



# Center for Connected Multimodal Mobility (C<sup>2</sup>M<sup>2</sup>)

## Semi-Annual Progress Report # 8

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**Project Title:** Center for Connected Multimodal Mobility (C<sup>2</sup>M<sup>2</sup>)

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Benedict College





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

### 1.1 What are the major goals of the program?

C<sup>2</sup>M<sup>2</sup>'s mission statement:

Our vision for the Center for Connected Multimodal Mobility (C<sup>2</sup>M<sup>2</sup>), 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<sup>2</sup>M<sup>2</sup>'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<sup>2</sup>M<sup>2</sup> 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<sup>2</sup>M<sup>2</sup> activities

C<sup>2</sup>M<sup>2</sup> 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.

1. C<sup>2</sup>M<sup>2</sup> Directors from five partner institutions continued their bi-weekly conference calls to coordinate the Center's activities and budget. (Ongoing)
2. Dr. Mashrur "Ronnie" Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, Dr. Sakib Khan, C<sup>2</sup>M<sup>2</sup> Assistant Director, and Ms. Naomi Nieves, C<sup>2</sup>M<sup>2</sup> Program Coordinator, met with Clemson University students daily to coordinate Center-related activities. (Ongoing)
3. Dr. Nathan Hyunh, C<sup>2</sup>M<sup>2</sup> Associate Director, University of South Carolina, held weekly meetings with two C<sup>2</sup>M<sup>2</sup> funded Ph.D. students to track research progress of C<sup>2</sup>M<sup>2</sup> 2020 funded project "Improving Freight Transport Mobility and Efficiency via Synchronization." (Ongoing)
4. Dr. Gurcan Comert, C<sup>2</sup>M<sup>2</sup> 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. (Ongoing)
5. Judith Mwakalonge, C<sup>2</sup>M<sup>2</sup> Associate Director, South Carolina State University, and her research team members held weekly research meetings every Friday for the C<sup>2</sup>M<sup>2</sup> 2020 funded project "Smart Monitoring and Warning System for Road/Lane(s) Closure for Connected and Non-connected Vehicles." (Ongoing)
6. Dr. Chin-Tser Huang, C<sup>2</sup>M<sup>2</sup> affiliated researcher, University of South Carolina, held regular weekly team meetings for the C<sup>2</sup>M<sup>2</sup> funded project "A Machine Learning-Assisted Framework for Determination of Performance Degradation Causes and Selection of Channel Switching Strategy in Vehicular Networks." (Ongoing)
7. Dr. Yu Qian, University of South Carolina, Dr. Gurcan Comert, C<sup>2</sup>M<sup>2</sup> Associate Director, Benedict College, and Dr. Nagesh Begashaw, C<sup>2</sup>M<sup>2</sup> Affiliated Researcher, Benedict College, and research team members held weekly research meetings for C<sup>2</sup>M<sup>2</sup> 2020 funded project "Strategic Management of Limited Transportation Recourses to Support Mobility of Disadvantaged and Disabled Travelers during the COVID-19 Pandemic or Similar Situations," (Ongoing)
8. The C<sup>2</sup>M<sup>2</sup> quantum artificial intelligence (Q-AI) lab offered a graduate-level course titled "Quantum Optimization and Artificial Intelligence" in the Spring of 2021. Nine graduate students attended the course. The course covered the basics of quantum computing for developing quantum optimization and machine learning algorithms. (January-April 2022)
9. Dr. William Davis, C<sup>2</sup>M<sup>2</sup> affiliated researcher, The Citadel, has hosted several academic sessions to recruit students, promote degree programs, and provide a tour of civil, environmental, and construction engineering labs, classrooms, and computer labs. (April 8, 2022)



10. In this reporting period, C<sup>2</sup>M<sup>2</sup> 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<sup>2</sup>M<sup>2</sup> 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 Speaker:
  - Anton Bezuglov, Valassis, presented his work on "Tuning Personalized Recommendations with the Multi-Armed Bandit Approach" on April 7<sup>th</sup>, 2022
11. Dr. Dan Nale, Dr. William Davis, and Jennifer Welch met with Trident Technical College officials for program coordination, recruiting, marketing, and student advising (April 15, 2022)
12. Dr. Mashrur "Ronnie" Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, and Dr. Sakib Khan, C<sup>2</sup>M<sup>2</sup> Assistant Director, and C<sup>2</sup>M<sup>2</sup> student Jacquan Pollard attended the Men of Color National Summit 2022. Jacquan Pollard served as a volunteer at the summit. He also participated in a panel discussion for high school and college students on undergraduate and graduate education. Jacquan stated, "Participating in the 5<sup>th</sup> annual Clemson University Men of Color National Summit provided the opportunity to engage with high school and college students, business professionals, educators, government officials, and community leaders worldwide." (April 21 and 22, 2022).
13. Dr. Mashrur "Ronnie" Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, had a meeting with Dr. Roslyn Clark Artis, CEO & President of Benedict College. C<sup>2</sup>M<sup>2</sup> has been working with Benedict College, an HBCU partner, on various projects since 2017. President Artis and Dr. Chowdhury discussed the future of their collaboration on transportation cybersecurity research and quantum computing. The establishment of a future lab on transportation cyber-physical-social systems lab at Benedict College was also discussed at the meeting. (May 23, 2022)
14. Dr. Mashrur "Ronnie" Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, Dr. Sakib Khan, C<sup>2</sup>M<sup>2</sup> Assistant Director, Ms. Naomi Nieves, C<sup>2</sup>M<sup>2</sup> Program Coordinator and C<sup>2</sup>M<sup>2</sup> students from Clemson University, traveled to Columbia (SC) to engage with students across South Carolina participating in the Summer Transportation Institute (STI) Program hosted by Dr. Vareva Harris at Benedict College. (July 12, 2022)
15. Dr. Mashrur "Ronnie" Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, Dr. Sakib Khan, C<sup>2</sup>M<sup>2</sup> Assistant Director, and Ms. Naomi Nieves, C<sup>2</sup>M<sup>2</sup> Program Coordinator worked with Clemson University's CECAS PROMO group to develop a short video explaining C<sup>2</sup>M<sup>2</sup>'s work with cybersecurity. This video is developed for the inaugural UTC video webinar series hosted by USDOT (August – September 2022)
16. C<sup>2</sup>M<sup>2</sup> was featured in the SC Centers of Economic Excellence 2.0 Newsletter. (August 2, 2022)
17. Dr. Mashrur "Ronnie" Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, Dr. Sakib Khan, C<sup>2</sup>M<sup>2</sup> Assistant Director, and Ms. Naomi Nieves, C<sup>2</sup>M<sup>2</sup> Program Coordinator, met with the Legislative Aide for the U.S. Senator Edward Markey, Danny Vinik to discuss a bill that is being introduced to Congress in regard to autonomous vehicle safety and cybersecurity.
18. Dr. Mashrur "Ronnie" Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, and Ms. Naomi Nieves, C<sup>2</sup>M<sup>2</sup> Program Coordinator, and C<sup>2</sup>M<sup>2</sup> Associate Directors, have been planning for the 6<sup>th</sup> Annual C<sup>2</sup>M<sup>2</sup> Conference to be held on November 3 and 4 (September 2022)



19. Dr. Mashrur "Ronnie" Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, Dr. Sakib Khan, C<sup>2</sup>M<sup>2</sup> Assistant Director, Ms. Naomi Nieves, C<sup>2</sup>M<sup>2</sup> Program Coordinator, and Parren Sanders, CECAS PROMO Staff, attended the USDOT webinar to review the cybersecurity promo videos submitted by Clemson University, New York University, Carnegie Mellon University, Virginia Tech and San Jose State University (September 28, 2022)
20. Dr. Mashrur "Ronnie" Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, Dr. Sakib Khan, C<sup>2</sup>M<sup>2</sup> Assistant Director, and Ms. Naomi Nieves, C<sup>2</sup>M<sup>2</sup> Program Coordinator, had several meetings with Innova EV to initiate research projects to support C<sup>2</sup>M<sup>2</sup>'s mission on cybersecure and connected mobility (September 12, 19 and 28, 2022)
21. Dr. Mashrur "Ronnie" Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, Dr. Sakib Khan, C<sup>2</sup>M<sup>2</sup> Assistant Director, and Ms. Naomi Nieves, C<sup>2</sup>M<sup>2</sup> Program Coordinator, and students from C<sup>2</sup>M<sup>2</sup>, IEEE ITSS and COMTO Clemson University Chapters attended the presentation from Dr. Mitch Shue (Professor, Clemson University) on the current and future trend of cloud computing for transportation applications (September 15, 2022)
22. In this reporting period, the Clemson branch of C<sup>2</sup>M<sup>2</sup> continued the C<sup>2</sup>M<sup>2</sup> 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<sup>2</sup>M<sup>2</sup> 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:
  - Zadid Khan, Walmart, Inc. presented his work on "Cybersecurity of connected automated vehicles in transportation cyber-physical systems with artificial intelligence" as a C<sup>2</sup>M<sup>2</sup> CPS Frontier Series speaker on April 21<sup>st</sup>, 2022
  - Manveen Kaur, Ph.D. candidate in the School of Computing at Clemson University, presented her work on "The Design and Validation of an ICN-Enabled Hybrid Unmanned Aerial System" as a C<sup>2</sup>M<sup>2</sup> CPS Frontier Series speaker on April 28<sup>th</sup>, 2022.

### **1.3 How have the results been disseminated?**

- Bhavya Padmanabhan, University of South Carolina, presented her research in a poster presentation at the C<sup>2</sup>M<sup>2</sup> 5<sup>th</sup> Annual Fall Conference, Clemson, SC. This work is based on the 2021 C<sup>2</sup>M<sup>2</sup> funded project "Real-time Decentralized Framework for Technology-Enabled Intermodal Freight Transport" (October 15, 2021) (Not reported in the earlier SAR report).
- Based on Dr. Yunyi Jia's C<sup>2</sup>M<sup>2</sup> funded project, a Master Thesis, "Cloud Based Collaborative Road Surface Monitoring Using Deep Learning and Smartphones" at Clemson University, has been completed.
- Dr. Richard Brooks, Clemson University, completed and published his 2018 funded project report, "Enhanced DSRC Security" (April 18, 2022).
- Dr. Mashrur "Ronnie" Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, was invited to speak at the webinar "Equity in Transportation Research and Funding Opportunities." The USDOT coordinated the webinar as part of the White House Initiative for HBCUs. This webinar focused on how researchers can include equity in transportation and impact on the lives of underserved and underrepresented communities. Dr. Chowdhury gave a brief overview of C<sup>2</sup>M<sup>2</sup> HBCU initiatives to a large audience from various organizations. (June 23, 2022)



- Dr. Mashrur "Ronnie" Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, was invited to speak at the Benedict Colleges' Summer Transportation Institute (STI) closing event. His presentation titled, *From Earth to Space: The Wonders of Transportation Technology*, included an overview of exciting research opportunities and future careers in STEM within autonomous transportation research, from surface to space transportation. This presentation was intended to give high school students exposure to future transportation technologies in a cyber-physical-social-systems environment. (July 28, 2022)
- Dr. Vareva Harris with her undergraduate research advisees - Jarvel Evans and Dejanija Jackson from Benedict College, attended the 1<sup>st</sup> Annual CCAT HBCU Conference at the University of Michigan. The Benedict College team represented the C<sup>2</sup>M<sup>2</sup> Quantum AI Lab, where their presentation focused on the application of quantum computing for optimal route solutions for the delivery of perishable goods. Food waste is a major concern in South Carolina and on a national level. Improving routes for delivery trucks carrying perishable foods was the focus of this study. The research team described how quantum computing could help address this problem. (September 9, 2022)
- Dr. Burak Eksioğlu, University of Arkansas, completed and published his 2018 funded project report, "Framework for Accommodating Emerging Autonomous Vehicles." (September 22, 2022).
- Dr. Judith Mwakalonge, C<sup>2</sup>M<sup>2</sup> Associate Director, SCSU, completed and published her 2018 C<sup>2</sup>M<sup>2</sup> funded project report, "Evaluation of Before and After Measures to Curb Distracted Walking" (September 20, 2022).
- Dr. Yu Qian, University of South Carolina, Dr. Gurcan Comert, C<sup>2</sup>M<sup>2</sup> Associate Director, Benedict College, and Dr. Nagesh Begashaw, C<sup>2</sup>M<sup>2</sup> Affiliated Researcher, Benedict College, published the following work based on the C<sup>2</sup>M<sup>2</sup> 2020 funded project "Strategic Management of Limited Transportation Recourses to Support Mobility of Disadvantaged and Disabled Travelers during the COVID-19 Pandemic or Similar Situations."
  - Liu, Y., Qian, Y., Comert, G., and Begashaw, N. (2023). "Mobility Support for Disadvantaged and Disabled Travelers during Pandemic or Similar Situations" Expert Systems with Applications. 212: 18786 (<https://doi.org/10.1016/j.eswa.2022.118786>) (September 2022)

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

- C<sup>2</sup>M<sup>2</sup> will continue its Distinguished Speaker Series and C<sup>2</sup>M<sup>2</sup> 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)
  - Fengjiao Zou, Ph.D. Candidate, Clemson University, will present his work on "Unmarked Midblock Crossing Behavior of Pedestrians at a Multilane Road when Interacting with Autonomous Vehicles" in a C<sup>2</sup>M<sup>2</sup> CPS Frontier Series on November 11, 2022
- Dr. Mashrur "Ronnie" Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, Clemson University, is continuing to work with Clemson University Facilities on expanding his South Carolina - Connected Vehicle Testbed (SC-CVT) from Perimeter Road to the entire Clemson University campus, which will enable real-time traffic monitoring, pedestrian safety warning, and signal-vehicle coordination systems. (Ongoing)



- Dr. Mashrur "Ronnie" Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, Clemson University, is continuing the effort to develop a Quantum-Artificial Intelligence or Q-AI lab at each of our consortium institutions. (Ongoing – 2020 - 2023)
- Dr. Nathan Huynh, C<sup>2</sup>M<sup>2</sup> Associate Director, USC, and Dr. William Ferrell, C<sup>2</sup>M<sup>2</sup> affiliated researcher, Clemson University, have submitted two revised manuscripts for journal publication based on their 2020-funded project, "Improving Freight Transport Mobility and Efficiency via Synchronization." (Ongoing – 2020-2022)
- Dr. Mashrur "Ronnie" Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, Clemson University, will give a presentation on C<sup>2</sup>M<sup>2</sup> research to Audi AV Validation Group Visit to CU-ICAR (October 12, 2022)
- Dr. Mashrur "Ronnie" Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, Dr. Sakib Khan, C<sup>2</sup>M<sup>2</sup> Assistant Director, and Ms. Naomi Nieves, C<sup>2</sup>M<sup>2</sup> Program Coordinator, and students from C<sup>2</sup>M<sup>2</sup>, IEEE ITSS and COMTO Clemson University Chapters will attend 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 14, 2022)
- Dr. Mashrur "Ronnie" Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, Dr. Sakib Khan, C<sup>2</sup>M<sup>2</sup> Assistant Director, and Ms. Naomi Nieves, C<sup>2</sup>M<sup>2</sup> Program Coordinator, and students from C<sup>2</sup>M<sup>2</sup> will visit Hickory Tavern Middle School to host a technology demonstration to students. The students will be introduced to Transportation Cyber-Physical Systems (TCPS), self-driving cars, connected drone applications, virtual traffic, and TCPS cybersecurity using Quantum Artificial Intelligence (October 14, 2022).
- Dr. Mashrur "Ronnie" Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, Abyad Enan and Jean Micheal Tine, C<sup>2</sup>M<sup>2</sup> students, will attend a Federal Motor Carrier Safety Administration-sponsored project meeting on workzone safety. This project is a result of C<sup>2</sup>M<sup>2</sup> collaboration between Clemson University, South Carolina State University and Benedict College (October 27, 2022).
- Dr. Pierluigi Pisu, C<sup>2</sup>M<sup>2</sup> Affiliated Researcher, Clemson University, and Dr. Gurcan Comert, C<sup>2</sup>M<sup>2</sup> Associate Director, Benedict College, are preparing a manuscript review in conjunction with their 2021 funded project, "Securing Deep Learning against Adversarial Attacks for Connected and Autonomous Vehicles." (Ongoing - 2021-2022)
  - C. Zhao, G. Comert, and P. Pisu, "Secure Connected and Automated Vehicles against False Data Injection Attack using Cloud-based Data Fusion," Modeling, Estimation and Control Conference (MECC), Oct. 24-27, 2021.
- Dr. Gurcan Comert, C<sup>2</sup>M<sup>2</sup> Associate Director, Benedict College, will present the following two papers in conjunction with their 2020-funded project, "Modeling Impact of Weather Conditions on 5G Communication and Mitigation Measures on Control of Automated Intersections."
  - Abuhdima, E, Comert. G., Pisu P., Huang C. T., Nazeri A., Liu J., Niyomugabo K., Chambers F., Nabeyou T., and Zhao C. (2022) The Effect of Dust and Sand on the Propagating EM Millimeter Plane Wave (IEEE WiSEE), Manitoba, Canada (October 2022)
  - Liu, J., Zhao C., Nazeri A., Abuhdima, E., Comert G., Huang C. T., and Pisu P. (2022) Investigation of 5G and 4G V2V Communication Channel Performance Under Severe Weather (IEEE WiSEE), Manitoba, Canada (October 2022)
- Dr. Gurcan Comert, C<sup>2</sup>M<sup>2</sup> Associate Director, Benedict College, will have the following journal article published based on his 2018 funded project, "Enhanced DSRC Security."



- F. Sun, R. R. Brooks, G. Comert and N. Tusing, "Side-Channel Security Analysis of Connected Vehicle Communications Using Hidden Markov Models," in IEEE Transactions on Intelligent Transportation Systems, vol. 23, no. 10, pp. 17562-17574, doi: 10.1109/TITS.2022.3164779. (October 2022)
- Dr. Paul Ziehl, C<sup>2</sup>M<sup>2</sup> Affiliated Researcher, University of South Carolina, has the following publications under review based on his 2020 C<sup>2</sup>M<sup>2</sup> funded project, "Building Smarter Cities via Intelligent Asset Management: South Carolina Case Study using IBM Maximo Application"
  - K C, L., Tabassum, N., Cole, C. and Ziehl, P., Image-Based Crack Detection by Extracting Depth of The Crack Using Machine Learning. To be submitted to a journal.
  - K C, L., Surface Damage Imaging for Input to Load Rating of Bridges, 23-27 October 2022, Dallas, TX.
- C<sup>2</sup>M<sup>2</sup> will host its 6<sup>th</sup> Annual Conference jointly hosted at Clemson University and University of South Carolina (November 3 and 4, 2022).
- Dr. Gurcan Comert, C<sup>2</sup>M<sup>2</sup> Associate Director, Benedict College, has submitted the final report of the 2020 C<sup>2</sup>M<sup>2</sup> funded project "Modeling Impact of Weather Conditions on 5G Communication and Mitigation Measures on Control of Automated Intersections." The report is under review and will be published soon.
- Dr. Mashrur Chowdhury, C<sup>2</sup>M<sup>2</sup> Director, has submitted the final report of the C<sup>2</sup>M<sup>2</sup> foundational project, "Vision-based Navigation of Autonomous Vehicle in Roadway Environments with Unexpected Hazards." The report is under review and will be published soon.
- Dr. Yu Qian, University of South Carolina, has submitted the final report of the 2020 C<sup>2</sup>M<sup>2</sup> funded project "Strategic Management of Limited Transportation Recourses to Support Mobility of Disadvantaged and Disabled Travelers during the COVID-19 Pandemic or Similar Situations." The report is under review and will be published soon.
- Dr. Paul Ziehl, University of South Carolina, has submitted the final report of the 2020 C<sup>2</sup>M<sup>2</sup> funded project "Digital Twins to Increase Mobility in Rural South Carolina." The report is under review and will be published soon.
- Dr. Bing Li, C<sup>2</sup>M<sup>2</sup> affiliated researcher, Clemson University International Center for Automated Research (CU-ICAR), has submitted the final report of the 2020 C<sup>2</sup>M<sup>2</sup> funded project, "Safe and Efficient E-Wayfinding (SeeWay) Guidance for the Transition to Autonomous Vehicles for the Visually Impaired." The report is under review and will be published soon.
- Dr. Nathan Huynh and Bhavya Padmanabhan, University of South Carolina, will present their research work on "Real-time Decentralized Framework for Technology-Enabled Intermodal Freight Transport" at the 102 annual meeting of Transportation Research Board, Washington, D.C, (January 8-12, 2023).
- Dr. Dimitra Michalaka, C<sup>2</sup>M<sup>2</sup> Associate Director, the Citadel, has submitted the following manuscript based on the C<sup>2</sup>M<sup>2</sup> funded project:
  - Kohneh, J.N., Sarasua, W., Michalaka, D., Stanley, M., Zou, F., Murray-Tuite, P., and Brown, K., "Potential Reduction of Fatal Crashes in South Carolina due to Automated Vehicles." Transportation Research Record: Journal of the Transportation Research Board.





- Dr. Judith Mwakalonge, C<sup>2</sup>M<sup>2</sup> Associate Director, South Carolina State University, has submitted the following manuscript based on the 2020 C<sup>2</sup>M<sup>2</sup> funded project “Smart Monitoring and Warning System for Road/Lane Closure in Connected and Non-Connected Environments”:
  - Ngeni, F., Mwakalonge, J., Comert, G., and Siuhi, S., "Monitoring of Illegal Removal of Road Barricades Using Intelligent Transportation Systems", International Journal of Transportation Interdisciplinary Research, 2022. (Under Review)
- Dr. Judith Mwakalonge, C<sup>2</sup>M<sup>2</sup> Associate Director, South Carolina State University, is preparing the following manuscript based on the 2020 C<sup>2</sup>M<sup>2</sup> funded project “Smart Monitoring and Warning System for Road/Lane Closure in Connected and Non-Connected Environments” for a journal submission:
  - Ngeni, F., Mwakalonge, J., Comert, G., and Siuhi, S., "Monitoring of Illegal Removal of Road Barricades Using Intelligent Transportation Systems in Non-Connected Environment". (Under Preparation)
- Dr. Chin-Tser Huang, C<sup>2</sup>M<sup>2</sup> Affiliated Researcher, University of South Carolina are preparing a manuscript based on their C<sup>2</sup>M<sup>2</sup> funded project “A Machine Learning-Assisted Framework for Determination of Performance Degradation Causes and Selection of Channel Switching Strategy in Vehicular Networks” to be submitted to a journal. (Ongoing activity from the previous SAR report)
- Dr. Bing Li, C<sup>2</sup>M<sup>2</sup>affiliated researcher, Clemson University International Center for Automated Research (CU-ICAR), has the following publications under review based on his 2020 C<sup>2</sup>M<sup>2</sup> funded project, “Safe and Efficient E-Wayfinding (SeeWay) Guidance for the Transition to Autonomous Vehicles for the Visually Impaired.”
  - J. Brooks, B. Li, C. Jenkins, L. Dylgjeri, Sarathkrishna, A. Ajayan, M. Ghodekar, S. Nikhal, A. Rana, and Z. Yang. “Transportation Preferences, Challenges & Opportunities for Visually Impaired Users.” Journal of Visual Impairment & Blindness (JVIB), 2021. (Under-Review)
  - Yang, Z., Yang, L., Kong, L., Wei, A., Leaman, L., Brooks, J., and Li, B., “SeeWay: Vision-Language Assistive Navigation for the Visually Impaired.” IEEE International Conference on Systems, Man, and Cybernetics, Accepted, Forthcoming; 2022 (<https://tinyurl.com/22-Zack-SMC>)
  - Leaman, J., Yang, Z., Elglaly, Y. N., La, H., and Li, B., “Embodied-AI Wheelchair Framework with Hands- free Interface and Manipulation.” IEEE International Conference on Systems, Man, and Cybernetics, Accepted, Forthcoming; 2022. (<https://tinyurl.com/22-Jesse-SMC>)

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

### **2.1 What organizations have been involved as key partners?**

The C<sup>2</sup>M<sup>2</sup> 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<sup>2</sup>M<sup>2</sup> 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<sup>2</sup>M<sup>2</sup> 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
- *Leidos/CARMA, Reston, Virginia*: research collaboration, in-kind support

## **2.2 Have other collaborators or contacts been involved?**

Along with the five institutions that make up the C<sup>2</sup>M<sup>2</sup> consortium, our Center has partnered with the following:

- *Charleston County Aviation Authority*, workforce development
- *South Carolina Aeronautics Commission*, workforce development
- *Heliplanners*, workforce development
- *Town of Mount Pleasant*, workforce development
- *Mead & Hunt*, workforce development
- *Cooper River Center for Advanced Studies*, workforce development
- *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
- *College of Charleston, Charleston, South Carolina*: research collaboration
- *Gotcha Group, Charleston, South Carolina*: research collaboration, data collection, implementation of research findings
- *Trident Technical College*: event collaborators
- *South Carolina Governor's School for Science and Mathematics, Columbia, South Carolina*: K-12 event collaboration, workforce development
- *Innova EV, Burr Ridge, Illinois*: 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 (T<sup>2</sup>) plan and are listed below, first numerically in a table format and then in-depth below.

In our T<sup>2</sup> plan, we identified three areas of 'Output' that we would focus on. Output #1 identifies the goals that C<sup>2</sup>M<sup>2</sup> 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 C<sup>2</sup>M<sup>2</sup> 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 01, 2022 – Sep 30, 2022)	Completed in this year (October 01, 2021 – September 30, 2022)
Output #1	Disseminate C <sup>2</sup> M <sup>2</sup> 's research results to a large audience utilizing different research distribution media	Number of technical reports published	5	3	5
		Number of conference presentations	20	8	20
		Number of peer-reviewed journal and magazine papers published	10	5	9
		Number of conferences solely based on C <sup>2</sup> M <sup>2</sup> 's research	1	0	1
Output #2	Develop new methods or products based on C <sup>2</sup> M <sup>2</sup> 's research	Number of new and/or improved research methods or products	10	2	9
Output #3	Demonstrate developed technologies	Number of pilot demonstrations of technology	3	1	4



## **3.1 Output#1: C<sup>2</sup>M<sup>2</sup>'s research results dissemination in this reporting period**

### ***Technical Reports***

1. Brooks, R., Fei, S., Comert, G., Enhanced DSRC Security. C<sup>2</sup>M<sup>2</sup> Final Report. (April 18, 2022).
2. Eksioglu, B., Schmid, M. J. A., Huynh, N., Comert, G. and Liu, D., Framework for Accommodating Emerging Autonomous Vehicles. C<sup>2</sup>M<sup>2</sup> Final Report. (September 22, 2022).
3. Akhter, S., Mwakalonge, J., Hong, J. D., Comert, G., Musa. I., and Mamun, M. M. H., Evaluation of Before and After Measures to Curb Distracted Walking. C<sup>2</sup>M<sup>2</sup> Final Report. (September 20, 2022).

### ***Conference Presentations***

1. Zhao, C., Comert, G., & Pisu, P. "Secure Connected and Automated Vehicles against False Data Injection Attack using Cloud-based Data Fusion". Modeling, Estimation and Control Conference, IFAC-PapersOnLine, (October 2021) (Not reported in the earlier SAR report)
2. Z. Feng, L. Jing, P. Yin, Y. Tian and B. Li. "Advancing Self-supervised Monocular Depth Learning with Sparse LiDAR.", Conference on Robot Learning (CoRL), (November 2021) (Not reported in the earlier SAR report)
3. F. Zou, W. Sarasua, J. Ogle, M. Stanley, K. Brown, D. Michalaka, J. Lloyd, P. Murray-Tuite, W. Davis, Ph.D., L. Wade, "Site Characterization for Fatal Crashes in South Carolina", 101<sup>st</sup> Transportation Research Board Annual Meeting, Washington, D.C. (January, 2022) (Not reported in the earlier SAR report)
4. Weimin, J., Chowdhury, M., Islam, M., and Rahman, M., "Risk-based Freeway Lane-Changing Decision-Making Framework for Autonomous Vehicles in Mixed Traffic Streams" 101<sup>st</sup> Transportation Research Board Annual Meeting, Washington, D.C. (January 2022) (Not reported in the earlier SAR report)
5. Salek, M.S., Chowdhury, M., Rahman, M., "An Asymmetric Linear Bilateral Control Model for an Automated Truck Platoon", 7<sup>th</sup> Annual UTC Conference held in Florida Atlantic University, Boca Raton, FL, (March, 2022) (Not reported in the earlier SAR report)
6. Biswas, P.K., Khan, S.M., Chowdhury, M. "A Cloud-based Quantum Artificial Intelligence-supported Autonomous Truck Platooning Model" Glenn Department of Civil Engineering Research Symposium, Clemson University (April 2022)
7. Salek, M.S., "Theoretical Development and Numerical Validation of an Asymmetric Linear Bilateral Control Model for an Automated Truck Platoon", Glenn Department of Civil Engineering Research Symposium, Clemson University (April 2022)
8. Franchi, M., Kahn, R., Chowdhury, M., Khan, S., Kennedy, K., Ngo, L. and Apon, A., 2022. Webots. HPC: A Parallel Simulation Pipeline for Autonomous Vehicles. In *Practice and Experience in Advanced Research Computing* (pp. 1-4). (July 2022)

### ***Peer-Reviewed Journal and Magazine Publications***

1. Ramesh, A., Nikam, D., Balachandran, V.N., Guo, L., Wang, R., Hu, L., Comert, G., Jia, Y., "Cloud-Based Collaborative Road-Damage Monitoring with Deep Learning and Smartphones". *Sustainability*; 14(14):8682. <https://doi.org/10.3390/su14148682> (July 2022)



2. Zhao, C., Gill, J., Comert, G. and Pisu, P. "Detection of False Data Injection Attack in Connected Vehicles via Cloud-Based Sandboxing," *IEEE Transactions on Intelligent Transportation Systems*, 23(7), pp. 9078-9088, (July 2022)
3. Rahman, M., Islam, M.R., Chowdhury, M. and Khan, T., 2022. "A Physics-Based Longitudinal Driver Model for Automated Vehicles." *IEEE Access*, 10, pp.80883-80899. (July 2022)
4. Liu, Y., Qian, Y., Comert, G., and Begashaw, N. "Mobility Support for Disadvantaged and Disabled Travelers during Pandemic or Similar Situations" *Expert Systems with Applications*. 212: 18786 (<https://doi.org/10.1016/j.eswa.2022.118786>) (September 2022)
5. Comert, G., and Begashaw, N. "Cycle-to-cycle queue length estimation from connected vehicles with filtering on primary parameters". *International journal of transportation science and technology*, 11(2), 283-297

### ***C<sup>2</sup>M<sup>2</sup> Sponsored Research Conferences***

Nothing to report

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

### ***3.2.1 New or improved methods***

1. Dr. Mashrur "Ronnie" Chowdhury and his team have developed quantum optimization-based virtual traffic lights (VTLs) where no physical traffic signal controllers are needed to guide the connected vehicles in the signalized intersection. Findings from the evaluation show that the quantum VTL model reduced waiting time per vehicle by 23% and 25%, respectively, compared with classical optimization-based VTL and conventional actuated traffic signal controls with traffic lights.
2. Dr. Nathan Huynh and his team have developed a framework based on a combinatorial auction for indirect decentralized collaboration among carriers; the trucks of each carrier in the collaboration outsource and/or insource their jobs in real-time. Mathematical models were developed to achieve specific steps in the framework, such as 1) selecting the most profitable bundles for the trucks to bid for and 2) creating a conflict resolution model to determine the winning trucks.

### ***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<sup>2</sup>M<sup>2</sup> Clemson University team participated in the Summer Transportation Institute (STI) Program hosted at Benedict College. The C<sup>2</sup>M<sup>2</sup> Clemson team demonstrated multiple sensors, communication devices, and controllers for autonomous vehicle maneuvering. The STI students also had hands-on experience in transportation cyberattack detection and mitigation strategies. (July 12, 2022)



## **3.4 Additional Outputs**

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

C<sup>2</sup>M<sup>2</sup>'s website address is ([cecas.clemson.edu/c2m2](https://cecas.clemson.edu/c2m2)). The website outlines the C<sup>2</sup>M<sup>2</sup>'s goal, participants, research in progress, and events, both upcoming and past.

C<sup>2</sup>M<sup>2</sup>'s website to showcase the evolution of our HBCU partnerships can be found at <https://storymaps.arcgis.com/stories/4cd34c0186214825a669dc1c5b38e07c>.

The C<sup>2</sup>M<sup>2</sup> twitter was expanded with user engagement increasing again in this reporting period and can be found at [twitter.com/SC\\_UTC](https://twitter.com/SC_UTC).

The C<sup>2</sup>M<sup>2</sup> YouTube account was updated by Ms. Naomi Nieves, C<sup>2</sup>M<sup>2</sup> 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](https://www.youtube.com/channel/UCITo_BgCYEjjH_PTU3vPFOw)

Our LinkedIn organization page is updated weekly by Ms. Naomi Nieves, C<sup>2</sup>M<sup>2</sup> 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](https://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 three final reports from our 2018 round of funded projects. The remainder of our 2018 funded research projects should be completed within the next reporting period, and their results will be disseminated at that time. We have also four final reports under review from our 2020 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<sup>2</sup> 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 01, 2022 – Sep 30, 2022)	Completed in this year (October 01, 2021 – September 30, 2022)
<b>Outcome #1</b>	Train the current and future transportation workforce to operate in an increasingly high-tech environment	Number of training events and workshops	2	3	6
<b>Outcome #2</b>	Incorporate new technologies (software and/or hardware) and/or techniques and/or practices that are deployment ready	Number of new technologies, and/or techniques and/or practices that offer implementation or deployment guidance	4	2	3
<b>Outcome #3</b>	Improve technologies and/or processes in addressing transportation issues	Number of improved technologies and/or processes disseminated from C <sup>2</sup> M <sup>2</sup> funded research projects	4	2	3

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

1. Our C<sup>2</sup>M<sup>2</sup> Distinguished Speaker Series and our C<sup>2</sup>M<sup>2</sup> Cyber-Physical Systems Frontiers Series have continued to draw a large audience of researchers, students, and industry members, allowing C<sup>2</sup>M<sup>2</sup> to share our ongoing research efforts with 46 people in this reporting period.
2. Dr. Michalaka taught two virtual week-long summer camps on June 20-24 and June 27-July 1, 2022, to 8<sup>th</sup>, 9<sup>th</sup>, and 10<sup>th</sup>-grade students through the South Carolina Governor's School for Science and Mathematics. 16 students attended the first week of camp and nine the second week. Camps' theme was "Engineering Around Home". Dr. Michalaka covered the basics of several engineering majors, including civil, mechanical, electrical, computer and software, through lectures, videos, hands-on activities, and the use of online software.
3. Dr. Michalaka and the Citadel team hosted academic sessions to recruit students, promote degree programs, and provide a tour of civil, environmental, and construction engineering labs, classrooms, and computer labs on April 8, 2022.



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

1. Dr. Mashrur "Ronnie" Chowdhury and his team have developed hybrid classical-quantum deep learning models for traffic sign detection and evaluated their performance during adversarial attacks on an autonomous vehicle's perception module. The two models, ResNet-18 and Inception-V3, had accuracies of 97.5% and 95%, respectively, on the original traffic sign images on the LISA dataset. Implementing Projected Gradient Descent (PGD) led to a sharp decrease in accuracy to 50% for ResNet-18 and 56.2% for Inception-V3. After employing the defensive strategies, InceptionV3 and ResNet-18 reached above 90% accuracy for both attacks.
2. Dr. Mashrur "Ronnie" Chowdhury and his team have developed an asymmetric linear bilateral control model which is used to help all the follower vehicles in a platoon to adjust their acceleration and deceleration to closely follow a constant desired time headway for improving operational efficiency. This model is used for a truck platooning in a cloud-supported smart city environment.

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

1. Dr. Yu Qian, C<sup>2</sup>M<sup>2</sup> affiliated researcher, University of South Carolina, with his research team, has developed a model and corresponding solutions to allocate fleets to serve disabled and disadvantaged people with transportation needs in difficult situations such as the pandemic.
2. Dr. Mashrur "Ronnie" Chowdhury's team has developed a hybrid in-vehicle cyberattack detection model using a classical neural network (NN) and a quantum Restricted Boltzmann Machine (QRBM) for a cloud-based cyber-physical systems environment. At first, a vehicle's controller area network or CAN bus data is converted to an image. In this hybrid model, the classical NN is used to extract features from CAN images, while the QRBM is dedicated to detecting fuzzy attacks. To evaluate the performance of the hybrid approach, a real-world CAN attack dataset is used to create four separate attack datasets associated with four different CAN nodes (i.e., electronic control units or ECUs). The performance of the hybrid approach was compared to a similar but classical-only approach by training the models on all four datasets. Based on the evaluation, the hybrid model achieved higher cyberattack detection accuracy. For the four datasets, the hybrid approach achieved 91%, 95%, 97%, and 95% cyberattack detection accuracies, respectively, whereas the best models in the classical-only approach achieved 87%, 84%, 97%, and 93% detection accuracies, respectively.

## **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 C<sup>2</sup>M<sup>2</sup> 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 T<sup>2</sup> 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 01, 2022 – Sep 30, 2022)	Completed in this year (October 01, 2021 – September 30, 2022)
Impact #1	Increase the adoption of new technologies, methods or practices based on C <sup>2</sup> M <sup>2</sup> 's research	Number of cases of adoption by transportation agencies and/or commercialization of C <sup>2</sup> M <sup>2</sup> 's technologies, methods or practices	2	2	3
Impact #2	Improve transportation system operations and/or transportation safety and/or quality of life	Number of cases of C <sup>2</sup> M <sup>2</sup> '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	2

### **5.1 Impact #1: Increase the adoption of new technologies, methods, or practices based on C<sup>2</sup>M<sup>2</sup>'s research in this reporting period**

1. A vision-based pedestrian collision warning system developed by C<sup>2</sup>M<sup>2</sup> is being adopted for a new project sponsored by the Federal Motor Carrier Safety Administration. In this new project, Clemson University is collaborating with South Carolina State University and Benedict College to apply the vision-based collision avoidance system for commercial motor vehicle safety in workzones.
2. A cloud-based efficient and cybersecure vehicle operational strategy developed by C<sup>2</sup>M<sup>2</sup> is being integrated with the Innova EV vehicles that will be a part of Clemson Smart City Testbed. SCRA and Innova EV are partners of C<sup>2</sup>M<sup>2</sup> in this project



## **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 for our 2017, 2018, and 2020 rounds of funded projects have been posted on our website and submitted to 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, three 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.