Semi-Annual Progress Report # 10

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

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Project Title: Center for Connected Multimodal Mobility (C²M²)

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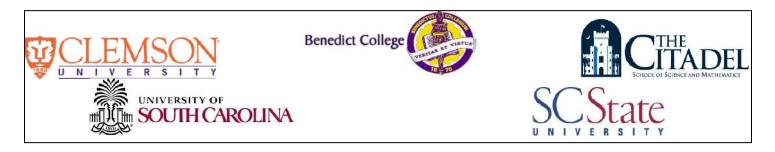Phone: (864) 656-3313, Email: mac@clemson.edu

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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.

- 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, and Ms. Naomi Nieves, C²M² Program Coordinator, 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 week. (Ongoing)
- The C²M² team consists of the C²M² director and associate directors, and their students continued their 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. Juan Caicedo, C²M² Associate Director, 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, Presented the research related to "Potential Reduction of Fatal Crashes in South Carolina due to Automated Vehicles" to Faculty of Technology, Policy and Management, Safety and Security Science Group at Delft University of Technology for the potential of future collaborations.
- Dr. Dimitra Michalaka, C²M² Associate Director, The Citadel, presented the research related to "Potential Reduction of Fatal Crashes in South Carolina due to Automated Vehicle" to SWOV, the Institute for Road Safety Research in Delft, Netherlands for the potential of future collaborations.
- Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, Ahmad Zaki Ghafari, C²M² Assistant Director, and Ms. Naomi Nieves, C²M² Program Coordinator, hosted our Annual Advisory Board Meeting to update our board on center progress and to discuss future activities. This meeting was hybrid. (August 17th, 2023)
- 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:
  - o Dr. Wayne Sarasua, Clemson University Civil Engineering Professor, presented his work on "Potential Reduction of Fatal Crashes in South Carolina due to

Automated Vehicles and Other Cool Topics". June 14th, 2023.

- o Dr. Pierluigi Pisu, Clemson University Automotive Engineering Professor, presented his work on "Security and Safety of Connected and Automated Vehicles Against Adverbial Attacks and Environmental Factors". July 21st, 2023.

- Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, and Ahmad Zaki Ghafari, C²M² Assistant Director, and students from C²M², IEEE ITSS and COMTO Clemson University Chapters visited the Clemson Area African American Museum (CAAAM). September 27th, 2023.

- Mr. Frank Ngeni and Mr. Cuthbert Ruseruka, C²M² graduate students from South Carolina State University, collaborated with other universities on the NSF MSI Cybersecurity project and other research activities. (Ongoing)

- Dr. Sabbir Salek, C²M² funded student, completed with his Doctor of Philosophy in Civil Engineering from Clemson University. His Ph.D. dissertation is titled "Generative Neural Network-Based Defense Methods Against Cyberattacks for Connected and Autonomous Vehicles".

- Ms. Ostonya Thomas, Benedict College, C²M² affiliated researcher, joined the team at Clemson University as a Graduate student. August 12th, 2023.

- Mr. Methusela Sulle and Mr. Paul Omulikoli, South Carlina State University, joined the C²M² research team.

- Dr. Mashrur "Ronnie" Chowdhury, C2M2 Director, Naomi Nieves, C2M2 Program Coordinator, and students from C2M2 participated in the FUSION 2023 Conference in Charleston, SC. June 27th-30th, 2023.

- Mr. Jean Michel Tine and Mr. Reek Majumder, Clemson University, Ph.D. students, presented their paper, "Hybrid Quantum-Classical Neural Network for Incident Detection" in the Fusion Conference in Charleston, SC. June 26th - June 29th, 2023.

- Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, Ahmad Zaki Ghafari, C²M² Assistant Director, and Ms. Naomi Nieves, C²M² Program Coordinator, and students from C²M² hosted a technology demonstration for a group of high School students who participated in Allen University's Summer Transportation Institute The students learned about the application of (1) hybrid classical-quantum deep learning models to detect adversarial attacks which affect the performance of the traffic sign detection module of autonomous vehicles, (2) virtual traffic signal control with cloud-based quantum computers, and (3) autonomous vehicle user experience through virtual reality. June 21st, 2023.

- Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, Ahmad Zaki Ghafari, C²M² Assistant Director, and Ms. Naomi Nieves, C²M² Program Coordinator, and students from C²M² hosted a technology demonstration for a group of high School students who participated in Clemson University's PEER/WISE Experience (PWE) program. Dr. Ronnie Chowdhury, C²M² Director, introducing students to Transportation Cyber-Physical-Social Systems (TCPSS) and self-driving cars. The students learned about the application of (1) hybrid classical quantum deep learning models to detect adversarial attacks which affect the performance of the traffic sign detection module of autonomous vehicles, (2) virtual traffic signal control with cloud-based quantum computers, and (3) autonomous vehicle user experience through virtual reality. July 12th, 2023

- Dr. Mashrur "Ronnie" Chowdhury, C2M2 Director, Ahmad Zaki Ghafari, C²M² Assistant Director, and Ms. Naomi Nieves, C2M2 Program Coordinator, and students from C²M² hosted a technology demonstration for a group of Hickory Tavern middle school students. Dr. Ronnie Chowdhury, C²M² Director, introducing students to Transportation Cyber-

Physical-Social Systems (TCPSS) and self-driving cars. The technology demonstration included hardware security, quantum computing, adversarial attacks, virtual traffic light, autonomous vehicles, and pedestrian safety systems. September 6th, 2023.

- Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, Ahmad Zaki Ghafari, C²M² Assistant Director and Ms. Naomi Nieves, C²M² Program Coordinator, hosted the 7th Annual Fall Conference, featuring keynote speaker Joachim Taiber, Founder and Managing Director, of International Operations for International Alliance for Mobility Testing and Standardization (IAMTS). This year's conference was opened by Dr. Jennifer Ogle, Clemson Professor and Chair of Civil Engineering. Dr. Chowdhury gave a presentation on "The Power of Our Collaboration". Dr. Chowdhury's presentation was followed by the State of the Center address by each of C²M² Associate Director. The afternoon session kicked off with a tutorial on Quantum Computing featuring fundamentals of quantum computing and hands on experience on quantum computers. On Friday, August 18th, ten students representing our five consortium institutions gave poster presentations. These presentations were rated by a panel of judges and the following students received recognition for their research presentation: Jean Michel Tine, Clemson University (1st Place), Abyad Enan and Sefatun-Noor Puspa, Clemson University (2nd Place), Ostonya, Thomas, Clemson University and Tony Munnings, Benedict College (3rd Place). August 17th-18th, 2023.

1.3 How have the results been disseminated?

- Dr. Chin-Tser Huang, The University of South Carolina, completed and published his C2M2-funded project report, "A Machine Learning-Assisted Framework for Determination of Performance Degradation Causes and Selection of Channel Switching Strategy in Vehicular Networks."

- Dr. Robert L. Mullen, The University of South Carolina, completed and published his C2M2-funded project report, "Data Fusion to Improve the Accuracy of Traffic Counts."

- Dr. Yunyi Jia, Clemson University, completed and published his C²M² funded project report, "Multimodal-AI based Roadway Hazard Identification and Warning using Onboard Smartphones with Cloud-based Fusion."

- Dr. Yunyi Jia, Clemson University, completed and published his C²M² funded project report, "Cloud-Based Collaborative Road Surface Monitoring using Deep Learning and Smartphones."

- 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)

- C²M² Clemson University student Jean Michelle Tine, presented a research poster at the C²M² 7th Annual Fall Conference, Columbia, SC. (August 18th, 2023)

- C²M² Clemson University student Sefatun-Noor Pushpu, Clemson presented a research poster at the C²M² 7th Annual Fall Conference, Columbia, SC. (August 18th, 2023)

- C²M² Benedict College students Tony Munnings, Anthony Stubbs presented a research poster at the C²M² 7th Annual Fall Conference, Columbia, SC. (August 18th, 2023)

- C²M² Clemson University student Nikhil Aditya presented a research poster at the C²M² 7th

Annual Fall Conference, Columbia, SC. (August 18th, 2023)

- C²M² Clemson University student Enan Abyad presented a research poster at the C²M² 7th Annual Fall Conference, Columbia, SC. (August 18th, 2023)

- C²M² University of South Carolina student Jian Liu presented a research poster at the C²M² 7th Annual Fall Conference, Columbia, SC. (August 18th, 2023)

- C²M² South Carolina State University student Cuthbert Ruseruka presented a research poster at the C²M² 7th Annual Fall Conference, Columbia, SC. (August 18th, 2023)

- C²M² Clemson University student Abdullah Al Mamun presented a research poster at the C²M² 7th Annual Fall Conference, Columbia, SC. (August 18th, 2023)

- C²M² Clemson University student Ostonya Thomas presented a research poster at the C²M² 7th Annual Fall Conference, Columbia, SC. (August 18th, 2023)

- C²M² University of South Carolina student Fahim Ahmed presented a research poster at the C²M² 7th Annual Fall Conference, Columbia, SC. (August 18th, 2023)

- C²M² Clemson University student Chunheng Zhao presented a research poster at the C²M² 7th Annual Fall Conference, Columbia, SC. (August 18th, 2023)

- C²M² Associate Director, Dr. Judith Mwakalonge, prepared manuscripts based on a C²M² funded project (Ongoing)
    - Frank Ngeni, Dr. Judith Mwakalonge, Dr. Gurcan Comert, Dr. Saidi Siuhi, Cuthbert Ruseruka, "Monitoring of Illegal Removal of Road Barricades Using Intelligent Transportation Systems" to be submitted to the Sustainability journal.
    - Frank Ngeni, Dr. Judith Mwakalonge, Dr. Gurcan Comert, Dr. Saidi Siuhi, Cuthbert Ruseruka "Monitoring of Illegal Removal of Road Barricades in Connected Environment" to be submitted to the Sensors journal.
    - 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", to be submitted to the International Journal of Transportation Science and Technology (IJTST).

- C²M² Director, Dr. Mashrur "Ronnie" Chowdhury, published the following work based on the C²M² funded project.
    - M Sabbir Salek, Pronab Kumar Biswas; Jacquan Pollard; Jordyn Hales, Zecheng Shen, Vivek Dixit, Mashrur Chowdury "A Novel Hybrid Quantum-Classical Framework for an In-Vehicle Controller Area Network Intrusion Detection," in IEEE Access, vol. 11, pp. 96081-96092, 2023, doi: 10.1109/ACCESS.2023.3304331.
    - Zadid Khan; Jean Michel Tine, Sakib Mahmud Khan; Reek Majumdar, Ayse Turhan Comert, Diamon Rice, Gurcan Comert, Dimitra Michalaka, Judith Mwakalonge, Mashrur Chowdhury "Hybrid Quantum-Classical Neural Network for Incident Detection," 2023 26th International Conference on Information Fusion (FUSION), Charleston, SC, USA, 2023, pp. 1-8, doi: 10.23919/FUSION52260.2023.10224090.

- C²M² Associate Director, Dr. Judith Mwakalonge, published the following work based on a

C²M² funded project.

- Ruseruka, C., Mwakalonge, J., Comert, G., Siuhi, S. and Perkins, J., 2023. Road Condition Monitoring Using Vehicle Built-in Cameras and GPS Sensors: A Deep Learning Approach. Vehicles, 5(3), pp.931-948.

- Dr. Yunyi Jia, C²M² affiliated researcher, Clemson University published the following work based on the C²M² funded project.

- Bhosale, M., Guo, L., Comert, G. and Jia, Y., 2023. On-Board Smartphone-Based Road Hazard Detection with Cloud-Based Fusion. Vehicles, 5(2), pp.565-582.

- Dr. Judith Mwakalonge, C²M² Associate Director, South Carolina State University, published the following work based on a C²M² funded project.

- Ruseruka, C., Mwakalonge, J., Comert, G., Siuhi, S., Ngeni, F. and Major, K., 2023. Pavement Distress Identification Based on Computer Vision and Controller Area Network (CAN) Sensor Models. Sustainability, 15(8), p.6438.

- Dr. Abuhdima C²M² affiliated researcher, Benedict College, published the following work based on the C²M² funded project,

- Abuhdima, E., Huang, C.T., Pisu, P., Comert, G., Liu, J., Zhao, C., Chambers, F., Niyomugabo, K., Tadessa, N. and Nazeri, A.H., 2023. Propagating Uniform Millimeter Wave in Dust and Sandstorm. IEEE Journal of Radio Frequency Identification.

- Jian Liu, C²M² affiliated researcher, University of South Carolina, published the following work based on the C²M² funded project.

- Liu, J., Nazeri, A., Zhao, C., Abuhdima, E., Comert, G., Huang, C.T. and Pisu, P., 2023. Switching Strategy for Connected Vehicles Under Variant Harsh Weather Conditions. IEEE Journal of Radio Frequency Identification.

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. Gurcan Comert, Associate Director, Benedict College will present his work on "Journey to my Success Story" in a C²M² Distinguished Speaker Series. October 26th, 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, 2024.
- C²M² Associate Director, Dr. Dimitra Michalaka is scheduled to join the panel discussing the possibility of teaching day camps, organized by GSSM for 6th-8th graders, in Charleston.
- 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. 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. Paul Zeihl, C2M2 Affiliated researcher, University of South Carolina, will submit the final report of the project "Building Smarter Cities via Intelligent Asset Management: South Carolina Case Study using IBM Maximo Application". The report will be published after review.

- Dr. Nathan Hyunh, C2M2 Affiliated researcher, University of South Carolina, submitted the final report of the project "Real-time Decentralized Framework for Technology-Enabled Intermodal Freight Transport". 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. Mashrur "Ronnie" Chowdhury, C²M² Director, and students from C²M² will participate in the IEEE International Automated Vehicle Validation Conference 2023 in Charleston, SC. C²M² students will also give a presentation based on their paper. (October 16th-18th, 2023)

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. 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.

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.*
- *Delft University of Technology, Department of Values, Technology and Innovation, Netherlands.*
- *K-12/Workforce Development*
  - *Cooper River Center for Advanced Studies*
  - *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*
- *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 (April 1, 2023 – September 30, 2023)
Output #1	Disseminate C²M²'s research results to a large audience utilizing different research distribution media	Number of technical reports published	5	4
		Number of conference presentations	20	12
		Number of peer-reviewed journal and magazine papers published	10	6
		Number of conferences solely based on C²M²'s research	1	1
Output #2	Develop new methods or products based on C²M²'s research	Number of new and/or improved research methods or products	10	3
Output #3	Demonstrate developed technologies	Number of pilot demonstrations of technology	3	3

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

Technical Reports

1. Yunyi Jia, Gurcan Comert; Akshatha Ramesh, Dhananjay Nikam, Venkat Narayanan Balachandran, Longxiang Guo, Rongyao Wang, Leo Hu "Cloud Based Collaborative Road Surface Monitoring using Deep Learning and Smartphones". (August 2023)
2. Mayuresh Bhosale, Longxiang Guo, Gurcan Comert, Yunyi Jia, Leo Hu "Multimodal-AI based Roadway Hazard Identification and Warning using Onboard Smartphones with Cloud-based Fusion". (July 2023)
3. Robert Mullen, Nathan Hyunh, Quentin Eloise "Data Fusion to Improve the Accuracy of Traffic Counts". (June 2023)
4. Chin-Tser Huang, Gurcan Comert, Esmail Abuhdima, Pierluigi Pisu, Jian Liu, Amirhossein Nazeri "A Machine Learning-Assisted Framework for Determination of Performance Degradation Causes and Selection of Channel Switching Strategy in Vehicular Networks. (May 2023)

Conference Presentations

1. Jean Michelle Tine, Clemson University, presented a research poster on "False data propagation

within a CV's in-vehicle network" at the C²M² 7th Annual Fall Conference, Columbia, SC. (August 18th, 2023)

2. Sefatun-Noor Pushpu, Clemson University, presented a research poster on "Hardware Trojan: A Covert threat to Intelligent Transportation Systems." at the C²M² 7th Annual Fall Conference, Columbia, SC. (August 18th, 2023)

3. Tony Munnings, Anthony Stubbs, Benedict College, presented a research poster on "Detecting Spatial Changes in Fugitive Methane in Urban Communities" at the C²M² 7th Annual Fall Conference, Columbia, SC. (August 18th, 2023)

4. Nikhil Aditya, Clemson University, presented a research poster on "Multi-Door Cross-Dock Scheduling Under Flexible Doors Mode And Material Handling Resource Restrictions" at the C²M² 7th Annual Fall Conference, Columbia, SC. (August 18th, 2023)

5. Enan Abyad, Clemson University, presented a research poster on "Enhancing Vehicle Safety with a Budget-Friendly Camera" at the C²M² 7th Annual Fall Conference, Columbia, SC. (August 18th, 2023)

6. Jian Liu, University of South Carolina, presented a research poster on "Switching Strategy for Connected Vehicles Under Variant Harsh Weather Conditions" at the C²M² 7th Annual Fall Conference, Columbia, SC. (August 18th, 2023)

7. Cuthbert Ruseruka, South Carolina State University, presented a research poster on "Application of Artificial Intelligence (AI) for Detecting and Estimating Pothole Size and Geolocation Using Built-in Vehicle Technologies" at the C²M² 7th Annual Fall Conference, Columbia, SC. (August 18th, 2023)

8. Abdullah Al Mamun, Clemson University, presented a research poster on "Predictive Modeling of Work Zone Crash Severity with Classical and Quantum Neural Networks" at the C²M² 7th Annual Fall Conference, Columbia, SC. (August 18th, 2023)

9. Ostonya Thomas, Clemson University, presented a research poster on "Using Convolutional Neural Networks to Predict the Prices of Vehicles" at the C²M² 7th Annual Fall Conference, Columbia, SC. (August 18th, 2023)

10. Fahim Ahmed, University of South Carolina, presented a research poster on "Vehicle Re-Routing For Integrated Vehicle Routing And Scheduling Problem With Cross-Dock Under Disruption" at the C²M² 7th Annual Fall Conference, Columbia, SC. (August 18th, 2023)

11. Chunheng Zhao, Clemson University, presented a research poster on "Securing Deep Learning against Adversarial Attacks for Connected and Automated Vehicles" at the C²M² 7th Annual Fall Conference, Columbia, SC. (August 18th, 2023)

12. Mr. Jean Michel Tine and Mr. Reek Majumder, Clemson University, Ph.D. students, presented their paper, "Hybrid Quantum-Classical Neural Network for Incident Detection" in the Fusion Conference on June 26th - June 29th, 2023, in Charleston, SC.

Peer-Reviewed Journal and Magazine Publications

1. Ruseruka, C., Mwakalonge, J., Comert, G., Siuhi, S. and Perkins, J., 2023. Road Condition Monitoring Using Vehicle Built-in Cameras and GPS Sensors: A Deep Learning Approach. Vehicles, 5(3), pp.931-948.

2. Bhosale, M., Guo, L., Comert, G. and Jia, Y., 2023. On-Board Smartphone-Based Road Hazard Detection with Cloud-Based Fusion. Vehicles, 5(2), pp.565-582.

3. Khan, S.M., Salek, M.S., Harris, V., Comert, G., Morris, E. and Chowdhury, M., 2023. Autonomous Vehicles for All?. Journal on Autonomous Transportation Systems.

4. Liu, J., Nazeri, A., Zhao, C., Abuhdima, E., Comert, G., Huang, C.T. and Pisu, P., 2023. Switching Strategy for Connected Vehicles Under Variant Harsh Weather Conditions. IEEE Journal of Radio Frequency Identification.

5. M Sabbir Salek, Pronab Kumar Biswas; Jacquan Pollard; Jordyn Hales, Zecheng Shen, Vivek Dixit, Mashrur Chowdury "A Novel Hybrid Quantum-Classical Framework for an In-Vehicle Controller Area Network Intrusion Detection," in IEEE Access, vol. 11, pp. 96081-96092, 2023, doi: 10.1109/ACCESS.2023.3304331.

6. Zadid Khan; Jean Michel Tine, Sakib Mahmud Khan; Reek Majumdar, Ayse Turhan Comert, Diamon Rice, Gurcan Comert, Dimitra Michalaka, Judith Mwakalonge, Mashrur Chowdhury "Hybrid Quantum-Classical Neural Network for Incident Detection," 2023 26th International Conference on Information Fusion (FUSION), Charleston, SC, USA, 2023, pp. 1-8, doi: 10.23919/FUSION52260.2023.10224090.

C²M² Sponsored Research Conferences

1. C²M² Seventh Annual Fall Conference held hybrid on August 17th-18th, 2023

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

3.2.1 New or improved methods

1. Dr. Yunyi Jia and his team developed a cost-effective approach to monitoring road conditions by a cloud-based collaborative monitoring using in-vehicle smartphones, which could come from any vehicle user. When a vehicle drives over a certain type of road defect, the acceleration signal, especially the vertical acceleration, will have a unique pattern in the trajectory. The type of road defect can be identified from the general shape of the acceleration wave. Meanwhile, the amplitude of the wave reflects the vehicle speed and the severity of the defect. The team trained a Long Short-Term Memory (LSTM) based deep learning network to complete the identification of defect types using the acceleration data.

2. Dr. Robert Mullen and his team developed a decision-level fusion method of a pneumatic tube and an infrared video for vehicle count and classification. The method was validated at three different locations in South Carolina. Errors in vehicle counts and vehicle classification were calculated using manual data collection from recorded videos as the baseline. In all locations, the results of data fusion are more accurate in both vehicle counts and vehicle classification when compared to either of the methods alone.

3. Dr. Yunyi Jia and his team developed a new method to deal with road hazards using smartphones. Since most of the population drives cars with smartphones onboard, they aimed to leverage this to detect road hazards in a more flexible, cost-effective, and efficient way. The study proposed a cloud-based deep-learning road hazard detection model based on a Long-Short Term Memory network (LSTM) to detect different types of road hazards from motion data. To address the issue of large data requests for deep learning, they proposed to fuse both simulation data and experimental data for the learning. The proposed approaches are validated by experimental tests, and the results demonstrate the accuracy of road hazard detection based on cloud-based fusion.

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 Ms. Naomi Nieves, C²M² Program Coordinator, and students from C²M² hosted a technology demonstration for a group of high School students who participated in Allen University's Summer Transportation Institute The students learned about the application of (1) hybrid classical-quantum deep learning models to detect adversarial attacks which affect the performance of the traffic sign detection module of autonomous vehicles, (2) virtual traffic signal control with cloud-based quantum computers, and (3) autonomous vehicle user experience through virtual reality. June 21st, 2023.

2. Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, Ahmad Zaki Ghafari, C²M² Assistant Director, and Ms. Naomi Nieves, C²M² Program Coordinator, and students from C²M² hosted a technology demonstration for a group of high School students who participated in Clemson University's PEER/WISE Experience (PWE) program. Dr. Ronnie Chowdhury, C2M2 Director, introducing students to Transportation Cyber-Physical-Social Systems (TCPSS) and self-driving cars. The students learned about the application of (1) hybrid classical quantum deep learning models to detect adversarial attacks which affect the performance of the traffic sign detection module of autonomous vehicles, (2) virtual traffic signal control with cloud-based quantum computers, and (3) autonomous vehicle user experience through virtual reality. July 12th, 2023.

3. Dr. Mashrur "Ronnie" Chowdhury, C2M2 Director, Ahmad Zaki Ghafari, C2M2 Assistant Director, and Ms. Naomi Nieves, C2M2 Program Coordinator, and students from C2M2 hosted a technology demonstration for a group of Hickory Tavern middle school students. Dr. Ronnie Chowdhury, C2M2 Director, introducing students to Transportation Cyber-Physical-Social Systems (TCPSS) and self-driving cars. The technology demonstration included hardware security, quantum computing, adversarial attacks, virtual traffic light, autonomous vehicles, and pedestrian safety systems. September 6th, 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 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 four 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 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 (April 1, 2023 – September 30, 2023)
Outcome #1	Train the current and future transportation workforce to operate in an increasingly high-tech environment	Number of trainings events and workshops	2	2
Outcome #2	Incorporate new technologies (software and/or hardware) and/or techniques and/or practices that are deployment ready	Number of new technologies, and/or techniques and/or practices that offer implementation or deployment guidance	4	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. C²M² organized a workshop featuring a presentation by Tommy Johnston, a Solutions Architect at AWS Worldwide Public Sector. During the workshop, Mr. Johnson provided in-depth insights into Amazon Web Services, their resources, and the architecture of cloud computing.
2. Dr. Shauzi Li and two of the Clemson University students offered a tutorial on Quantum Computing featuring fundamentals of quantum computing and hands-on experience on quantum computers.

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

1. Dr. Yunyi Jia and his team validated road hazard data using BeamNG Tech software, the g-force/acceleration sensor to measure the motion data and its similarity to the real world. They generated a solution to a cost-effective and time-efficient method for data collection and deep learning model-based validation.

4.3 Outcome #3: Improvement of technologies in addressing transportation issues 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. Their approach uses MATLAB to simulate the effect of dust and sand on the propagating electromagnetic millimeter wave. The simulation result showed that the amplitude of the propagating electric field in linear polarization is affected less by dust and sand compared to circular polarization. The effect of dust and sand is more evident when the visibility is less than 10m. The results would help design a wireless system in similar dusty/sandy regions to avoid disconnected channels.
2. Dr. Robert Mullen and his team developed of data fusion method involving thermal imaging data and pneumatic tube data, which provides a more accurate classification compared to either method when used by itself.

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 32 C²M² funded reports with an additional four 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 (April 1, 2023 – September 30, 2023)
Impact #1	Increase the adoption of new technologies, methods or practices based on C^{2}M^2's research	Number of cases of adoption by transportation agencies and/or commercialization of C^{2}M^2's technologies, methods or practices	2	1
Impact #2	Improve transportation system operations and/or transportation safety and/or quality of life	Number of cases of C^{2}M^2's research that resulted in societal benefits, such as lives saved, congestion reduced, and fuel conserved through changing behavior, practices, decision making, policies (including regulatory policies), and/or social actions	2	0

5.1 Impact #1: Increase the adoption of new technologies, methods, or practices based on C^{2}M^2's research in this reporting period

1. The research project "Data Fusion to Improve the Accuracy of Traffic Counts" proposed a fusion method of pneumatic tube and infrared video for vehicle classification at night. The results of data fusion are more accurate in both vehicle counts and vehicle classification when compared to either of the methods alone. South Carolina Department of Transportation (SCDOT) purchased a trailer to support the deployment of a thermal imaging video recorder for use in future vehicle classification efforts.

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

Nothing to Report.

6. CHANGES/PROBLEMS

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.