Center for Connected Multimodal Mobility (C^{2}M^2)

Semi-Annual Progress Report # 9

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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?

C^2M^2's mission statement:

Our vision for the Center for Connected Multimodal Mobility (C^2M^2), a Tier 1 University Transportation Center, is to become a globally recognized multimodal mobility innovation center for moving people and goods, specializing in connectivity, data analytics, automation, and cybersecurity. To achieve this bold vision, our multidisciplinary research team from five leading higher education and research institutions in the state of South Carolina are working together to create and develop new initiatives and inventions by combining our complementary research strengths, our education and workforce development activities, our commitment to diversity, and our expertise in emerging communication and computing technologies.

C^2M^2's main goals are to:

- Conduct interdisciplinary research and drive innovation through data science, data-driven computing, seamless vehicle, traveler and infrastructure connectivity, and automation
- Conduct education and workforce development/leadership activities
- Disseminate C^2M^2 knowledge and technologies
- Support complementary collaborations with consortium members, private partners, and the public sector
- Broaden diversity by integrating consortium members' existing diversity programs with the C^2M^2 activities

C^2M^2 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.

- C^2M^2 Directors from five partner institutions continued their bi-weekly conference calls to coordinate the Center's activities and budget. (Ongoing)
- Dr. Mashrur "Ronnie" Chowdhury, C^2M^2 Director, Dr. Sakib Khan, C^2M^2 Assistant Director, and Ms. Naomi Nieves, C^2M^2 Program Coordinator, met with C^2M^2 students daily to coordinate Center-related activities. (Ongoing)
- Dr. Judith Mwakalonge, C^2M^2 Associate Director, South Carolina State University, and her research team members held weekly virtual research meetings every week. (Ongoing)
- Dr. Judith Mwakalonge, C^2M^2 Associate Director, South Carolina State University, and C^2M^2 students conducted research on "Smart Monitoring of Illegal Removal of Road Barricades using Asset Tracking Technologies in Connected and non-connected environment". (September 2020-January 2023)
- The C^2M^2 team consists of the C^2M^2 director and associate directors, and their students conducted research on "A Cloud-based Quantum Artificial Intelligence-supported Truck Platooning Strategy for Safety and Operational Performance" in Collaboration with other partner Universities. (Ongoing)
- Dr. Nathan Hyunh, C^2M^2 Associate Director, University of South Carolina, held weekly meetings with two C^2M^2 funded Ph.D. students to track research progress of C^2M^2 2020 funded project "Improving Freight Transport Mobility and Efficiency via Synchronization". (Ongoing)
- Dr. Gurcan Comert, C^2M^2 Associate Director, Benedict College, held regular meetings with his team working on the "Modeling Impact of Weather Conditions on 5G Communication and Mitigation Measures on Control of Automated Intersections" project. (September 2020-October 2022)
- Judith Mwakalonge, C^2M^2 Associate Director, South Carolina State University, and her research team members held weekly research meetings every Friday for the C^2M^2 2020 funded project "Monitoring of Illegal Removal of Road Barricades using Intelligent Transportation Systems in Connected and Non-Connected Environments". (September 2020-January 2023)
- Dr. Chin-Tser Huang, C^2M^2 affiliated researcher, University of South Carolina, held regular weekly team meetings for the C^2M^2 2021 funded project "A Machine Learning-Assisted Framework for Determination of Performance Degradation Causes and Selection of Channel Switching Strategy in Vehicular Networks". (September 2021-February 2023)
- Dr. Yunyi Jia, C^2M^2 Affiliated Researcher, Clemson University, Dr. Gurcan Comert, C^2M^2 Associate Director, Benedict College, and research team members held biweekly research meetings for C^2M^2 2020 funded project "Cloud-based Collaborative Road Condition Monitoring using In-Vehicle Smartphone Data and Deep Learning". (Ongoing)

- Dr. Mashrur "Ronnie" Chowdhury, C^2M^2 Director, Dr. Sakib Khan, C^2M^2 Assistant Director, and Ms. Naomi Nieves, C^2M^2 Program Coordinator, hosted our Annual Advisory Board Meeting to update our board on center progress and to discuss future activities. This meeting was hybrid. (November 3rd, 2022)
- In this reporting period, C^2M^2 continued the Distinguished Speaker Series, where notable scholars from within the transportation community are invited to speak to faculty and students on a range of multimodal transportation-related topics. These events are broadcast as webinars to all partner institutions within the C^2M^2 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:
    - Joachim Taiber, presented his work on, "What are the challenges to bring highly automated vehicles into safe operational deployment and regulatory compliance" on February 3rd, 2023
    - Yu Qian, presented his work on "Intelligent Railroad Monitoring and Connected Community" on March 24th, 2023

- Dr. Mashrur "Ronnie" Chowdhury, C^2M^2 Director, Ms. Naomi Nieves, C^2M^2 Program Coordinator and C^2M^2 students attended the Men of Color National Summit 2023. They also participated in a breakout and panel session for high school and college students on "Frontiers to Successful Cybersecurity Careers and Entrepreneurships" by Robert Hampshire, Deputy Assistant Secretary for Research Technology for the United States Department of Transportation, and Willie Smith, Senior Procurement Executive for the United States Department of Transportation. (March 28th and 29th, 2023)
- Dr. Mashrur "Ronnie" Chowdhury, C^2M^2 Director, Dr. Sakib Khan, C^2M^2 Assistant Director, and Ms. Naomi Nieves, C^2M^2 Program Coordinator, and students from C^2M^2, IEEE ITSS and COMTO Clemson University Chapters attended a presentation from Dr. Mhafuzur Rahman, Senior Researcher, General Motors, on the "Improving the safety of automated vehicle cars through machine learning and its future challenges". (October 14th, 2022)
- Mr. Frank Ngeni and Mr. Cuthbert Ruseruka, C^2M^2 graduate students from South Carolina State University collaborated with other universities on the NSF MSI Cybersecurity project and other research activities. (Ongoing)
- Mr. Frank Ngeni, C^2M^2 South Carolina State University graduate student, completed the study on "Smart Monitoring of Illegal Removal of Road Barricades using Asset Tracking Technologies in Connected and non-connected environment". (January 2023)
- Mr. Frank Ngeni, South Carolina State University ,C^2M^2 funded student, completed his Graduate school studies (December 15th, 2022)
- Dr. Mashrur "Ronnie" Chowdhury, C^2M^2 Director, Ms. Naomi Nieves, C^2M^2 Program Coordinator, Jacquan Pollard, C^2M^2 Student, had a meeting with Dr. Robert N Garner, Dean of the School of Science and Engineering at Benedict College. C^2M^2 has been working with Benedict College, an HBCU partner, on

various projects since 2017. Dr. Robert Garner and Dr. Chowdhury discussed C²M² support for STEM education at Benedict College. (January 26th, 2023)

- Mr. Daniel Salazar, Benedict College, C²M² affiliated researcher, was accepted to Iowa State University, Civil Engineering Ph.D. program with a research assistantship. He will start the program during the summer of 2023. (2023)
- Bright Elijah, Benedict College, C²M² affiliated researcher, after finishing two master's programs in transportation and environmental engineering, started transportation engineering career at a construction engineering firm in Columbia, SC. (2023)
- C²M² students participated in Clemson Elementary Schools STEAM night where they showcased technology for the elementary school students and their families. (February 3rd, 2023).
- C²M² students interviewed Dr. Joachim Taiber, Managing Director and Founder International Alliance for Mobility Testing & Standardization, on Autonomous Vehicle Certification. (January 27th, 2023)
- Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, Clemson University, gave a presentation on C²M² research to Audi AV Validation Group Visit to CU-ICAR. (October 3rd, 2022)
- Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, Clemson University, gave a presentation on C²M² research to British Transportation companies. This event was hosted by CU-ICAR and the British Embassy. (February 22nd, 2023)
- Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, Dr. Sakib Khan, C²M² Assistant Director, and Ms. Naomi Nieves, C²M² Program Coordinator, and students from C²M² visited Hickory Tavern Middle School to host a technology demonstration to students. The students were introduced to Transportation Cyber-Physical Systems (TCPS), self-driving cars, connected drone applications, virtual traffic, and TCPS cybersecurity using Quantum Artificial Intelligence. (October 25th, 2022).
- Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, Naomi Nieves, C²M² Program Coordinator, and students from C²M² visited Seneca High School to host a technology demonstration for students. The students were introduced to Transportation Cyber-Physical Systems (TCPS), self-driving cars, hybrid classical quantum deep learning models to detect adversarial attacks which affect the performance of the traffic sign detection module of autonomous vehicles, virtual traffic signal control with cloud-based quantum computers, and autonomous vehicle user experience through virtual reality. (March 10th, 2023).
- Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, Naomi Nieves, C²M² Program Coordinator, and students from C²M² hosted a technology demonstration for the media news outlet. The students presented Quantum AI-supported resilient traffic sign classification system, pedestrian at signalized crosswalk (PSCW) application, Quantum optimization-supported virtual traffic light system, virtual reality for autonomous vehicle user experience research and network security. (March 1st, 2023)
- Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, and Ms. Naomi Nieves, C²M² Program Coordinator, hosted the 6th Annual Fall Conference, featuring keynote speaker, April Rai, President and CEO, The Conference of Minority Transportation Officials (COMTO) along with an HBCU panel

discussion as part of our morning session, and an afternoon of student research presentations and research briefs from our various funded research partners. (November 3rd and November 4th, 2022)

- Mr. Fred Chambers, Benedict College, was selected as our C^{2}M^2 UTC Student of the Year for his work with Dr. Gurcan Comert. Fred was recognized at the CUTC 2023 Winter Awards Banquet. (January 7th, 2023)

- C^{2}M^2 along with Dr. Mashrur "Ronnie" Chowdhury, C^{2}M^2 Director, presented Ms. Vareva Harris and Mr. Gurcan Comert with a "Outstanding Leadership and Contributions of C^{2}M^2 Award," for their advancements of the mission of C^{2}M^2 in the preparation of students for their professional careers. These awards were presented at our 6th Annual Fall Conference. (November 3rd, 2022)

- In this reporting period, the Clemson branch of C^{2}M^2 continued the C^{2}M^2 Cyber-Physical Systems (CPS) Frontier Series to showcase emerging scholars from within the transportation community, inviting them to speak to faculty and students on a range of multimodal transportation-related topics. Like our Distinguished Speaker series, these events are broadcast via webinar to all partner institutions within the C^{2}M^2 consortium and any other interested audience. These talks are recorded and then posted to our Youtube channel and website. In this reporting period, Clemson University has hosted the following CPS Frontier Speakers:
  - Fengjiao Zou, Ph.D. Candidate , presented her work on "Design of an Effective Virtual Reality Environment to Study Pedestrian's Midblock Crossing Behavior at a Multilane Road When Interacting with Autonomous Vehicles" (November 11th, 2022)

1.3 How have the results been disseminated?

- C^{2}M^2 Associate Director, Dr. Dimitra Michalaka and C^{2}M^2 affiliated faculty, Dr. Kweku Brown attended the American Society of Engineering Education (ASEE) Southeastern Section (SE) Conference in Arlington, VA. Dr. Michalaka moderated the "Curriculum Development 1" session and presented two engineering education related peer-reviewed articles, "Applying Agile Business Solutions as a Graduate Capstone Project" and "Incorporating Gamification at an Engineering Statistics course to improve student learning and engagement". (March 12th and 14th, 2023)

- Dr. Mashrur "Ronnie" Chowdhury, C^{2}M^2 Director, Abyad Enan and Jean Micheal Tine, C^{2}M^2 students, attended a Federal Motor Carrier Safety Administration-sponsored project meeting on work zone safety. This project is a result of C^{2}M^2 collaboration between Clemson University, South Carolina State University and Benedict College. (October 27th, 2022)

- Dr. Judith Mwakalonge, C^{2}M^2 Associate Director, South Carolina State University, completed and published her 2020 C^{2}M^2 funded project report, "Monitoring of Illegal Removal of Road Barricades Using Intelligent Transportation Systems in Connected and Non-Connected Environments".

(November 18th, 2022)

- Dr. Paul Ziehl, C^{2}M^2 affiliated faculty, completed and published his 2020 C^{2}M^2 funded project report, "Digital Twins to Increase Mobility in Rural South Carolina". (February 7th, 2023)

- Dr. Yu Qian, C^{2}M^2 affiliated faculty, completed and published his 2020 C^{2}M^2 funded project report, "Strategic Management of Limited Transportation Recourses to Support Mobility of Disadvantaged and Disabled Travelers during the COVID-19 Pandemic or Similar Situation". (January 31st, 2023)

- Dr. Bing Li, C^{2}M^2 affiliated faculty, completed and published his 2020 C^{2}M^2 funded project report, "Safe and Efficient E-Wayfinding (SeeWay) Assistive Navigation for the Visually Impaired". (January 19th, 2023)

- Dr. Gurcan Comert, C^{2}M^2 Associate Director, completed and published his 2020 C^{2}M^2 funded project report, "Modeling Impact of Weather Conditions on 5G Communication and Mitigation Measures on Control of Automated Intersections". (December 16th, 2022)

- Dr. Mashrur "Ronnie" Chowdhury, C^{2}M^2 Director, completed and published his 2019 C^{2}M^2 funded project report, "Vision-based Navigation of Autonomous Vehicle In Roadway Environments With Unexpected Hazards". (November 21st, 2022)

- Several collaborations with teams across SC and beyond 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)

- Dr. Nathan Hunyh's, C^{2}M^2 Associate Director, University of South Carolina, student K C Laxamn, University of South Carolina, presented a research poster at the C^{2}M^2 6th Annual Fall Conference, Columbia, SC. (November 4th, 2022)

- Dr. Nathan Hunyh's, C^{2}M^2 Associate Director, University of South Carolina, student Ahmed Fahim, University of South Carolina, presented a research poster at the C^{2}M^2 6th Annual Fall Conference, Columbia, SC. (November 4th, 2022)

- Dr. Mashrur "Ronnie" Chowdhury's, C^{2}M^2 Director, Clemson University, student Sabbir Salek, Clemson University, presented a research poster at the C^{2}M^2 6th Annual Fall Conference, Columbia, SC. (November 4th, 2022)

- Dr. Mashrur "Ronnie" Chowdhury's, C^{2}M^2 Director, Clemson University, student Jean Tine, Clemson University, presented a research poster at the C^{2}M^2 6th Annual Fall Conference, Columbia, SC. (November 4th, 2022)

- Dr. Yunyi Jia's, C^{2}M^2 Affiliated Researcher, Clemson University, student Mayuresh Bhosale, Clemson University, presented a research poster at the C^{2}M^2 6th Annual Fall Conference, Columbia, SC. (November 4th, 2022)

- Dr. Nathan Hunyh's, C^{2}M^2 Associate Director, University of South Carolina, student Liu Jian, University of South Carolina, presented a research poster at

the C^{2}M^2 6th Annual Fall Conference, Columbia, SC. (November 4th, 2022)

- Dr. Mashrur "Ronnie" Chowdhury's, C^{2}M^2 Director, Clemson University, student Jacquan Pollard, Clemson University, presented a research poster at the C^{2}M^2 6th Annual Fall Conference, Columbia, SC. (November 4th, 2022)
- Dr. Mashrur "Ronnie" Chowdhury's, C^{2}M^2 Director, Clemson University, student Abyad Enan, Clemson University, presented a research poster at the C^{2}M^2 6th Annual Fall Conference, Columbia, SC. (November 4th, 2022)
- Dr. Mashrur "Ronnie" Chowdhury's, C^{2}M^2 Director, Clemson University, student Reek Majumder, Clemson University, presented a research poster at the C^{2}M^2 6th Annual Fall Conference, Columbia, SC. (November 4th, 2022)
- Dr. Mashrur "Ronnie" Chowdhury's, C^{2}M^2 Director, Clemson University, student Pronab Biswas, Clemson University, presented a research poster at the C^{2}M^2 6th Annual Fall Conference, Columbia, SC. (November 4th, 2022)
- Dr. Wayne Sarasua's, C^{2}M^2 affiliated researcher, Clemson University, student Jamal Nahofti, Clemson University, presented a research poster at the C^{2}M^2 6th Annual Fall Conference, Columbia, SC. (November 4th, 2022)
- Dr. Judith Mwakalonge's, C^{2}M^2 Associate Director, South Carolina State University, student Frank Ngeni, South Carolina State University, presented a research poster at the C^{2}M^2 6th Annual Fall Conference, Columbia, SC. (November 4th, 2022)
- Dr. Nathan Hunyh's, C^{2}M^2 Associate Director, University of South Carolina, student Bhavya Padmanabhan, University of South Carolina, presented a research poster at the C^{2}M^2 6th Annual Fall Conference, Columbia, SC. (November 4th, 2022)
- C^{2}M^2 Associate Director, Dr. Judith Mwakalonge, submitted manuscripts based on the C^{2}M^2 2020 funded project, "Smart Monitoring of Illegal Removal of Road Barricades using Asset Tracking Technologies in Connected and non-connected environment" to the following journals (Ongoing)
  - "Monitoring of Illegal Removal of Road Barricades Using Intelligent Transportation Systems" to be submitted to *Sustainability* journal
  - "Monitoring of Illegal Removal of Road Barricades in Connected Environment" to be submitted to the *Sensors* journal
- C^{2}M^2 Associate Director, Dr. Judith Mwakalonge, submitted manuscripts based on a C^{2}M^2 funded project (Ongoing)
  - Cuthbert Ruseruka, Dr. Judith Mwakalonge, Dr. Gurcan Comert, Dr. Saidi Siuhi, Frank Ngeni, Quincy Anderson, "The Determination of Pothole Sizes and Locations Using Artificial Intelligence and Vehicle Built-in Technologies", submitted to the *International Journal of Transportation Science and Technology (IJTST)*. (Ongoing)
  - Cuthbert Ruseruka, Dr. Judith Mwakalonge, Dr. Gurcan Comert, Dr. Saidi Siuhi, "Deep Learning Model for Identification of Flexible Pavement Distresses Using Vehicle Built-in Cameras and GPS Sensors", submitted to the *IEEE Intelligent Transportation Systems Transactions* (Ongoing)
- Dr. Yunyi Jia, C^{2}M^2 affiliated researcher, Clemson University submitted the following manuscript based on the C^{2}M^2 2021 funded project, "Multimodal-AI based Roadway

Hazard Identification and Warning using Onboard Smartphones with Cloud-based Fusion" to *Vehicles* (Ongoing)

- "On-board Smartphone-based Road Hazard Detection with Cloud-based Fusion"

- C²M² Associate Director, Dr. Dimitra Michalaka, submitted a manuscript based on the C²M² 2021 funded project, "A Cloud-based Quantum Artificial Intelligence-Supported Truck Platooning Strategy for Safety and Operational Performance" to *IEEE Open Journal of Intelligent Transportation Systems.* (Ongoing)

  - "Adversarial Attack-Resilient Perception Module for Traffic Sign Classification"

- Dr. Paul Ziehl, C²M² affiliated researcher, University of South Carolina, published the following work based on the C²M² 2021 funded project, "Building Smarter Cities via Intelligent Asset Management: South Carolina Case Study using IBM Maximo Application" to *Construction and Building Materials*

  - "Determination of Vehicle Loads on Bridges by Acoustic Emission and an Improved Ensemble Artificial Neural Network" (November 19th, 2022)

  - "Automated Crack Detection and Crack Depth Prediction for Reinforced Concrete Structures using Deep Learning" (February 9th, 2023)

- Dr. Nathan Hunyh, C²M² Associate Director, University of South Carolina, published the following work based on the C²M² 2020 funded project, "Improving Freight Transport Mobility and Efficiency via Synchronization" to *International Journal of Systems Science: Operations & Logistics* (January 9th, 2023)

  - "A Two-stage Stochastic Model for Intermodal Terminal Location and Freight Distribution under Facility Disruptions''

- Dr. Nathan Hunyh, C²M² Associate Director, University of South Carolina, published the following work based on the C²M² 2020 funded project, "Real-time Decentralized Framework for Technology-Enabled Intermodal Freight Transport''. (November 10th, 2022)

  - "Evaluation of Three Collaboration and Profit Sharing Methods for Carriers in Pickup-and-Delivery Problems"

- Dr. Judith Mwakalonge, C²M² Associate Director, South Carolina State University, published the following work based on a C²M² funded project, to *Sustainability Journal* (March 30th, 2023)

  - "Pavement Distress Identification Based on Computer Vision and Controller Area Network (CAN) Sensor Models"

- Dr. Abuhdima C²M² affiliated researcher, Benedict College, published the following work based on the C²M² 2021 funded project, "A Machine Learning-Assisted Framework for Determination of Performance Degradation Cause and Selection of Channel Switching Strategy in Vehicular Networks " to the following journals

  - "The Effect of Dust and Sand on the Propagating EM Millimeter Plane Wave" *IEEE Journal of Radio Frequency Identification* (November 4th, 2022)

- "Investigation of 5G and 4G V2V Communication Channel Performance Under Severe Weather IEEE International Conference on Wireless for Space and Extreme Environments" *IEEE International Conference on Wireless for Space and Extreme Environments* (November 4th, 2022)
- "Propagating Uniform Millimeter Plane Wave in Dusty and Sandy Medium" *IEEE Journal of Radio Frequency Identification* (April 19th, 2023)

- Jian Liu, C²M² affiliated researcher, University of South Carolina, submitted the following work based on the C²M² 2021 funded project "A Machine Learning-Assisted Framework for Determination of Performance Degradation Causes and Selection of Channel Switching Strategy in Vehicular Networks" to the *IEEE Journal of Radio Frequency Identification* (Ongoing)
    - "Switching Strategy for Connected Vehicles Under Variant Harsh Weather Conditions"

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)
    - o Larry Lowe, Benedict College will present his work on "Journey to my Success Story" in a C²M² Distinguished Speaker Series on April 28th, 2023
- C²M² Associate Director, Dr. Dimitra Michalaka is scheduled to teach a virtual summer camp on Engineering Around Town 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, 2023)
- Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, Clemson University, will give a presentation at Benedict College STEM Week. His presentation is titled, "Path to Exciting Careers in Future Frontiers" (April 4th, 2023)
- Dr. Yunyi Jia, C²M² Affiliated Researcher, Clemson University, has submitted the final report of the project, "Cloud-based Collaborative Road Condition Monitoring using In-Vehicle Smartphone Data and Deep Learning". The report is under review and will be published soon. (Ongoing)
- Dr. Wayne Sarasua, C²M² Affiliated researcher, Clemson University, has submitted the final report of the project, "Potential Reduction of Fatal Crashes in South Carolina due to Connected and Automated Vehicles". The report is under review and will be published soon. (Ongoing)
- Dr. Robert Mullen, C²M² Affiliated researcher, University of South Carolina, has submitted the final report of the project, "Data Fusion to Improve the Accuracy of Multi-Modal Traffic Counts". The report is under review and will be published soon. (Ongoing)
- 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. (Ongoing)

- Dr. Chin Huang, C²M² Affiliated researcher, University of South Carolina, has submitted the final report of the project, "A Machine Learning-Assisted Framework for Determination of Performance Degradation Causes and Selection of Channel Switching Strategy in Vehicular Networks". The report is under review and will be published soon. (Ongoing)

- Dr. Pierluigi Pisu, C²M² Affiliated researcher, Clemson University, has submitted the final report of the project, "Securing Deep Learning against Adversarial Attacks for Connected and Autonomous Vehicles". The report is under review and will be published soon. (Ongoing)

- Ostonya Thomas, Benedict College, will join Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, Clemson University, as a Civil Engineering Graduate Student at Clemson University (May, 2023)

- Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, Naomi Nieves, C²M² Program Coordinator, and students from C²M² will host a technology demonstration for high school students participating in Clemson's PEER/WISE Experience (PWE) program. (July 12th, 2023)

- Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, Naomi Nieves, C²M² Program Coordinator, and students from C²M² will participate in the FUSION 2023 Conference in Charleston, SC. C²M² students will also give a presentation based on the paper, "Hybrid Quantum-Classical Neural Network for Incident Detection". (June 27th-30th, 2023)

- Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, Naomi Nieves, C²M² Program Coordinator, will host a AWS 101 Immersion Day at Benedict College for C²M² students. (Fall, 2023)

- Dr. Gurcan Comert, C²M² Associate Director, Benedict College is preparing a manuscript for the following work based on the C²M² 2021 funded project, "Securing Deep Learning against Adversarial Attacks for Connected and Automated Vehicles". (Ongoing)
  - o "A Robust Adversarial Ensemble with Causal (Feature Interaction) Interpretations" to be submitted to Robotics and Automation Letters (RA-L).

- Dr. Esmail Abuhdima, C²M² Affiliated researcher, Benedict College, has submitted a manuscript based on the C²M² 2021 funded project "A Machine Learning-Assisted Framework for Determination of Performance Degradation Causes and Selection of Channel Switching Strategy in Vehicular Networks." (Ongoing)
  - o "Switching Strategy for Connected Vehicles Under Variant Harsh Weather Conditions"

- Dr. Wayne Sarasua, C²M² affiliated researcher, Clemson University is preparing two papers to submit based on the C²M² 2020 funded project, "Potential Reduction of Fatal Crashes in South Carolina due to Automated Vehicles". (Ongoing)
  - o "Site Characterization for Fatal Crashes in South Carolina Transportation Research Board"
  - o "Analysis on Contributing Factors of Fatal Crashes in South Carolina"

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

2.1 What organizations have been involved as key partners?

The C^{2}M^2 consortium is made up of five South Carolina schools; Clemson University, the lead institution; Benedict College; The Citadel; South Carolina State University; and the University of South Carolina. Benedict College and South Carolina State University are categorized as Historically Black Colleges/Universities. These five schools work together, collaborating on research projects, workshops, developing courses, and supporting C^{2}M^2 with financial and in-kind support. Since the creation of this consortium, Clemson's Board of Trustees approved the creation of the Center for Connected Multimodal Mobility at Clemson University and pledged their support of its ongoing programs.

The C^{2}M^2 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), Innova EV and Leidos on the pilot deployment of smart city technology developed by our Center and in the pursuit of sustainable, external funding for our Center. We have also partnered with SCRA and several HBCUs to organize and host multiple webinars aimed at connecting HBCU students with academic and industry partners. The following information shows the location and collaboration type of these partners.

- *SCRA, Columbia, South Carolina*: research collaboration, event collaborator
- *Innova EV, Burr Ridge, Illinois:* research collaboration, in-kind support

2.2 Have other collaborators or contacts been involved?

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

- *Charleston Moves, Bicycle and Pedestrian Advocacy Organization, collaborative research*
- *City of Columbia Bicycle and Pedestrian Advisory Committee (BPAC), collaborative research*
- *The Citadel, Department of Health & Human Performance, Charleston, SC, collaborative research*
- *Gotcha Group, Charleston, South Carolina: data collection, collaborative research, broader implementation of research findings*
- *South Carolina Governor's School for Science and Mathematics, Columbia, South Carolina: K-12 event collaboration, workforce development*
- *University of Nebraska, College of Engineering, collaborative research*
- *University of Alabama at Birmingham, School 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 this Section 3 of our Semi-Annual Progress Report fall solidly into the categories as outlined in our Technology Transfer (T²) plan and are listed below, first numerically in a table format and then in-depth below.

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

No.	Goals	Research Performance Measures	Target per year	Completed in this reporting period (October 01, 2022 – March 31, 2023)
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	6
		Number of conference presentations	20	21
		Number of peer-reviewed journal and magazine papers published	10	7
		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	5
Output #3	Demonstrate developed technologies	Number of pilot demonstrations of technology	3	5

3.1 Output#1: C^{2}M^2's research results dissemination in this reporting period

Technical Reports

1. Ngeni, F., Mwakalonge, J., Comert, G., Siuhi, S., Vaidyan, V. "Monitoring of Illegal Removal of Road Barricades using Intelligent Transportation Systems in Connected and Non-Connected Environments". (November 2022)

2. Chowdhury, M., Isam, M., Li, H., Hu, H. "Vision-based Navigation of Autonomous Vehicle In Roadway Environments With Unexpected Hazards". (November 2022)

3. Comert, G., Abuhdima, E., Huang, C., Pisu, P., Liu, J., Zhao, C. "Modeling Impact of Weather Conditions on 5G Communication and Mitigation Measures on Control of Automated Intersections". (December, 2022)

4. Li, B., Comert, G., Brooks, J., Arditi, A., Visibility Metrics LLC. "Safe and Efficient E-Wayfinding (SeeWay) Guidance for the Transition to Autonomous Vehicles for the Visually Impaired". (January 2023)

5. Qian, Y., Liu, Y., Comert, G., Begashaw, N. "Strategic Management of Limited Transportation Recourses to Support Mobility of Disadvantaged and Disabled Travelers during the COVID-19 Pandemic or Similar Situations" (January, 2023)

6. Ziehl, P., Comert, G., Bayat, M. "Digital Twins to Increase Mobility in Rural South Carolina" (February, 2023)

Conference Presentations

1. Cuthbert Ruseruka, C^{2}M^2 affiliated researcher, Dr. Judith Mwakalonge, C^{2}M^2 Associate Director, Dr. Gurcan Comert, C^{2}M^2 Associate Director, Dr. Saidi Siuhi, C^{2}M^2 affiliated faculty, Frank Ngeni C^{2}M^2 student, Kristin Major, "Pavement Distress Identification Based on Computer Vision and Controller Area Network (CAN) Sensor Models", at the Southern District International Transportation Engineers (SDITE), Savannah, GA. (March 21st, 2023)

2. Bhavya Padmanabhan, C^{2}M^2 student, University of South Carolina, presented his research on, "Real-time Decentralized Framework for Technology-Enabled Intermodal Freight Transport" at the 102nd annual meeting of Transportation Research Board (TRB), Washington, D.C. (January 10th, 2023).

3. Dr. Chin Tser Huang, C^{2}M^2 affiliated researcher, University of South Carolina, and Dr. Esmail Abuhdima, C^{2}M^2 affiliated researcher, Benedict College, attended the IEEE WiSee Conference in Manitoba, Canada, and presented their work based on,
   a. "A Machine Learning-Assisted Framework for Determination of Performance Degradation Causes and Selection of Channel Switching Strategy in Vehicular Networks" (October, 2022)
   b. "The Effect of Dust and Sand on the Propagating EM Millimeter Plane Wave"
   c. "Investigation of 5G and 4G V2V Communication Channel Performance Under Severe Weather" (October, 2022)

4. Dr. Paul Ziehl, C^{2}M^2 affiliated researcher, and his research team, presented their work on, "Surface Damage Imaging for Input to Load Rating of Bridges. In Emerging Methods for Surface Damage Monitoring and Imaging, Part 2 of 2. ACI Concrete Convention" at the ACI Fall convention in Dallas, TX. (October 23th-27th, 2022)

5. C^{2}M^2 Associate Director, Dr. Dimitra Michalaka and C^{2}M^2 affiliated faculty, Dr. Kweku Brown presented their work on "Applying Agile Business Solutions as a Graduate Capstone Project" and "Incorporating Gamification at an Engineering Statistics course to improve student learning and engagement" at the American Society of Engineering Education (ASEE) Southeastern Section (SE) Conference in Arlington, VA. (March 12th and 14th, 2023)

6. K C Laxman, University of South Carolina, presented his work on "Automated Inspection of Precast Reinforced Concrete Slabs in South Carolina" at the C^{2}M^2 6th Annual Fall Conference, Columbia, SC. (November 4th, 2022)

7. Fahim Ahmed, University of South Carolina, presented his work on "Real-time Vehicle Re-routing under Disruption in Cross-dock Network with Time Constraints" at the C^{2}M^2 6th Annual Fall Conference, Columbia, SC. (November 4th, 2022)

8. Sabbir Salek, Clemson University, presented his work on "A Hybrid Approach using Classical Neural Network and Quantum Restricted Boltzmann Machine for Cloud-Supported In-vehicle Cyberattack Detection" at the C^{2}M^2 6th Annual Fall Conference, Columbia, SC. (November 4th, 2022))

9. Jean Tine, Clemson University, presented his work on "Hybrid Quantum-Classical Neural Network for Incident Detection" at the C^{2}M^2 6th Annual Fall Conference, Columbia, SC. (November 4th, 2022)

10. Mayuresh Bhosale, Clemson University, presented his work on "Multimodal-Deep Learning-based Roadway Hazard Identification and Warning using Onboard

Smartphones with Cloud-based Fusion" at the C^{2}M^2 6th Annual Fall Conference, Columbia, SC. (November 4th, 2022)

11. Liu Jian, University of South Carolina, presented his work on "Investigation of 5G and 4G V2V Communication Channel Performance Under Severe Weather" at the C^{2}M^2 6th Annual Fall Conference, Columbia, SC. (November 4th, 2022)

12. Jacquan Pollard, Clemson University, presented his work on "Edge-Centric Cloud-Based Distributed Environmental Detection Surveillance" at the C^{2}M^2 6th Annual Fall Conference, Columbia, SC. (November 4th, 2022))

13. Abyad Enan, Clemson University, presented his work on "Quantum Optimization for Virtual Traffic Light" at the C^{2}M^2 6th Annual Fall Conference, Columbia, SC. (November 4th, 2022)

14. Reek Majumder, Clemson University, presented his work on "Resilient Quantum Machine Learning model for Traffic Sign Detection" at the C^{2}M^2 6th Annual Fall Conference, Columbia, SC. (November 4th, 2022)

15. Pronab Kumar Biswas, Clemson University, presented his work on "Trajectory Prediction of an Automated Truck Platoon using Quantum Artificial Intelligence" at the C^{2}M^2 6th Annual Fall Conference, Columbia, SC. (November 4th, 2022)

16. Jamal Nahofti, Clemson University, presented his work on "Potential Reduction of Fatal Crashes in South Carolina due to Automated Vehicles" at the C^{2}M^2 6th Annual Fall Conference, Columbia, SC. (November 4th, 2022)

17. Frank Ngeni, South Carolina State University, presented his work on "Monitoring of Illegal Removal of Road Barricades using Intelligent Transportation Systems in Connected and Non-Connected Environments" at the C^{2}M^2 6th Annual Fall Conference, Columbia, SC. (November 4th, 2022)

18. Bhavya Padmanabhan, University of South Carolina, presented his work on "Multiple Bundles Combinatorial Auction for Job Exchange in Dynamic Pickup and Delivery Problem" at the C^{2}M^2 6th Annual Fall Conference, Columbia, SC. (November 4th, 2022)

19. Liu, J., Nazeri, A., Zhao, C., Abuhdima, E., Comert, G., Huang, C., Pisu, P., "Investigation of 5G and 4G V2V Communication Channel Performance Under Severe Weather: accepted for publication in *2022 IEEE International Conference on Wireless for Space and Extreme Environments (WiSEE)* (November 4th, 2022)

20. Jamal Nahofti, Clemson University, presented his work on, "Potential Reduction of Fatal Crashes in South Carolina Due to Automated Vehicles" at the Transportation Research Board (TRB) 102nd Annual Meeting, Washington, DC (January 8th-12th, 2023)

21. "Securing Deep Learning against Adversarial Attacks for Connected and Automated Vehicles", at Doctoral Symposium on 14th Annual Conference of the Prognostics and Health Management Society. (Oct. 31st, 2022)

Peer-Reviewed Journal and Magazine Publications

1. Ruseruka, S., Mwakalonge, J., Comert, G., Siuhi, S., Ngeni, F., Major, K., "Pavement Distress Identification Based on Computer Vision and Controller Area Network (CAN) Sensor Models", accepted for publication in *Sustainability Journal: Sustainable Transportation*, 2023 (March 30th, 2023)

2. Abuhdima E., Comert, G., Huang C., Jian L., Nazeri A., Pisu P., Tadessa N., Chambers F., Niyomugabo, K., "Propagating Uniform Millimeter Plane Wave in Dusty and Sandy Medium", accepted for publication in *IEEE Journal of Radio Frequency Identification* (April 19th, 2023)

3. Abuhdima, E., Comert, G., Tadessa, N., Chambers, F., Niyomugabo, K., Pisu, P., Nazeri, A., Huang, C., Liu, J., Zhao, C., "The Effect of Dust and Sand on the Propagating EM Millimeter Plane Wave," *IEEE Journal of Radio Frequency Identification* (November 4th, 2022)

4. Badyal, V. W.G. Ferrell, N. Huynh, and B. Padmanabhan, "A Two-stage Stochastic Model for Intermodal Terminal Location and Freight Distribution under Facility Disruptions'' accepted for publication in *International Journal of Systems Science: Operations & Logistics*, 2023, Vol. 10, No. 1, 2169055. https://doi.org/10.1080/23302674.2023.2169055. (January 9th, 2023)

5. Padmanabhan, B., N. Huynh, W.G. Ferrell, and V. Badyal, "Evaluation of Three Collaboration and Profit Sharing Methods for Carriers in Pickup-and-Delivery Problems" accepted for publication in *Multimodal Transportation,* 2023, Vol. 2, No. 2, 100066. https://doi.org/10.1016/j.multra.2022.100066. (November 10th, 2022)

6. Laxman, K C., Ross A., Ai L., Henderson A., Elbatanouny E., Bayat M., Ziehl P.", "Determination of vehicle loads on bridges by acoustic emission and an improved ensemble artificial neural network" accepted for publication in *Construction and Building Materials Volume* 364, 18 January 2023, 129844 (November 19th, 2022)

7. Laxman, K C., Tabassum N., Ai L., Cole C., Ziehl, P., "Automated crack detection and crack depth prediction for reinforced concrete structures using deep learning" accepted for publication in *Construction and Building Materials* Volume 370, 17 March 2023, 130709 (February 9th, 2023)

C²M² Sponsored Research Conferences

1. C²M² Sixth Annual Fall Conference held hybrid on November 3rd and November 4th, 2022

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

3.2.1 New or improved methods

1. The C²M² team consists of the C²M² director and associate directors, and their students developed a classical and hybrid classical quantum prediction model for the trajectory of automated truck platoon. They also evaluated the platoon efficacy and string stability of the platoon using both prediction models. They found that the platoon using the trajectory prediction from hybrid classical quantum model showed better platoon efficacy and string stability.

2. Dr. Nathan Huynh and his team developed the following:

   a. Cross-dock Scheduling Problem (CDSP):
      i. Real-time tool for cross-dock scheduling for multiple dock doors and scheduling both inbound and outbound trailers.
      ii. Provides a population-based simulation annealing meta-heuristics to solve the scheduling problem in a very short period of time.

   b. Vehicle Routing Problem with Cross-dock (VRPCD) under disruption:
      i. Real-time tool to re-route vehicles after disruption incident in the network
      ii. Provides dynamic rerouting solution that allows minimum tardiness to the customers after a disruption event in the network.
      iii. Measures the impacts of disruptions for different scenarios.

   c. Synchronized CDSP and VRPCD under disruption:
      i. Real-time tool to tackle disruption in the network and optimize routing and cross-dock scheduling plan.
      ii. Real-time communication interface that allows trucks to communicate with their dispatchers and the cross-dock operator.
      iii. Strategies developed to reroute vehicle and repair cross-dock material handling plan that allows updated arrival times of inbound trucks at the cross-dock.

3. Dr. Gurcan Comert and his team developed and tested a universal image adversarial against YOLO-based object detector neural network. The adversarial example can fool the object detector and reduce the detection accuracy. The universal perturbation can be applied on a variety of images and there is no need to generate different perturbations for different images. A deep ensemble network is proposed for image classification. The deep ensemble network combines a generative model and discriminative features to improve the robustness of the original network. After robustification, the ensemble network can improve the detection accuracy and reduce the attack success rate.

4. Dr. Chin Tser Huang and his team developed NS3 simulations to collect data about the impact of dust, sand, humidity, visibility, distance, and height of the installation, on the receive power and throughput of 5G and LTE communication channels based on a testbed for measuring the impact of weather on the performance of 5G and LTE channels. They also proposed a dynamic channel switching strategy for connected vehicles under different severe weather conditions.

5. Dr.Pisu and his team developed the following:

   a. 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 is created to build Bayes-based generative classifier. The inputs consist of both original inputs and discriminative features.

b. An evaluation method using adversarial examples as counterfactual metrics is proposed. The proposed ensemble model 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. C^2M^2 Clemson University students participated in Clemson Elementary Schools STEAM night where they showcased technology demonstrations for the elementary school students and their families (February 3rd, 2023).

2. Dr. Mashrur "Ronnie" Chowdhury, C^2M^2 Director, Dr. Sakib Khan, C^2M^2 Assistant Director, and Ms. Naomi Nieves, C^2M^2 Program Coordinator, and students from C^2M^2 visited Hickory Tavern Middle School to host a technology demonstration to students. The students were introduced to Transportation Cyber-Physical Systems (TCPS), self-driving cars, connected drone applications, virtual traffic, and TCPS cybersecurity using Quantum Artificial Intelligence (October 25th, 2022).

3. Dr. Mashrur "Ronnie" Chowdhury, C^2M^2 Director, Naomi Nieves, C^2M^2 Program Coordinator, and students from C^2M^2 visited Seneca High School to host a technology demonstration for students. The students were introduced to Transportation Cyber-Physical Systems (TCPS), self-driving cars, hybrid classical quantum deep learning models to detect adversarial attacks which affect the performance of the traffic sign detection module of autonomous vehicles, virtual traffic signal control with cloud-based quantum computers, and autonomous vehicle user experience through virtual reality (March 10th, 2023).

4. Dr. Mashrur "Ronnie" Chowdhury, C^2M^2 Director, Naomi Nieves, C^2M^2 Program Coordinator, and students from C^2M^2 hosted a technology demonstration for the media news outlet. The students presented Quantum AI-supported resilient traffic sign classification system, pedestrian at signalized crosswalk (PSCW) application, Quantum optimization-supported virtual traffic light system, virtual reality for autonomous vehicle user experience research and network security (March 1st, 2023)

5. Dr. Mashrur "Ronnie" Chowdhury, C^2M^2 Director, Naomi Nieves, C^2M^2 Program Coordinator, and students from C^2M^2 hosted a technology demonstration for SCDOT officials including, Christy Hall, Secretary of Transportation, Justin Powell, Chief of Staff, Leland Colvin, Deputy Secretary for Engineering, Maggie Hendry, Acting Deputy Secretary for Finance and Administration, Brent Rewis, Deputy Secretary for Intermodal Planning, Kelly Moore, Director of Public Engagement. The students presented Quantum AI-supported resilient traffic sign classification system, pedestrian at signalized crosswalk (PSCW) application, Quantum optimization-supported virtual traffic light system, virtual reality for autonomous vehicle user experience research and network security (March 27th, 2023).

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

Our LinkedIn organization page is updated weekly by Ms. Naomi Nieves, C²M² Program Coordinator, and has seen consistent growth in engagement during this reporting period. It can be found at www.linkedin.com/in/center-for-connected-multimodal-mobility-304527163

3.4.2 Inventions, patent applications, and/or licenses

Nothing to report at this time.

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

In this reporting period, we published six final reports from our round of 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 five final reports under review from our round of 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 T^2 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 01, 2022 – March 31, 2023)
Outcome #1	Train the current and future transportation workforce to operate in an increasingly high-tech environment	Number of training 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 C²M² funded research projects	4	2

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

1. Our C²M² Cyber-Physical Systems Frontiers Series have continued to draw an audience of researchers, students, and industry members, allowing C²M² to share our ongoing research efforts with 18 people in this reporting period.

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

1. Dr. Chin Tser Huyang and his team have tested and verified that there is substantial performance degradation in vehicular network communication under harsh weather conditions. They have confirmed that machine learning based models can achieve high accuracy when applied to predict the channel performance degradation rate under weather conditions. They have proposed a dynamic switching strategy between 5G and 4G for connected vehicles under normal and severe weather conditions. Their work should benefit the auto driving communication research area.

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

1. Dr. Paul Zeihl and his team focused on the development of an autonomous damage detection method for bridge components and a semi-autonomous load rating framework for bridges. This project improves the load rating process for bridges. It is expected to reduce the cost of load rating and does not require traffic closures .

2. Dr. Yunyi Jia and his team increased the understanding of road hazard detection using smartphones and cloud-based services. They Improved processes and technology to monitor the road hazards in a more efficient and cost-effective way.

5. IMPACTS – What is the impact of the program? How has it contributed to improving the transportation system: safety, reliability, durability, etc.; transportation education; and the workforce?

To date, we have published 17 C²M² funded reports with an additional three reports under external review. We continue to see the biggest impact from our Center's investment in our relationship between partner institutions and their surrounding communities through our workshops, webinar series, course development, and collaborative research efforts. We are working diligently to facilitate the adoption of and subsequent impacts from our sponsored research on community and state policies. Our researchers continue to work to disseminate the results of their sponsored research, working with individuals from industry, city planners, and departments of transportation to improve transportation infrastructure, safety, and legislation at the local, state, and national levels.

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

No.	Goals	Research Performance Measures	Target per year	Completed in this reporting period (October 01, 2022 – March 31, 2023)
Impact #1	Increase the adoption of new technologies, methods or practices based on C²M²'s research	Number of cases of adoption by transportation agencies and/or commercialization of C²M²'s technologies, methods or practices	2	0
Impact #2	Improve transportation system operations and/or transportation safety and/or quality of life	Number of cases of C²M²'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. Nothing to report.

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

1. Models and results developed in the research project, "Real-time Vehicle Re-routing Under Disruption in Cross-dock Network with Time Constraints'' will be incorporated into IE 8540, Fundamentals of Supply Chain Logistics, at Clemson University and ECIV 790, Intermodal Freight Transport, at the University of South Carolina (UofSC). The developed tool will be demonstrated in outreach efforts at Clemson and UofSC.

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 six projects for our 2019, 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, six 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.