Center for Connected Multimodal Mobility (C²M²)

Semi-Annual Progress Report # 4

Project Title: Center for Connected Multimodal Mobility (C²M²)

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1. Accomplishments - What was done? What was learned?

1.1 What are the major goals of the program?

C²M²'s mission statement:

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

C²M²'s main goals are to:

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

C²M² intends to meet these goals through the following means:

- Using data, connectivity, automation, and cybersecurity to promote access to opportunities and equity, and assist those with physical and cognitive disabilities, by fostering on-demand mobility services for those unable or unwilling to drive
- Creating strategies to improve the mobility of people and goods, and optimize passenger and freight movement through numerous techniques that will improve vehicle and system performance (e.g., by maximizing existing infrastructure capacity via vehicle-to-vehicle and vehicle-to-infrastructure connectivity)
- Contributing to Smart Cities that collect and process big data, often in real-time, to optimize the transportation system performance (including more intensive use of shared infrastructure)
- Developing innovations to improve multimodal planning and modeling for the movement of both people and goods, using connectivity and data to seamlessly guide transfers between vehicles, infrastructure, and modes
- Assisting regional planning and the setting of transportation priorities through innovations that leverage limited dollars to create large positive impacts (e.g., by using "Big Data" to aid in regional travel demand forecasting efforts)

1.2 What was accomplished under these goals?

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

- C²M² Directors continued their bi-weekly conference calls to coordinate the Center's activities, and budget. (Ongoing)
- Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, Dr. Mizanur Rahman, C²M² Assistant Director, and Ms. Charlotte Ryggs, C²M² Program Coordinator, and Center supported Clemson University students met daily to co-ordinate Center-related activities during the ongoing Covid-19 situation. (Ongoing)
- Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, Clemson University, has continued meeting periodically with a team led by the Clemson University International Center for Automotive Research (CU-ICAR) to work on the OPEN CAV CU-ICAR project, which is the result of a collaboration of researchers who are acquiring a connected and automated vehicle to further vehicle automation research in a transportation cyber-physical system environment. (Ongoing)
- Drs. Jennifer Ogle and Wayne Sarasua, C²M² affiliated researchers, Clemson University, in conjunction with the Clemson University Glenn Department of Civil Engineering NSF RED Grant worked to develop real-world project-based courses to supplement the existing curriculum with a focus on student success in attaining professional formation as engineers. (Ongoing)
- Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, Dr. Mizanur Rahman, C²M² Assistant Director, and Ms. Charlotte Ryggs, C²M² Program Coordinator, are part of the planning committee for the 7th Annual UTC Conference for the Southeastern Region. This conference will be held in two parts, first, a virtual student spotlight on November 4, 2020, and second in-person in Boca Raton, Florida tentatively scheduled for May 2021 (postponed until 2021 due to COVID-19). (Ongoing)
- In this reporting period, the Clemson branch of C²M² continued the Distinguished Speaker Series, where notable scholars from within the transportation community are invited to come to Clemson University, Clemson, South Carolina, and speak to faculty and students on a range of transportation-related topics. Due to COVID-19 related travel restrictions, some of the webinars were held virtually. These events are also broadcasted via webinar to the four other partner institutions within the C²M² consortium and any other interested participants. In this reporting period, Clemson University has hosted the following Distinguished Speakers:
  - Ivan Lichtenstein of the Georgia Department of Transportation presented his work on "Media and the Traffic Management Center," (April 2, 2020)
  - Dimitra Michalaka of The Citadel presented "Dr. Michalaka's Path – What is Leadership in Today's Society?," (April 3, 2020) – this talk is available on our website and our YouTube Channel
  - Gurcan Comert of Benedict College presented his work on "Uncertain Quantification from Cyber Attacks and Detection Problems in Connected and Autonomous Vehicles," (April 3, 2020) –

- o Mac Devine of IBM presented "Enabling the Age of Autonomy with the Internet of Moving Things," (April 10, 2020) – this talk is available on our website and our YouTube Channel

- o Carla Bailo from the Center for Automotive Research (CAR) presented on "Smart Cities, Mobility, and Human Behavior – Seamless Integration?," (April 17, 2020) – this talk is available on our website and our YouTube Channel

- o Lily Elefteriadou of the University of Florida presented her work on "Optimizing Traffic Signal Control with Connected and Autonomous Vehicles in Traffic Stream," (May 27, 2020) – this talk is available on our website and our YouTube Channel

- o Mitch Shue of Clemson University presented his work on "Cloud for Connected Mobility – Current State of Cloud Computing," (July 7, 2020) – this talk is available on our website and our YouTube Channel

- o Kara Kockelman of the University of Texas, Austin presented her work on "Shifting toward Shared Fleets & Shared Rides, via Autonomous Vehicles & Congestion Pricing," (July 10, 2020) - this talk is available on our website and our YouTube Channel

- o Mashrur "Ronnie" Chowdhury of Clemson University presented his work on "Generating Personal Safety Messages (PSMs) for Pedestrian Safety in a Connected Vehicle Environment," (July 17, 2020) - this talk is available on our YouTube Channel

- o James H. Lambert of the University of Virginia presented on "Resilience of Advanced Logistics Systems with Emergent and Future Conditions," (August 12, 2020) - this talk is available on our website and our YouTube Channel

- o Mashrur "Ronnie" Chowdhury of Clemson University presented his work on "Public Digital Infrastructure Deployment for Future Mobility," (August 27, 2020) - this talk is available on our website and our YouTube Channel

- o Richard R. Brooks of Clemson University spoke on his work "Autonomous Systems Need to be Designed using Game Theory," (September 18, 2020) - this talk is available on our website and our YouTube Channel

- C^{2}M^2 wrapped up the eight-week program titled C^{2}M^2 Future Leaders Program. This program was led by Clemson University and offered to our partner institutions via webinar. Each session featured a speaker and group discussion and focused on practical skills such as how to be an effective writer/speaker, what makes a good leader, real-world examples from professionals in the transportation industry, and opportunities for students to improve their presentation skills including a three-minute presentation competition. (February 28 – April 24, 2020)

- C^{2}M^2 completed the 2020 Call for Proposals. Invitations to apply were sent out to our five partner institutions and posted on our website. Proposals were submitted by April 30, 2020, and then sent out for blind review. (May - June 2020)

- Mr. Md Zadid Khan, C^{2}M^2 sponsored doctoral student, Clemson University, was awarded the 2020 Outstanding Graduate Research Assistant Award given by the Clemson University Graduate Student Government. (May 2020)

- C^{2}M^2 launched a six week, online, computer programing mini-course titled C^{2}M^2 Coders. This pilot program was aimed at female students enrolled in SC colleges. It was led by Clemson University and offered to our partner institutions via webinar. (May 11- June 18, 2020)

- Dr. Mashrur "Ronnie" Chowdhury, C^{2}M^2 Director, Dr. Mizanur Rahman, C^{2}M^2 Assistant Director, and Ms. Charlotte Ryggs, C^{2}M^2 Program Coordinator, coordinated with the Palmetto Clean Fuels Coalition to organize and hold the following webinar, "Energy Efficient Future Mobility Systems with Connected and Automated Vehicles." This webinar featured three speakers from C^{2}M^2, Palmetto Clean Fuels Coalition, and the US Department of Energy. It was attended by the US Department of Transportation employees, as well as the transportation industry and academia members. (May 18, 2020)

- Dr. Mashrur "Ronnie" Chowdhury, C^{2}M^2 Director, Dr. Mizanur Rahman, C^{2}M^2 Assistant Director, and Ms. Charlotte Ryggs, C^{2}M^2 Program Coordinator, held a Zoom meeting with Mohan Atluri, Ayush Krishnamoorty, and Eric Dillon from Infrastructure Consulting and Engineering to discuss potential collaboration on research involving traffic engineering and coding workshops. (June 1, 2020)

- Ms. Rajai Ouzir, C^{2}M^2 sponsored student, Benedict College, was a Creative Project Award Recipient as part of her Carolina Cluster internship for her work on, "Developing Resilient Cyber Attack Detection Methods for Connected and Autonomous Vehicles." (June 2, 2020)

- Dr. Mashrur "Ronnie" Chowdhury, C^{2}M^2 Director, Dr. Mizanur Rahman, C^{2}M^2 Assistant Director, and Ms. Charlotte Ryggs, C^{2}M^2 Program Coordinator, attended all sessions of the 2020 CUTC Virtual Summer Meeting. (June 9 & 10, 2020)

- Dr. Mashrur "Ronnie" Chowdhury, C^{2}M^2 Director, Dr. Mizanur Rahman, C^{2}M^2 Assistant Director, and Ms. Charlotte Ryggs, C^{2}M^2 Program Coordinator, held a Zoom meeting with Riadul Islam from the University of Maryland, Baltimore County, to discuss potential research collaboration on future machine learning projects. (June 10, 2020)

- Dr. Mashrur "Ronnie" Chowdhury, C^{2}M^2 Director, Dr. Mizanur Rahman, C^{2}M^2 Assistant Director, and Ms. Charlotte Ryggs, C^{2}M^2 Program Coordinator, held a Zoom meeting with Fred Payne (Carolina Alliance 4 Innovation) and Abul Hasan (Greenville Technical College Center for Manufacturing Innovation) to discuss providing a Connected and Automated Vehicle Software coding workshop and potential to develop further training for the Center for Manufacturing Innovation instructors. (June 17, 2020)

- Dr. Dimitra Michalaka, C^{2}M^2 Associate Director, The Citadel, hosted a "Tour of Engineering" virtual summer camp organized by the South Carolina Governor's School of Science and Mathematics (SCGSSM). Sixteen rising 8th and 9th graders participated and learned about what engineers do, types of engineering, necessary skills to be successful, civil engineering, and others. (June 22 -26, 2020)

- Ms. Charlotte Ryggs, C^{2}M^2 Program Coordinator, joined the Clemson University, Glenn Department of Civil Engineering's Strategic Goal Committee to work on the Diversity Recruitment and Retainment Taskforce at Clemson University. This committee met weekly to develop a set of goals and tasks to help the department recruit and retain diverse scholars. (June – September 2020)

- Dr. Mashrur "Ronnie" Chowdhury, C^{2}M^2 Director, Dr. Mizanur Rahman, C^{2}M^2 Assistant Director, and Ms. Charlotte Ryggs, C^{2}M^2 Program Coordinator, held a Zoom meeting with Anjan Rayamajhi, Sujith Racha, and Amir Ghiasi of Leidos to discuss potential research collaboration on signal priority/coordination for C/AVs. (June 19, 2020)

- C^{2}M^2 Associate Directors met virtually with Dr. Mashrur "Ronnie" Chowdhury, C^{2}M^2 Director, and Ms. Charlotte Ryggs, C^{2}M^2 Program Coordinator to discuss and select projects for

funding from our 2020 Call for Proposals. Of the 15 projects submitted eight were selected for funding in this round. (July 2, 2020)

- The following eight research projects were selected by our Directors for funding, emphasis was placed on projects that focused on collaboration to tackle big issues facing transportation. Of these eight projects, one is led by Benedict College, three are led by Clemson University, one by South Carolina State University, and three are led by the University of South Carolina. After selection PIs were asked to revise their projects based on their reviews prior to starting. Projects were approved to start after revisions had been approved by the Center Directors. (July – August 2020)

2020 Accepted Proposals		
Project Title	**Lead PI**	**Co-PIs**
Cloud-based Collaborative Road Condition Monitoring using In-Vehicle Smartphone Data and Deep Learning	Yunyi Jia	Gurcan Comert
Digital Twins to Increase Mobility in Rural South Carolina	Paul Ziehl	Gurcan Comert, Vafa Soltangharaei, Mahmoud Bayat
Strategic Management of Limited Transportation Recourses to Support Mobility of Disadvantaged and Disabled Travelers during the COVID-19 Pandemic or Similar Situations	Yu Qian	Gurcan Comert, Negash Begashaw
Potential Reduction of Fatal Crashes in South Carolina due to Connected and Automated Vehicles	Wayne Sarasua	Dimitra Michalaka, Pam Murray-Tuite, Kweku Brown, Jennifer Ogle, William J. Davis
Safe and Efficient E-Wayfinding (SeeWay) Guidance for the Transition to Autonomous Vehicles for the Visually Impaired	Bing Li	Gurcan Comert, Johnell Brooks, Aries Arditi

Modeling Impact of Weather Conditions on 5G Communication and Mitigation Measures on Control of Automated Intersections	Gurcan Comert	Pierluigi Pisu, Esmail Abuhdima, Chin Tser Huang
Smart Monitoring and Warning System for Road/Lane Closure in Connected and Non-Connected Environments	Judith Mwakalonge	Saidi Siuhi, Gurcan Comert
Improving Freight Transport Mobility and Efficiency via Synchronization	Nathan Huynh	William Ferrell, Scott Mason

- Drs. Dimitra Michalaka, C^{2}M^2 Associate Director, William J. Davis, C^{2}M^2 Co-Associate Director, and Kweku Brown, C^{2}M^2 affiliated researcher, The Citadel, hosted prospective Citadel students (popularly known on campus as pre-knobs) in a series of virtual recruiting/orientation meetings over the summer. These events were meant to recruit high school students into the civil and construction engineering programs. Five sessions, with each having 2 groups, involving a total of 40 students were held. (July 7, 13, 14, 22, 23, 2020)

- Dr. Mashrur "Ronnie" Chowdhury, Director of C^{2}M^2, Clemson University, presented his career path and current research to high school students attending the School-to-Work Transportation Program hosted by Benedict College. (July 13, 2020)

- Dr. Mizanur Rahman, C^{2}M^2 Assistant Director, completed his time with C^{2}M^2, leaving our Center to join the faculty at the University of Alabama as Assistant Professor. (August 7, 2020)

- Drs. Dimitra Michalaka, C^{2}M^2 Associate Director, and Ryan Giles, C^{2}M^2 affiliated researcher, The Citadel, participated in the "Civil Engineering (focus on Transportation Engineering) Professional Interview Program." Twenty-one (21) West Ashley High School students taking the Principles of Engineering course were assigned a "Professional Interview" exercise, where they had to conduct a personal interview with a professional in the field of engineering, engineering technology, or another high-tech field. (September 18 & 25, 2020)

1.3 How have the results been disseminated?

- Dr. Jennifer Ogle, C^{2}M^2 affiliated researcher, Clemson University, completed and published her 2017 funded project report, "Assessment of Safety Benefits of Technologies to Reduce Pedestrian Crossing Fatalities at Midblock Locations." (May 18, 2020)

- Dr. Mashrur "Ronnie" Chowdhury, Director of C^{2}M^2, Clemson University, and his team of researchers published their Personal Safety Message Generating software that they

developed as part of one of C²M²'s Foundational projects. Information on this software can be found on our C²M² website. (May 18, 2020)

- Dr. James Martin, C²M² affiliated researcher, Clemson University, completed and published his 2017 funded project report, "Uncertainty Quantification of Cyber Attacks on Connected Vehicles and Infrastructure (Part 1)." (June 8, 2020)

- Dr. Mashrur "Ronnie" Chowdhury, Director of C²M², and his team of researchers published the following paper on In-Vehicle Security software in the IEEE Sensors Letter. (June 2020)

    o Z. Khan, M. Chowdhury, M. Islam, C. Huang and M. Rahman, "Long Short-Term Memory Neural Network-Based Attack Detection Model for In-Vehicle Network Security," in IEEE Sensors Letters, vol. 4, no. 6, pp. 1-4, June 2020, Art no. 7500904, doi: 10.1109/LSENS.2020.2993522.

- Dr. Mashrur "Ronnie" Chowdhury, Director of C²M², hosted a "Connected Vehicles Supported Adaptive Signal Control Workshop," for C²M² partners and affiliated students. Fifteen participants from our partner institutions attended this hour and a half long workshop, where they learned about adaptive signal control systems. This workshop included a demonstration of one of such systems (i.e., Centracs Adaptive, which is an improved version of the original ACS Lite controller, developed by Econolite) that the Center for Connected Multimodal Mobility uses in our connected vehicle research. (August 7, 2020)

- Dr. Mashrur "Ronnie" Chowdhury, C²M² Director, led the workshop "CAV in the Transportation Cyber-Physical Systems (TCPS)," for faculty from the Greenville Technical College Center for Manufacturing Innovation. This day-long virtual workshop offered interactive training with connected and autonomous vehicle simulation software and example problems. (August 17, 2020)

- Dr. Amy Apon, C²M² affiliated researcher, Clemson University, completed and published her 2017 funded project report, "Real-time and Secure Analysis of Pedestrian Data for Connected Vehicles." (August 25, 2020)

- Dr. Yuche Chen, C²M² affiliated researcher, University of South Carolina, completed and published his 2018 funded project report, "Data-driven Multimodal Transportation Energy Consumption Prediction and Analysis Framework for Sustainable Transit and Transportation Planning." (September 25, 2020)

- Drs. Dimitra Michalaka, C²M² Associate Director, and William J. Davis, C²M² Co-Associate Director The Citadel, held a Zoom meeting with John Fellows and Shane Shaunessy, planners representing the City of Columbia, SC, to submit a draft program presenting research findings for the purpose of informing public policy and identifying network improvements, safety concerns/enhancements, and stakeholder communication/empowerment. (August 2020)

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

- Clemson University's C²M² affiliates will continue their Distinguished Speaker Series and will be sponsoring notable transportation researchers whose talks will be made available via webinar and announced on our social media platforms. Currently, we have scheduled. (Ongoing)

    o Judith Mwakalonge, of South Carolina State University, scheduled to speak on October 9, 2020.

- o Brian D. Taylor, of the University of California Los Angeles, scheduled to speak on October 16, 2020.
  - o Jennifer Ogle, of Clemson University, scheduled to speak on October 29, 2020.
  - o Kaan Ozbay, of New York University Tandon School of Engineering, scheduled to speak on November 13, 2020.
  - o Mizanur Rahman, the University of Alabama, scheduled to speak in November TBD, 2020.
- Dr. Mashrur "Ronnie" Chowdhury, C^{2}M^2 Director, Clemson University, is continuing to work with Clemson University Facilities on expanding his Clemson University - Connected Vehicle Testbed (CU-CVT) from Perimeter Road to the entire Clemson University campus, which includes real-time traffic monitoring, pedestrian safety warning, and signal-vehicle coordination systems. (Ongoing)
- Dr. Sakib Mahmud Khan, Postdoctoral Research Scholar, University of California, Berkley, will be joining the C^{2}M^2 team as our new Assistant Director, replacing Dr. Mizanur Rahman. (October 1, 2020)
- Dr. Mashrur "Ronnie" Chowdhury, C^{2}M^2 Director, Clemson University, has been invited to speak at the virtual GAITE Technical Exchange. (October 23, 2020)
- Dr. Mashrur "Ronnie" Chowdhury, C^{2}M^2 Director, Dr. Sakib Mahmud Khan, C^{2}M^2 Assistant Director, and Ms. Charlotte Ryggs, C^{2}M^2 Program Coordinator, will be holding a Zoom meeting with Carol Jones, and Tony Fallow of Mead and Hunt to discuss potential research collaboration on connected infrastructure deployment. (October 6, 2020)
- Drs. Dimitra Michalaka, C^{2}M^2 Associate Director, and William J. Davis, C^{2}M^2 Co-Associate Director The Citadel, will hold a Zoom meeting with the City of Charleston Mayor's Wellness Council, to submit a draft program presenting research findings for the purpose of informing public policy and identifying network improvements, safety concerns/enhancements, and stakeholder communication/empowerment. (October 7, 2020)
- Dr. Mashrur "Ronnie" Chowdhury, C^{2}M^2 Director, Dr. Sakib Mahmud Khan, C^{2}M^2 Assistant Director, and Ms. Charlotte Ryggs, C^{2}M^2 Program Coordinator, will be holding a Zoom meeting with Craig Stratton and John Ballato of Luna to discuss potential research collaboration on smart sensor deployment. (October 8, 2020)
- Drs. Dimitra Michalaka, C^{2}M^2 Associate Director, and William J. Davis, C^{2}M^2 Co-Associate Director The Citadel, will hold a Zoom meeting with the City of Charleston's city planners and Traffic and Transportation Committee, to submit a draft program presenting research findings for the purpose of informing public policy and identifying network improvements, safety concerns/enhancements and stakeholder communication/empowerment. (October 16, 2020)
- Dr. Mashrur "Ronnie" Chowdhury, C^{2}M^2 Director, Clemson University, will be leading a two-day workshop titled, "Application of Public Cloud Services for Transportation Applications." This workshop has been offered to students attending minority-serving institutions as a diversity recruiting effort. (October 26 & 28, 2020)
- Dr. Mashrur "Ronnie" Chowdhury, C^{2}M^2 Director, Clemson University, will be giving an invited talk as a Distinguished Speaker to the Arizona State University on "Security and Resilience of Transportation Cyber-Physical-Social Systems" (November 5, 2020)

- C^{2}M^2 affiliated students will be taking part in the Regional UTC Student Spotlight Virtual Conference for the Southeastern Region. They will be giving a five-minute presentation on their center funded research. (November 4, 2020)

- C^{2}M^2 will be hosting our Fourth Annual Fall Conference this year. This will be a one-day, virtual event split up into two main sessions which will include a guest keynote speaker, a "State of the Center" address from our Director and Associate Directors, a student presentation session, and a quantum computing for transportation workshop. (November 20, 2020)

- Dr. Mashrur "Ronnie" Chowdhury, C^{2}M^2 Director, Clemson University, will be giving an invited talk to Institute of Transportation Engineers on "Road Safety Fundamentals (5 of 10): ITS, TSMO, and Safety in Operations." (December 1, 2020)

- C^{2}M^2 has been invited by IEEE Intelligent Transportation Systems Magazine to be featured in their ITS Research Lab Spot Light column focusing on our C^{2}M^2 Transportation Cyber-Physical Systems Laboratory located at Clemson University. (January 2021)

- Multiple C^{2}M^2 supported students will be presenting papers at the 100th Transportation Research Board's Annual Meeting. (January 2021)

- C^{2}M^2 anticipates participating in the 2021 Countdown to Success - NASA STEM Fair (postponed due to COVID-19). 1500 high school students from Dorchester, Berkeley, and Charleston counties in SC have been invited to participate in a day of STEM demonstrations. (March 3, 2021)

- C^{2}M^2 expects to see the remaining final reports from our 2018 round of funded projects listed below to be published in the coming reporting period of 2021.
  - "Assessing Potential of Bike Share Networks and Active Transportation to Improve Urban Mobility, Physical Activity and Public Health Outcomes in South Carolina," William Davis, P.I., The Citadel
  - "Enhanced DSRC Security," Richard R. Brooks, P.I., Clemson University
  - "Framework for Accommodating Emerging Autonomous Vehicles," Burak Eksioglu, P.I., Clemson University
  - "Assessment of Autonomous Vehicle Sharing for Evacuation and Disaster Relief," Pamela Murray-Tuite, P.I., Clemson University
  - "Security of Connected Vehicles via Sandboxing against False Data Injection Attack," Pierluigi Pisu, P.I., Clemson University
  - "Tool to Assess Effectiveness of Intermodal Facility Location and Carrier Collaboration," Nathan Huynh, P.I., University of South Carolina
  - "Data Fusion to Improve the Accuracy of Multi-Modal Traffic Counts," Robert Mullen, P.I., University of South Carolina
  - "Intelligent Camera Aided Railway Emergency System (i-CARES)," Yu Qian, P.I., University of South Carolina
  - "Attribution Theory and Collisions at Intersections," Judith Mwakalonge, P.I., South Carolina State University
  - "Evaluation of Before and After Measures to Curb Distracted Walking," Judith Mwakalonge, P.I., South Carolina State University

- Dr. Mashrur "Ronnie" Chowdhury, C^{2}M^2 Director, Clemson University, is leading the effort to develop a Quantum Lab for Artificial Intelligence at each of our consortium institutions beginning with Benedict College. They are in the process of obtaining sensors, computers, and other equipment for the lab. (Ongoing – 2020 - 2021)

- Ms. Samia Akter, a C^{2}M^2 supported graduate student, Benedict College, will be presenting a paper at the ASCE International Conference on Transportation and Development. (Summer 2021)
  - Akter, S., Mamun, M. Md. H., Mwakalonge, J., Siuhi, S., Comert, G., "Application of Attribution Theory to Predict Drivers' Cognitive Behavior at Highway Intersection."

- Dr. Gurcan Comert, C^{2}M^2 Associate Director, Benedict College, is currently developing a manuscript in conjunction with his 2020 funded project, "Modeling Impact of Weather Conditions on 5G Communication and Mitigation Measures on Control of Automated Intersections." (Ongoing - 2020-2021)

- Dr. Pamela Murray-Tuite, C^{2}M^2 affiliated researcher, Clemson University, is currently developing two journal manuscripts in conjunction with her 2019 funded project, "Assessment of Autonomous Vehicle Sharing for Evacuation and Disaster Relief." (Ongoing – 2020 -2021)

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

2.1 What organizations have been involved as partners?

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

The C^{2}M^2 Advisory Board continues to be a vital asset to the success of our center. Our current board is made up of 16 members. To date, we have four industry members, seven members from academia, four members from government agencies, 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. We are currently working closely with our board to increase industry support for our center and on the establishment of quantum computing labs at each of our partner institutions.

The center also continues to partner with the South Carolina Department of Transportation (SCDOT), which provides data, research collaboration, and in-kind support. In this reporting period, we have begun to work closely with industry partners, i.e., IBM and SoftServe. We have also closely worked with

Carolinas Alliance 4 Innovation, Greenville County, and Charleston County on the pilot deployment of smart city technology developed by our center.

2.2 Have other collaborators or contacts been involved?

Along with the five institutions that make up the C²M² consortium partnership, C²M² has and is collaborating on projects with or received support from the followings:

- *College of Charleston, Charleston, South Carolina*: research collaboration
- *City of Columbia Bicycle and Pedestrian Advisory Committee (BPAC), Charleston, South Carolina*: research collaboration
- *Charleston County, Charleston, South Carolina*: research collaboration
- *City of Columbia Planning and Development Department, Columbia, South Carolina*: research collaboration
- *South Carolina Governor's School of Science and Mathematics, Hartsville, South Carolina*: event collaborators
- *Engineering Project Lead the Way, Charleston, South Carolina*: event collaboration
- *West Ashley High School, Charleston, South Carolina*: event collaboration
- *Charleston Moves, Charleston, South Carolina:* research collaboration
- *SoftServe, Austin, Texas*: research collaboration
- *IBM, Charlotte, North Carolina:* research collaboration
- *Facility Solutions Group, Perth Amboy, New Jersy*: research collaboration, in-kind support
- *AutonomousStuff, Detroit, Michigan*: research collaboration
- *Holy Spokes, Charleston, South Carolina*: data collection, research collaboration
- *Richland County District, Columbia, South Carolina*: event collaborators
- *Clemson University International Center for Automotive Research (CU-ICAR), Greenville, South Carolina*: in-kind support, facilities, collaborative research
- *Qualtrics, Provo, UT*: data collection
- *TrafficVision, Clemson, South Carolina*: equipment, research collaboration, in-kind support
- *Carolinas Alliance 4 Innovation, Greenville, South Carolina*: in-kind support, research collaboration
- *Greenville County, Greenville, South Carolina*: in-kind support, research collaboration
- *Palmetto Clean Fuels, Columbia, South Carolina*: in-kind support, event collaboration
- *Michelin, Greenville, South Carolina*: research collaboration
- *AT&T, Greenville, South Carolina*: research collaboration
- *Facilities Solutions Group, Austin, Texas:* research collaboration, conference support
- *Carolinas Alliance 4 Innovation, Greenville, South Carolina:* conference support, research collaboration
- *As We See It, Greenville, South Carolina:* research collaboration
- *South Carolina School for the Deaf and Blind, Spartanburg, South Carolina:* research collaboration
- *Visibility Metrics LLC, Chappaqua, New York:* 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^2) plan and are listed below, first numerically in a table format, and then in-depth below.

In our T^2 plan, we identified three areas of 'Output' that we would focus on. Output #1 identifies the goals that C^2M^2 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^2M^2 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. We have seen a decrease in certain Center activities in this reporting period due to the ongoing Covid 19 pandemic, to offset this decrease we have worked to increase our activities in other areas such as webinars, workshops, and virtual events to increase our online engagement.

No.	Goals	Research Performance Measures	Target per year	Completed in this reporting period
Outputs				
Output #1	Disseminate C²M²'s research results to a large audience utilizing different research distribution media	Number of technical reports published	5	6
		Number of conference presentations	20	0
		Number of peer-reviewed papers published	10	4
		Number of conferences solely based on C²M²'s research	1	0
Output #2	Develop new methods or products based on C²M²'s research	Number of new and/or improved research methods or products	10	1
Output #3	Demonstrate developed technologies	Number of pilot demonstrations of technology	3	0

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

Technical Reports

1. Shirley, T. (2020). Sharing is Caring: Assessing Willingness to Share Autonomous Vehicles for Evacuation and Disaster Relief. MS Thesis, Clemson University.
2. Sun, F. (2020). Security Evaluation of a Dedicated Short Range Communications (DSRC) Application. MS Thesis, Clemson University.
3. Ogle, J., Islam, S., Brown, K., Mwakalonge, J., Michalaka, D, and Chowdhury, M.. "Assessment of Safety Benefits of Technologies to Reduce Pedestrian Crossing Fatalities at Midblock Locations." Center for Connected Multimodal Mobility (C^{2}M^2) Final Report, 96 pages.
4. Martin, J., Comert, G., Kaur, M., Alsuhaim, A. "Uncertainty Quantification of Cyber Attacks on Connected Vehicles and Infrastructure (Part One)." Center for Connected Multimodal Mobility (C^{2}M^2) Final Report, 30 pages.
5. Apon, A., Chowdhury, M., Comert, G., Rahman, M., Islam., Sood, E. D., Deng, H. S." Real-time and Secure Analysis of Pedestrian Data for Connected Vehicles." Center for Connected Multimodal Mobility (C^{2}M^2) Final Report, 39 pages.
6. Chen, Y., Huynh, N., Comert, G., Zhang, Y. "Data-driven Mulitmodal Transportation Energy Consumption Prediction and Analysis Framework for Sustainable Transit and Transportation Planning." Center for Connected Multimodal Mobility (C^{2}M^2) Final Report, 37 pages.

Conference Presentations

Due to the on-going Covid 19 pandemic, we do not have anything to report for this section.

Peer-Reviewed Publications

1. M. Islam, M. Rahman, M. Chowdhury, G. Comert, E. D. Sood and A. Apon, "Vision-Based Personal Safety Messages (PSMs) Generation for Connected Vehicles," in IEEE Transactions on Vehicular Technology, vol. 69, no. 9, pp. 9402-9416, Sept. 2020, doi: 10.1109/TVT.2020.2982189.
2. Khan, Z., Chowdhury, M., Islam, M., Huang, C., and Rahman, M. "Long Short-Term Memory Neural Network-Based Attack Detection Model for In-Vehicle Network Security," in IEEE Sensors Letters, vol. 4, no. 6, pp. 1-4, June 2020, Art no. 7500904, doi: 10.1109/LSENS.2020.2993522.
3. Islam, M., Rahman, M., Khan, S.M., Chowdhury, M., and Deka, L., 2020. Development and Performance Evaluation of a Connected Vehicle Application Development Platform. Transportation Research Record, vol 2674, no. 5, May 2020.
4. Morris, E.A., Brown, A.E., Zhou, Y., Khan, S.M., Derochers, J.L., Pratt, A.N., Campbell, H., and Chowdhury, M. (2020). "Are drivers cool with Pool? Driver attitudes towards the shared TNC services UberPool and Lyft Shared." *Transport Policy* 94, 123-138.

3.2 Output#2: New methods and products

1. Dr. Richard Brooks and his team have developed a tool to generate a Hidden Markov Model of DSRC network analysis as part of his "Enhanced DSRC Security" project. This tool will be made available to the public when his final report is published.

3.3 Output#3: Technology demonstrations

Nothing to report at this time.

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

C²M²'s website was updated as needed by Ms. Charlotte Ryggs, C²M² Program Coordinator. The center'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.

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 as needed by Ms. Charlotte Ryggs, C²M² Program Coordinator. Twelve new distinguished speaker videos were added during this reporting period. Our YouTube channel can be found at www.youtube.com/channel/UCITo_BgCYEjjH_PTU3vPFOw

Ms. Charlotte Ryggs, C²M² Program Coordinator created a LinkedIn profile which can be found at www.linkedin.com/in/center-for-connected-multimodal-mobility-304527163
Ms. Ryggs has been updating our LinkedIn page weekly and has seen consistent growth in engagement during this reporting period.

3.5 Technologies or techniques

1. Dr. Richard Brooks developed software-defined networking (SDN) based real-time communication system as part of his ongoing sponsored project. This allows communications between processes on different onboard units (OBUs).

3.6 Inventions, patent applications, and/or licenses

Nothing to report at this time.

3.7 Other products, such as data or databases, physical collections, audio or video products, software or NetWare, models, educational aids or curricula, instruments, or equipment

1. Dr. Richard Brooks's project "Enhanced DSRC Security" has produced a data bank and simulation code that will be available for further analysis by security researchers.

2. <u>Strategic Model (Intermodal Terminal Location Problem)</u>: A model was developed by Dr. Huynh and his team to determine the number and location of intermodal terminals (IMTs) that minimize the total relevant transportation and operational costs, given a set of constraints like specific pickup/delivery demands to/from customers, budget, and a limited set of candidate IMT locations.

3. <u>Operational Model (Less than Truckload Carrier Collaboration Problem)</u>: A model was developed by Dr. Huynh and his team for the less than truck load (LTL) carrier collaboration under centralized planning to optimally allocate jobs in the common pool to each carrier in the alliance by determining the optimal vehicle routes for each carrier to serve both retained and allocated jobs. To solve the Carrier Collaboration Vehicle Routing Problem with Pickup and Delivery (CCVRPPD), a new insertion algorithm was developed for a large neighborhood search (LNS) heuristic.

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 the three final reports from our first round of funded projects bringing this round of projects to a close, and one additional project from our 2018 round published their final report. We currently have four of our 2018 project PIs in the process of finalizing their final reports and beginning the review process and we expect to see these reports published in the coming reporting period. The remainder of our 2018 funded research projects should be completed within the next reporting period and their results will be disseminated. As we see the majority of our projects finish we expect to be able to report multiple journal publications, databases, workshops/training programs, and transportation engineering curriculum to disseminate their results. We also expect to see a larger adoption of our research results in the coming reporting period as our researchers will have had more time to market their research to potential stakeholders.

In our T² plan, we established three outcome goals for our center to strive towards each year. These goals are to create/host at least two training or workshop events a year; to develop at least four techniques and practices and offer implementation/deployment guidance for the adoption of these techniques, and to develop at least four new technologies and/or processes each year.

No.	Goals	Research Performance Measures	Target per year	Completed in this reporting period
Outcomes				
Outcome #1	Train the current and future transportation workforce to operate in an increasingly high-tech environment	Number of training events and workshops	2	4

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

4.1 Outcome #1: Training for workforce development

1. Dr. Mashrur "Ronnie" Chowdhury, Director of C^2M^2 and Dr. Mizanur Rahman, Assistant Director of C^2M^2, led an eight-week program titled C^2M^2 Future Leaders Program. This program was offered to our partner institutions via webinar. Each session featured a speaker and group discussion and focused on practical skills such as how to be an effective writer/speaker, what makes a good leader, real-world examples from professionals in the transportation industry, and opportunities for students to improve their presentation skills including a three-minute presentation competition. (February 28 – April 24, 2020)

2. Dr. Mashrur "Ronnie" Chowdhury, Director of C^2M^2 , and Dr. Mizanur Rahman, Assistant Director of C^2M^2, launched a six week, online, computer programing mini-course titled C^2M^2 Coders. This pilot program was aimed at female students enrolled in SC colleges. It was led by Clemson University and offered to our partner institutions via webinar. Participants in this course each had a hands-on learning experience with the Python programming language for developing an automated vehicle application. The lecture topics covered the basics of Python language for connected and automated vehicles. The class was two hours per week, on Tuesdays and Thursdays from 2:00 pm – 3:00 pm. Female students from throughout South Carolina participated in this inaugural class. C^2M^2 awarded a certificate to each participant at the end of this six-week-long course. (May 11- June 18, 2020)

3. Dr. Mashrur "Ronnie" Chowdhury, Director of C^2M^2, hosted a "Connected Vehicles Supported Adaptive Signal Control Workshop," for C^2M^2 partners and affiliated students. Fifteen participants from our partner institutions attended this hour and a half workshop where they learned to use adaptive signal control systems and they were demonstrated one of such systems (i.e., Centracs Adaptive, which is an improved version of the original ACS Lite controller, developed by Econolite) that the USDOT Center for Connected Multimodal Mobility uses in our connected vehicle research. (August 7, 2020)

4. Dr. Mashrur "Ronnie" Chowdhury, C^2M^2 Director, led the workshop "CAV in the Transportation Cyber-Physical Systems (TCPS)," for faculty from the Greenville Technical College Center for Manufacturing Innovation. This day-long virtual workshop offered interactive training with connected and autonomous vehicle simulation software and example problems. (August 17, 2020)

4.2 Outcome #2: New technologies, techniques, and practices

1. Researchers at Clemson University (led by Dr. Mashrur "Ronnie" Chowdhury) have developed in-vehicle security (IVS) software for detecting cyber-attacks in the in-vehicle network. IVS is developed using software-defined networking and artificial intelligence concepts to detect cyber attacks. The software consists of a long-short term memory (LSTM) neural network model used for detecting cyber-attacks. The software can be deployed inside an in-vehicle electronic control unit (ECU). It continuously monitors the in-vehicle network data stream and detects cyber-attacks that alter the contents of the network data packets through remote access to ECUs. While monitoring, the software trains the model with the recent data and updates the model parameters. The unique aspect of the software is that it considers the in-vehicle network data as correlated time series data and the LSTM model can detect anomalies effectively in time series data containing longer-term patterns. The software was tested on two real-world CAN bus datasets and two types of attacks: replay attack and amplitude-shift attack and showed superior performance compared to baseline detection models.

2. Dr. Mashrur "Ronnie" Chowdhury led a team at Clemson University to develop a computer vision-based software that processes information from video cameras to generate alerts for at-risk pedestrians at intersections creating a Personal Safety Message (PSM) Generator. This software uses the error-bounded lossy compression (EBLC) strategy to reduce the communication bandwidth requirements under different environmental conditions. Our EBLC strategy dynamically changes the video compression level depending on different environmental conditions (i.e., rain, dark and cloudy) in order to maintain a high pedestrian detection accuracy. The EBLC strategy can reduce the communication bandwidth usage of a video feed, which allows more videos to be transmitted concurrently through a fixed bandwidth. Furthermore, dynamic EBLC significantly reduces the storage requirements to archive videos for offline analysis. The generated PSMs using our EBLC technique can generate a pedestrian warning to alert connected vehicles and pedestrians, and ultimately improve safety while reducing pedestrian-vehicle conflicts. The vision-based approach generates PSMs in real-time following the standard of the society of automotive engineers (SAE), which can be used by any connected vehicle pedestrian safety applications.

4.3 Outcome #3: Improvement of technologies

1. Dr. Richard Brooks and his team have identified critical vulnerabilities in current DSRC communication tools as part of their "Enhanced DSRC Security" project. Their project also identified security flaws in DSRC channels, specifically that the clear-text broadcast method of DSRC is vulnerable to attack by malicious DSRC applications as well as Denial of Service vulnerability that is not covered by the current WSMP standard. Identification of these vulnerabilities will help future researchers and application designers improve the safety and reliability of their application and WAVE protocols.

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?

At the time of this reporting period, fourteen C²M² funded reports have been published in total. We still feel that it is too early to see quantifiable impacts as a result of our sponsored research. We believe that we will begin seeing the adoption of and subsequent impacts from our sponsored research soon. Our researchers are still working diligently to disseminate the results of their sponsored research and are 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
Impacts				
Impact #1	Increase the adoption of new technologies, methods or practices based on C²M²'s research	Number of cases of adoption by transportation agencies and/or commercialization of C²M²'s technologies, methods or practices	2	1
Impact #2	Improve transportation system operations and/or transportation safety and/or quality of life	Number of cases of C²M²'s research that resulted in societal benefits, such as lives saved, congestion reduced, and fuel conserved through changing behavior, practices, decision making, policies (including regulatory policies), and/or social actions	2	0

5.1 What is the impact on the effectiveness of the transportation system?

Dr. Joseph Burgett is continuing to work with the SCDOT to develop a training module on the use of unmanned aircraft systems for bridge inspection based on his completed 2018 C²M² project. Currently, two South Carolina State Department of Transportation employees have been trained via this module and Dr. Burgett has been working to recruit others for this training.

At the time of reporting, we have completed our first round of funded projects and are starting to see the second round of funded research projects begin to wrap up. We have been working with our Advisory Board and our researchers to promote the development of workshops, courses, and training modules based on the results of these completed projects for our consortium institutions, State DOTs, Technical Colleges, and transportation professionals as well.

5.2 What is the impact on the adoption of new practices, or instances where research outcomes have led to the initiation of a start-up company?

Nothing to report.

5.3 What is the impact on the body of scientific knowledge?

1. Models developed in Dr. Huynh's research project have been incorporated into IE 8540, Fundamentals of Supply Chain Logistics, at Clemson University. This course is part of Clemson's online Master of Engineering program for working professionals. Specifically, a module focused on Collaborative Logistics was developed which drew on the knowledge generated from the research project.

2. The models and experimental data generated from the "Tool to Assess Effectiveness of Intermodal Facility Location and Carrier Collaboration," project have been incorporated into ECIV 790, Intermodal Freight Transport, at the University of South Carolina taught in the fall of 2020. The materials were used in lectures that addressed facility location problems and pickup-and-delivery problems.

5.4 What is the impact on transportation workforce development?

As with previous reporting periods, our biggest impact on workforce development comes from our supported students. In this reporting period, we had two students successfully defend their theses based on research they completed under C²M² funded projects. Our minority-serving partner affiliates are supporting 11 students through C²M² funded projects and expanding their labs and course offerings. Benedict College has continued to develop its "Connected and Automated Vehicles Systems Laboratory" to further support the research that is taking place there and to promote collaboration between engineering majors. This lab is being used in collaboration with their Computer Science and Math departments. They are also working to establish a Quantum Computing Lab for Artificial Intelligence research in collaboration with Dr. Mashrur "Ronnie" Chowdhury and IBM.

C²M² launched and completed a Future Leaders Program and C²M² Coders in this reporting period and will be offering these free courses again in the coming reporting period.

Clemson University has continued to offer its "Connected and Autonomous Vehicle Technologies in the Transportation Cyber-Physical Systems" workshop to its partner institutions and has expanded that audience to local technical colleges.

Drs. Mashrur "Ronnie" Chowdhury, C^{2}M^2 Director is working to develop an "Application of Public Cloud Services for Intelligent Transportations Systems," workshop to be offered to minority-serving institutions and then on our website.

Drs. Dimitra Michalaka, C^{2}M^2 Associate Director and William J. Davis, C^{2}M^2 Co-Associate Director, are working with the city of Charleston, South Carolina, the South Carolina Department of Transportation (SCDOT), and several area bike rental companies on the adoption of the findings from their 2018 funded project, "Assessing Potential of Bike Share Networks and Active Transportation to Improve Urban Mobility, Physical Activity and Public Health Outcomes in South Carolina."

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

Due to the continually evolving COVID-19 Coronavirus situation, all C^{2}M^2 affiliated partner institutions have restricted their campus access and moved all courses, programs, events, and research meetings online when possible and postponed or canceled activities that cannot be conducted online. At this time is still too early to know how long these actions will be necessary and to what extent they will affect our ongoing work and future goals. C^{2}M^2 leadership is holding bi-weekly check-in calls to monitor progress, and each Associate Director is coordinating with their institution and team to maintain as much forward progress as possible. We have seen that the limitations placed on travel have led to the delay or cancellation of a large majority of conferences and symposiums where our students and researchers would normally present their research findings. We are only just beginning to see the impact that is going to have on our Outcomes, Outputs, and Impacts.

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

All funded projects for both our 2017 and 2018 rounds of funded projects have been submitted to Transportation Research Board's (TRB) Research in Progress (RiP) database and subsequently updated as required by OST-R and the Fast Act Grant Deliverables. As our 2020 funded projects receive their

funding they are also being added. 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 have been created and published on our Center website in their entirety along with the archived data as required by the Fast Act Grant Deliverables. TRB RiP updates and the final submission requirements have and will continue to be completed within the USDOT established deadline.