CENTER FOR CONNECTED AND AUTOMATED TRANSPORTATION

UMTRI-2023-12
July 2023

CCAT Ann Arbor Connected Environment (AACE) Operations and Maintenance

Debby Bezzina, PMP
Mary Lynn Buonarosa, PMP

UMTRI

CENTER FOR CONNECTED AND AUTOMATED TRANSPORTATION

Report No. UMTRI-2023-12

July 2023

Project Start Date: November 1, 2021

Project End Date: June 30, 2023

CCAT Ann Arbor Connected Environment (AACE) Operations and Maintenance

by

Debby Bezzina, PMP and

Mary Lynn Buonarosa, PMP

University of Michigan Transportation Research Institute

CENTER FOR CONNECTED AND AUTOMATED TRANSPORTATION

DISCLAIMER

Funding for this research was provided by the Center for Connected and Automated Transportation under Grant No. 69A3551747105 of the U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology (OST-R), University Transportation Centers Program. The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. This document is disseminated under the sponsorship of the Department of Transportation, University Transportation Centers Program, in the interest of information exchange. The U.S. Government assumes no liability for the contents or use thereof.

Suggested APA Format Citation:

Bezzina, D.A., Buonarosa, M.L. (2023). CCAT Ann Arbor Connected Environment (AACE) Operations and Maintenance. Final Report. DOI: 10.7302/7996.

Contacts

For more information:

PI Name: Debby Bezzina
Address: 2905 Baxter Road
Ann Arbor, MI 48105
Phone: 734-763-2498
Email: dbezzina@umich.edu

CCAT
University of Michigan Transportation Research Institute
2901 Baxter Road
Ann Arbor, MI 48152
umtri-ccat@umich.edu
(734) 763-2498

CENTER FOR CONNECTED AND AUTOMATED TRANSPORTATION

Technical Report Documentation Page

1. Report No.	**2. Government Accession No.**	**3. Recipient's Catalog No.**
I		

4. Title and Subtitle
CCAT Ann Arbor Connected Environment (AACE) Operations and Maintenance
DOI: 10.7302/7996

5. Report Date
July 2023

6. Performing Organization Code

7. Author(s)
Buonarosa, M.L. (0000-0002-2691-6637), Bezzina, D. (0000-0003-4196-2575)

8. Performing Organization Report No.

9. Performing Organization Name and Address
Center for Connected and Automated Transportation
University of Michigan Transportation Research Institute
2901 Baxter Road
Ann Arbor, MI 48109

10. Work Unit No.

11. Contract or Grant No.
Contract No. 69A3551747105

12. Sponsoring Agency Name and Address
U.S. Department of Transportation
Office of the Assistant Secretary for Research and Technology
1200 New Jersey Avenue, SE
Washington, DC 20590

13. Type of Report and Period Covered
Final Report

14. Sponsoring Agency Code
OST-R

15. Supplementary Notes
Conducted under the U.S. DOT Office of the Assistant Secretary for Research and Technology's (OST-R) University Transportation Centers (UTC) program.

16. Abstract
This funding augmented maintenance and operations of the Ann Arbor Connected Environment. The Ann Arbor Connected Environment is one of the largest operational, real-world deployment of DSRC connected vehicles and infrastructure in the world. In 2017, it was expanded to encompass the entire City of Ann Arbor – 29 square miles. It has 70 infrastructure sites to include three curve speed warning sites, four pedestrian crosswalks, five freeway sites, one roundabout, two test sites, and fifty-five intersections that are instrumented. More than 2,200 cars, commercial trucks, and transit vehicles were equipped with global positioning systems and dedicated short-range communications. All devices pass industry certification testing and use production security. Additionally, the environment complies with all regulatory requirements such as FCC licensing. This project contributes to the continued operations and maintenance of the Ann Arbor Connected Environment, which is currently funded by Mcity. The Ann Arbor Connected Environment is used by many CCAT researchers and industry stakeholders. It enables research in all CCAT research thrusts for connected and automated transportation including Enabling Technology; Planning and Policy; Human Factors; Infrastructure Design and Management; Control and Operations; and Modeling and Implementation.

17. Key Words	**18. Distribution Statement**
Connected Vehicles, V2X, V2V, V2I, Safety, Transportation	No restrictions.

19. Security Classif. (of this report)	**20. Security Classif. (of this page)**	**21. No. of Pages**	**22. Price**
Unclassified	Unclassified	18	Leave blank – not used

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

UMTRI · The University of Akron · Illinois Center for Transportation · Purdue University · Washtenaw Community College · Central State University

CENTER FOR CONNECTED AND AUTOMATED TRANSPORTATION

Table of Contents

Table of Figures

Tables

1. Introduction[1]

The Ann Arbor Connected Environment (AACE) was originally launched in 2012, as part of the United States Department of Transportation (U.S. DOT) Connected Vehicle Safety Pilot Model Deployment program under U.S. DOT contract DTFH611C00040. Governed by the ITS Joint Program Office within U.S.DOT, this project was known at the time as the Safety Pilot Model Deployment (SPMD) and included over 2,800 vehicles and 25 infrastructure locations equipped with connected vehicle (CV) devices. UMTRI led a diverse team of industry, public agencies, and academia as the official Test Conductor for the SPMD.

The in-vehicle onboard units (OBUs) served to evaluate emerging vehicle safety applications that implemented dedicated short-range communication (DSRC) technology to exchange telemetry and other situational messages between vehicles. These vehicles were operated on public streets in an area highly concentrated with CV-equipped vehicles. The DSRC-based roadside units (RSUs) were installed in Northeast Ann Arbor, as shown in Figure 1. The RSUs served to convey traffic signal timing, intersection geometry, speed limits and other safety critical infrastructure information to OBUs. As with the vehicle applications, SPMD served to evaluate vehicle-to-infrastructure (V2I) CV applications.

Collectively, the model deployment was originally designed to determine the effectiveness of DSRC technology at reducing crashes by evaluating V2V and V2I applications operationally in a real-world, concentrated environment; to gauge user acceptance of the technology; and to generate data to support estimates of safety system effectiveness. The project included a mix of cars, trucks and transit vehicles and was the first test of this magnitude of connected vehicle technology in a real-world, multimodal, operating environment.

[1] Kuciemba, Steve, Timcho, Tom, McLaughlin, Katie, Perry, Frank, and Bezzina, Debby. Evaluation and Synthesis of Connected Vehicle Technologies. June 2021.

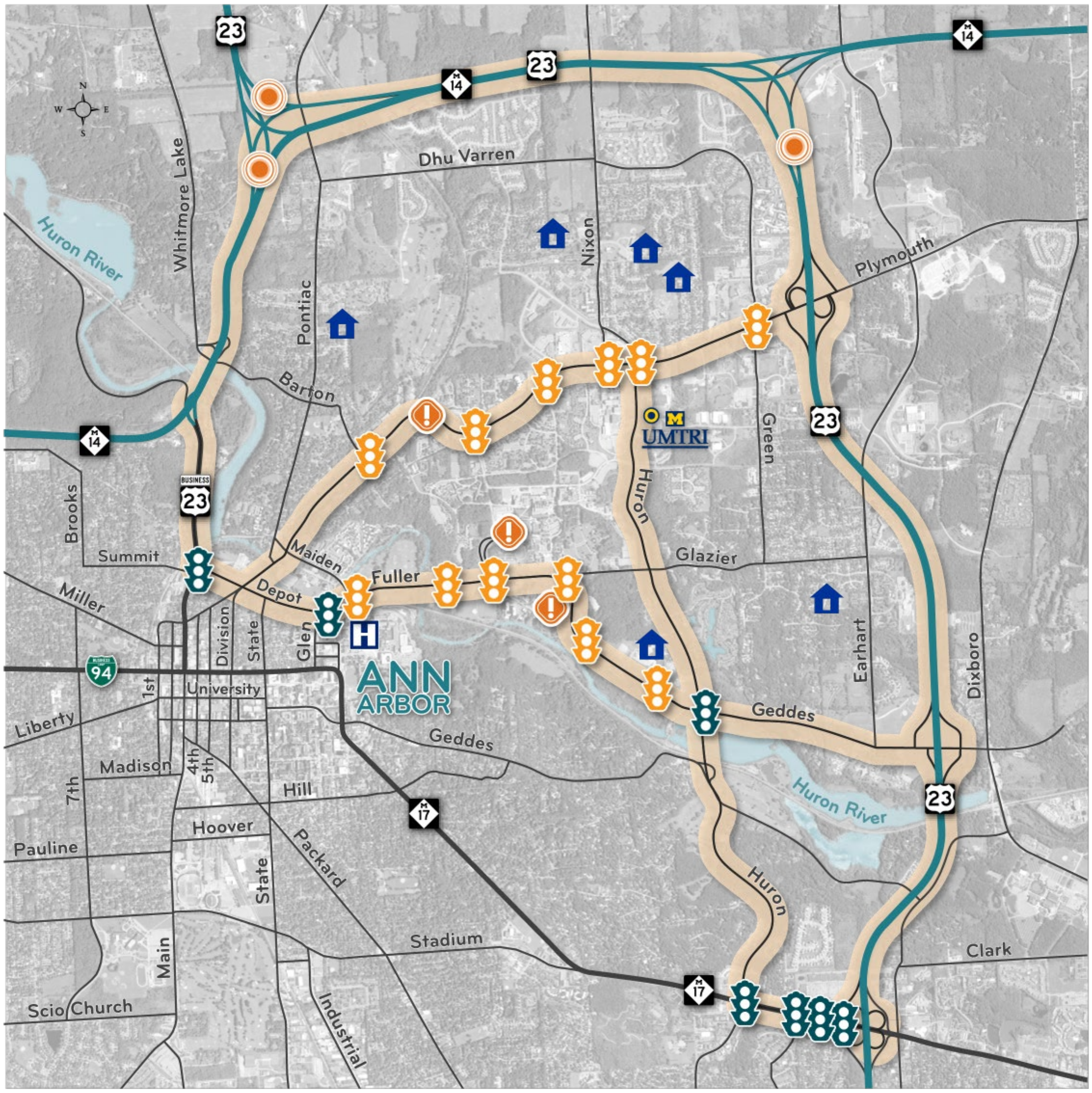

Figure 1: SPMD Project Area

The SPMD was impactful. The data generated from the model deployment was critical to supporting National Highway Transportation Safety Administration (NHTSA) agency decision regarding connected vehicle communications for safety and led to the NHTSA Notice of Proposed Rulemaking – making DSRC-based V2V technologies standard on all new vehicles (Docket No. NHTSA-2016-0126). The proposed rulemaking included:

- New Federal Motor Vehicle Safety Standards (FMVSS) No. 150: V2V communication capability for light vehicles

- Minimum performance requirements for V2V devices and messages

Moreover, lessons learned from this project were incorporated into industry standards including RSU 4.1, SAE J2735, SAE J2945/x (and by extension the C-V2X-focused SAE J3161/x series of standards), and IEEE 1609.2-4. This project also was the starting point for the production Security Credential Management System (SCMS) developed by the Crash Avoidance Metrics Partners, LLC (CAMP) and implemented by Green Hills Software (now a part of ISS).

The total cost of SPMD was $30M, with the DSRC equipment and deployment elements accounting for roughly $16M of this overall cost. As the SPMD completed its research mission, in 2015 UMTRI began to transition and expand the effort into the Ann Arbor Connected Vehicle Test Environment (AACVTE) under FHWA Cooperative Agreement DTFH6115H00005. The main goal for AACVTE was to transition from a model deployment to an early operational production environment.

Secondary goals included:

- Serve as a national reference architecture for connected vehicles and infrastructure
- Conduct focused research
- Support other related research activities
- Transition from government funded to a sustainable environment

A major part of the project was to update the existing devices to be compliant with the revised industry standards that were developed from the results of the SPMD. A second major element was to expand the infrastructure footprint from the original 25 RSUs in Northeast Ann Arbor to a total of 75 RSUs deployed throughout the City of Ann Arbor, as shown in Figure 2 below.

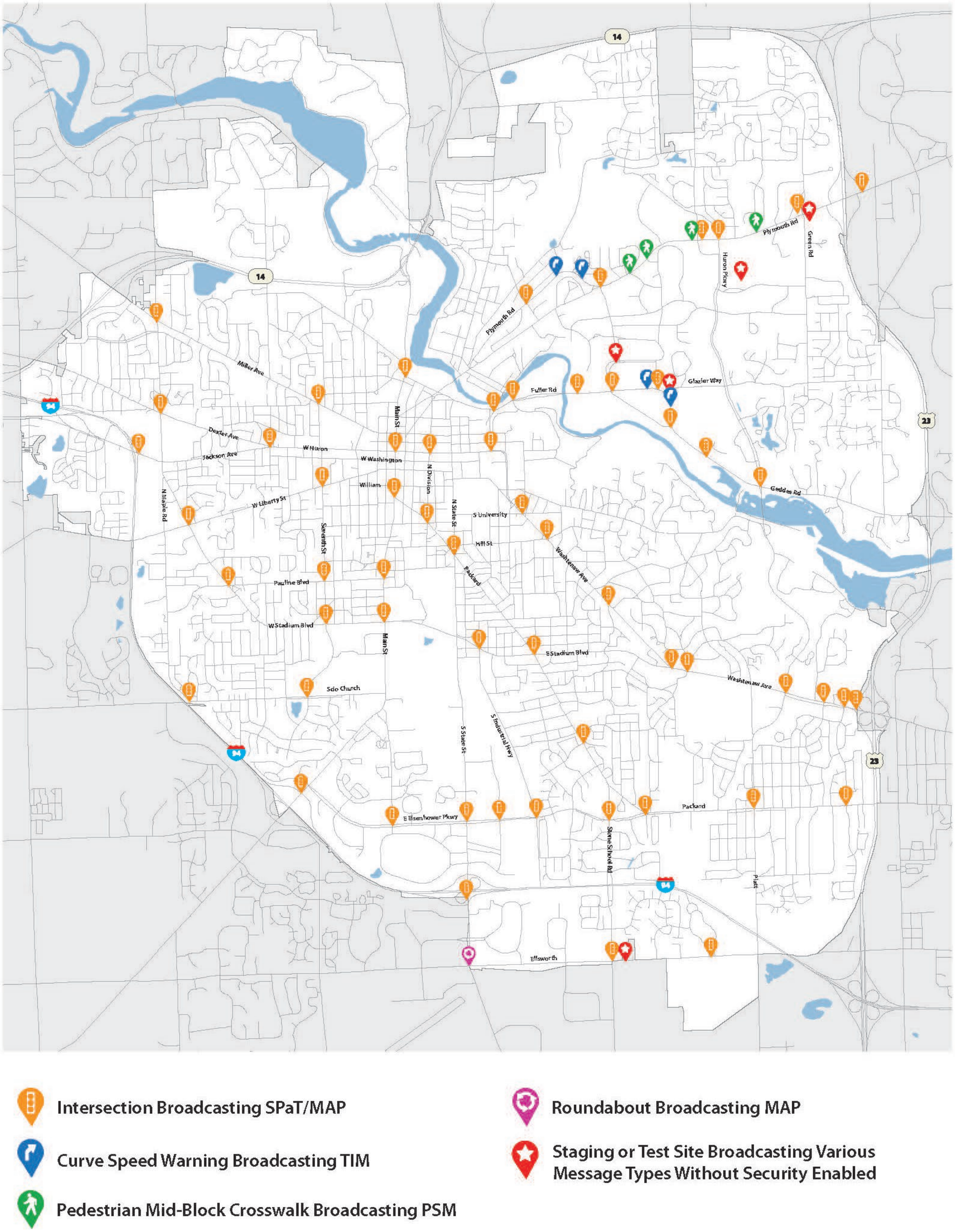

Figure 2: The AACVTE Deployment Area

The AACVTE deployment was not as straightforward as initially anticipated, however.

Additional security requirements, an outcome of the rigorous SPMD activities, required replacement of existing RSUs and OBUs, rather than a simple software update. This one change alone made the AACVTE integration activities nearly as complex as standing up the original SPMD. The cost of this replacement, including both equipment and manpower, was $15.2M. With the operational environment numbering 2,175 DSRC-equipped vehicles and 75 DSRC-based RSUs, the Ann Arbor Connected Environment (AACE), as it is now known, was the second largest DSRC deployment in the country, with only New York City having more DSRC devices deployed. AACE was in full operations and maintenance mode and was funded by Mcity, a private-public partnership of industry stakeholders including Aptiv, Denso, Econolite, Ford, GM, Honda, Intel, LG, State Farm, Toyota, and Verizon.

On May 3, 2021, the Federal Communications Commission (FCC) published the final rule related to the use of the 5.850-5.925 GHz Band. This action had two immediate impacts: (1) setting in motion the reallocation of the 5.9 GHz spectrum that would reduce the dedicated bandwidth allocated to vehicle safety from 75 MHz to 30 MHz; and (2) formalizing the FCC's roadmap that would eventually dictate the use of cellular vehicle-to-everything (C-V2X) technology in the remaining portion of the dedicated band instead of the currently specified dedicated short-range communications (DSRC) technology. Because of this FCC rule, all DSRC RSU and OBUs were decommissioned.

2. Findings

This project was not responsible for the full operations and maintenance of the Ann Arbor Connected Environment, rather it was to augment funds provided by Mcity Leadership Circle Members to keep the environment operational. To put this in perspective, all funding sources are shown Table 1 below.

Table 1: Total Funds Invested to Date in the Ann Arbor Connected Environment

Program	SPMD	AACVTE	AACE
Federal Funds	$25.5M	$8.99M	$-0-
Cost Share Funds	$4.8M	$6.19M	$4.6M
Cost Share Sources	UM ($3.9M) MEDC ($450K) MDOT ($300K) Program Partners ($196K)	MEDC ($3M) Mcity ($2.25M) Program Partners and Suppliers ($950K)	***Mcity:*** O&M 2.6M ISS $150K V2P $550K CCI $459K SCMS 2.0 $351K Heat Map $366K ***CCAT:*** O&M $172K
Total Federal Funds		**$34.5M**	
Total Cost Share		**$15.6M**	
Total Funds (FED + CS)		**$50.1**	

AACE enables research and product development. All major vehicle manufacturers and suppliers have a significant presence in Southeast Michigan. Of North America's top 150 global automotive suppliers, 85% are headquartered within a 4-hour drive, and there are R&D facilities for 12 global automotive manufacturers located within a 1-hour drive of Ann Arbor. Automobile manufacturers and suppliers regularly use the AACE for testing and development. But AACE is also used for research. Through UMTRI and Mcity, many OEMs and Tier 1s use the deployment to conduct research on topics such as dynamic traffic control, transit signal priority, revenue generating applications, and so much more. Some of the more prominent research projects that were enabled by maintaining AACE operations, which was extended through funding by CCAT, are detailed below.

a. Vehicle-to-pedestrian (V2P)

Four crosswalks in Ann Arbor were equipped with overhead cameras with the ability to detect pedestrians. When a pedestrian was detected, roadside equipment nearby began to broadcast a message alerting approaching vehicles to the presence of a pedestrian in the crosswalk. Vehicles equipped with Aftermarket Safety Devices as part of the Ann Arbor Connected Environment (AACE) could receive and process these messages and potentially warn their driver about the pedestrian ahead. Of interest was both the ability of the overhead camera system to correctly detect and warn vehicles of the presence of pedestrians and also the affect these warnings may have on the drivers' behavior.

- This project determined the accuracy and limitations of a of pedestrian detection system which employed a coarse, fairly simple visual detection system.
- The drivers' stopping behavior at crosswalks using only vehicle dynamics data collected by roadside units was also evaluated.

Overall, there were few misses, and after some filtering, relatively few false alarms in the overhead camera pedestrian detection system. Furthermore, with some knowledge of the road environment, connected vehicle dynamics are reasonably reliable enough to identify connected vehicles stopping for mid-block pedestrians. No significant differences were found in drivers' stopping behavior at crosswalks when comparing vehicle dynamics data from stopping vehicles when drivers did and did not receive in-vehicle warnings about the presence of a pedestrian in the crosswalk ahead. However, the crosswalks were equipped with a beacon, which has already been shown to improve stopping behavior.

b. SCMS 2.0

In order to ensure the highest levels of security among communicating connected vehicles, the Security Credential Management System (SCMS) must also identify and remove any misbehaving devices. This project focused on misbehavior detection by incorporating and testing the following methodologies for misbehavior detection:

- Proximity overlap – when two vehicles report overlapping positions for an extended period.
- Warning-based – when a warning is issued by the OBU, but the driver takes no action because the data in the received BSM was not valid.

The algorithms were developed by leveraging previous federally funded research[2]. Before vehicle testing began, the algorithms were thoroughly tested on the bench. Upon successful bench testing, several devices were updated and installed on development vehicles. Those vehicles were used to test the misbehavior algorithms first at Mcity. The misbehavior detection s/w release were than updated based on the Mcity test results. The next step was to test the algorithms in the Ann Arbor Connected Environment. For testing in the connected environment, a pilot fleet of about 25-vehicle connected vehicle fleet and several development vehicles were employed. All vehicles drove along a prescribed route in the Ann Arbor Connected Vehicle Environment. At least one vehicle intentionally sent erroneous BSMs (i.e., misbehaved). The team studied:

- The reaction of the test fleet to vehicles that are misbehaving (true identification)
- The reaction of the test fleet to vehicles that are not misbehaving – the heat map pilot fleet (false identification)

The team successfully integrated CAMP's misbehavior detection algorithms deployed and deployed equipped vehicles in a real-world environment.

c. Heat Map (IMA and LTAP)

Simulation results indicated that the interactions for vehicle-to-vehicle (V2V) applications such as Intersection Movement Assist (IMA) and Left Turn Across Path (LTAP) are low at the currently levels of deployment. Ten hours of testing may only produce one valid interaction for these

[2] Vehicle-to-Vehicle Field Level Evaluation of Local Misbehavior Detection (LMBD) in a Controlled Environment, CAMP, LLC.

applications. Adding additional non-fleet vehicles does not provide linear benefits. To guarantee enough interactions while using AACVTE for testing, we created a critical mass of DSRC-equipped vehicles by strategically driving vehicles on a set route in Ann Arbor. We plan on using this proven approach with the OEMs in the 5GAA through the recently announced ATTAIN grant – AACE 2.0: The Ann Arbor Connected Environment Reimagined.

3. Recommendations

Recommendation from this project are described below.

National Deployment. Only movement for a national connected vehicles and infrastructure deployment will deter the FCC from taking away the remaining bandwidth in the safety spectrum. As it is, there is only room for one C-V2X channel in the safety spectrum. This is not enough bandwidth for all the C-V2X applications that have been developed or are in development, let alone the thousands of potential applications. Therefore, there will be a need for auxiliary technology and/or communications channels for mobility and sustainability applications, which are not as time sensitive. For example, mobility applications can use the existing cellular (Uu) network. Even more importantly, each year we wait for a national deployment, crashes causing fatalities and life-altering injuries will continue to occur on US roadways. NHTSA predicts that 80% of unimpaired crashes can be avoided by connected technologies and systems.[3] Furthermore, an UMTRI white paper[4] calculated the impact of delaying deployment of DSRC and waiting three (3) years for C-V2X. First, it has already been over three years and still neither DSRC nor C-V2X are deployed at a national scale! A big part due to the uncertainty caused by the FCC. Second, Dr. Sayer estimates that from 2019, when we could have started deploying DSRC, and allowing for a 3-year rollout in new cars, in 5 years up to 520,000 crashes and 3,152 fatalities could be avoided. Every year we wait, more

---

[3] Federal Register/Vol.82, No. 8/Thursday, January 12, 2017/Proposed Rules (p3985)

[4] James R. Sayer, Carol A. C. Flannagan, Andrew J. Leslie. The Cost in Fatalities, Injuries and Crashes Associated with Waiting to Deploy Vehicle-toVehicle Communication. May 2018. (http://umtri.umich.edu/sites/default/files/The%20Cost%20Associated%20with%20Waiting%20to%20Deploy%20DSRC.pdf)

accidents will occur, resulting in more fatalities and more life-altering injuries – accidents that could have been avoided if we only deployed connected vehicle technology sooner.

Use V2X to Slow Climate Change. Connected technologies and systems have the potential to slow climate change and improve the environment by reducing GHG and other emissions. For example, the green wave speed may be encoded into the SPaT messages and broadcast to the CVs on the road. Through a human-machine-interface (HMI), CV drivers can take the green wave speed as the suggested speed. In this way, not only the mobility performance can be enhanced, but the CVs also generate smoother trajectories, improve fuel efficiency, and reduce energy consumption.

Implement Misbehavior Detection. Rigorous misbehavior detection (MBD) algorithms should be implemented on day 1. The benefits of MBD, were shown in the testing described in section 2 above.

4. Outputs

Several presentations were given at various events, including:

- V2X Summit (8/25/22). The U.S. DOT V2X Summit was a two day event held on August 24 and 25, 2022. This presentation was part of the "Deployers Panel." Panelists discussed their respective connected vehicle deployments, lessons learned, and why these deployments are important. Debby Bezzina presented on the Ann Arbor Connected Environment to over 1,000 professionals.
- NHTSA Office of Defects (4/7/22). Introduction to Connected Vehicles (CV) Technology and Applications. This was a two-hour class for NHTSA Office of Defects Employees to familiarize them with CV technologies and how it can be used to safe lives, improve congestion, and reduce our carbon footprint. It also provided an overview of UM's evolution of connected vehicle technology deployments, including AACE. Debby Bezzina presented to a class of 55 professionals.
- Elderwise. Elderwise is a local Ann Arbor community group that focuses on education for seniors. This presentation provided an overview of connected vehicle and

infrastructure technology and the Ann Arbor Connected Environment deployment. Mary Lynn Buonarosa presented to 35 community members.

- American Association of University Women (11/16/23) . "Just over 115 years ago a small group of women graduates in Ann Arbor, Michigan gathered together to form the Ann Arbor Branch of the Association of Collegiate Alumni, the forerunner of AAUW, the American Association of University Women. Today we are a vibrant, active group of some 300 intellectually curious women, devoted to improving the lives of women and girls through education." Mary Lynn Buonarosa presented on the connected vehicle and infrastructure technologies and systems, their benefits, and the Ann Arbor deployments.
- IEEE Roundtable (3/27/23). This virtual roundtable discussion on trust, security, and privacy for connected vehicles consisted of four panelists with backgrounds from both industry and academia. The writeup of the panel discussions was published in IEEE IoT Magazine.
- ITSA Member Webinar (6/14/23). This one-hour webinar titled "Improving Safety and E-mobility through Connectivity" provided ITSA members with an overview of connected technologies and systems as well as EV charging technology. Debby Bezzina was one of the four panelists and presented on the benefits and potential V2V, V2X, V2P, and V2X applications.

5. Outcomes

There were several outcomes:

- AACE kept high-technology jobs in Michigan and helped maintain the State's established leadership position in connected and automated vehicles and infrastructure. Furthermore, it attracts talent from around the globe, competing with places like Silicon Valley.
- AACE provided CAV stakeholders with an environment to test and develop safe equitable, and efficient transportation and mobility systems.
- Awareness of transportation issues around the FCC R&O was increased.

- The potential benefits of CV technology were reported out broadly at meetings and conferences.

6. Impact

Although CCAT funding was only a small portion of the evolution of the Ann Arbor Connected Environment, that evolution had significant impacts.

Job Creation. During SPMD and AACVTE many jobs were created at UMTRI, WSP, and several suppliers. The initial SPMD team consisted of 75 professionals from UMTRI, the City of Ann Arbor, WSP, Liedos, Mixon-Hill, and HNTB. Additionally, suppliers were contracted to build the connected devices. Three suppliers (Savari, Arada, and Commsignia) opened offices in Metro Detroit to be able to compete in the connected vehicle and infrastructure market. Savari and Arada are both startup companies from California. Arada was eventually bought by Lear (Southfield); Savari was bought by Harman (Novi). Commsignia is originally from Budapest but their current home office is in Santa Clara, California and a satellite office in Southfield. A fourth supplier, Cohda Wireless from Australia, opened a remote office in Indiana to better support SPMD and AACVTE. Furthermore, Danlaw, the AACVTE aftermarket safety device (ASD) manufacturer, fabricated the ASDs at their factory in Saline.

Leadership. The Safety Pilot Model Deployment was a first-of-its-kind deployment in the world which led to the creation of several industry standards. Furthermore, The University of Michigan has been a leader and collaborator in connected vehicles and infrastructure by providing workshops on lessons learned and training documentation to pilots across the country. The environment requires a multidisciplinary approach that allows the University to expand its expertise in areas including accessibility, equity, and more.

Research. The connected environment, originally named Safety Pilot Model Deployment (SPMD), was sponsored by USDOT, NHTSA, ITS Joint Program Office, FHWA, FMCSA, and FTA. Since 2012, over $50 million has been invested in the environment, with another $32.7M in new sponsored funding, and more than 100 TB of transportation data has been collected.

Roughly 25 projects rely on data collected in the environment or actively improve it. Additionally, the environment is an asset for future projects:

- MDOT's Connected and Automated Vehicles (CAV) Corridor – AACE is the west anchor for the project
- ATCMTD grant "Smart Intersections: Paving the Way for a National CAV Deployment." The Smart Intersection Project ($20M) – builds upon AACE to convert 3 corridors to smart intersections for better traffic control and improved safety for both drivers and pedestrians
- ATTAIN grant "AACE 2.0: The Ann Arbor Connected Environment Reimagined." Announced in May of 2023, this project ($12.7M), when underway, will retrofit the remaining 54 RSUs to C-V2X technology. The team will work with the OEMs in the 5GAA consortium to develop and deploy day 1 applications identified in the 5GAA V2I Deployment Guide.

Education and Workforce Development. Over 20 students at the University of Michigan have received sponsorship to attend national conferences including the Transportation Research Board's Annual Meeting in D.C. and Over 100 students participated in research and internships directly tied to the environment including students attending Washtenaw Community College. There are opportunities for future collaboration with students to provide them with hands-on experience that can lead to employment. The Washtenaw Community College internship took students that were part of the Advanced Transportation Center (members of CCAT) and gave them hands-on experience with the instrumentation of connected vehicle equipment. This internship program led to students being employed in crash testing and autonomous vehicle testing at May Mobility.

Strategic Alignment with U.S. DOT Goals. The Ann Arbor Connected Environment actively aims to meet the vision of the College of Engineering, the State of Michigan, and the United States. Connected vehicle deployments could address 80% of unimpaired car crashes – on lives lost, this should be considered a global health crisis. Connected technologies and systems can provide $178 billion in societal benefits and bring an 11% reduction in CO_2 emissions and fuel consumption. Continued support from the University, the State of Michigan, and Industry for connected vehicle and infrastructure technology sends a message to the nation that we are invested in greatly reducing the 42,795 lives we lose each year to car crashes. In summary, AACE is necessary if we are to see country-wide implementation of connected vehicles: we cannot have a patchwork of deployments all following different criteria.

7. Challenges and Lesson Learned

The main challenge is that a national deployment was significantly delayed because of the FCC and the introduction of C-V2X. More data analysis needs to be done around reducing crashes and fatalities. Using the heat map model, additional targeted testing could provide needed data which will be incorporated in the recent ATTAIN grant.

High-level lessons learned were:

- Trajectory data can be used for optimizing traffic signal timing to increase throughput, which was then deployed by an IOO (Oakland County).
- V2P is difficult, but worth figuring out. With the exponential increase in pedestrian and other vulnerable road users (VRU) fatalities, solutions need to be deployed now. And even worse, is that VRU fatalities are disproportionate when comparing race and ethnicity. A recent study[5] published in the American Journal of Preventive Medicine found:
    - Non-Hispanic Blacks experience a pedestrian (walking) death rate 118% higher than non-Hispanic whites
    - Non-Hispanic Blacks experience a cycling fatality rate 348% higher than non-Hispanic whites

[5] Raifman, Matthew A, Choma, Ermani F., Disparities in Activity and Traffic Fatalities by Race/Ethnicity, American Journal of Preventative Medicine, Volume 63, Issue 2, pp160-167, August 2022. DOI: https://doi.org/10.106/j.amerpre.2022.03.012.

- The disparities are even sharper when comparing fatality rates for pedestrian (walking) deaths occurring at night:
  - Non-Hispanic Black pedestrians experience a fatality rate 236% higher than non-Hispanic whites
  - Hispanic or Latino pedestrians experience a fatality rate 84% higher than non-Hispanic whites

- RSUs are not one size fits all.
- The more functionality enabled, the more things tend to go wrong.
- Each deployment has different requirements.
- Many ambiguities in the industry standards – optional fields may lead to non-interoperability on a national scale.
- Manufacturers and Operators are still learning.
- Most manufacturer's QA processes are inadequate.
- Device certification doesn't mean it will work in the real world.
- Adding production security adds complexity and unintentional consequences (issues at the device level).

GLOSSARY

AACE	Ann Arbor Connected Environment
AACVTE	Ann Arbor Connected Vehicle Test Environment
AAUW	American Association of University Women
ASD	Aftermarket Safety Device
ATCMTD	Advanced Transportation and Congestion Management Technologies Deployment
ATTAIN	Advanced Transportation Technology and Innovation
BSM	Basic Safety Message
CAMP	Crash Avoidance Metrics Partnership
CAV	Connected and Automated Vehicle
CCAT	Center for Connected and Automated Transportation
CCI	Clarifications for Consistent Implementation
CS	Cost Share
CV	Connected Vehicle
C-V2X	Cellular Vehicle to Everything
DOI	Digital Object Identifier
DOT	Department of Transportation
DSRC	Dedicated Short-range Communications
EV	Electric Vehicle
FCC	Federal Communications Commissions
FED	Federal
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FMVSS	Federal Motor Vehicle Safety Standard
FTA	Federal Transit Administration
GHG	Greenhouse Gasses
GM	General Motors

HMI	Human-Machine Interface
IEEE	Institute of Electrical and Electronic Engineers
IMA	Intersection Movement Assist
IOO	Infrastructure Owner/Operator
ISS	Integrity Security Services
ITS	Intelligent Transportation Systems
LLC	Limited Liability Corporation
LMBD	Local Misbehavior Detection
LTAP	Left Turn Across Path
MBD	Misbehavior Detection
MDOT	Michigan Department of Transportation
MEDC	Michigan Economic Development Coporation
NHTSA	National Highway Traffic Safety Administration
OBU	On-board Unit
OEM	Original Equipment Manufacturer
QA	Quality Assurance
R&O	Report and Order
RSU	Roadside Unit
SAE	Society of Automotive Engineers
SCMS	Security Credential Management System
SPMD	Safety Pilot Model Deployment
TB	Terabyte
UM	University of Michigan
UMTRI	University of Michigan Transportation Research Institute
US	United States
U.S. DOT	United States Department of Transportation
Uu	LTE's uplink and downlink used to implement vehicle-to-vehicle communication

V2I	Vehicle to Infrastructure
V2P	Vehicle to Pedestrian
V2V	Vehicle to Vehicle
V2X	Vehicle to Everything
VRU	Vulnerable Road User