseruka, C²M² graduate students from South Carolina State University, collaborated with other universities on the NSF MSI Cybersecurity project, completed his graduate school studies and accepted an offer to work as a highway engineer with



Conсор Engineers LLC. (December 15th, 2023).

- Mr. Denis Ruganuza, a graduate student from South Carolina State University, joined the C²M² Associated Director, Dr. Judith Mwakalonge, research team.
- Metrid Okumu, a Computer Engineering major at Benedict College and part of Dr. Comert and Dr. Begashaw research group at the C²M², completed a summer 2023 internship at the University of California. She joined Iowa State University, School of Civil Engineering to pursue a Ph.D. in Intelligent Infrastructure Engineering.
- Ms. Tumlumbe Chengula, a C²M² student from South Carolina State University, was selected to receive a 2023 IBM Masters Fellowship Award.
- Ms. Tumlumbe Chengula, a C²M² student from South Carolina State University, was selected to receive the Traffic Safety Scholar (TSS) for the 2024 Lifesavers Conference on Roadway Safety in Denver, Colorado.
- Ahmad Zaki Ghafari, C²M² Assistant Director, and Clemson students participated in 103rd TRB Annual Meeting in Washington D.C. (January 7-11, 2024)
- C²M² students from South Carolina State University presented their research to 7th and 8th graders at the Felton Charter School. Also, they discussed the careers available in the Transportation industry.
- Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, presented at the GAITE/SCITE Technical Exchange 2023 on the technologies developed through C²M² research projects in transportation cyber-physical systems (CPS) for connected and automated vehicles (CAVs). (Nov 14th, 2024)
- Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, participated in the ARPA-I Listening Tour Workshop in Atlanta, Georgia, hosted by Georgia Tech. (February 9th, 2024)
- Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, presented at the Center for Regional and Rural Connected Communities Seminar Series, on "Transportation Cyber-Physical-Social Systems: Next Frontiers". He talked about the diverse CPSS applications and their effectiveness for multimodal connected and autonomous mobility, drawing from the ongoing C²M² research projects conducted. (March 28th, 2024)
- Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, Ahmad Zaki Ghafari, C²M² Assistant Director, and students from C²M² hosted a technology demonstration for the senior management of Habitat of Humanity Greenville County. Dr. Ronnie Chowdhury, C²M² Director, introducing them to Transportation Cyber-Physical-Social Systems (TCPSS), self-driving cars and possible career in the field of quantum computation and cybersecurity. The technology demonstration included hardware security, quantum computing, adversarial attacks, virtual traffic light, autonomous vehicles, and pedestrian safety systems. (February 19th, 2024)

1.3 How have the results been disseminated?

- Dr. Nathan Huynh, The University of South Carolina, completed and published his C²M² funded project report, "Real-Time Decentralized Framework for Technology-Enabled Intermodal Freight Transport."
- Dr. Paul Ziehl, The University of South Carolina, completed and published his C²M² funded project report, "Building Smarter Cities via Intelligent Asset Management: South Carolina Case Study using IBM Maximo Application."
- Dr. Wayne Sarasua, Clemson University, completed and published his C²M² funded



project report, “Potential Reduction of Fatal Crashes in South Carolina due to Automated Vehicles.”

- Dr. Pierluigi Pisu, Clemson University, completed and published his C²M² funded project report, “Securing Deep Learning against Adversarial Attacks for Connected and Automated Vehicles.”
- Dr. Gurcan Comert, Associate Director, Benedict College and his team presented their results based on the partially funded C²M² projects at the 4th IEEE Forum for Innovative Sustainable Transportation Systems, Riverside, California (February 26-28, 2024)
 - Musau, H. M., Mwakalonge, J., Comert, G., & Siuhi, S. (2024). Analyzing The Impact of COVID-19 Pandemic on Factors Affecting School Travel Mode Choice in the United States.
 - Osei, E., Mwakalonge, J., Comert, G., & Siuhi, S. (2024). Human and Animal Detection in Electric and Autonomous Vehicles Using Quantum Computing and Advanced Machine Learning Techniques.
 - Omulokoli, P. O., Mwakalonge, J.L, Comert, G., Siuhi, S. (2024) Optimal location selection for electric vehicle infrastructure using location-allocation models with socio-economic consideration.
 - "Indah, D. A., Mwakalonge, J.L, Comert, G., Siuhi, S. (2024) Sustainable Freight Through Topological Data Analysis: Optimizing Freight Routes for Environmental Impact.
 - "Indah, D. A., Mwakalonge, J.L, Comert, G., Siuhi, S. (2024) An Investigation of Location-based Factors Influencing Electric Vehicles Charging Behavior.
 - Chengula, T. J., Mwakalonge, J., Comert, G., & Siuhi, S. (2024). Examination of Urban Micromobility Dynamics: A Geospatial Analysis of Scooter Crash Hotspots and Temporal Patterns.
- Dr. Gurcan Comert, Associate Director, Benedict College and his team presented their results based on the partially funded C²M² projects at the 2024 STEM Showcase, Leroy Davis Hall Engineering & Computer Science Complex, South Carolina State University, Orangeburg, South Carolina (March 27th, 2024)
 - Ruganuzo, D, Omulokoli, P. O., Mwakalonge, J.L, Comert, G., Siuhi, S. (2024), Enhancing Road Safety: Investigating Animal-Autonomous Vehicle Collision Avoidance Using F1/10 Vehicles to Warn Human Drivers and Nearby Traffic.
 - Omulokoli, P. O., Mwakalonge, J.L, Comert, G., Siuhi, S. (2024) Explanatory analysis of spatiotemporal distribution trends of electric vehicle charging stations in two cities in South Carolina.
 - Omulokoli, P. O., Mwakalonge, J.L, Comert, G., Siuhi, S. (2024) A causal inference study of crashes at Highway-Rail Grade crossings.
 - Musau, H. M., Mwakalonge, J., Comert, G., Sulle, M., & Siuhi, S. (2024). Analysis of Twitter Data on COVID-19 and School



Transportation: A Topic Modeling Approach.

- Indah, D. A., Mwakalonge, J.L, Comert, G., Siuhi, S. (2024) Sustainable Freight Through Topological Data Analysis: Optimizing Freight Routes for Environmental Impact.
- Osei, E., Mwakalonge, J., Comert, G., Siuhi, S. (2024) Developing computer vision and sensor models for Parking facilities using Machine Learning techniques: Optimizing Parking Space Allocation.
- Chengula, T. J., Mwakalonge, J., Comert, G., Sulle, M., & Siuhi, S. (2024). Enhancing Advanced Driver Assistance Systems Through Explainable Artificial Intelligence for Driver Anomaly Detection.
- Sulle, M., Mwakalonge, J., Comert, G., Siuhi, S., Roberts, J. (2024) Cybersecurity Threats in Autonomous Vehicle Technologies: Perceptions and Preparedness, A Case Study.
- Dr. Gurcan Comert, Associate Director, Benedict College and his team presented their results based on the partially funded C²M² projects at the Safe Mobility Conference, Chapel Hill, North Carolina (March 26-27, 2024)
 - Musau, H. M., Mwakalonge, J., Comert, G., & Siuhi, S. (2024). A national survey on the effect of the COVID-19 pandemic on school travel in the US: Parents perspective.
 - Indah, D. A., Mwakalonge, J.L, Comert, G., Siuhi, S. (2024) Conditional Density Estimation for CMV Crash Severity Analysis and uncertainty Quantification in Work Zones.
 - Chengula, T. J., Mwakalonge, J., Comert, G., & Siuhi, S. (2024). Spatial Instability of Crash Prediction Models: A Case of Scooter Crashes.
- Collaborations with Charleston Moves, Bicycle and Pedestrian Advocacy Organization, and City of Columbia Bicycle and Pedestrian Advisory Committee (BPAC) have been formed to further analyze the bike share data from the “Assessing Potential of Bike Share Networks and Active Transportation to Improve Urban Mobility, Physical Activity and Public Health Outcomes in South Carolina” project. (Ongoing)
- Ahmad Zaki Ghafari, C²M² Assistant Director, presented a research poster at the TRB 103rd Annual Fall Conference, Washington, D.C. (January 9th, 2024)
- Dr. Sabbir Salek, C²M² affiliated researcher, presented a research poster at the TRB 103rd Annual Fall Conference, Washington, D.C. (January 9th, 2024)
- Dr. Gurcan Comert, Associate Director, Benedict College published the following work based on the partially funded C²M² projects.
 - Chengula, Tumlumbe Juliana, Judith Mwakalonge, Gurcan Comert, and Saidi Siuhi. "Improving road safety with ensemble learning: Detecting driver anomalies using vehicle inbuilt cameras." Machine Learning with Applications 14 (2023): 100510.
 - Indah, D.A., Mwakalonge, J., Comert, G. and Siuhi, S., 2024. Enhancing data efficiency for autonomous vehicles: Using data sketches for detecting driving anomalies. Machine Learning with



Applications, p.100530

- Dr. Pierluigi Pisu, C²M² affiliated researcher, Clemson University published the following work based on the C²M² funded project.
 - C. Zhao, P. Pisu, G. Comert, V. Vaidyan, N. Begashaw and N. C. Hubig, "A Robust Adversarial Ensemble with Causal (Feature Interaction) Interpretations for Image Classification", IEEE/RSJ International Conference on Intelligent Robots and Systems, submitted for review.
- Dr. Paul Ziehl, C²M² affiliated researcher, University of South Carolina, published the following work based on the C²M² funded project.
 - Ai, L., K C, L., Elbatanouny, E., Henderson, A., &Ziehl, P. Assisting Load Rating Testing of Precast Reinforced Concrete Bridge Slab through Digital Twins and Field Monitoring Data. Journal of Testing and Evaluation. (Accepted on January 24).
- Dr. Wayne Sarasua, C²M² affiliated researcher, Clemson University published the following work based on the C²M² funded project.
 - Michalaka, Dimitra & Nahofti, Jamal & Sarasua, Wayne & Brown, Kweku. (2024). Potential Fatal Crashes Reduction in South Carolina Due to Different Levels of Automated Driving. To be Presented at The International Conference on Transportation and Development (ICTD 2024) (June, 2024).
- Dr. Mashrur Chowdhury, C²M² Director, Clemson University, published the following work based on the partially funded C²M² funded project.
 - Comert, G., Amdeberhan, T., Begashaw, N., Medhin, N. and 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, 10.1016/j.eswa.2024.124076.

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

- C²M² will continue its Distinguished Speaker Series and C²M² Cyber-Physical Systems (CPS) Frontier Series. They will be sponsoring notable transportation researchers whose talks will be made available via webinars and announced on our social media platforms. Currently, we have scheduled the following speakers. (Ongoing)
 - Dr. Christopher Post, C²M² affiliated researcher, Clemson University, will present his work on "Mobility Disruption due to heavy flood and intelligent monitoring system" in a C²M² Distinguished Speaker Series. (July 2024).
- C²M² Associate Director, Dr. Dimitra Michalaka is scheduled to teach a summer camp with topics Engineering Adventures at Home and Transportation Engineering Explorers to rising 8th, 9th, and 10th graders organized by the South Carolina Governor's School for science and mathematics in order to build connections and synergies among K-12 and college institutions. (June 2024).



- C²M² Associate Director, Dr. Gurcan Comert and his team will present their results based on the partially funded C²M² projects at the 65th International Meeting of the Transportation Research Forum in Arlington, Virginia (April 4 & 5, 2024):
 - Omulokoli, P. O., Mwakalonge, J.L, Comert, G., Siuhi, S. (2024) Spatiotemporal Modeling for Enhanced Road Safety: Bayesian Hierarchical Approach with INLA-SPDE in Analyzing Large Truck Crashes, Texas (2016-2021)
 - Ruganuzza,D, Omulokoli, P. O., Mwakalonge, J.L, Comert, G., Siuhi, S. (2024): Enhancing Road Safety: Investigating Animal-Autonomous Vehicle Collision Avoidance Using F1/10 Vehicles to Warn Human Drivers and Nearby Traffic.
 - Sulle, M., Mwakalonge, J.L., Comert, G., Siuhi, S., Roberts, J. (2024) Analysis of Distracted Pedestrians Crossing Behavior: An Immersive Virtual Reality Application.
 - Osei, E., Mwakalonge, J.L., Comert, G., Siuhi, S. (2024) Developing Computer Vision and Sensor Models for Parking Facilities Using Machine Learning Techniques: Optimizing Parking Space Allocation.
- C²M² Associate Director, Dr. Gurcan Comert and his team will present their results based on the partially funded C²M² projects at the Southern District of ITE Annual Meeting in Wilmington, NC, USA (April 7 – 10,2024):
 - Sulle, M., Mwakalonge, J.L., Comert, G., Siuhi, S., Roberts, J. (2024), Evaluating the Environmental Impact of Connected Autonomous Vehicles: Combustion Engine vs Electric Vehicles.
 - Omulokoli, P. O., Mwakalonge, J.L, Comert, G., Siuhi, S. (2024) Spatiotemporal Modeling for Enhanced Road Safety: Explanatory analysis of spatiotemporal distribution trends of electric vehicle charging stations in two cities in South Carolina.
- C²M² Associate Director, Dr. Gurcan Comert and his team will present their results based on the partially funded C²M² projects at the South Carolina EPSCoR State Conference, Columbia, SC (April 9th, 2024):
 - Sulle, M., Mwakalonge, J.L., Comert, G., Siuhi, S., Roberts, J. (2024) Cybersecurity Threats in Autonomous Vehicle Technologies: Perceptions and Preparedness, A Case Study.
 - Musau, H. M., Mwakalonge, J., Comert, G., Sulle, M., & Siuhi, S. (2024). Evaluating Factors Influencing School Travel Mode Choice in the United States Using Explainable Artificial Intelligence.
 - Ruganuzza,D, Omulokoli, P. O., Sulle, M, Mwakalonge, J.L, Comert, G., Siuhi, S. (2024): Creating a Comprehensive Dataset to Explore Retroreflectivity Degradation in Traffic Signs: Incorporating Environmental Factors.
 - Indah, D. A., Mwakalonge, J.L, Comert, G., Siuhi, S. (2024) Conditional Density Estimation for CMV Crash Severity Analysis and uncertainty Quantification in Work Zones.
- Dr. Jennifer Ogle, C²M² Affiliated researcher, Clemson University, has submitted the final report of the project, "A Statistical and Machine Learning Approach to Assess Contextual Complexity of the Driving Environment Using Autonomous Vehicle Data". The report is



under review and will be published soon.

- Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, Clemson University, 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. Nathan Hyunh, C²M² Affiliated researcher, University of South Carolina, will submit the final report of the project "Improving Freight Transport Mobility and Efficiency via Synchronization". The report will be published after review.
- Dr. William Davis, C²M² Affiliated researcher, 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, Clemson University, will submit the final report of the project, "Potential Reduction of Fatal Crashes in South Carolina due to Connected and Automated Vehicles". The report will be published after review. (Ongoing)
- Dr. Joseph Burgett, C²M² Affiliated researcher, Clemson University, will submit the final report of the project, "Transfer of Unmanned Aircraft Systems Technology to SCDOT for Enhanced Bridge Inspections". (Ongoing)
- Dr. Pierluigi Pisu, C²M² Affiliated researcher, Clemson University, 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. William G. Ferrell, C²M² Affiliated researcher, Clemson University, and his team started working on the new research project funded by C²M² "A Web-Based Tool for Cross Dock Trailer Scheduling". The report will be published after review. (Ongoing)
- Dr. Christopher Post, C²M² Affiliated researcher, Clemson University, will submit the final report of the project, "Intelligent River[®] Bridge Flood Monitoring System to Improve Transportation Mobility". The report will be published after review. (Ongoing)
- Dr. Chin Tser Huang, C²M² Affiliated researcher, University of South Carolina, will submit 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. (Ongoing)
- Dr. Yuche Chen, C²M² Affiliated researcher, University of South Carolina, 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, University of South Carolina, 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, C²M² Affiliated researcher, University of South Carolina, 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, University of South Carolina, 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. Mashrur "Ronnie" Chowdhury, C²M² Director, and students from C²M² will participate in the South Carolina EPSCoR State Conference, Columbia, SC. The students will present their work in the poster competition. (April 9th, 2024)

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

2.1 What organizations have been involved as key partners?

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

The C²M² Advisory Board is a vital asset to the success of our center. Our current board is made up of 12 members. To date, we have four industry members, three members from academia, two retired from academia, one member from 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 SCRA and several HBCUs to organize and host multiple webinars aimed at connecting HBCU students with academic and industry partners. C²M² partner institution University of South Carolina through the project Intelligent Asset Management for Improved Mobility: Technology Transfer for South Carolina, working closely with IBM, Verizon and Luna Innovations to expand on the results of the project The following information shows the location and collaboration type of these partners.

- *SCRA, Columbia, South Carolina: research collaboration, funding support.*
- *Innova EV, Burr Ridge, Illinois: research collaboration, funding support.*
- *SCDOT, Columbia, South Carolina: center administration related collaboration, in-kind support.*
- *IBM, expand the results.*
- *Verizon, expand the results.*
- *Luna Innovations, expand the results.*

2.2 Have other collaborators or contacts been involved?

Along with the five institutions that make up the C²M² consortium, our Center has partnered with the



following:

- *Charleston Moves, Bicycle and Pedestrian Advocacy Organization, collaborative research.*
- *City of Columbia Bicycle and Pedestrian Advisory Committee (BPAC), collaborative research*
- *Gotcha Group, Charleston, South Carolina: data collection, collaborative research, broader implementation of research findings.*
- *Delft University of Technology, Department of Values, Technology and Innovation, Netherlands.*
- *K-12/Workforce Development*
 - *Cooper River Center for Advanced Studies*
 - *South Carolina Governor's School for Science and Mathematics*
 - *The Citadel STEM Center of Excellence, School of Engineering, Zucker Family School of Education, and Swain Family School of Science and Mathematics*
 - *Engineering Project Lead The Way (Dorchester Co., Charleston, Co.)*
 - *The Citadel Office of Admissions*
 - *Classical Conversation Groups Downtown and Mount Pleasant Campuses – Homeschool Curriculum*
 - *Southern District Institute of Transportation Engineers (SDITE)*
 - *South Carolina Section ITE*
- *University of Nebraska, College of Engineering, collaborative research*
- *South Carolina Department of Transportation, Columbia, USA: research collaboration, in-kind support*

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 below.

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

No.	Goals	Research Performance Measures	Target per year	Completed in this reporting period (October 1, 2023 – March 31, 2024)
		Number of technical reports published	5	4



Output #1	Disseminate C ² M ² 's research results to a large audience utilizing different research distribution media	Number of conference presentations	20	28
		Number of peer-reviewed journal and magazine papers published	10	9
		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	4
Output #3	Demonstrate developed technologies	Number of pilot demonstrations of technology	3	1

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

Technical Reports

1. Paul Ziehl, Gurcan Comert; Akshatha Ramesh, Dhananjay Nikam, Venkat Narayanan Balachandran, Nathan Huynh “Building Smarter Cities via Intelligent Asset Management: South Carolina Case Study using IBM Maximo Application”. (November 2023)
2. Wayne Sarasua, Dimitra Michalaka, William J. Davis, Kweku Brown, Pam Murray-Tuite, Jennifer Ogle “Potential Reduction of Fatal Crashes in South Carolina due to Automated Vehicles”. (November 2023)
3. Nathan Hyunh, William Ferrell, Bhavya Padmanabhan “Real-Time Decentralized Framework for Technology-Enabled Intermodal Freight Transport”. (October 2023)
4. Pierluigi Pisu, Gurcan Comert, Negash Begashaw, Chuncheng Zhao “Securing Deep Learning against Adversarial Attacks for Connected and Automated Vehicles”. (October 2023)

Conference Presentations

1. Ahmad Zaki Ghafari, Clemson University, presented a research poster on “Comprehensive Tool for Engineering Design Services Development of Transport Infrastructure Projects” at the TRB 103rd Annual Fall Conference, Washington, D.C. (January 9th, 2024).
2. Dr. Sabbir Salek, Clemson University, presented a research poster on “Generative Adversarial Network-Based Defense Method Against Adversarial Attacks on the Traffic Sign Classification System of Autonomous Vehicles” at the TRB 103rd Annual Fall Conference, Washington, D.C. (January 9th, 2024).
3. Musau, H. M., Mwakalonge, J., Comert, G., & Siuhi, S. (2024). Analyzing The Impact of COVID-19 Pandemic on Factors Affecting School Travel Mode Choice in the United States, 4th IEEE Forum for Innovative Sustainable Transportation Systems, Riverside, California, (February 26-28, 2024).
4. Osei, E., Mwakalonge, J., Comert, G., & Siuhi, S. (2024). Human and Animal Detection in Electric and Autonomous Vehicles Using Quantum Computing and Advanced Machine



- Learning Techniques., 4th IEEE Forum for Innovative Sustainable Transportation Systems, Riverside, California, (February 26-28, 2024).
5. Omulokoli, P. O., Mwakalonge, J.L, Comert, G., Siuhi, S. (2024) Optimal location selection for electric vehicle infrastructure using location-allocation models with socio-economic considerations, 4th IEEE Forum for Innovative Sustainable Transportation Systems, Riverside, California, USA (February 26-28, 2024).
 6. Indah, D. A., Mwakalonge, J.L, Comert, G., Siuhi, S. (2024) Sustainable Freight Through Topological Data Analysis: Optimizing Freight Routes for Environmental Impact, FISTS 2024: 4th IEEE Forum for Innovative Sustainable Transportation Systems, Riverside, California. (February 26-28, 2024).
 7. Indah, D. A., Mwakalonge, J.L, Comert, G., Siuhi, S. (2024) An Investigation of Location-based Factors Influencing Electric Vehicles Charging Behavior, FISTS 2024: 4th IEEE Forum for Innovative Sustainable Transportation Systems, Riverside, California. (February 26-28, 2024).
 8. Chengula, T. J., Mwakalonge, J., Comert, G., & Siuhi, S. (2024). Examination of Urban Micromobility Dynamics: A Geospatial Analysis of Scooter Crash Hotspots and Temporal Patterns, 4th IEEE Forum for Innovative Sustainable Transportation Systems, Riverside, California, (February 26-28, 2024).
 9. Chengula, T. J., Mwakalonge, J., Comert, G., Sulle, M., & Siuhi, S. (2024). Enhancing Advanced Driver Assistance Systems Through Explainable Artificial Intelligence for Driver Anomaly Detection, 50th Annual Convention, National Society of Black Engineers, Atlanta, Georgia, (March 20-24, 2024).
 10. Musau, H. M., Mwakalonge, J., Comert, G., Sulle, M., & Siuhi, S. (2024). Evaluating Factors Influencing School Travel Mode Choice in the United States Using Explainable Artificial Intelligence, 50th Annual Convention, National Society of Black Engineers, Atlanta, Georgia, (March 20-24, 2024).
 11. Sulle, M., Mwakalonge, J.L., Comert, G., Siuhi, S., Roberts, J. (2024) Analysis of Distracted Pedestrians Crossing Behavior: An Immersive Virtual Reality Application, 50th Annual Convention, National Society of Black Engineers, Atlanta, Georgia, (March 20-24, 2024).
 12. Indah, D. A., Mwakalonge, J.L, Comert, G., Siuhi, S. (2024) Sustainable Freight Through Topological Data Analysis: Optimizing Freight Routes for Environmental Impact, 50th Annual Convention National Society of Black Engineers, Atlanta, Georgia. (March 20-24, 2024).
 13. Musau, H. M., Mwakalonge, J., Comert, G., & Siuhi, S. (2024). Analysis of Twitter Data on COVID-19 and School Transportation: A Topic Modeling Approach, South East Decision Science Institute, Charleston, South Carolina, (February 21-24, 2024).
 14. Indah, D. A., Mwakalonge, J.L, Comert, G., Siuhi, S. (2024) Leveraging Quantile Sketches for Efficient Management of Transportation Big Data: An Experimental Approach, The 53rd Annual Meeting of Southeast Decision Sciences Institute (SEDSI), Charleston, South Carolina. (February 21-24, 2024).
 15. Omulokoli, P. O., Mwakalonge, J.L, Comert, G., Siuhi, S. (2024) A causal inference study of crashes at Highway-Rail Grade crossings, 53rd SEDSI annual conference Charleston, SC. (February 21-24, 2024).
 16. Sulle, M., Mwakalonge, J.L., Comert, G., Siuhi, S., Roberts, J. (2024) Analysis of Distracted Pedestrians Crossing Behavior: An Immersive Virtual Reality Application, 53rd Annual Meeting of Southeast Decision Sciences Institute (SEDSI), Charleston, SC (February 21-24,



- 2024).
17. Chengula, T. J., Mwakalonge, J., Comert, G., & Siuhi, S. (2024). Exploring Autonomous Vehicle Disengagements Via Latent Dirichlet Allocation Analysis: A Natural Language Processing Approach, South East Decision Science Institute, Charleston, South Carolina. (February 21-24, 2024).
 18. Ruganuza, D., Omulokoli, P. O., Mwakalonge, J.L, Comert, G., Siuhi, S. (2024), Enhancing Road Safety: Investigating Animal-Autonomous Vehicle Collision Avoidance Using F1/10 Vehicles to Warn Human Drivers and Nearby Traffic, 2024 STEM Showcase, Leroy Davis Hall Engineering & Computer Science Complex, South Carolina State University. (March 27th, 2024).
 19. Omulokoli, P. O., Mwakalonge, J.L, Comert, G., Siuhi, S. (2024) Explanatory analysis of spatiotemporal distribution trends of electric vehicle charging stations in two cities in South Carolina, STEM-T Showcase, Orangeburg, USA. (March 27th, 2024).
 20. Omulokoli, P. O., Mwakalonge, J.L, Comert, G., Siuhi, S. (2024) A causal inference study of crashes at Highway-Rail Grade crossings, STEM-T Showcase, Orangeburg, USA. (March 27th, 2024).
 21. Musau, H. M., Mwakalonge, J., Comert, G., Sulle, M., & Siuhi, S. (2024). Analysis of Twitter Data on COVID-19 and School Transportation: A Topic Modeling Approach, Science, Technology, Engineering, Mathematics and Transportation Showcase, Orangeburg, South Carolina. (March 27th, 2024).
 22. Indah, D. A., Mwakalonge, J.L, Comert, G., Siuhi, S. (2024) Sustainable Freight Through Topological Data Analysis: Optimizing Freight Routes for Environmental Impact, South Carolina State University STEM Showcase, Orangeburg, South Carolina. (March 27th, 2024).
 23. Osei, E., Mwakalonge, J., Comert, G., Siuhi, S. (2024) Developing computer vision and sensor models for Parking facilities using Machine Learning techniques: Optimizing Parking Space Allocation, 2024 Science, Technology, Engineering, Mathematics and Transportation (STEM) Showcase, Orangeburg, South Carolina. (March 27th, 2024).
 24. Chengula, T. J., Mwakalonge, J., Comert, G., Sulle, M., & Siuhi, S. (2024). Enhancing Advanced Driver Assistance Systems Through Explainable Artificial Intelligence for Driver Anomaly Detection, 2024 Science, Technology, Engineering, Mathematics and Transportation (STEM) Showcase, Orangeburg, South Carolina. (March 27th, 2024).
 25. Sulle, M., Mwakalonge, J., Comert, G., Siuhi, S., Roberts, J. (2024) Cybersecurity Threats in Autonomous Vehicle Technologies: Perceptions and Preparedness, A Case Study, 2024 Science, Technology, Engineering, Mathematics and Transportation (STEM) Showcase, Orangeburg, South Carolina. (March 27th, 2024).
 26. Musau, H. M., Mwakalonge, J., Comert, G., & Siuhi, S. (2024). A national survey on the effect of the COVID-19 pandemic on school travel in the US: Parents perspective, Safe Mobility Conference, Chapel Hill, North Carolina, (March 26-27, 2024).
 27. Indah, D. A., Mwakalonge, J.L, Comert, G., Siuhi, S. (2024) Conditional Density Estimation for CMV Crash Severity Analysis and uncertainty Quantification in Work Zones, Safe Mobility Conference. Chapel Hill, North Carolina. (March 26-27, 2024).
 28. Chengula, T. J., Mwakalonge, J., Comert, G., & Siuhi, S. (2024). Spatial Instability of Crash Prediction Models: A Case of Scooter Crashes, Safe Mobility Conference, Chapel Hill, North Carolina. (March 26-27, 2024).



Peer-Reviewed Journal and Magazine Publications

1. L Ai; Laxman K C; E Elbatanouny; A Henderson; P Ziehl. Assisting Load Rating Testing of Precast Reinforced Concrete Bridge Slab through Digital Twins and Field Monitoring Data. *Journal of Testing and Evaluation*. 2024. <https://doi.org/10.1520/JTE20230748>
2. Ngeni, F., Mwakalonge, J., Comert, G., Siuhi, S., Chengula, T.J. and Ruseruka, C., 2024. The role of socioeconomic and environmental factors on pediatric vehicular heatstroke (PVH) deaths and sentiment analysis: An investigation. *Transportation Research Interdisciplinary Perspectives*, 23, p.101012.
3. Chengula, Tumlumbe Juliana, Judith Mwakalonge, Gurcan Comert, and Saidi Siuhi. "Improving road safety with ensemble learning: Detecting driver anomalies using vehicle inbuilt cameras." *Machine Learning with Applications* 14 (2023): 100510.
4. Indah, D.A., Mwakalonge, J., Comert, G. and Siuhi, S., 2024. Enhancing data efficiency for autonomous vehicles: Using data sketches for detecting driving anomalies. *Machine Learning with Applications*, p.100530.
5. Wang, J., Comert, G., Begashaw, N., Huynh, N., Kouyate, A., Mullen, R., Gassman, S. and Pierce, C., 2024. Comparative Analysis of Three Modeling Approaches for Predicting Pavement Conditions. *Transportation Research Record*, p.03611981241234924.
6. Ruseruka, C., Mwakalonge, J., Comert, G., Siuhi, S., Ngeni, F. and Anderson, Q., 2024. Augmenting roadway safety with machine learning and deep learning: Pothole detection and dimension estimation using in-vehicle technologies. *Machine Learning with Applications*, 16, p.100547.
7. Musau, H., Mwakalonge, J., Comert, G. and Siuhi, S., 2024. A national survey on the effect of the COVID-19 pandemic on school travel in the US. –Parents perspective. *Transportation research interdisciplinary perspectives*, 24, p.101061.
8. Liu, D., Eksioglu, B., Schmid, M., Huynh, N. and Comert, G., 2024. Decentralized platoon formation for a fleet of connected and autonomous trucks. *Expert Systems with Applications*, 249, p.123650.
9. Comert, G., Amdeberhan, T., Begashaw, N., Medhin, N. and 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*, 10.1016/j.eswa.2024.124076.

C²M² Sponsored Research Conferences

Nothing to report at this time.

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

3.2.1 *New or improved methods*

1. Dr. Nathan Huynh and his team developed an approach based on a multi-round combinatorial auction (CA) for truckload pickup and delivery problem where carriers collaborate in a decentralized and dynamic manner. They also developed codes for solving the dynamic decentralized carrier collaboration models.
2. Dr. Pierluigi Pisu and his team developed a bottom-up discriminative-generative



ensemble model for image classification, which leverages both generative and discriminative models with built-in adversarial causal relationships. A causal graph with latent variables has created to build Bayes-based generative classifier. The inputs consist of both original inputs and discriminative features.

3. Dr. Paul Ziehl and his team developed an improved load rating procedure utilizing digital twin technology. By using potentiometers, strain gauges, and fiber optic sensors to monitor a laboratory bridge slab, data related to crack evolution and strain during loading were obtained. Subsequently, calibrated three-dimensional finite element models representing different loading scenarios were produced, laying the foundation for a digital twin model of the bridge slab. The bridge slab model was then integrated into a bridge span to form the digital twin model of the actual bridge span for load rating tests. The digital twin model was calibrated with field monitoring data from potentiometers, strain gauges, fiber optic sensors, and drones, The digital twin model developed was applied to a bridge in Abbeville, South Carolina.
4. Dr. Pierluigi Pisu and his team developed an evaluation method using adversarial examples as counterfactual metrics. This new ensemble method not only shows better classification accuracy against adversarial examples but also shows better model causality.

3.2.2 New or improved products

Nothing to report at this time.

3.3 Output#3: Technology demonstrations in this reporting period

1. Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, Ahmad Zaki Ghafari, C²M² Assistant Director, and students from C²M² hosted a technology demonstration for the senior management of Habitat of Humanity Greenville County. Dr. Ronnie Chowdhury, C²M² Director, introducing them to Transportation Cyber-Physical-Social Systems (TCPSS), self-driving cars and possible career in the field of quantum computation and cybersecurity. The technology demonstration included hardware security, quantum computing, adversarial attacks, virtual traffic light, autonomous vehicles, and pedestrian safety systems. (February 19th, 2024)

3.4 Additional Outputs

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

C²M²'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.

C²M's website to showcase the evolution of our HBCU partnerships can be found at <https://storymaps.arcgis.com/stories/4cd34c0186214825a669dc1c5b38e07c>.

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

The C²M² YouTube account was updated. One new videos were added during this reporting period. Our YouTube channel can be found at www.youtube.com/channel/UCITo_BgCYEijH_PTU3vPFOw



Our LinkedIn organization page has seen consistent growth in engagement during this reporting period. It can be found at www.linkedin.com/in/center-for-connected-multimodal-mobility-304527163

3.4.2 Inventions, patent applications, and/or licenses

Nothing to report at this time.

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

In this reporting period, we published four final reports from our funded projects. The remainder of our funded research projects should be completed within the next reporting period, and their results will be disseminated at that time. We also have two final reports under review from our funded projects. 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 (October 1, 2023 – March 31, 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	1



Outcome #2	Incorporate new technologies (software and/or hardware) and/or techniques and/or practices that are deployment ready	Number of new technologies, and/or techniques and/or practices that offer implementation or deployment guidance	4	1
Outcome #3	Improve technologies and/or processes in addressing transportation issues	Number of improved technologies and/or processes disseminated from C ² M ² funded research projects	4	1

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

1. Dr. Burgett and his team through a one-day workshop provided latest advancements in unmanned aircraft system technology, safety regulations and practical application of drones with Clemson Police Department.

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

1. Dr. Nathan Huynh and his team developed a framework for dynamic decentralized carrier collaboration based on iterative combinatorial auction. They developed two mathematical programming models and solution methods that implement the framework. This framework can be used by carriers to collaborate in real time by exchanging jobs through an auction process.

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

1. Dr. Paul Ziehl and his team developed a digital twin-based load rating method that integrates lab data with finite element models for precise structural evaluations. It significantly enhances bridge maintenance processes. The method uses an automated procedure to precisely detect, measure and visualize precise cracks on the bridge, leading to more informed repair and maintenance strategies.

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 36 C²M² funded reports with an additional two reports under review. We continue to see the biggest impact from our Center's investment in our relationship between partner institutions and their surrounding communities through our workshops, webinar series, course



development, and collaborative research efforts. We are working diligently to facilitate the adoption of and subsequent impacts from our sponsored research on community and state policies. Our researchers continue to work to disseminate the results of their sponsored research, working with individuals from industry, city planners, and departments of transportation to improve transportation infrastructure, safety, and legislation at the local, state, and national levels.

In our T² plan, we set two goals for the impact that we would like to see as a result of our center's yearly activities. These goals are to see at least two of our Center's developed technologies, methods, or practices adopted per year and to track at least two cases where these technologies, techniques/methods, and practices quantifiably improved transportation.

No.	Goals	Research Performance Measures	Target per year	Completed in this reporting period (October 1, 2023 – March 31, 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	1

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

1. Dr. Paul Ziehl and his team developed an innovative framework for load rating using digital twin technology. Specifically, it includes: (1) a method that uses a drone to detect bridge cracks and estimate the depth of bridge cracks, as well as the spacing of the cracks; (1) a 3D finite element model of the bridge span for load testing. The University of South Carolina is working closely with IBM, Verizon and Luna Innovations to expand on the results of this project and meets weekly with representatives from IBM.
2. Dr. Joseph Burgett through C²M² project developed a comprehensive DOT-specific



Unmanned Aircraft System (UAS) flight proficiency assessment tool. One of the seven districts of SCDOT has adopted the tool and will pilot-test the assessment tool to evaluate their bridge inspection engineers' skills and knowledge to operate a drone safely in the national airspace.

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

1. Dr. Wayne Sarasua developed a Creative Inquiry course that included more than a dozen students in the Clemson University that focused on analyzing the contributing factors of fatal crashes in South Carolina. This course was developed from the C²M² project title.

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

Nothing to report.

6.3 Changes that have a significant impact on expenditures

Nothing to report.

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

Nothing to report.

7. SPECIAL REPORTING REQUIREMENTS

7.1 Research Project Requirements

In keeping with reporting requirements, the completed projects four projects for our 2020, and 2021 rounds of funded projects have been posted on our website and submitted to the Transportation Research Board's (TRB) Research in Progress (RiP) database. These project entries have also been subsequently updated as required by OST-R and the Fast Act Grant Deliverables. Each project description includes the project title, brief abstract, project start and completion dates, project status, and funding amount.

These submissions also include details of all the sponsoring organizations and research programs contributing to the project, including the Federal sponsor (OST-R) and all non-federal sponsors, as outlined in the Fast Act Grant Deliverables. This information is displayed on our Center website as well. In keeping with these requirements, PIs of all funded projects are also required to obtain an ORCID, which is reported on the TRB RiP database and included in all final reports.



7.2 Submission of Final Research Reports

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