Research on Connected Vehicle Technology

Introduction

Section 24219 "Research on Connected Vehicle Technology" of the Bipartisan Infrastructure Law (BIL), enacted as the Infrastructure Investment and Jobs Act (IIJA), directed that

> The Administrator of the National Highway Traffic Safety Administration, in collaboration with the head of the Intelligent Transportation Systems Joint Program Office and the Administrator of the Federal Highway Administration, shall—
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> (1) not later than 180 days after the date of enactment of this Act, expand vehicle-to-pedestrian research efforts focused on incorporating bicyclists and other vulnerable road users into the safe deployment of connected vehicle systems; and
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> (2) not later than 2 years after the date of enactment of this Act, submit to Congress and make publicly available a report describing the findings of the research efforts described in paragraph (1), including an analysis of the extent to which applications supporting vulnerable road users can be accommodated within existing spectrum allocations for connected vehicle systems.

To meet this requirement, NHTSA submits the following:

Expanded Connected Vulnerable Road User (VRU) Research Efforts

As directed in Section 24219, NHTSA collaborated with the Intelligent Transportation Systems Joint Programs Office (ITS JPO) and Federal Highway Administration (FHWA) to expand vehicle-to-pedestrian research efforts to incorporate bicyclists and other vulnerable road users. NHTSA worked with FHWA and ITS JPO to identify existing projects that previously included only vehicle-to-pedestrian research but could be expanded to include bicyclists and other road users. New projects including bicyclists and other road users are also included in this report. Several of these efforts are ongoing, with interim results available. These expanded research efforts are described in the following paragraphs.

Enhancing VRU Detection and Volume Data Through Advanced Imaging Techniques

This project, sponsored by FHWA, incorporates vulnerable road users into research toward the safe deployment of connected vehicle systems by investigating ways to improve infrastructure-based detection of pedestrians, bicyclists, and other VRUs. These devices have many uses in intelligent transportation systems, as well as in a connected vehicle environment where they can detect VRUs and broadcast messages on their behalf when the VRU does not have a personal connectivity device (e.g., mobile phone). Research involving thermal camera detection is complete with a report anticipated to publish in early 2024. Active data collection is underway for light detection and ranging (LiDAR) and LiDAR/thermal detection fusion systems. This research will characterize how different imaging technologies may be able to work in concert to improve VRU detection in degraded environmental conditions, such as rain, fog, or solar glare from direct sunlight.

ITS Architecture Tools and Reference Evolution for Multimodal and Accessible Travel

This effort, sponsored by the ITS JPO, has updated the Architecture Reference for Cooperative and Intelligent Transportation (ARC-IT, www.arc-it.net) to include new VRU-related services, communications solutions, and objects. ARC-IT is a systems engineering tool that provides a reference architecture for transportation professionals to design and deliver ITS systems. A larger system architecture is built of smaller "service packages" representing the elements of the complete ITS deployment, such as traffic signal control or VRU detection. This update is the result of ongoing research to identify and cover gaps for VRUs in connected vehicle systems. On September 15, 2023,[1] the ITS JPO released ARC-IT version 9.2. The most significant VRU-related enhancements for version 9.2 are:

- Multimodal Accessible Travel (MAT): Concepts supporting complete trip, integrated payment, safety for vulnerable road users, and pathway/indoor navigation use cases. Most directly impacted service packages:
    - SU15: Vulnerable Road User Device Transition Support
    - TI03: En-Route Guidance
    - TI04: Trip Planning and Payment
    - TI05: Integrated Multi-Modal Electronic Payment (previously PT18)
    - TI06: Shared Use Mobility and Dynamic Ridesharing
    - TI08: Personal Wayfinding
    - VS12: Vulnerable Road User Safety
    - VS18: Vulnerable Road User Clustering
- Many new physical objects supporting MAT and other new and refined concepts, such as the Micro-Mobility Vehicle On-Board Equipment (OBE), Electric Charging Management Center, and Shared Use Transportation Center.

ARC-IT is used by both practitioners and researchers in the development of safe connected vehicle system deployments. The inclusion of a wider range of VRU features will improve the ability to include VRUs in connected vehicle system deployments.

V2X Communications Requirements

This research effort, sponsored by the ITS JPO, incorporates all connected road users into the research toward the safe deployment of interoperable connected and automated vehicle systems by examining the performance and limitations of Cellular Vehicle-to-Everything (C-V2X) technologies, particularly the 4G long-term evolution V2X (or "LTE-V2X"). This technology enables connectivity via direct communications instead of conventional cellular network towers. ITS JPO testing, conducted in closed course facilities, has shown that under nominal conditions, LTE-V2X performs similarly to Dedicated Short Range Communications (DSRC) and with sufficiently short latencies to support safety-related use cases. In nominal conditions where a small number of connected vehicles were physically unobstructed and without radio interference, both technologies were able to produce basic safety messages (BSMs) at the 10 Hz rate required for crash avoidance applications. Testing was also conducted to show radio performance under edge cases, such as heavy wireless congestion and out-of-band emissions (OOBE) interference; initial results suggest similar performance to DSRC radios; however, interference under

[1] Intelligent Transportation Systems Joint Program Office. (2023). "What's New in ARC-IT" https://www.arc-it.net/html/whatsnew/whatsnew.html

edge cases requires further investigation with actual applications. Future testing will focus on demonstrating any new power and OOBE requirements from the second FCC report and order.[2]

This research is also tracking the emerging specifications to create a 5G-V2X communications capability, although there is currently no spectrum allocated for this type of communications protocol (it is not compatible with the LTE-V2X communications and cannot share the dedicated 30 MHz band).

In addition, the potential for additional testing to demonstrate the performance of 5G Multi-access Edge Computing (MEC) and other technologies is being explored and could be conducted within the next 1-2 years to determine if any other technologies can support safety related V2X use cases, including VRU use cases. The ITS JPO Next Generation Wireless Testing program is developing a strategy and roadmap for all future testing. It will include specific test cases focused on VRU use cases, such as bicyclists and other road users. The ITS JPO publishes the results of its testing program regularly at https://www.its.dot.gov/research_areas/emerging_tech/htm/ITS_V2X_Testing.htm. Finally, the USDOT is tracking industry efforts to create opportunities for applications used by transportation of first responders/public safety as well as bicyclists to migrate and become part of V2X, interoperable, connected transportation environments.[3]

US DOT Intersection Safety Challenge

The Intersection Safety Challenge, sponsored by FHWA, ITS JPO, and the Office of the Secretary (OST) with support from other USDOT modal partners, seeks to transform intersection safety through the innovative application of emerging technologies to identify and mitigate unsafe conditions involving vehicles and vulnerable road users. For the Challenge, VRUs include pedestrians, cyclists, and micro-mobility devices, such as wheelchairs, scooters, skateboards, and other conveyances. The Challenge takes an innovative research approach for VRU safety, by soliciting emerging technologies through a multi-stage prize competition, encouraging teams of innovators and end-users to develop and test their intersection safety systems and competing for up to $6 million total in prizes. Leveraging emerging technologies to anticipate, prevent, and mitigate unsafe roadway conditions could augment traditional safety engineering in roadway design and intersection control. These emerging technologies are expected to include machine vision, machine perception, sensor fusion, real-time decision-making, artificial intelligence, and vehicle-to-everything (V2X) communications. These technologies in most cases rely on real-time decision-making informed by data ingested and analyzed from multiple sensor systems. Stage 1A of the Challenge closed on September 25, 2023, with evaluation ongoing at the time of this report. Information on the Challenge is available at https://www.challenge.gov/?challenge=us-dot-intersection-safety-challenge.

ITS4US Evaluation of VRU Solutions of Underserved Communities

The ITS4US program, sponsored by the ITS JPO and supported by the Office of the Secretary, FHWA, and the Federal Transit Administration (FTA), is conducting research to identify ways to provide more efficient, affordable, and accessible transportation options for underserved communities that often face greater challenges in accessing essential services. The program aims to pilot and evaluate connected

[2] Federal Communications Commission. (2023). "Request for Waiver of 5.9 GHz Band Rules to Permit Initial Deployment of Cellular Vehicle-to-Everything Technology" DA-23-343. https://www.fcc.gov/document/pshsb-oet-wtb-waiver-order-permits-c-v2x-operations-59-ghz-band

[3] Two examples include Spoke Safety (https://www.spokesafety.com/) and HAAS Alert (https://www.haasalert.com/).

solutions for mobility challenges of all travelers and VRUs, with a specific focus on underserved communities, including people with disabilities, older adults, low-income individuals, rural residents, veterans, and limited English proficiency travelers. Specific implementations that aim to expand the safe deployment of connected vehicle systems beyond V2P elements to other road users include:

University of Washington (UW)

- UW will collect sidewalk data and make it available to VRUs so they can customize their trip depending on the infrastructure needs and slope limitations of their individual mobility devices.
- This project will help those who may use a wheelchair, white cane, or other mobility device to find a trip path that maximizes their trip efficiency while accommodating their safety needs and avoiding obstacles.

Heart of Iowa Regional Transit Agency (HIRTA)

- HIRTA will provide coordinated trip planning through an appointment booking app and an indoor navigation system to meet the needs of rural VRUs seeking healthcare services.
- This project will implement wayfinding technologies as part of the project to assist rural VRUs, especially those using mobility devices, in getting to and from the HIRTA vehicle safely and efficiently, whether at initial pickup, navigating from the HIRTA vehicle to the healthcare facility intake location, or finding their way to the HIRTA vehicle picking up for the return journey.

Georgia Department of Transportation (GDOT)

- GDOT will integrate existing advanced transportation technology solutions including connected vehicles, transit signal priority (TSP), machine learning, and predictive analytics through a single trip planning app to support safe and complete trips for VRUs. This deployment includes coordinated and automated extended crosswalk times for VRUs such as persons in a wheelchair or others who require additional time to navigate intersections.
- This project will allow VRUs to create a custom profile on a trip planning app that will then provide accessible routes depending on their preferences and specific mobility devices.
- This project will provide V2X safety messages to transit bus drivers alerting them of a passenger at an upcoming stop and their onboarding needs. Depending on each VRUs app profile, TSP may also be deployed to optimize transit schedule and travel times if additional time is needed to board the vehicle.

Niagara Frontier Transportation Authority (NFTA)

- NFTA will increase connectivity and safety of travelers including VRUs using mobility devices between a hospital campus, transit stations, and surrounding neighborhoods through a variety of mechanisms. These include: a trip planning tool, indoor/outdoor wayfinding, community-based on-demand shuttle services that include a fully automated shuttle, and intersection crossing safety applications for pedestrians and other VRUs.
- This project improves safety and mobility for VRUs to navigate their paths and safely cross intersections. Wayfinding applications help with a VRU’s ability to transition from being a pedestrian to hailing and boarding a vehicle or navigating inside the medical campus.

These implementations will provide the ITS JPO a better understanding of the feasibility of deploying V2X solutions for vulnerable road users who may use mobility devices. More information on ITS4US is available at https://www.its.dot.gov/its4us/.

Ensuring Cooperative Automated Driving System (C-ADS) Vehicles and Vulnerable Road Users (VRU's) Safety Through Infrastructure: Phase 1

This project, sponsored by FHWA, incorporates VRUs into research towards the safe deployment of cooperative Automated Driving Systems[4] which depend on connectivity. Phase 1 of the project is complete, and a literature review and gap analysis investigating VRU requirements has been published.[5] Phase 2 has been awarded and will investigate the effectiveness of infrastructure-based devices designed to provide a warning to VRUs about potential conflicts with conventional and connected vehicles approaching an intersection.

Key Automated Vehicle Human Factors Safety Issues Related to Infrastructure

This project, sponsored by FHWA, broadly assesses interactions between humans, vehicle automation, and infrastructure in connected vehicle systems where some vehicles have a mix of automation and connectivity. A specific element of the project examines driver behavior when approaching a bicyclist in a shared or dedicated bike lane while driving a conventional or connected/automated vehicle.[6] The project's research has concluded and a report detailing findings is anticipated to publish in Spring 2024.

Savings Lives with Connectivity Notice of Funding Opportunity (NOFO)

In October 2023, DOT released the "Saving Lives with Connectivity" NOFO, deploying $40 Million in FHWA/ITS JPO funding to invest in connected vehicle technologies.[7] This technology enables vehicles to communicate with each other, with other road users such as pedestrians and cyclists, and with roadside infrastructure, thereby advancing our Vision Zero and National Roadway Safety Strategy goals.

Strengthening Mobility and Revolutionizing Transportation (SMART) Grants Program

This discretionary grant program, funded through the Bipartisan Infrastructure Law and sponsored by the Office of the Assistant Secretary for Research and Technology, was established to provide grants to eligible public sector agencies to conduct demonstration projects focused on advanced smart community technologies and systems in order to improve transportation efficiency and safety. In FY22,

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[4] SAE International defines cooperative driving automation (CDA) as "Automation that uses [machine-to-machine] communication to enable cooperation among two or more entities with capable communications technology and is intended to facilitate the safer, more efficient movement of road users, including enhancing performance of the [dynamic driving task] for a vehicle with driving automation feature(s) engaged." Cooperative-Automated Driving Systems are defined as "The hardware and software that are collectively capable of performing the entire [dynamic driving task] on a sustained basis, regardless of whether it is limited to a specific operational design domain (ODD); this term is used specifically to describe a Level 3, 4, or 5 driving automation system." (Standard J3216: "Taxonomy and Definitions for Terms Related to Cooperative Driving Automation for On-Road Motor Vehicles" https://www.sae.org/standards/content/j3216_202107/).

[5] Weaver et al. (2022). "CDA". Ensuring Cooperative Driving Automation (CDA) and Vulnerable Road Users (VRUs) Safety Through Infrastructure. FHWA-HRT-22-085. p. 13-16. https://highways.dot.gov/research/publications/safety/FHWA-HRT-22-085

[6] For the purposes of this research, connected/automated vehicles (CAVs) are defined as vehicles which use messages broadcast by other road users to improve operations of an Automated Driving System.

[7] https://grants.gov/search-results-detail/350731

the SMART Grants program awarded several grants for programs that integrate many VRUs into the connected and automated environment.[8]

Gwinnett County Board of Commissioners

- "Singleton Road Corridor Technology Improvements" include V2X notifications for VRUs at bus stops along the corridor, along with other pedestrian improvements.
- Prototype safety technologies along Gwinnett County's Singleton Road Corridor, including passive pedestrian detection and Transit Signal Priority.

Road Commission for Oakland County

- "Leading in Sustainable Safety with V2X Technology" in Oakland County, Michigan, provides resources for the local government to plan for V2X deployments, working with stakeholders and engaging the community.
- Create a framework for deploying C-V2X in a sustainable manner, which includes VRUs.

Texas Department of Transportation

- "Smarter Intersections Pilot Project" focuses on electronic signs that alert VRUs of turning buses and emergency vehicles.
- Install smart intersection technology featuring visual and auditory devices in College Station for VRUs without connected devices to integrate into a V2X environment.

Utah Department of Transportation

- "Enabling Trust and Deployment Through Verified Connected Intersections" builds on previous work creating connected intersections in Utah by validating field data.
- Prototype a Connected Intersection Corridor and develop a plan for nationwide V2X systems deployment.

VRU-Supporting Applications Within Existing Spectrum Allocations

In November 2020, the Federal Communications Commission (FCC) issued an order[9] in which FCC selected C-V2X technology, particularly the 4G long-term evolution V2X (or "LTE-V2X"), for transportation safety communications. Since issuance of that order, the ITS JPO, in partnership with the National Telecommunications and Information Administration (NTIA), conducted a series of tests to assess the effectiveness and limitations of LTE-V2X technology in the 30 MHz range. This testing was largely focused on the number of devices and device densities that may be able to support a group of vehicles, bicycles, pedestrians, other VRUs in the form of a combination of multimodal connected road users. Congestion testing targeted radio performance only (i.e. not V2X application performance) and demonstrated a drop off in performance with 250 devices operating within a 300 meter line of sight from each other, similar to results from previous modeling and simulation. While not specific to V2P or other VRUs in a connected environment, the testing used devices applicable to a broad mix of road users. Preliminary results from this testing activity suggest 30 MHz of spectrum may not be adequate to support a large number of VRUs exchanging V2X messages in close proximity with connected vehicles and connected infrastructure devices, conditions that are found in dense urban areas. While C-V2X may perform similarly to DSRC in nominal conditions where a small group of devices are unobstructed, there

[8] https://www.transportation.gov/sites/dot.gov/files/2023-03/FY22%20SMART%20Project%20List.pdf

[9] Federal Communications Commission. (2020). "Use of the 5.850-5.925 GHz Band". FCC-20-164, 35 FCC Rcd 13440 (16). https://www.fcc.gov/document/fcc-modernizes-59-ghz-band-improve-wi-fi-and-automotive-safety-0

are interference concerns with a large number of devices in close proximity which, then, require use of a congestion control algorithm that slows the rate of V2X messaging.

These results are consistent with previous theoretical models and simulation. Rules for use are pending FCC action; message prioritization schemes that have been described in the SAE J3161 family of standards may be necessary such that in degraded conditions due to congestion, basic safety messages (BSMs) or VRU personal safety messages (PSMs) would be prioritized over other V2X applications although congestion may lead to delays. Such delay could potentially reduce safety benefits, which require very low latencies.

Testing has also demonstrated specific concerns and degradation with OOBE interference from unlicensed devices operating within the UNII-4 band (below the V2X 30 MHz band) and very low power (VLP) devices operating within the UNII-5 band (above the V2X 30 MHz band); both bands are adjacent to the 5.895-5.925 GHz band. One specific concern observed was from a mobile Wi-Fi hotspot operating within a nearby vehicle utilizing the Wi-Fi channels directly above 5.925 GHz and below 5.895 GHz. This communication reduced the effective range in non-line-of-sight conditions well below 250 meters. This testing showed that many safety use cases are not achievable with the reduced range, especially at speeds above 45 mph. In some cases, the range was reduced to around 25 meters where even low speed (<25 mph) use cases that could involve pedestrians, bicyclists, and other vulnerable road users would not be achievable.

In many connected vehicle implementations, deployers assume that many VRUs will not have a device capable of broadcasting or receiving messages on the 5.9 GHz Safety Band. One solution that is being explored is the use of "cooperative perception" where an infrastructure- or vehicle-based sensor detects a VRU and broadcasts information about that VRU on the VRU's behalf. Several types of implementations are referenced earlier in this report, including the ITS4US and the Intersection Safety Challenge. However, cooperative perception generates messages that are larger and sometimes more frequent than current messages (i.e., vehicles sharing sensor data to track a bicyclist obscured by a delivery vehicle) and requires more spectrum without interference; the existing 30 MHz does not offer enough spectrum to achieve these benefits.

USDOT is also working in partnership with SAE International to develop standards for such cooperative sensing, notably J2945/8: Cooperative Perception System, described at https://www.sae.org/standards/content/j2945/8/.[10] Currently, the bandwidth requirements for cooperative perception are being developed. At a minimum, the bandwidth would be the same as for a VRU with a broadcasting device. However, where multiple vehicles or infrastructure-based sensors can view a single VRU, it is reasonable to assume that each vehicle or infrastructure-based sensor would broadcast a PSM on behalf of the VRU, leading to a case where a single VRU could have dozens of messages broadcast by proxy. In congested operations described earlier, this could lead to performance that is further degraded, further reducing potential safety benefit.

At present and as mentioned in the ITS4US description, most implementations of connected vehicle systems are limited to small fleets and VRUs with specific mobility needs. Therefore, it is unlikely that any of the limitations outlined here would affect the adequacy of the existing spectrum to meet

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[10] The European Telecommunication Standards Institute (ETSI) has done studies and is creating standards (TR 103 562 - V2.1.1 and TS 103 324 - V2.1.1) that are being leveraged by SAE who has a liaison agreement with ETSI.

deployers needs in the near- and medium-term. Because technology is changing at such a rapid pace, ongoing research is needed to determine how such limitations can be overcome to support wide-scale deployment. The ITS JPO’s Next Generation Wireless Testing program is developing a strategy to continuously and repeatably characterize these new technologies and their potential for overcoming the limitations of existing LTE-V2X devices.