UNITED STATES DEPARTMENT OF COMMERCE
National Telecommunications and Information Administration
Washington, D.C. 20230

MAR 13 2020

Marlene H. Dortch
Secretary
Federal Communications Commission
445 12th Street, S.W.
Washington, DC 20554

Re: In the Matter of Use of the 5.850-5.925 GHz Band, ET Docket No. 19-138

Dear Ms. Dortch:

At its request, the National Telecommunications and Information Administration (NTIA) submits the enclosed materials[1] from the U.S. Department of Transportation (DOT) for inclusion in the record of the above-referenced proceeding.

NTIA respectfully asks the Commission to take into consideration the views and issues raised by DOT as it moves forward with this proceeding.

Please feel free to contact me with any questions, at (202) 482-2215 or ccooper@ntia.gov.

Sincerely,

Charles Cooper
Associate Administrator for Spectrum Management

Enclosures

[1] Letter from Steven G. Bradbury, General Counsel, U.S. Dep't of Transportation, to Douglas Kinkoph, Associate Administrator, NTIA (Mar. 9, 2020); Letter from Steven G. Bradbury, General Counsel, U.S. Dep't of Transportation, to Hon. Ajit Pai, Chairman, FCC (Mar. 9, 2020) (includes "Supplemental Technical Comments"); Letter from Elaine L. Chao, Secretary, U.S. Dep't of Transportation, to Hon. Ajit Pai, Chairman, FCC (Nov. 20, 2019) (includes memorandum with appendices).

U.S. Department of Transportation

Office of the Secretary of Transportation

GENERAL COUNSEL

1200 New Jersey Avenue, S.E.
Washington, D.C. 20590

March 9, 2020

Douglas Kinkoph
Associate Administrator
Office of Telecommunications and Information Applications
National Telecommunications and Information Administration (NTIA)
1401 Constitution Avenue, N.W.
Washington, D.C. 20230

Re: ***Use of the 5.850-5.925 GHz Band***
ET Docket No. 19-138; FCC 19-129; FRS 16447; 85 Fed. Reg. 6841 (Feb. 6, 2020)

Dear Associate Administrator Kinkoph:

The Department of Transportation (US DOT) has carefully considered the Notice of Proposed Rulemaking issued by the Federal Communications Commission (FCC) relating to the 5.9 GHz radio spectrum band. This spectrum band is critical to US DOT and to the Nation, given its key role in promoting life-saving Vehicle-to-Everything (V2X) transportation technology.

US DOT has prepared the enclosed comments and supplemental materials to FCC on this proposal. We respectfully ask that NTIA consider these comments, share them with FCC, and file them on FCC's public docket. These materials expound upon US DOT's comments on the draft of FCC's proposal in November 2019. We look forward to continuing our work with FCC, NTIA, and other stakeholders on these important issues.

Sincerely,

Steven G. Bradbury

Enclosures

cc: Derek Khlopin, Senior Advisor, Office of the Assistant Secretary, NTIA

U.S. Department of Transportation

Office of the Secretary of Transportation

GENERAL COUNSEL

1200 New Jersey Avenue, S.E.
Washington, D.C. 20590

March 9, 2020

The Honorable Ajit Pai
Chairman, Federal Communications Commission
445 12th Street, S.W.
Washington, D.C. 20554

Re: ***Use of the 5.850-5.925 GHz Band***
ET Docket No. 19-138; FCC 19-129; FRS 16447
85 Fed. Reg. 6841 (Feb. 6, 2020)

Dear Chairman Pai:

The Department of Transportation (Department or US DOT) has reviewed and carefully considered the Notice of Proposed Rulemaking (NPRM or the proposal) issued by the Federal Communications Commission (FCC or Commission) relating to the 5.9 GHz radio spectrum band. As the Commission knows, the 75 MHz of spectrum at 5.850-5.925 GHz—the "5.9 GHz band"—is of critical interest to the Department and to the Nation. This band plays a key role in promoting life-saving transportation technology. Vehicle-to-Everything (V2X) technology, including Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), and the associated safety and mobility applications they support, are not merely theoretical; instead, they have already become an important part of our transportation network.

These innovations are expected to play a key role in reducing the number of fatalities, injuries, and other social costs of motor vehicle crashes, which remains the Department's overarching priority. According to the most recent annual crash statistics (from 2018), our Nation faces over 6 million U.S. police-reported vehicle crashes per year, which resulted in 36,560 lives lost and over 2.7 million injuries; 4,807,058 of these crashes resulted in property damage.[1] These crashes translate into an annual economic harm to the Nation of approximately $300 billion in direct costs and over $800 billion when accounting for the loss of life, injuries, and other quality-of-life factors.[2] The Department continues to believe that V2X communications can play a significant

[1] Statistics generated from the National Highway Traffic Safety Administration's (NHTSA) query tool at: https://cdan.nhtsa.gov/query.

[2] For the methodology used to determine costs, *see* Blincoe, L. J., Miller, T. R., Zaloshnja, E., & Lawrence, B. A. (2015, May). The economic and societal impact of motor vehicle crashes, 2010. (Revised) (Report No. DOT HS 812 013). Washington, DC: National Highway Traffic Safety Administration, at:

role in reducing these crashes, particularly crashes involving conditions that remain challenging for vehicle-based technologies, such as radar. Further, numerous V2I applications exist that can help reduce congestion, which, based on estimates from the transportation industry, leads to over $166 billion in annual costs,[3] and also assist States in maintaining their existing infrastructure.

V2X communications will also play a crucial role in advancing vehicle automation. Vehicles equipped with automated driving systems (ADS) are anticipated to have significant safety and mobility benefits. And while V2X technology is not a requirement for deployment of ADS vehicles, it is broadly acknowledged that V2X communications can be leveraged to enhance safety and improve system performance. In particular, there is significant potential in emerging "cooperative automated driving systems," such as platooning, which are expected to rely on the full existing allocation of the 5.9 GHz band, and have only just begun to be developed.

The preservation of the entire 5.9 GHz band for V2X communications offers the Nation an advantage for maintaining and extending leadership in the deployment of innovative V2X applications, including those related to automation. However, these safety innovations and improvements may be lost should the Commission proceed with its proposed reallocation of the 5.9 GHz band. Reducing the spectrum available for V2X communications from 75 MHz to 30 MHz, and then further dividing that 30 MHz between two communication technologies, will reduce the utility of V2X by severely limiting the amount and type of messages that can be sent at any one time. Such a restriction will also hamper the future development of cooperative automated driving systems, given their expected spectrum needs. Further, the Department's preliminary testing of the proposed reallocation, shared with the Commission in November 2019 and discussed in the comments below, shows that the proposed reallocation will likely lead to harmful interference from Wi-Fi devices operating in the lower 45 MHz of the 5.9 GHz band on V2X devices operating in the remaining upper 30 MHz. This potential interference would be compounded if Wi-Fi devices were also permitted to operate directly above the spectrum allocated to V2X. If this interference occurs, the actual value and efficacy of the remaining spectrum for V2X applications will be significantly compromised, particularly for safety-of-life applications.

Given the potential safety benefits, the Department seeks to foster the continued development of V2X and to ensure that its full safety potential is realized. This requires a careful balancing of interests and a collaborative effort across industries and disciplines, particularly given the investments that numerous public and private stakeholders have made in V2X technology in reliance upon the FCC's allocation of the 5.9 GHz band for this purpose. The Department appreciates the Commission's continued attention to the issues raised in this proceeding, which are complex as a matter of law, policy, and technology. Nonetheless, for the reasons explained below, US DOT remains of the view that the Commission's proposal fails to account for all relevant factors bearing upon its proposal, including V2X spectrum benefits, technology maturity, innovation and growth in V2X applications, and the likelihood of harmful interference

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https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812013. Although the report itself is somewhat dated, the relevant statistics remain remarkably similar in 2018, the most recent year of available statistics.

[3] Statistics from Urban Mobility Report by Texas A&M Transportation Institute with cooperation from INRIX at: https://static.tti.tamu.edu/tti.tamu.edu/documents/mobility-report-2019.pdf, pages 2 and 10.

from adjacent-channel Wi-Fi operations. Furthermore, the Commission has not addressed the concerns that US DOT previously raised about the NPRM before it was issued.

US DOT is providing additional information here in support of the views it has consistently maintained: that the full 75 MHz of the 5.9 GHz band should be retained for safety and other transportation purposes; that FCC should revisit its proposal and seek broader stakeholder engagement on any reworking of the 5.9 GHz band; and that any reallocation of this band to include unlicensed use should be grounded in robust science demonstrating that V2X applications will not be subject to harmful interference, and showing that these applications will retain their key functionality. The Department remains ready to continue to work with FCC and other parties to achieve these goals and to establish a stable, lasting regulatory framework.

Background

Twenty years ago, the Commission recognized the value and promise of V2X communications, and wisely allocated the 5.9 GHz band to be used for this purpose. In so doing, FCC sought not only to make spectrum available for applications that existed at that time, but was also forward-looking in its approach. It shared the vision of a sea-change in the vehicle safety ecosystem, and recognized that this ecosystem would have to evolve. The Commission therefore set all stakeholders on a path toward the successful development and implementation of this technology, adapting technical rules and other necessary standards as appropriate, but retaining its overarching vision for promoting transportation safety.[4] FCC provided the regulatory framework needed for investments in V2X technology.

Consistent with this vision, on November 20, 2019, the Department shared its views on the draft of the Commission's NPRM. The Department expressed concern that the proposal would significantly reduce the spectrum available for transportation safety and unduly disrupt the V2X ecosystem that has been developing since 2014, when critical safety test results were completed that demonstrated the technological capabilities of V2X safety-of-life applications. Thus, US DOT asked that FCC refrain from moving forward with the NPRM, and requested that FCC re-engage with DOT and other stakeholders to develop a revised proposal that would strike the right balance in promoting transportation safety and spectrum efficiency. In the event that the Commission nonetheless decided to proceed with its rulemaking, the Department offered a variety of suggestions to revise the NPRM and to ensure that FCC could take full advantage of the government and industry resources available to aid in this endeavor.

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[4] *See* Report and Order, *In the Matter of Amendment of Parts 2 and 90 of the Commission's Rules to Allocate the 5.850-5.925 GHz Band to the Mobile Service for Dedicated Short Range Communications of Intelligent Transportation Services*, ET Docket No. 98-85, at ¶ 1 (released Oct. 22, 1999) (noting that the Commission's allocation of the 5.9 GHz band "will further the goals of the United States[] Congress and [US DOT] to improve the efficiency of the Nation's transportation infrastructure and will facilitate the growth and development of the [Intelligent Transportation Systems] industry."); Mem. Op. and Order, *In the Matter of Amendment of the Commission's Rules Regarding Dedicated Short-Range Communication Services in the 5.850-5.925 GHz Band, et al.*, WT Docket No. 01-90, ET Docket No. 98-95, at ¶ 1 (released July 26, 2006) (modifying service rules in the 5.9 GHz band to "further[] the Commission's goal of implementing widespread deployment of [Dedicated Short-Range Communications] systems in the ITS Radio Service in order to promote the safety of life and property of the traveling public and to improve the efficiency of the nation's surface transportation infrastructure.").

Unfortunately, upon review, FCC's published NPRM is essentially unchanged, and the Department's concerns remain the same, as the Commission did not appear to take account of US DOT's comments or of the far-reaching effects of this proposal. In seeking to reallocate the 5.9 GHz band for unlicensed Wi-Fi and other uses, FCC is jeopardizing the safety and other benefits of V2X.[5] Indeed, these concerns are even more acute now, as FCC has coupled its proposal with a sweeping freeze on applications for new, expanded, or renewed use of V2X installations in the 5.9 GHz band—even for improvements to infrastructure that are ready to be deployed, and that are fully compliant with FCC's longstanding regulations for use of the band.[6]

The Department is therefore re-submitting both its prior comments, enclosed here, and additional supplemental comments, and asks that the Commission examine this information, consider the magnitude of the public benefits to transportation, and pause its efforts to proceed with the NPRM. Moving forward, US DOT asks that FCC initiate a more robust dialogue with the Department and transportation stakeholders about the concerns they have raised about the proposal, as well as create a working partnership to improve the proposal for use of the 5.9 GHz band. US DOT's view is that the Commission should preserve the full 75 MHz of the 5.9 GHz band for transportation safety and other Intelligent Transportation Systems (ITS) purposes. In addition, US DOT notes the importance of gathering more information about available V2X technologies. The NPRM advances an allocation of spectrum between these technologies—Dedicated Short-Range Communications (DSRC) and Long-Term Evolution Cellular V2X (LTE-CV2X) —that is unsupported by science and may cause irreparable harm to industry's efforts to coalesce around a shared "cooperative" technology. Rather than having to revisit, and perhaps completely rewrite, this allocation plan upon the receipt of public comments, FCC could do further initial work with stakeholders on a proposal that would gain broader support.

Even before the publication of the NPRM, stakeholders began to raise similar concerns to those of the Department, and we expect that parties will continue to raise these issues throughout the public comment period. For example, on January 22, 2020, Members of the House Committee on Transportation and Infrastructure wrote to the Commission to voice their agreement with US DOT's earlier comments, and recognized that the "[t]he support for the safety benefits of V2X technologies is broad and deep."[7] The Committee Members also recognized the life-saving potential of V2X; the widespread deployment of V2X technology in vehicles and infrastructure; and the regulatory uncertainty resulting from the Commission's proposal. In addition, the Committee Members indicated that the proposal would undermine Congress's purpose in the 2015 Fixing America's Surface Transportation Act, P.L. 114-94, which established an Advanced

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[5] The proposal would also strand the investments of stakeholders who have successfully innovated and implemented this technology.

[6] Public Notice, *Wireless Telecommunications Bureau and Public Safety and Homeland Security Bureau Announce Temporary Filing Freeze on the Acceptance and Processing of Part 90 Applications for Certain 5850-5925 MHz (5.9 GHz Band) Spectrum*, DA 19-1298, ET Docket No. 19-138 (released Dec. 10, 2019). The Commission's freeze, which took immediate effect without notice and comment, was meant to counteract a potential "influx of applications" for use of the 5.9 GHz band. *Id.* at 1-2.

[7] Letter from Hon. P.A. Defazio, Chair; Hon. S. Graves, Ranking Member, *et al.*; Committee on Transportation and Infrastructure, U.S. House of Representatives; to Hon. A. Pai, Chairman, *et al.* (Jan. 22, 2020).

Transportation Technologies Deployment program. Consequently, they requested that the Commission revisit its proposal and reaffirm the safety-based 5.9 GHz framework.

Numerous other public stakeholders have also submitted concerns to the Commission, arguing that this shift will undermine State and local efforts to promote transportation safety, public safety, and system efficiency. For example, the American Association of State Highway and Transportation Officials (AASHTO), in coordination with the Intelligent Transportation Society of America (ITS America), has argued that the Commission should preserve the 5.9 GHz band for V2X purposes, and that the proposal jeopardizes safety as well as taxpayer-based investments and initiatives of public safety stakeholders nationwide.[8] In support of this view, AASHTO and ITS America provided the Commission with a letter signed by transportation authorities in all fifty States, the District of Columbia, and Puerto Rico—a rare demonstration of such uniform support. Other State and local authorities have submitted similar comments to the Commission, explaining their investments in and successful implementation of V2X technology and how the Commission's proposal will undermine those efforts.[9]

The automotive industry and other industry groups have also expressed concerns about the proposal and have explained the importance of regulatory certainty to promote V2X development. For example, the Association of Global Automakers, Inc. (now the Alliance for Automotive Innovation) has argued that FCC's proposal underestimates the lifesaving potential of the 5.9 GHz band, and that it does not account for the continued need for, and the ongoing development of, all existing channels in the band across the full 75 megahertz that FCC originally allotted.[10] Other industry groups have raised similar concerns and have requested that FCC revisit its proposal.[11]

US DOT's Additional Comments and Concerns

To assist the Commission in its examination of the issues here, the Department is providing additional comments, which supplement and expound on the points raised in our previous response to the Commission's draft NPRM. In particular, US DOT seeks to provide the Commission with further data and analysis on the following:

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[8] Letter from C. Braceras and J. Tymon, *et al.*, AASHTO, to Hon. A. Pai (Aug. 19, 2019); Notice of *Ex Parte* Presentation from R.B. Kelly, Counsel to ITS America, to Sec. M.H. Dortch (Feb. 18, 2020).

[9] *See, e.g.*, Letter from P. Smith, Interim Exec. Dir., DriveOhio, to Sec. M.H. Dortch, at 1 (Jan. 17, 2020) ("DriveOhio has been working with private sector innovators utilizing DSRC and [LTE] C-V2X to deploy technological solutions utilizing this spectrum. Preserving the entire 75 MHz allocation for transportation safety is critical to save the lives of our traveling public."); Letter from S. Lew, Exec. Dir., Col. Dep't of Transp., to FCC, at 2 (Jan. 3, 2020) (noting that Colorado had almost 200 deployed V2X devices, which are expected to triple in the near future, and arguing that "the uncertainty of the dedication of airwaves to transportation safety is concerning"); Letter from M. Stevens, Chief Innovation Officer, City of Columbus, Ohio, to Sec. M.H. Dortch, at 2 (Jan. 16, 2020) ("[I]t is imperative that the full 75 MHz of the 5.9 GHz Band is preserved for its designated purposes, including transportation safety and other intelligent transportation purposes.").

[10] Notice of *Ex Parte* Presentation from S. Delacourt, Counsel to Global Automakers, to Sec. M.H. Dortch, at 2 (Nov. 27, 2019) (arguing that "the NPRM ignores significant evidence in the record pertaining to [V2X] services and the relationship between those services and automotive safety").

[11] *See, e.g.*, Letter from C. Spear, Pres. & CEO, Am. Trucking Ass'ns, to Hon. A. Pai *et al.*, at 2 (Feb. 5, 2020) (expressing the American Trucking Association's opposition to the NPRM, and arguing that "the proposal jettisons the work done in good faith to test concepts that would retain the 5.9 GHz band for vehicle communications....").

- The motor vehicle safety challenges that V2X technologies are designed to address, and their lifesaving potential;
- The elements and requirements of a properly functioning V2X ecosystem that the spectrum allocation enables;
- The complementary role of V2X in the continuing development and deployment of automated vehicles;
- The successful deployment of V2X in various jurisdictions nationwide;
- The benefits that will be lost if the NPRM is adopted, along with the substantial costs that would be borne by stakeholders and the public from the transition FCC proposes;
- The need for additional robust scientific testing of any proposed changes to the band that may affect critical safety-of-life applications; and
- The results of US DOT's testing and analysis demonstrating that the proposal would result in harmful interference to V2X applications.

Further technical and economic analysis is critical to any decision here, given the interests and spectrum value at stake.[12] As just one example, although the Commission indicates that its proposal moots the need for additional interference testing,[13] that view overlooks the potential harm and impact from out-of-band interference to human life and property. Only through a rigorous scientific examination can the Commission address that concern and determine how it affects the proposal. If such interference from unlicensed devices does pose a threat to V2X applications, as US DOT's analysis indicates, that means that the proposal will effectively provide even *less* spectrum for V2X than the Commission intended. That would only magnify the concerns expressed here.

The Department remains committed to working with FCC, as well as all other public and private stakeholders, to provide expertise and resources to assist in evaluating the complex issues involved here. US DOT would welcome the opportunity to share and use the results from the Department's testing of V2X technology safety performance (both DSRC and LTE-CV2X), the sharing of spectrum with unlicensed devices, and the coexistence with other co-primary users in the band, to inform a more robust proposal for public comment. Such a process would also allow stakeholders from the automotive and telecommunications industries to engage in dialogue and to allow market-driven innovations to help shape the regulatory framework.

One well-established means of facilitating such an approach would be through a negotiated rulemaking, which provides Federal agencies with a structured but supple process for bringing all stakeholders to the table in instances like this one, where there are deeply held disagreements on fundamental underlying issues that could be better resolved through a robust dialogue rather than a written public comment period. FCC could partner with US DOT safety experts to work with stakeholders from the telecommunications and automotive industries; States and local authorities; transportation safety advocates; other relevant public interest entities; and interested Federal agencies in a collaborative endeavor to share resources and identify solutions. As part of this process, FCC and US DOT could work to promote agreement among V2X stakeholders on

[12] In reviewing the comments of States and localities that have deployed V2X, US DOT notes that the Commission has not yet articulated how it would address the lost value of existing licenses, many of which would be substantially diminished in value, or effectively mooted, by the adoption of the proposal here.
[13] *See* NPRM § 46 (noting that exploring within-band spectrum sharing would involve "extensive further testing").

the appropriate "cooperative" technology or blend of technologies, including DSRC, cellular, and/or other forms. The result of this endeavor would be the development of an improved proposal that would be more widely embraced, leading to a durable, comprehensive solution for the 5.9 GHz band.

Pending a collaborative effort to revisit the issues identified here and in our prior communications, the Department remains concerned that FCC's proposal remains unworkable—the proposal will hamper the Department's and other stakeholders' abilities to improve and address transportation safety and efficiency. The Department looks forward to further discussions on an appropriate path forward.

Sincerely,

Steven G. Bradbury
General Counsel

Enclosures

Supplementary Technical Comments

In the following sections, the Department has provided additional technical comments intended to supplement both the foregoing letter and the Department's earlier comment to FCC on the draft of its proposal in November 2019. These technical comments provide additional details on:

I. The unique role played by V2X communications in the transportation system;
II. Existing V2X deployments;
III. How the entire existing 75 MHz is being and will continue to be used to support a connected and automated transportation system;
IV. The financial disruption to existing deployment that would occur should the FCC NPRM be finalized; and
V. The significant additional technical work and testing that would be needed to justify any change to the 5.9 GHz band.

V2X technology holds tremendous promise to enhance safety because it has capabilities that other vehicle technologies do not. This includes the ability to detect approaching objects outside the line of sight, including from behind buildings or large trucks. These benefits, though, depend on the continued availability of the full 75 MHz and the assurance that V2X communications can reliably occur without harmful interference. Therefore, this supplementary material reemphasizes the Department's overarching message that, due to the immense safety and other transportation benefits offered by V2X, any decision on the 5.9 GHz band should be made carefully, accounting for these significant transportation benefits and including the support of affected stakeholders.

I. The Role of V2X Communications

At the outset, it is important to consider the safety and congestion problems that V2X can help to address. Transportation connectivity is needed to advance our transportation system, by addressing crash fatalities and injuries that other technology cannot and increasing efficiencies in the transportations system.

As noted in the letter above, according to the most recent annual crash statistics (from 2018), over 6 million U.S. police-reported vehicle crashes resulted in 36,560 lives lost, as well as 1,893,704 crashes that led to more than 2.7 million injuries and 4,807,058 crashes resulting in property damage.[14] These crashes resulted in annual economic harm of approximately $300 billion in direct costs and over $800 billion when accounting for the loss of life, injuries, and other quality-of-life factors. Further, the transportation industry estimates regular traffic congestion costs at over $166 billion annually, which translates into significant personal and business costs, including:[15]

- Delays of up to 54 hours in congestion annually for each commuter (nearly seven full working days in extra traffic delay), which translates to over $1,000 in personal costs;
- Waste of up to 21 gallons of fuel due to congestion at a cost of $1,080 for each commuter; and

[14] Statistics generated from NHTSA's query tool at: https://cdan.nhtsa.gov/query.
[15] Statistics provided by Texas A&M Transportation Institute with cooperation from INRIX at: https://static.tti.tamu.edu/tti.tamu.edu/documents/mobility-report-2019.pdf, pages 2 and 10.

- While trucks account for only six percent of the miles traveled in urban areas, they account for 26 percent of the total cost of congestion as measured in delay and wasted fuel. These annual costs top $23 billion. Further, accidents in the trucking industry result in $19B in damage, lost goods, lost driver time, and accidents resulting in approximately 5000 deaths each year.[16]

V2X technology using the 5.9 GHz band can significantly reduce crashes, system inefficiencies, and traffic congestion in ways that are unique from vehicle-based sensors and other technologies, most notably by having significantly greater capability to address non-line-of-sight crashes.

However, the NPRM's proposed reallocation of spectrum introduces many constraints upon V2X communications and hampers its ability to work successfully. These constraints will effectively reduce or eliminate the utility of V2X communications, including vehicle-to-vehicle (V2V) safety applications, vehicle-to-infrastructure (V2I) system efficiency applications, applications associated with vehicle-to-pedestrian (V2P) or other vulnerable road users (VRUs) and emerging cooperative automated driving (CAD) systems. Thus, to provide further context for the Commission's consideration of the issues here, this section discusses how V2X communications work and explains their continued importance in increasing safety and mobility.

a. How V2X Transportation Communications Work

V2X communications provide a powerful and innovative 360-degree sensor of threats and hazards forming in the roadway. V2X communications use the 5.9 GHz band by broadcasting the Basic Safety Message (BSM) and other application data frequently (every 100 milliseconds) between devices on vehicles, within roadway infrastructure, and in portable devices. These communications are based on a "one-to-many" (or broadcast) concept that does not require "multiple point-to-point hops" between source and destination, in the way that today's cellular or common Wi-Fi communications do; nor do V2X communications encounter "network join" delays. Since the source and the recipient of V2X communications connect directly, privacy can be protected as long as a way to establish trust (and security) between each party is available (*e.g.*, trusted security credentials are part of the data exchange).

Using data from short-range communication broadcasts and peer-to-peer exchanges within approximately 300 meters to "sense" what the other travelers (vehicles, bicyclists, pedestrians, wheelchairs, motorcycles, buses, trucks, and others) are doing, V2X applications provide the ability to identify when movements of surrounding travelers begin to set up imminent crash situations, as illustrated in Figure 1.

[16] Commercial Truck Platooning Demonstration in Texas – Level 2 Automation Texas A&M Transportation Institute, TTI: 0-6836, page 1 at: https://static.tti.tamu.edu/tti.tamu.edu/documents/0-6836-1.pdf.

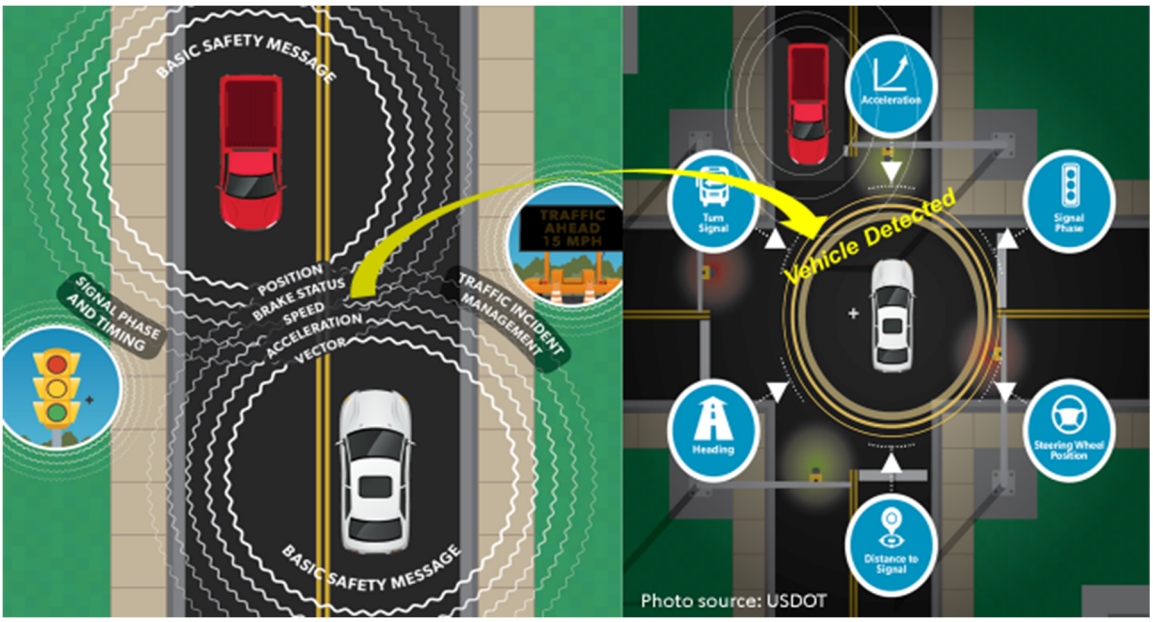

Figure 1: Image of V2V Safety-of-Life, Crash-Avoidance Functionality

V2X exchanges are non-networked—transmitting devices are able to forego the delay associated with creating a link with a cell tower or Wi-Fi infrastructure to communicate with the receiving device—which supports *very fast (known as "low latency")* communications. This is a particularly effective feature in rural areas where less telecommunications infrastructure is installed. Because existing V2X devices are interoperable, all makes and models of devices can "hear" and understand the data exchanges, allowing a constant monitoring of all data surrounding a vehicle or mobile device within a short range. This combination of range and low latency creates time to warn travelers—whether a nearby vehicle or pedestrian—to take action before an accident can occur.

V2X devices are omnidirectional (*i.e.*, offer 360 degrees of coverage). Communicating via radio signals allows two equipped vehicles to "see" each other and exchange critical information—regardless of whether the vehicles are in view, around a corner, or behind a building or even a cornfield. In comparison, a vehicle that is only relying on line-of-sight sensors is unable to detect the presence of another vehicle that is not directly visible, let alone determine the other vehicle's heading, speed, movement-related information, or its operational status.[17] V2X communications operate predominantly within a 300-meter range between vehicles to facilitate identification of intersecting paths that may potentially result in a crash if no intervening driver or vehicle action is taken. Also, V2X signals are largely unaffected by environmental conditions, including rain, fog, snow or darkness, compared to existing onboard sensors. Thus, V2X is uniquely suited for crash scenarios characterized by late "reveal times"—*i.e.*, those "game-changing" shifts in which the vehicles, pedestrians or other objects involved in a crash "see" each other only moments before the crash, such as intersection crashes, which account for 22 percent of all motor vehicle crashes. In addition to preventing crashes as the primary source

[17] Harding, J., Powell, G., R., Yoon, R., Fikentscher, J., Doyle, C., Sade, D., Lukuc, M., Simons, J., & Wang, J. (2014, August). Vehicle-to-vehicle communications: Readiness of V2V technology for application. (Report No. DOT HS 812 014). Washington, DC: National Highway Traffic Safety Administration, page 26. https://www.nhtsa.gov/staticfiles/rulemaking/pdf/V2V/Readiness-of-V2V-Technology-for-Application-812014.pdf.

of information, V2X can also augment other in-vehicle sensors to improve crash prediction capabilities in many other scenarios in which conspicuity of objects, vehicles, or pedestrians is compromised due to environmental and other factors.

Finally, V2X communications have been designed to offer significant security and privacy protection. For security, each message is trustworthy through use of a security credential that allows the receiving device immediately to authenticate that the message is from a trusted (and not misbehaving or malicious) sender. Use of constantly randomized security credentials makes it challenging to identify sending and receiving devices, thus delivering a strong measure of privacy protection. With these elements in place, ad hoc connected vehicle environments can be created in which vehicles, pedestrians, bicyclists, and other travelers—including those out of line-of-sight—move into and out of trusted exchanges in a dynamic and rapidly moving environment.

b. V2X has unique requirements for safety communications

V2X applications are comprised of fundamental message types, including the basic safety message (the "BSM" or the "payload"); geographic messages (*i.e.*, GPS corrections, timing messages, or digital intersection maps); data uploads; and security certificates. The safety messages and security certificates are the foundation of the V2V and V2I safety applications. By virtue of their availability, they also feed system efficiency, public safety, and mobility applications. The geographic messages support accuracy in the safety applications' real-time analysis. The data uploads allow transportation operators and managers to gather localized data for integration into local and region-wide decision support systems. The certificate exchanges provide new credentials to devices that request a "refresh" as credentials are used and reused only a few times to protect privacy.

The safety messages are transmitted in a standardized format so that messages can be read by all other similarly equipped vehicles and devices. The BSM includes information about the vehicle's behavior such as the vehicle's GPS position, its predicted path, its lateral and vertical acceleration, and its yaw rate. The messages are time-stamped so the receiving vehicle knows when the message was sent. Nearby vehicles and device applications analyze the data to address a variety of crash avoidance applications.[18] When the BSM is combined with other types of data, for instance road-weather information (*i.e.*, icing on the roadway or wind speeds strong enough to blow a tractor-trailer over), or work zone geographic layout/mapping (or even position of workers through devices worn on safety vests), an even wider variety of V2I, V2P, or other V2X public-benefit applications become available.[19]

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[18] Harding, J., Powell, G., R., Yoon, R., Fikentscher, J., Doyle, C., Sade, D., Lukuc, M., Simons, J., & Wang, J. (2014, August). Vehicle-to-vehicle communications: Readiness of V2V technology for application. (Report No. DOT HS 812 014). Washington, DC: National Highway Traffic Safety Administration. page 74, footnote 129. At: https://www.nhtsa.gov/staticfiles/rulemaking/pdf/V2V/Readiness-of-V2V-Technology-for-Application-812014.pdf.

[19] *See* the ITS Architecture Reference for the list of existing public-benefit services (at: https://local.iteris.com/arc-it/html/servicepackages/servicepackages-areaspsort.html). The architecture is beginning the process of incorporating cooperative automation services.

As noted in Table 1, to accomplish these cooperative applications, communications for V2X have unique needs that include (among others):

Table 1: Communications Requirements for V2X

Requirements	Characteristics
Speed of Transmission	➔ Low latency, rapid message delivery ➔ Relatively few messaging protocol requirements[20] ➔ Delays of well under 100 microseconds[21] ➔ Allows for data exchange of over 6 megabytes/second
Free from Harmful Interference	➔ Spectrum is protected from interference from other users to result in a low packet error rate for V2X transmissions since vehicles in motion could travel far enough to cause a crash if packets are lost and a warning consequently does not occur in time to prevent the crash[22] ➔ Appropriate transmission masks specified by industry standards and FCC regulations, which limit emissions outside the intended channel and protect adjacent channel users[23] ➔ V2X devices incorporate adjacent channel rejection,[24] which means that the receiver portion of the radio can listen to messages on the intended channel and ignore messages on neighboring channels ➔ Communications are "polite"—all licensees cooperate in the selection and use of channels in order to reduce interference. This includes monitoring for communications in progress and any other measures as may be necessary to minimize interference.

[20] A simplified protocol stack – called WAVE Short Message Protocol (WSMP) - was developed specifically for this purpose by IEEE as part of the V2X safety system development. This protocol was developed over a number of years in order to minimize the computational load on the vehicle's computer system, thus speeding the message through the communications protocol stack, and allowing nearly immediate delivery of messages to the safety applications on all channels. This same simplified communications protocol is used with all of the proposed radio access technologies, and is documented in the IEEE 1609.x series of standards. This protocol is also used with all of the proposed radio access technologies (*i.e.*, DSRC or the recent LTE-CV2X). Fewer protocols support faster data speeds. The WAVE Service Announcement (WSA) on Channel 178 announces the availability of application-services on specific service channels (see IEEE 1609.4). More information is located at https://www.standards.its.dot.gov/Factsheets/Factsheet/80.

[21] A key performance metric is that of "information age," which helps to measure whether a device was able to access the spectrum to send the message immediately or whether there was a delay in sending. A delay that causes messages to be missed by surrounding vehicles may establish a crash potential, and may cause a warning not to be delivered in time. Spectrum interference—both in-band and from out-of-band channels—is a primary cause of message delay. Other causes can include problems with device performance under real-world operating conditions and channel congestion.

[22] Another key performance metric for communications is the fraction of packets that dropped during transmission. The V2V and V2I safety applications are designed to tolerate a 10 percent packet error rate (PER), which translates into one missed packet during a 10-packet transmission string.

[23] Transmission masks are also known as "spectral masks." The masks define the allowable radio frequency (RF) energy inside and outside of the defined transmission channel.

[24] Adjacent channel rejection is the amount of attenuation applied to RF energy outside of the main receive channel.

Requirements	Characteristics
Coverage/Scale	➔ Devices offer both broadcast *and* point-to-point communications over very short distances without the need for a network ➔ Limited range between exchange allows for spectrum reuse and limits interference ➔ System needs to be interoperable and adaptable for extension to all types of vehicle systems, mobile devices, and applications ➔ System implementation needs to be national in scale and should be capable of extension across North America
High Reliability and Stability	➔ Performance is immune to extreme weather conditions ➔ Devices are designed to be tolerant to multi-path transmissions typical within roadway environments where transmissions can bounce off the road itself, as well as buildings and other roadside features, arriving at the receiver after taking different paths, and potentially interfering with the main line-of-sight path transmissions[25] ➔ Works in high vehicle-speed mobility conditions ➔ Provides a platform that can be readily interpreted and implemented, but offers both backward and forward interoperability over time to allow a solid technical foundation for continuing innovation and improvement of transportation safety and efficiency through the lifecycle of devices ➔ Has a tailored system of over-the-air security and message authentication that works at high speeds and is capable of granting different permissions to (for instance) police or emergency vehicles
Dedication and Availability	➔ Operations are in a licensed frequency band that has a primary allocation for transportation to protect against interference ➔ Critical crash-avoidance safety messages are prioritized over other messages

These requirements revolve around two core needs, both of which are currently met by the existing V2X technology and the spectrum allocation:

- **V2X communications must work in crash-imminent situations and complex traffic environments**. V2X communications are designed to work well in a rapidly moving environment, where the broadcaster and a receiver may be moving toward or away from one another at speeds greater than 100 miles per hour; or vehicles are moving at varied speeds in the same environment. Due to its unique combination of attributes (broadcast

[25] Multipath error results from interference between two radio waves, which have travelled paths of different lengths between the transmitter and the receiver or from reflection or diffraction (*e.g.*, reflection from nearby bushes) from the local objects. For example, there is the direct path and the path that is reflected off the road surface. They arrive out of phase and may cause destructive or constructive interference. *See* IEEE definitions at: https://ieeexplore.ieee.org/. Errors can also be caused by the Doppler effect, which is an increase (or decrease) in the frequency of radio waves as the source and observer move toward (or away from) each other.

messaging that requires no network connection; messages small enough to be broadcast frequently and processed quickly; anonymous and trusted communications; and robust functionality in a rapidly moving environment), today's V2X communications are proven as a viable technology for safety-critical communications.

- **The "dedicated" allocation and the careful attention to the band plan design provide the ability to exchange messaging in a manner that is free of harmful interference**. Interference will increase the risk that crash-prevention applications will not work due to suppression of the BSM, collisions of BSMs with other data messages, corruption of the safety data, or the inability of the receiving device to "hear" the message. As discussed in detail in the last section of this document, we are concerned that there is a high probability of interference from the proposed band plan in the NPRM.

c. The current allocation of the 5.9 GHz band is ideally suited for V2X

In 1999, the FCC allocated the spectrum for transportation safety from 5850 MHz to 5925 MHz as an application within the mobile service. The mobile service is co-primary in this band with the Fixed Satellite Services (FSS), military radar, and indoor Industrial, Scientific, and Medical (ISM). In 2006, the FCC provided the service rules that established a band plan with specific designated channels, as shown in Figure 2.

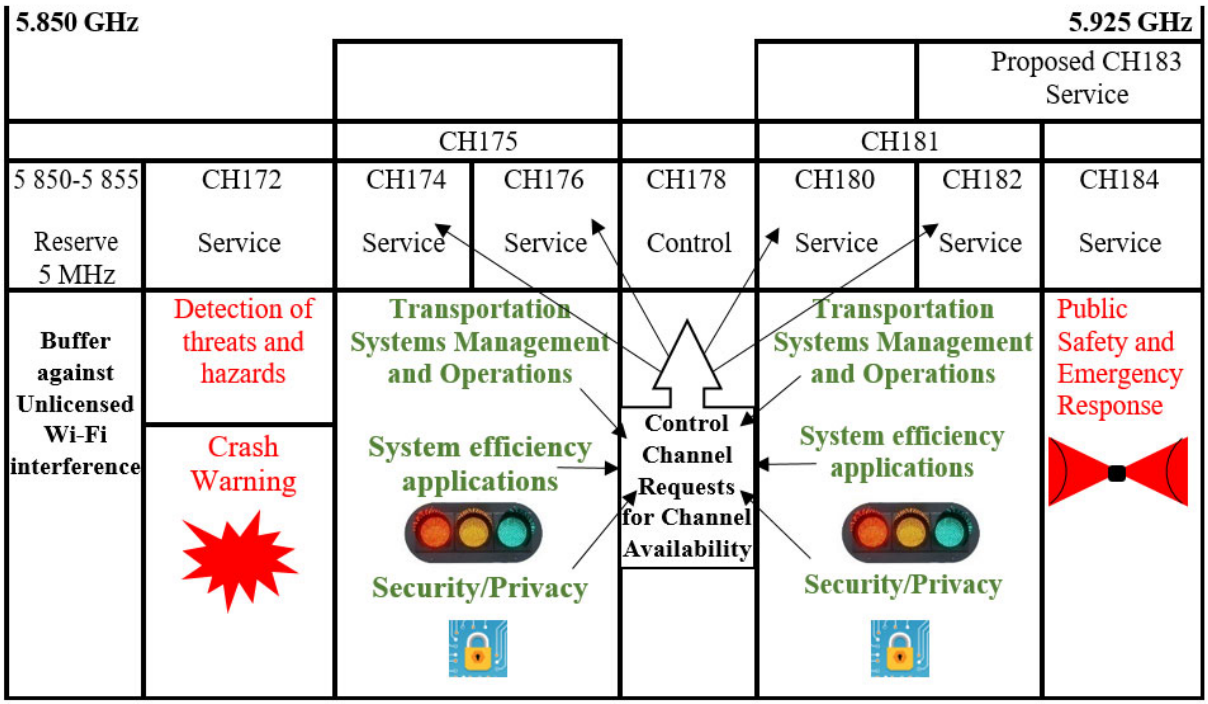

Figure 2: Transportation Spectrum Use in the 75 MHz in the United States[26]

[26] FCC 03-324 Report and Order, December 2003, ET Docket No. 98-95.

Under these rules, safety-of-life and property communications have the highest priority and public safety communications have the second-highest priority.[27] In this respect, two separate channels are designed—one for crash avoidance V2X (CH. 172) and one for public safety V2X (CH. 184). The crash-avoidance channel is protected from spectrum interference from unlicensed Wi-Fi devices operating below the 5.9 GHz by a protective 5 MHz reserve band that absorbs the energy from those unlicensed devices. The public safety channel is higher-powered for those times when public safety and emergency response must silence or suppress nearby communications in order to provide priority. The remaining channels are for safety, system efficiency, and mobility applications that can tolerate a small amount of interference or that can wait a few hundred milliseconds to transmit. In order to use and reuse the available spectrum, a control channel helps applications navigate to open spectrum.

These channel allocations have been used to support a basic set of V2X messages that underpin a wide range of public benefit applications and use the entirety of the existing 75 MHz in real-world use, which include:

- Basic Safety Messaging (the BSM);
- Signal Phase and Timing (SPaT) and MAP (road geometry descriptions (particularly important for traversing intersections) that describe complex intersections, road segments, and high-speed curve outlines);
- Probe data management (PDM) and probe vehicle data (PVD) for mobility services;
- Personal safety message (PSM) that includes the kinematic state of various types of vulnerable road users (VRU), such as pedestrians, cyclists or road workers;
- Road traffic information data, such as public safety and first responder warnings, incident warnings, construction zones alerts, weather and road condition warnings, or curve speed warnings;
- Signal Status Message (SSM) and Signal Request Message (SRM) for preemption services;
- Security Credential Management System (SCMS) services;
- Over-the-Air (OTA) updates; Wireless Access in Vehicular Environment (WAVE) messages that are a critical element in managing channel use and reuse—they identify which channels are available for the applications to use;
- Roadside Signal Alert (RSA) and the Traveler Information Message (TIM) to alert travelers to nearby hazards; and
- GPS corrections, including the Radio Technical Commission for Maritime Services corrections (RTCM) for differential corrections for GPS and other radio navigation signals.

As discussed in detail below and as illustrated in Figure 3, transportation agencies and other stakeholders are currently deploying V2X applications that use many of these messages across the entire 5.9 GHz band.[28]

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[27] 47 C.F.R. § 90.377(d).

[28] The wide range of public-benefit applications that utilize these component messages are described in the ITS reference architecture (known as the Architecture Reference for Cooperative and Intelligent Transportation (ARC-

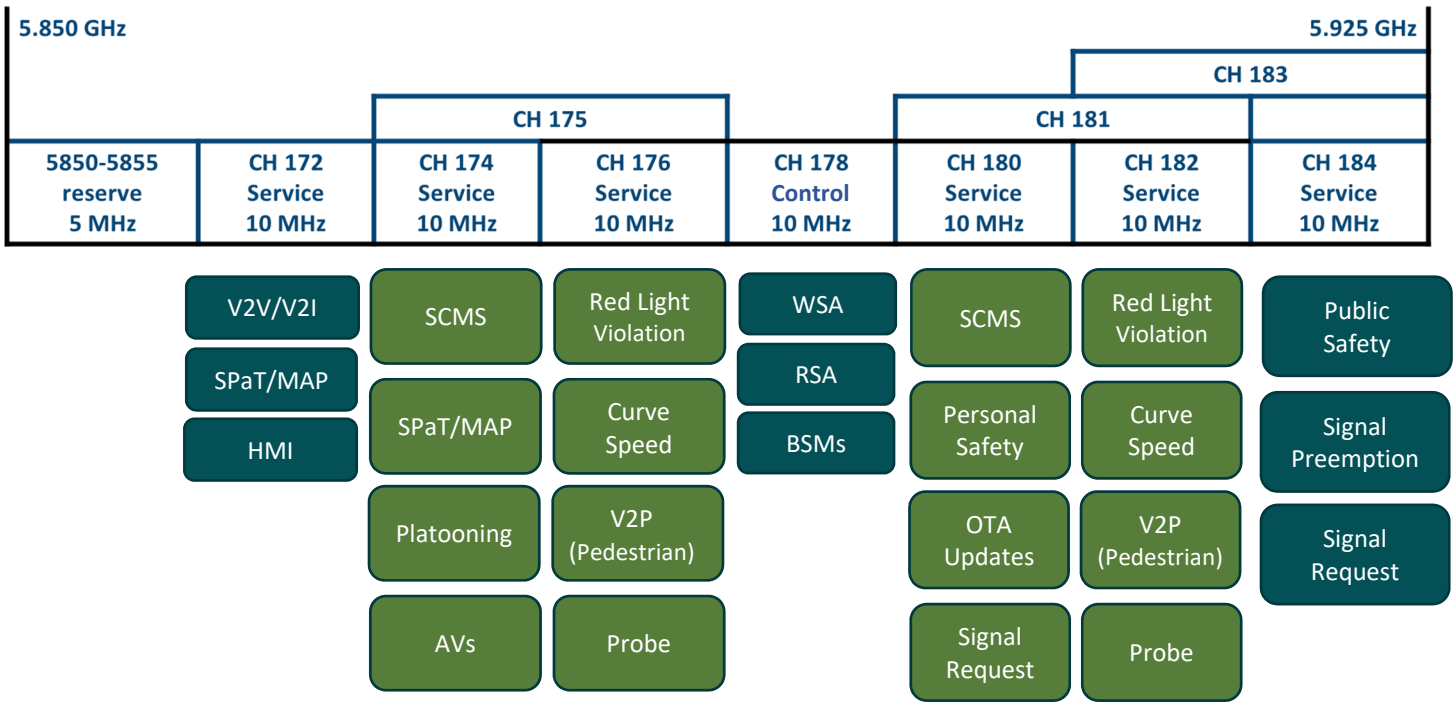

Figure 3: V2X Communications in Use

d. V2X will save lives and reduce congestion

Due to these unique characteristics of V2X technology, the Department and the transportation community in general remain of the view that the 5.9 GHz band plays a critical role in reducing crashes and relieving congestion.

Advanced driver assistance systems (ADAS) such as forward collision warning, automatic emergency braking, lane keep assist, and blind spot warning are based on in-vehicle sensors (*e.g.*, automotive radar, camera, LiDAR), and play an important role in crash avoidance and vehicle safety. They are, however, susceptible to having "blind spots" in instances where the vehicles involved do not have a direct line-of-sight relationship with each other. For example, vehicle-based sensors are unlikely to be able to address many crashes adequately that occur at intersections. This is because the vehicles involved in such crashes often "reveal" themselves to each other (establish a line-of-sight condition) very late in the crash scenario, such that there is insufficient time for onboard crash avoidance systems to assess crash probabilities and then warn the driver appropriately. For example, Continental (an automotive technology manufacturing company) performed an analysis using crash databases and concluded that these ADAS technologies could be limited to addressing only 40 percent of intersection crashes in urban areas due to this limitation.[29]

IT), which also provides a common framework for planning, defining, and integrating intelligent transportation systems. *See* https://local.iteris.com/arc-it/. Over 100 applications address twelve core aspects of transportation system management. ARC-IT is now evolving to include cooperative automation applications and services. *See* https://local.iteris.com/arc-it/html/servicepackages/servicepackages-areaspsort.html.

[29] Continental presentation at the 2020 SAE Government-Industry meeting, January 2020.

In contrast, because V2X technologies can assess locations and trajectories of other equipped vehicles (or pedestrians) prior to the point at which a line-of-sight condition is established, they are able to estimate crash probabilities much earlier, and warn drivers with sufficient time to avoid or mitigate the crash. In addition, vehicle location and trajectory information available through V2X communications can be fused with today's vehicle-based sensor technologies to provide game-changing enhancements to advanced driver assistance systems, including crash avoidance applications such as intersection movement assist (IMA), left-turn assist (LTA), emergency brake-light warning, blind spot warning and several others.

The Department considered the types of crashes that V2V could best address as the primary technological countermeasure, particularly when compared to then-existing in-vehicle sensors, as part of NHTSA's NPRM on V2V. NHTSA determined that, out of 37 different crash types (comprising 100 percent of all crashes), 17 crash types could be addressed with V2V technologies as the primary crash-avoidance technology. Of those 17, ten were further identified as the top priorities that could be addressed by six specific V2V safety applications:[30]

> (1) Forward Collision Warning (FCW): warns drivers of stopped, slowing, or slower vehicles ahead. FCW addresses rear-end crashes that are separated into three key scenarios based on the movement of lead vehicles: lead-vehicle stopped (LVS), lead-vehicle moving at slower constant speed (LVM), and lead-vehicle decelerating (LVD).
>
> (2) Emergency Electronic Brake Light (EEBL): warns drivers of heavy braking ahead in the traffic queue. EEBL would enable vehicles to broadcast an emergency brake and allow the surrounding vehicles' applications to determine the relevance of the emergency brake event and alert the drivers. EEBL is expected to be particularly useful when the driver's visibility is limited or obstructed.
>
> (3) Intersection Movement Assist (IMA): warns drivers of vehicles approaching from a lateral direction at an intersection. IMA is designed to avoid intersection crossing crashes, the most severe crashes based on the fatality counts. Intersection crashes include intersection, intersection-related, driveway/alley, and driveway access related crashes. IMA crashes are categorized into two major scenarios: turn-into path into same direction or opposite direction and straight crossing paths.
>
> (4) Left Turn Assist (LTA): warns drivers to the presence of oncoming, opposite-direction traffic when attempting a left turn. LTA addresses crashes where one involved vehicle was making a left turn at the intersection and the other vehicle was traveling straight from the opposite direction.
>
> (5) Do Not Pass Warning (DNPW): warns a driver of an oncoming, opposite-direction vehicle when attempting to pass a slower vehicle on an undivided two-lane roadway. DNPW would assist drives to avoid opposite-direction crashes that result from passing maneuvers. These crashes include head-on, forward impact, and angle sideswipe crashes.

[30] *Id.* at 3862-63.

(6) Blind Spot/Lane Change Warning (BS/LCW): alerts drivers to the presence of vehicles approaching or in their blind spot in the adjacent lane. BS/LCW addresses crashes where a vehicle made a lane changing/merging maneuver prior to the crashes.

LTA and IMA were further identified as offering significant non-line-of-sight capabilities that in-vehicle sensors are not expected to be able to replicate, which is crucial in avoiding crashes at intersection and when making left turns, since visibility can be more easily compromised in these scenarios.[31] Beyond LTA and IMA, V2V messaging and safety applications are expected to offer significant additional safety benefits because they have the potential to be fused with in-vehicle sensors to enhance advanced driver assistance systems that can improve safety in numerous ways, such as in avoiding rear impact crashes and crashes involving lane changes.

There also exist significant potential benefits from the many V2I applications that have been developed and, in certain cases, already begun to be deployed. For example, separate studies by the Federal Highway Administration (FHWA), another operating administration of USDOT, analyzed how V2I systems could address crashes where information from the infrastructure, (*e.g.*, the presence of stop sign, signal status, speed limit, surface condition, or pedestrians in crosswalks) could assist drivers in avoiding crashes or optimizing their travel times. V2I systems that can provide real-world benefits[32] include:

- V2I signal applications that deal with crossing path pre-crash scenarios at signalized junctions, and violations of red lights or stop signs;
- V2I traffic gap applications that assist when crossing against traffic at a stop sign;
- V2I railroad crossing applications that issue warnings to prevent violations;
- V2I pedestrian applications that can present crashes in crosswalks;
- V2I road-based applications that can assist drivers in crashes where speeding is cited as a contributing factor such as loss of control on roadways or curves, road departure, rollover, and object contacted pre-crash scenarios;
- V2I road-weather applications that can address crashes on freeways due to winter weather;
- V2I system efficiency applications that can reduce congestion on and within freeway segments and on arterial corridors;
- V2I transit signal priority applications that can reduce travel time for transit vehicles;
- V2I Public Safety/Emergency Response applications that can reduce travel time and number of stops for emergency vehicles;
- V2I work zone applications that can reduce network-wide delay due to alerts to incident zone workers; and
- V2I energy applications that can produce a significant fuel savings when signal operations and freeway lane management are optimized.

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[31] *Id.*

[32] *See Benefits of Dynamic Mobility Applications* at https://rosap.ntl.bts.gov/view/dot/3385/dot_3385_DS1.pdf. Additional information on V2I benefits can be found at the Department's Safety Band website at: https://www.transportation.gov/content/safety-band.

The Department has consistently stated that, combined, V2V and V2I technologies have the potential to address approximately 80 percent of unimpaired light vehicle crashes.[33] That is not to say that none of these crashes could be avoided through other means, whether that be in-vehicle sensors or changes in driver behavior. Rather, due to the many unique characteristics discussed above, the Department, and the transportation community more generally, continue to believe that V2X communications will play a vital role in reducing crashes and decreasing congestion. V2X will improve the crash-predictive capability of advanced crash avoidance systems by increasing their accuracy and reducing false positives, thus improving the performance of these systems, particularly in challenging conditions that would likely limit in-vehicle sensors, such as in scenarios where line of sight is compromised or in adverse weather conditions. However, these benefits are likely to be lost without access to appropriately dedicated spectrum that can be relied on to deliver the communications needed for these applications in a timely and reliable manner that is free of interference.

II. V2X is in Use and Being Deployed at an Increasing Scale

In light of these enormous potential benefits, V2X deployments are now occurring at an increasing rate throughout the U.S. These deployments use the entire 5.9 GHz band and have begun to demonstrate real-world benefits to State, regional, and local transportation agencies, as well as for travelers (including vulnerable populations of road users).

Currently, over 123 sites across the Nation are putting the 5.9 GHz band into use. This number grew from 87 sites in June 2019. However, growth in the number and scope of deployments has also been halted by the FCC's temporary filing freeze, which, as of December 19, 2019 has resulted in a very significant number of stalled applications. It appears that this includes as many as 1020 location registration applications from ten States (Ohio, Colorado, New York, Florida, Hawaii, California, Georgia, Michigan, Pennsylvania, and Tennessee), not to mention additional States that are likely holding off on filing until they receive further direction from the Commission on how to proceed.[34]

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[33] *See, e.g., Frequency of Target Crashes for Intellidrive Safety Systems* (Najm, Koopmann, Smith, and Brewer, October 2010, Report No. DOT HS 811 381). *See also*: https://www.nhtsa.gov/DOT/NHTSA/NVS/Crash%20Avoidance/Technical%20Publications/2010/811381.pdf and Analysis of Light Vehicle Crashes and Pre-Crash Scenarios Based on the 2000 General Estimates System (Najm, Sen, Smith, and Campbell, Nov. 2002, Report No. DOT HS 809 573), https://rosap.ntl.bts.gov/view/dot/8882/dot_8882_DS1.pdf; and *Connected Vehicle Deployment Decision-Support Analysis and Stakeholder Impact Analysis: Summary* Findings. http://transportation.gov/research-and-technology/connected-vehicle-deployment-decision-support-analysis-and-stakeholder. As noted above, although these reports are somewhat dated, the relevant statistics remain remarkably similar in 2018, the most recent year of available statistics.

[34] All current DSRC licensing and application information were gathered directly from the FCC's Universal Licensing System (ULS) search database at https://www.fcc.gov/wireless/systems-utilities/universal-licensing-system#searching.https://www.fcc.gov/wireless/systems-utilities/universal-licensing-system#searching. Current licenses can be found via the advanced license search tool at https://wireless2.fcc.gov/UlsApp/UlsSearch/searchAdvanced.jsp; for applications made by entities holding a license, via the advanced application search tool at https://wireless2.fcc.gov/UlsApp/ApplicationsSearch/searchAdvanced.jsp. This is a "live" database that is actively updated as license and location applications are made. Using the ULS advanced license search tool, DOT obtained a

This freeze is detrimental from another perspective. To implement this leading-edge technology, the planning process requires that public agencies compare the outcomes and benefits against other types of investments. The growth to nearly 100 agencies that are planning, deploying, and/or operating V2X systems indicates the importance of such investments to produce transportation benefits. If the funds set-aside for these "on-hold" installations are not used, they may be repurposed for other projects, putting V2X installation off until another planning and investment analysis cycle can provide new funds, which will only further postpone the benefits of these projects.

a. Benefits are beginning to accrue from V2X deployments

Despite the early stages of installation and adoption at leading-edge sites across the Nation, critical successes are emerging that apply to transportation environments.

V2V/V2I Safety Warnings Work—Tampa, Florida[35]

Though more results from this deployment will be available in later 2020, there are already three highlights from the emerging Tampa/THEA deployment evaluation where early findings are showing positive results in terms of increasing vehicle safety through the deployment of V2V and V2I applications:

Figure 4: Wrong Way Entry Problem

- **Intersection Safety:** Since Spring 2019, Intersection movement assists (IMA) issued 1,120 warnings to 582 vehicles in incident-prone areas in downtown Tampa.[36]
- **Crash Avoidance:** On a weekday, out of 325 vehicles in the study area, V2V-based forward collision warning (FCW) applications warned 10 drivers in older vehicles (with no OEM-provided safety applications) of a possible collision.
- **Resolving a Unique Problem—Wrong Way Entry onto a Ramp**: Over the same period, V2I alerted 11 drivers of wrong way entry into an expressway.

listing of all Licenses (known as Call Signs to the FCC) for both known ITS radio services; the ITS Public Safety (IQ – radio service) and the ITS Non-Public Safety (QQ – radio service). Once selecting those two radio services, the search query is run to identify all entities holding a license. These were then filtered to identify active licenses. In order to operate a DSRC Road Side Unit, an IQ/QQ license holder must also file an application with the FCC for the unique location where the DSRC unit will be located/operated. To identify pending DSRC locations, the team used the ULS advanced application tool and selected both relevant radio service codes (IQ & QQ), and selected pending status (2 – Pending). This query returned all current pending DSRC applications within the ULS.

[35] Image courtesy of the Tampa Vehicle Pilot.

[36] False positive rate of 7.2 percent.

Achieving Cost-Effective Capabilities to Address the Urban Canyon Problem

New York City has taken action to resolve a challenging problem that exists for effective V2X communications in all major cities—that of the inability of Global Positioning System (GPS)-reliant sensor systems to operate properly when in urban canyons.

In seeking lane-level accuracy (which will be particularly important for automated vehicles), the New York City team explored various techniques and then developed a hybrid capability that uses a combination of inputs from vehicle sensors and GPS signals when available, and standard RSU-transmitted service messages (such as an intersection MAP) from the NYCDOT-installed equipment to establish the vehicle's location with lane level accuracy. The new system is known as *V2X Locate.* Preliminary testing results are very promising and exceed the threshold (within 1.5 m 68% of time) referenced in SAE J2945/1, even under these "urban canyon" conditions.

The end product is referred to as an "RSU time-of-flight measurement capability." The capability requires the software on a V2X aftermarket safety device to perform the processing of inputs and data fusion. In addition, the capability alleviates the need to use broadcast RTCM (Radio Technical Commission for Maritime Services) positioning corrections, which frees up spectrum for other types of messaging.

For now, for urban canyon environments, the results from the NYCDOT effort will benefit other cities by providing options for environments with similar dense grid street networks through use of enhanced positioning utilizing RSUs at intersections. This result also supports the evolution of V2X standards as they help to understand positioning-related topics in connected vehicles, such as positional accuracy for the BSM.

b. Additional examples of successful V2X deployments

Further examples of the over 100 V2X deployments throughout the country, many of which are already beginning to see benefits, include:

Alabama	Truck platooning technology pilots illustrated a reduction in travel times by up to 13 seconds per vehicle on a five-mile section of I-85.[37]
Arizona	In the Phoenix area, four signal control applications deployed in coordination (including freight and transit signal priority) reduced vehicle travel time 6-27%.
Colorado	Colorado has deployed nearly 200 devices that utilize DSRC or CV2X technologies, and expects to triple this number in the next three years.

[37] From: Evaluation of Driver Assistive Truck Platooning on Traffic Flow, Mikhail M. Gordon, Auburn University. Summarized in the ITS Knowledge Resource database at: https://www.itsknowledgeresources.its.dot.gov/ITS/benecost.nsf/0/84B77B3C3D88468B852581D70060634C?OpenDocument&Query=Home. *See also*: https://static.tti.tamu.edu/tti.tamu.edu/documents/0-6836-1.pdf, page 99 that discusses findings of fuel savings of up to 12 percent on average from platoons in Texas.

	In addition, the City and County of Denver, Colorado can provide signal priority to freight vehicles along designated freight corridors throughout the city to reduce freight related travel times and concentrate freight movements on those corridors rather than on other neighborhood streets.
Georgia	Georgia DOT is equipping 1700 intersections in Atlanta with V2I capable roadside equipment to support red light violation warnings to equipped vehicles that are in danger of running a red light. These applications can also extend an intersection all-red interval to allow safe passage for the violating vehicle. Red light violations represent 2 percent of all traffic fatalities (~700 deaths per year) and 27 percent of fatalities at signalized intersections.[38] This application is intended to warn human drivers today, but the underlying capability can also inform automated vehicles of the traffic signal timing plan, potentially providing a source of information to complement other vehicle-based sensors to help them navigate the intersection efficiently.
Florida	Florida DOT has deployed V2I equipment at 45 sites along corridors in northern Florida and are deploying signal phase and timing (SPaT) at an additional 68 intersections. The goal is to improve travel time reliability, safety, throughput, and traveler information; and to deploy and test pedestrian and bicyclist safety CV and smartphone-based applications. In addition to SPaT, deployment includes: map display; signaling remaining time to a green signal; red-light violation warning; wrong way entry (WWE); exit ramp deceleration warning (ERDW); curve speed warning (CSW); emergency electronic brake lights; forward collision warning (FCW); intersection movement assist; work zone warning; do not pass warning; speed limit warning. Other connected vehicle deployments are planned for this region including the I-75 Florida's Regional Advanced Mobility Elements (FRAME) that will deploy emerging technologies to better manage, operate, and maintain the multi-modal transportation system and create an Integrated Corridor Management solution on I-75 and state highway systems in the Cities of Gainesville and Ocala. The emerging technologies being planned include automated traffic signals (to evaluate performance); V2X RSUs and OBUs for effective traffic operations; Transit Signal Priority; and Freight Signal Priority.
Michigan	Michigan DOT has equipped 209 locations with V2I-capable roadside equipment to broadcast signal phase and timing information for

[38] FHWA Office of Safety: https://safety.fhwa.dot.gov/intersection/conventional/signalized/rlr/. Analysis based on NHTSA's Fatality Analysis Reporting System (FARS) data.

	automakers to test new applications, and to provide work zone information to equipped vehicles. Signal phase and timing information enables a multitude of applications, including red light violation warnings, turning movement assistance, and eco-drive applications that advise vehicles of recommended speeds to minimize stopping through a series of intersections, improving throughput and reducing fuel consumption and emissions.
New York City	New York City is equipping 353 locations in Manhattan and Brooklyn with V2I roadside units. These high crash rate locations include work zones, intersections, short-radius curves, and facilities with height restrictions. New York will also test 5.9 GHz communications-based applications to detect pedestrian crossings and to assist visually impaired travelers with intersection crossings. As noted previously, the NYCDOT CV Pilot uses a positioning system, *V2X Locate,* on the DSRC control channel to augment GPS' location accuracy, demonstrating that low-latency V2X safety applications can also be practically deployed in a dense urban environment. Testing results have been favorable and have often even exceeded the location accuracy threshold referenced in SAE J2945/1 (within 1.5 m 68% of time). For example, testing in the 6th Avenue (Avenue of the Americas) urban canyon resulted in location accuracy of <1 m 95% of the time. The NYCDOT CV pilot uses six 10 MHz DSRC channels to support the safety applications, data collection, and operations & maintenance. In addition to the V2V safety applications, the DSRC infrastructure is used to 1) upload performance and traffic data from the vehicles, 2) manage and update the in-vehicle safety applications, 3) maintain the security of DSRC communications, 4) provide evacuation, work zone, and other roadway restriction information, 5) provide real-time traffic signal status, and 6) provide localized roadway geometric information for the safety applications.
Pennsylvania	Pennsylvania DOT has equipped 46 intersections in the Pittsburgh area with V2I capable roadside equipment with 90 more planned this year. It is using data to adapt traffic signal functioning to real time conditions and to prioritize and optimize transit trips.
Utah	Utah DOT has been deploying DSRC for four years and currently has 127 intersections and 82 fleet vehicles with DSRC equipment installed and operating. A DSRC corridor in Utah improves transit reliability by 12 percent and reduces late bus arrivals by 40 percent. Utah is giving

	signal preemption priority to snow plows during inclement weather this winter and plans to equip several more corridors and deploy applications for curve speed warnings and slick road surfaces due to weather hazards.
Virginia	Virginia DOT has equipped 51intersections in northern Virginia with V2I capable roadside equipment to support red light violation warnings.
Washington State	An application to apply variable speed limits (VSL) during unsafe weather on I-90 in Washington showed that the system reduced average speed by up to 13%.
Wyoming	Wyoming DOT is installing 75 V2I roadside units on I-80 across the State to provide weather warnings (*e.g.*, low visibility, high wind, etc.) and spot roadway conditions to equipped motor carriers and fleet vehicles to prevent catastrophic, condition related crashes (sometimes multi-car pile-ups). The equipment will also broadcast information about truck parking availability. V2I allows targeting of messages to vehicles in a specific area without requiring the driver to tune into a radio channel or check an application. The integration of connected vehicle data into its TMC was instrumental for improving road management capabilities on I–80 and the rest of Wyoming's highways. As WYDOT moves into the operational phase, a "friendly fleet" of 50+ snowplows and Trihydro vehicles are already sending continuous data to the TMC. Through discussions with the States, we understand Colorado is interested in a similar system and Nebraska received funding to build or extend the Wyoming system further across their State.

These individual deployments are also being supplemented by other broader efforts being undertaken by the transportation community. For example, the National Operations Center of Excellence (NOCoE)—including the American Association of State Highway and Transportation Officials (AASHTO), ITS America, and the Institute of Transportation Engineers (ITE)—issued a signal phase and timing challenge to members to equip at least 20 intersections in every State with V2I equipment by 2020.[39] This effort has assisted in the growth of roadside units throughout the Nation—over 6,000 are installed and are in use in 34 States. NOCoE has also announced a connected fleet challenge. This initiative will build on the over 15,000 vehicles that are equipped or planned today.[40]

[39] https://transportationops.org/spatchallenge.
[40] https://transportationops.org/connected-fleet-challenge

In addition, US DOT and automotive companies[41] are conducting a research initiative on "Traffic Optimization for Signalized Corridors (TOSCo)" which is an innovative CV application that uses information from the infrastructure (V2X communications between traffic signal controllers and equipped vehicles) to plan speed trajectories that allow vehicles to move more efficiently through TOSCo-supported intersections. TOSCo analysis has demonstrated substantial reductions in stop delays and the number of stops in both corridors (40 % in the low-speed corridor and 80% in the high-speed corridor). Based on simulation results, the impacts on traffic performance indicate that at only 30% market penetration, TOSCo will be able to reduce stop delay during rush hour by 7-24 percent in the morning and 38-51 percent in the evening.[42] For intersections experiencing saturated conditions, TOSCo provided enough increase in intersection capacity to eliminate queue formation. TOSCo will next be demonstrated on roadways in the City of Conroe, Texas.

State and local agencies have also described their deployments to both US DOT and FCC in other proceedings, including: the 2018 US DOT Request for Comment on V2X Communications;[43] the FCC's V2X-DSRC docket at 13-49;[44] and the FCC's LTE-CV2X docket at 18-357.[45] Additional deployment information can also be found on the ITS JPO's website, which documents the CV Pilot sites,[46] the Smart City site,[47] and a knowledge resources site[48] that presents detailed information about deployments based on an every-three-year survey. The site presents summaries on the benefits, costs, deployment levels, and lessons learned for ITS deployment and operations from over 20 years of ITS evaluation studies, research syntheses, handbooks, journal articles, and conference papers tracking the effectiveness of deployed ITS. The next update is expected to be released in Summer 2020.

III. A Connected and Automated Future Will Require the Use of the Full 75 MHz

These existing deployments depend on and use the entire 75 MHz of spectrum that FCC has allocated for V2X purposes. The following discussion explains: how existing deployments use the spectrum; the relationship between V2X and vehicle automation, particularly how the two technologies combine into Cooperative Automated Driving (CAD) systems; and how the spectrum will be used in a future of even greater connectivity. Together, these show that V2X communications that can be relied on to support nationwide interoperability for the safety-critical applications must be able to receive time-sensitive critical information across the entire spectrum.

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[41] OEM research partners include Ford, GM, Honda, Hyundai, Mazda, Nissan, Subaru, Volkswagen

[42] TOSCo results to date are documented in two reports: *Traffic Optimization for Signalized Corridors (TOSCo) Phase 1 Project – Traffic-Level Simulation and Performance Analysis Report* and *Traffic Optimization for Signalized Corridors (TOSCo) Phase 1 Project Final Report* located at https://www.campllc.org/traffic-optimization-for-signalized-corridors-tosco-fhwa/.

[43] *See* https://www.regulations.gov/docket?D=DOT-OST-2018-0210.

[44] *See* https://www.fcc.gov/ecfs/search/filings?q=13%5C-49&sort=date_disseminated,DESC.

[45] *See* https://www.fcc.gov/ecfs/search/filings?q=18%5C-357&sort=date_disseminated,DESC.

[46] *See* https://www.its.dot.gov/pilots/index.htm, https://www.cvp.nyc/, https://www.tampacvpilot.com/ and https://wydotcvp.wyoroad.info/.

[47] *See* https://www.transportation.gov/smartcity and https://smart.columbus.gov/.

[48] *See* https://www.itsknowledgeresources.its.dot.gov/its/itsbcllwebpage.nsf/KRHomePage.

a. Existing use of the 5.9 GHz Band

As shown in Figure 2 previously, the different channels allocated for V2X purposes are associated with different applications and uses. The existing requirements for these uses are well-defined in the ITS standards and support the ability for each device to receive data from nearby devices (within a 300-1000 meter range) for data such as trajectory of other moving devices, speed, yaw rate (among other data points) combined with infrastructure messages delivering signal phase and timing and/or geometric road characteristics (MAP). By receiving this data up to 10 times per second, a moving device (*e.g.*, on a vehicle, wheelchair, or bicycle) can understand the location of all surrounding devices and anticipate where they will be moving so as to determine if a crash might occur.

By combining these existing uses and other established applications, we can envision how a channel plan could work in a representative "edge-case," such as Los Angeles, which contains both dense and spread-out populations that use a roadway system comprised of:

- Interstates running through the city at high speeds (averaging 55-65 mph, which can translate into closing speeds of 150 mph with traffic on the opposite side of the roadway);
- Interstates elevated over major arterial streets with speeds between 25-45 mph;
- Smaller nearby side streets with sidewalks supporting pedestrians and vulnerable road users;
- Traffic signals at a spacing of 1-2 city blocks, which could mean overlapping roadside units; and
- Short buildings that might block line-of-sight when a road joins an intersection at an angle.

These characteristics represent a challenging environment for V2X communications unless carefully structured and implemented. The existing band plan and device features such as adjacent channel rejection have been demonstrated to allow V2X communications to work in such an environment. Under this operating environment, the following spectrum uses would be needed to deliver the wide variety of fundamental V2V/V2I safety, system efficiency, security, and mobility communications in this type of environment:

Use of the Spectrum	Observations	Amount of bandwidth used
Safety-Critical Communications All vehicles/devices performing safety-critical communications for crash prevention. Messages include Basic Safety Messages (BSMs), Signal Phase and Timing (SPaT), and GPS corrections. To address intersection dynamics appropriately, the MAP message (roadway geometrics) is needed—the complexity of the geography determines message size. Since	Based on US DOT and industry testing, we can expect vehicles and traffic signals broadcasting in a 300 meter zone. All should be accommodated. Channel will be near- or fully saturated in places such as major cities most of the time. Use of critical safety-of-life applications under these conditions demands success with key performance metrics such as Information Age or Packet Error Rate. Congestion	• 10 MHz in Channel 172 with DSRC in full use—can support approximately 1200 vehicles in a 300 meter range • 20 MHz in Channel 183 with LTE-CV2X transmitting each message twice—how congested the channel might get under these conditions and how many vehicles can be supported for safety-of-life communications is under test

Use of the Spectrum	Observations	Amount of bandwidth used
most vehicles traverse the same routes daily, the device needs only the update and can tune to a different channel to receive the update.	algorithms using information from these metrics have been developed to manage the saturation so that V2X critical-safety applications continue to work properly.	
MAP delivery by an RSU at intersections. Other types of downloads such as the **refresh of security credentials** might also be accommodated on this channel.	If RSUs are located 100-200 meters apart, distributing large static documents, we can expect to fill another channel.	• 10 MHz of a lower-powered channel, say Channel 174 (can also be 176, 180, 182) • This data exchange use will need to fit into the LTE-CV2X proposed 20 MHz channel.
Public safety applications— Channel 184 is reserved for public safety uses when needed. A channel needs to be available to support police, fire, and emergency responders in getting safely and quickly to and from a crash. When a crisis is imminent, availability of this spectrum is critical.	Public safety vehicles will use spectrum to: • Perform V2V safety for their own vehicles • Use signal preemption to move safely and quickly through intersections • Send alerts through RSUs to warn traffic ahead about their route and speed—and allow those vehicles to move over safely and quickly • Send out roadside alerts to keep personnel safe • May send messages or stream video at the site back to emergency rooms	• 10 MHz Channel 184 with DSRC • In addition, for DSRC, an additional channel is used to send Traveler Information Messaging (TIM) to alert nearby and approaching traffic of the incident (similar to a Work Zone alert) and to reroute around the crash site. • This use will need to fit into the LTE-CV2X proposed 20 MHz channel.

Use of the Spectrum	Observations	Amount of bandwidth used
Control Channel: At this point, 30+ MHz are in use before other key, critical needs are met for any other V2I safety, system efficiency, and mobility applications. Because the control channel is useful during these times with DSRC use, the band plan allocates a 10 MHz channel for active spectrum management.		• 10 MHz Channel 178 with DSRC • LTE-CV2X does not need a control channel since all data exchanges have to occur within the proposed 20 MHz channel. Given the theoretical use limits to any channel, testing is still needed to determine how the LTE-CV2X 20 MHz channel will accommodate the safety-critical broadcasts plus MAP/security downloads plus public safety and surrounding traveler information in this one channel.
V2I safety, system efficiency, and mobility messages and other public benefit applications such as those represented in the ITS architecture reference.[49] Key applications include: • Transit Signal Preemption • Work Zone Alerts • Spot Weather Warning • Queue Warnings when slowing or queued traffic is over a hill, behind an obstruction or weather-related • Probe data for region-wide system management • Rail-grade crossings • Freight logistics from ports through cities out to Interstates • Wrong-Way Entry onto Ramps or Streets	These messages can range in size from 300-800 octets (a BSM with security is approximately 365 octets) and can range in priority from low to high, depending on the prevailing conditions.	• It is unclear how the proposed 20 MHz channel for LTE-CV2X will accommodate all of these types of messages when in use in a dense urban environment. US DOT is preparing for tests to understand the capability of these devices within this one 20 MHz channel

[49] At: www.arc-it.net.

b. V2X enhances vehicle automation capabilities

Automation has the potential to reduce crashes, improve our quality of life, and enhance the mobility and independence of millions of Americans. The Department discussed the relationship between V2X communications and automated vehicles (AV) at length in AV 3.0, concluding that:

> Connectivity enables communication among vehicles, the infrastructure, and other road users. Communication both between vehicles (V2V) and with the surrounding environment (V2X) is an important complementary technology that is expected to enhance the benefits of automation at all levels, but should not be and realistically cannot be a precondition to the deployment of automated vehicle.[50]

That is, while connected vehicle technology is not an absolute requirement for ADS technology, V2X communications are likely to play a critical role the development of ADS-equipped vehicles by enhancing safety, extending operational design domain, and improving interactions with other vehicles and the infrastructure. High-speed V2X communications and data exchange allows AVs to receive and contribute data beyond their on-board sensors' physical range (as noted previously), which allows automated vehicles to influence and take into consideration the behavior of pedestrians, bicyclists, and other humans and vehicles using the roadway.[51] In addition, V2X messaging will be an absolute requirement for cooperative automated driving (CAD) applications, such as platooning, which rely on constant communications between connected automated vehicles. Thus, the Department, and the broader transportation community, expect that the move towards automation will increase spectrum demands to allow for greater and more sophisticated automation systems.

The Department is currently investing in CAD technologies through several efforts, including:

- The Cooperative Automation Research Mobility Applications (CARMA) open source platform that is accelerating CAD research and enabling Automated Driving Systems (ADS) to facilitate tactical maneuvers in complex transportation scenarios;
- Traffic optimization on signalized corridors that is delivering smoother traffic flow especially at higher market penetration rates and network level benefits in mobility in terms of total delay, stopped delay and total travel time;
- Cooperative Automated Truck Platooning that results in substantial fuel savings;
- Cooperative Automated Integrated Highways that include technologies that extend ADS performance limitations to improve system performance and safety through CDA; and
- Participation in an SAE International standards-setting effort to define cooperative automated driving maneuvers enabled through communications to support or enable ADS.

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[50] Preparing for the Future of Transportation: Automated Vehicles 3.0 (AV 3.0), page 13. At: https://www.transportation.gov/sites/dot.gov/files/docs/policy-initiatives/automated-vehicles/320711/preparing-future-transportation-automated-vehicle-30.pdf.

[51] Testimony of Dr. James C. Owens, Acting Administrator National Highway Traffic Safety Administration Before the Committee on Commerce, Science & Transportation United States Senate Highly Automated Vehicles: Federal Perspectives on the Deployment of Safety Technology November 20, 2019. At: https://www.commerce.senate.gov/services/files/683FBDA2-F073-4853-A1A4-E671970EE3E9.

A major focus and leading-edge effort for US DOT is the development of the open-source ecosystem—CARMA—that is designed to accelerate market readiness and the deployment of cooperative automated driving technology. US DOT modal agencies have invested over $23 million in research and development funding in the development of CARMA over the past 7 years. In addition, the CARMA program is growing across the United States as a tool being used by research programs at leading academic institutions that are accelerating innovation of cooperative automated driving systems. The CARMA platform is a unique, open-source platform that was created to work collaboratively with any vehicle, hardware, or control system, and, thus provides a wider range of State and local agency test engineers, academic researchers, and private sector developers with new tools to use in their work. CARMA partners are developing and advancing the cooperative features that will rely on the 5.9 GHz band to enable CAD functionality.

The new safety and operational features that are enabled by CAD are combined in the following seven feature groups that are aimed to improve system wide safety, operations, and efficiency: (1) Cooperative Collision Avoidance; (2) Cooperative Lane Change; (3) Cooperative Lane Follow; (4) Cooperative Right of Way; (5) Cooperative Traffic Signal; (6) Cooperative Traffic Management; and (7) Cooperative Accessible Transportation. These features build from the existing V2X applications that use the existing basic messaging (*e.g.*, BSMs, SPaT/MAP, etc.) to integrate new types of messaging to resolve complexities associated with automated vehicle maneuvers, including: Cooperative Perception Messages (CPM); Maneuver Coordination Messages (MCM); Platooning Control Messages (PCM). CARMA is also beginning to provide new strategies for first responder use cases interacting with ADS.

c. Spectrum Use in a Connected and Automated Future

Another way to understand use of the 75 MHz is through analysis of each vehicle's spectrum access needs as it traverses through its environment. In 2018, the Car-2-Car Communication Consortium (C2C-CC) performed an analysis of how many megahertz of spectrum an individual vehicle might use in a typical day.[52] Figure 5 illustrates types of exchanges that any one vehicle might have in one trip. The arrows illustrate the data flows that are defined by the existing standards (once the LTE-CV2X standards are complete, they will need to be added as will standards and data flows associated with emerging automation applications).

[52] See: https://www.car-2-car.org/fileadmin/documents/General_Documents/C2CCC_TR_2050_Spectrum_Needs.pdf.

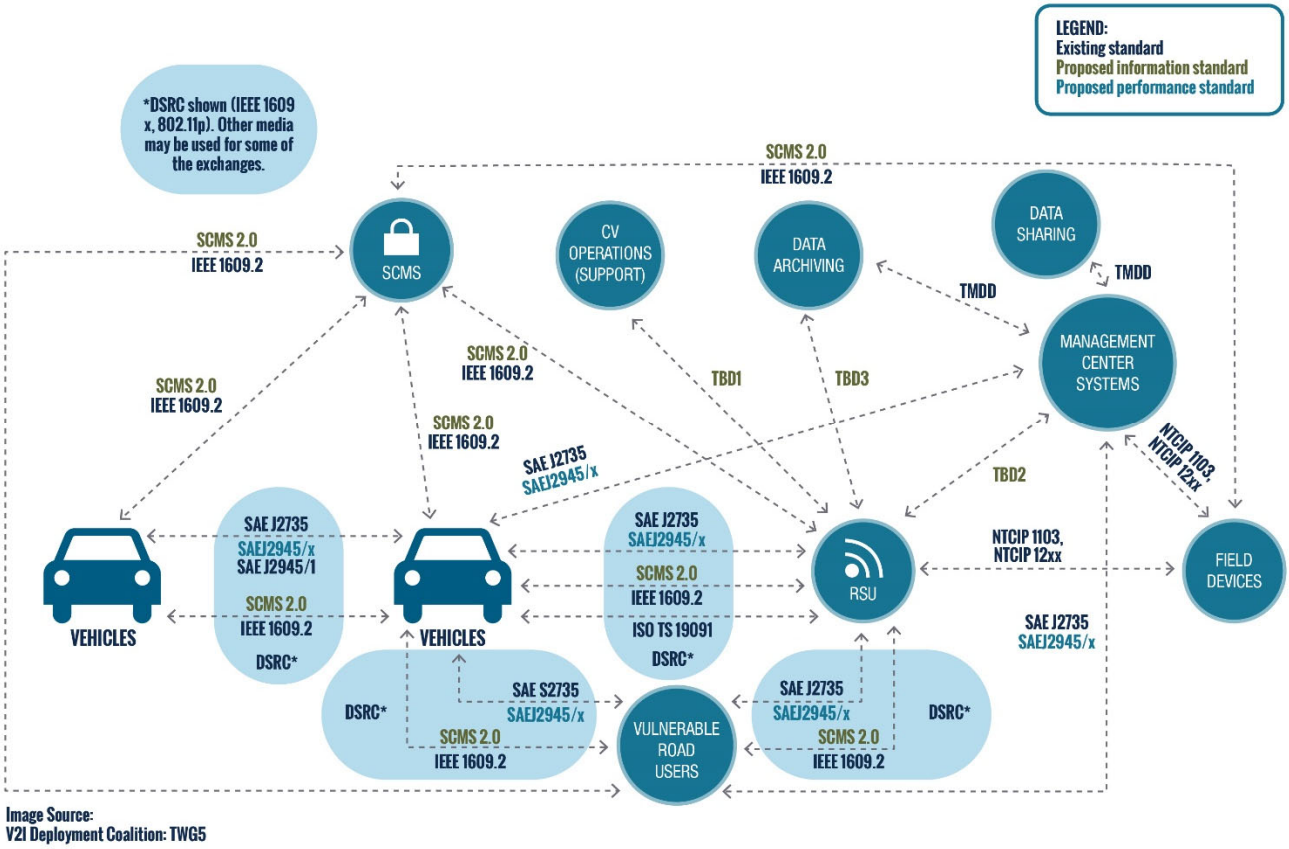

Figure 5: V2X communications between vehicles and with infrastructure during a trip

C2C-CC's analysis of spectrum use for existing applications also considers additional connectivity that may be needed or used for automation. Adding near-future cooperative automation messages and using data from European deployments, Continental and C2C-CC have recently updated their calculations to consider the spectrum needed to perform today's V2X applications and account for near-future cooperative automation applications, as shown in Table 2:[53]

[53] Continental expertise and C2C-CC white paper, *Position Paper on Road Safety and Road Efficiency Spectrum Needs in the 5.9 GHz for C-ITS and Cooperative Automated Driving* at https://www.car-2-car.org/fileadmin/documents/General_Documents/C2CCC_TR_2050_Spectrum_Needs.pdf; ETSI TR 103 562 https://www.etsi.org/deliver/etsi_tr/103500_103599/103562/02.01.01_60/tr_103562v020101p.pdf; and https://docbox.etsi.org/ITS/ITSWG1/05-CONTRIBUTIONS/2019//ITSWG1(19)000012_Collective_Perception_Simulation_Study.pdf

Table 2: C2C-CC and Continental's Calculations of Spectrum Needs for V2X Message Types[54]

	Scenario			
Message type	**Urban [MHz]**	**Suburban [MHz]**	**Highway [MHz]**	**No of 10 MHz channels**
BSM	9	10	9	1
I2V	1	1	1	0.5
PSM	4	1	2	0.5
PCM	3	6	10	1
CPM	23	26	24	2
MCM	23	26	24	2
∑	**63**	**70**	**70**	**7**

Annex A of their 2018 filing illustrates the amount of spectrum needed for a variety of scenarios including an urban, suburban, and rural scenario at a particular moment in time. Table 2 details the assumptions associated with the parameters of the environment (including speed and density of vehicles and devices), messages (including packet size and periodicity, bits/hertz), and maximum channel load. Our experience with US-based V2X deployments has validated these scenarios as typical, expected scenarios that require this type of spectrum availability.

We note further note that this set of messages does not include the security credentials or other data upload requirements, nor does it include many of the additional data to support V2I applications. We believe that the entire 75 MHz will be employed (including the 5 MHz guarding against unlicensed Wi-Fi below the band) when we add these additional message sets.

Finally, when analyzing the need for spectrum to support V2X communications, it is important to consider the potential spectrum needs of a 5G-based V2X system. If an allocation is made without consideration for this technology, which is not expected to be interoperable with existing forms of V2X, there may be no spectrum available in which we can perform the necessary research on 5G V2X[55] to determine both its safety capabilities and how to transition 5G into use in a cooperative environment, let alone have sufficient spectrum for deployment. Other countries, though, may be able to take advantage of these advancements, leaving U.S. businesses at a competitive disadvantage. Retaining the existing 75 MHz, therefore, also provides room for innovation in V2X technologies, which would be foreclosed under this NPRM.

Thus, with the addition of these advanced applications and future innovative technologies, we anticipate the full and productive use of the 5.9 GHz band for life-saving and cooperative automated applications.

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[54] *See* the Car-to-Car Communication Consortium's filing at https://ecfsapi.fcc.gov/file/1030955870143/FCC_NPRM_2019_5.9%20GHz_CAR2CAR_Communication_Consortium.pdf, page 2.

[55] At this time, the specification development for 5G V2X is still underway. *See* the 3GPP schedule at https://www.3gpp.org/news-enews/1674-timeline.

d. Retaining the entire 75 MHz is consistent with international allocations

The U.S. spectrum allocation of 75 MHz for V2X communications is consistent with the International Telecommunication Union (ITU) recommendation[56] for ITS spectrum[57] and with similar allocations made by the US's major trading partners, including:[58]

- The European Union has allocated 5875-5905 MHz for cooperative-ITS[59] and is seeking additional bandwidth;
- South Korea in the TTA standard for Vehicle Communications Systems has set aside 5850-5925 MHz;
- Singapore for ITS in 5875-5925 MHz;
- Australia has allocated 5850-5925 MHz for cooperative ITS;[60]
- India has allowed the frequency from 5875 to 5925 MHz to be considered for ITS applications;[61]
- Canada in RSS-252 has set aside 5850-5925 MHz for ITS;
- Mexico had considered the same band allocation[62] and, in the past, had identified that US use of the band at the border for ITS purposes is allowable from a coexistence perspective with their primary users in the band;
- Japan allocated available spectrum in two bands—at 755.5-764.5 MHz for V2V and V2I and at 5770-5850 MHz for interoperable V2I tolling and flexible zone systems (fourteen channels) based on the ARIB standard;[63] and
- China has allocated 20 MHz in the band—5905-5925 MHz—as they intend to use the LTE-CV2X technology in a manner similar to the 5GAA proposal.[64]

At this time, our exchanges with other governments whose initial allocations were less than 75 MHz suggest that these governments are considering more spectrum, not less, to support their V2X and cooperative automated vehicle deployment. For example, the European Union is seeking to expand its initial allocation of 30 MHz to cooperative-ITS in the 5.9 GHz band between 5875 MHz and 5905 MHz after resolving issues of potential interference with the

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[56] ITU-R Recommendation M.2121: Harmonization of frequency bands for Intelligent Transport Systems in the mobile service.
[57] ITU-R.M. 2445-0, "Intelligent transport systems (ITS) usage," (https://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-M.2445-2018-PDF-E.pdf) lists an initial globally identified 59 applications (use cases) for ITS. Of these use cases, only roughly 10 are currently supported by the 10 MHz for DSRC and proposed 20 MHz for LTE-CV2X.
[58] https://www.ecodocdb.dk/download/19a361a9-d547/CEPTRep071.pdf.
[59] *Id.*
[60] https://www.computerworld.com/article/3476396/acma-releases-class-licence-for-intelligent-transport-systems.html and https://www.acma.gov.au/sites/default/files/2019-07/Five-year%20spectrum%20outlook%202018-22.pdf.
[61] Government of India Department of Telecommunications, Wireless Planning and Coordination Wing, *National Frequency Allocation Plan 2018* http://dot.gov.in/sites/default/files/NFAP%202018.pdf?download=1.
[62] FCC 03-324 REPORT AND ORDER, December 2003, ET Docket No. 98-95., pages 17, 42-43, and A-13 to A-14.
[63] At: http://www.arib.or.jp/english/html/overview/doc/5-STD-T109v1_1-E1.pdf for the 760 band and at: https://www.arib.or.jp/english/std_tr/telecommunications/desc/std-t88.html and http://www.arib.or.jp/english/html/overview/doc/5-STD-T55v1_0-E.pdf for the 5.8 GHz band.
[64] https://vtsociety.org/2018/08/chinas-connected-car-f-band-ieee-802-11-on-nextgen-v2x/

neighboring tolling systems in the 5.8 GHz band. A March 2019 report issued by CEPT (CEPT 71 report) proposes "a change of the spectrum regulation from 5875-5905 MHz (30 MHz) to 5875-5915 (40 MHz) and sharing possibilities between 5915-5925 MHz (10 MHz) with urban rail."[65] Similarly, Japan is considering an expansion of spectrum available for V2X the two allocated bands to deliver additional cooperative ITS services[66] and is further exploring the relationship between V2X and automation,[67] as well as the development of "a roadside system that provides vehicles with information on detected vehicles, pedestrians, etc. not visible from the vehicles"[68] and platooning systems.[69]

This alignment with major trading partners is important to the transportation industry and the Department. Alignment allows U.S. industry to sell our transportation technologies in global marketplaces—the standards that support use of the 75 MHz are predominantly similar (and some countries have adopted or adapted the US or European versions of the standards). The U.S. has had a leadership position with these technologies and the Department is concerned that, influenced in part by the recent NPRM, U.S. production has slowed, making it harder for US deployment sites to have their orders filled. In addition, the alignment with the band and the standards keeps costs lower for vehicle manufacturers as, with only minor changes, V2X devices can be sold anywhere in the world. Further, it will be important for travelers to have the ability to continue V2X application operations when they cross borders throughout North America. Finally, as many other governments are preserving their existing allocations for V2X, as well as seeking more spectrum for current uses and future innovations, the U.S. may lose additional important economic benefits and market leadership opportunities.

IV. The Financial Cost to Existing Deployments of Changing the Band Plan

The build-out of transportation environments is based on long-term investment commitments, which move at a different pace than the market for consumer wireless devices and their associated communications standards. For example, 3GPP specifications releases tend to occur on a three-year cycle with a full shift to the next generation (*i.e.*, 4G to 5G) occurring over the course of less than a decade.[70] By comparison, the average age of personally owned vehicles and

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[65] The CEPT 71 report further notes: "There is no evidence that spectrum availability is currently a constraint on the development of ITS, and there is no immediate need to take regulatory action in this regard." However, given the momentum of policy and standardization development for ITS, the report recommends "that the options for ITS to expand to share spectrum for safety-related ITS in the 20 MHz above the existing designation and, for non-safety ITS, in the 20 MHz below, should be kept available for the time being." *See* https://www.acea.be/uploads/publications/ACEA-CLEPA_paper-Spectrum_needs-November_2019.pdf and https://www.ecodocdb.dk/download/19a361a9-d547/CEPTRep071.pdf.

[66] *See* http://www.acecc-world.org/ITS_Introduction_Guide(Draft)_version1.1.pdf, page 46.

[67] *See* http://en.sip-adus.go.jp/evt/workshop2018/file/SIP_adus_Workshop_Connected_Vehicles.pdf.

[68] *See* http://en.sip-adus.go.jp/evt/workshop2018/file/C-1.pdf.

[69] *See* https://japan.kantei.go.jp/policy/it/itsinitiative_roadmap2017.pdf.

[70] For example, note that 5G is scheduled for three major releases over the course of 5 years. Each release is between 1-3 years. *See* https://www.3gpp.org/ftp/Information/presentations/presentations_2020/Poster_2020_MWC_v6_OPTIMIZED.pdf.

light trucks on the road is approximately 12 years[71] and 14 years for heavy vehicles, [72] and the average lifecycle of infrastructure technology installations is approximately 12-15 years[73]. This has obvious implications for the speed at which transportation providers can deploy V2X at scale, as the longer vehicles are kept and the longer an installation remains in operation, the longer it takes a new transportation technology to penetrate the market in a significant way. In addition, public officials must wait until new V2X technologies are sufficiently mature to justify long-term investments. Importantly, before long-term V2X investments can be made in infrastructure, new technologies must first be tested and proven safe and effective, including providing assurance that the technology is free from spectrum interference and achieves the required latency.

The NPRM would dramatically alter the existing spectrum allocation by significantly reducing the spectrum available for DSRC, while also introducing LTE-CV2X in a small portion of the upper band. These changes would force transportation agencies to make unfortunate and costly choices. Deployers may choose to pause their operations in order to procure, install, test, and replace their systems with new technologies. These deployers will likely wait until the standards are finalized, and the technology is tested, stable, and proven. We estimate that this transition will require approximately five years. Due to this delay, we believe that many existing deployers may, instead, choose to remove their existing installations and forego V2X communications fully.

The following discussion outlines the magnitude of the existing deployments that could either be delayed or eliminated if the FCC NPRM were to be finalized. We also provide an estimate of the potential negative effect of a five-year delay.

a. The magnitude and impact of a disruptive change to the allocation

The financial magnitude and impact of the disruptive change caused by the proposed reallocation to existing V2X deployments would be significant and would be felt by a wide range of stakeholders, including agency infrastructure owners and operators, the traveling public, and the private sector.

Focusing solely on those deployments that include some level of Federal investment, the Department has offered numerous grant and research opportunities over the last several years for deployers of V2X technology, which include:

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[71] *See* https://news.ihsmarkit.com/prviewer/release_only/slug/automotive-average-age-cars-and-light-trucks-us-rises-again-2019-118-years-ihs-markit-

[72] *See* https://www.bts.dot.gov/sites/bts.dot.gov/files/docs/browse-statistical-products-and-data/transportation-statistics-annual-reports/Preliminary-TSAR-Full-2018-a.pdf, page 50.

[73] *See* NCHRP Report 713: Estimating Life Expectancies of Highway Assets, Volume 1: Guidebook. http://www.trb.org/Main/Blurbs/167189.aspx. *See also* National Deployment Estimate of the Metropolitan ITS Infrastructure at https://www.its.dot.gov/itspac/may2012/pdf/B_NationalDeploymentEstimate.pdf and *2019 Traffic Signal Benchmarking and State of the Practice Report*, Washington, DC. National Operations Center of Excellence and the Institute of Transportation Engineers, December 2019 at https://transportationops.org/trafficsignals/benchmarkingreport.

- The Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD) program,[74] which began in 2016 and which has been a critical funding mechanism for State and local agencies to deploy V2X technologies and applications;
- The Connected Vehicle Pilot Deployment Program of 2015[75] and the Smart City Challenge of 2015;[76]
- The BUILD[77] program (Better Utilizing Investments to Leverage Development grants);
- The CARMA platform;[78]
- The recent Automated Driving System (ADS) Demonstration Grants[79] (six of the eight awarded proposals include a V2X, cooperative communications component);
- The upcoming First Responder Safety Technology Pilot Program, a funding program to equip emergency response vehicles, transit vehicles and related infrastructure, including traffic signals and highway-rail-grade crossings, with V2X technology. [80]

These programs have resulted in **over $2.7 billion** in advanced research and deployment investments across the Nation, as described in Table 3. Each program includes funding matches from State and local budgets as well as private sector financial and expert time/labor matches. US DOT expects that the actual investment figure may be higher as it does not account for deployments funded solely by State or local funds or private sector investments.

Table 3: V2X Investment Analysis

Estimate of Impact to Existing V2X Deployments: Advanced Research, Development, Testing and Deployment	**Investment Estimate** *as of March 2020*
Loss of Federal, State, and Local Agency Investments (sum of all known grants and matching State/local investments plus matching private sector funds)	**$1,237,506, 179**
Loss of V2X Research and Testing Investment (estimate of US DOT investments in research and testing)	**$804,000,000**
Loss of Investment in Cooperative Automated Driving Systems (estimate of US DOT investments in research)	**$23,000,000**
Loss of Academia Investment (sum of projects in the US DOT's Research Hub—tracks Federal funding only)	**$7,151,129**
Minimum required Funding for Transition (initial estimate; full estimate with all sites still needs to be performed)	**$645,611,045**
Total	**$2,717,268,353**

[74] *See* https://www.fhwa.dot.gov/fastact/factsheets/advtranscongmgmtfs.cfm
[75] *See* https://www.its.dot.gov/pilots/index.htm
[76] *See* https://www.transportation.gov/smartcity
[77] *See* https://www.transportation.gov/BUILDgrants/about
[78] *See* https://cms7.fhwa.dot.gov/research/research-programs/operations/carma-overview
[79] *See* https://www.transportation.gov/av/grants
[80] *See* material at: https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/first_responder_safety_technology_pilot_program011620.pdf.

If FCC enacts its proposal, these ongoing research, planning, and operational activities will slow or cease, and near-future deployments, which were on track to exceed these current levels, will be hampered.

b. Costs to transition to a new technology or band plan

Some deployers, though, may proceed with their existing projects in the event that the proposed band plan is finalized by transitioning to either a re-channeled DSRC or LTE-CV2X, if such a transition is even feasible given the spectrum interference issues discussed in greater detail below. Although this might allow the projects to continue, it would result in increased costs and delays for State and local agencies to transition to a new proposed band plan or technology. We have worked with a set of deployment sites to assess the planning, procurement, installation, integration, and testing activities—and expenses—that would likely be incurred in transitioning and ensuring that any technology and band plan will work properly.

Based on our work assessing the change, we conclude that it would cost more than **$645 million** to "rip and replace" all existing technologies, re-test the technologies within each unique operational environment, and re-institute operations. While the specific approaches and levels-of-effort may vary by project, we have identified the following work that must be accomplished to change existing deployments:

- Plan the installation, including site-specific civil and spectrum engineering for each roadside unit and its antennae;
- Apply for and manage the requisite FCC licenses;
- Procure, receive, and test the V2X devices;
- Install and test (or retest) the entire V2X system;
- Integrate the V2X system into existing traffic management systems; and
- Enact cross-jurisdictional agreements regarding data, operations, device maintenance, and other considerations.

These types of costs will be incurred should the deployer decide to either keep its DSRC technology under a band plan modification (*i.e.*, to retune and retest existing radios based on new channels) or to remove DSRC equipment and replace with all new LTE-CV2X equipment. We further note that current V2I applications have not fully been translated for LTE-CV2X, adding a need to recode and test the majority of the public-benefit applications. Costs include:

- Average costs range from **$360,000** to over **$60,000,000** for operational sites with units already deployed in the field, in direct costs to State or local DOTs, for planning, labor, acquisition, testing, removal, and reinstallation costs, depending on the geographic size and amount of current or planned installations and operations a site has.
    - Using the production-level deployments already in place as a baseline, we estimate **$60.0 million** per site for the most complex installations. Each of these sites deploy more than 1000 DSRC units in the form of OBUs or RSUs. Projects

include high-density urban areas, as well as initiatives covering large urban, suburban, or rural neighborhoods, city streets, arterials, and highways.
  - **$7.2 million** represents an average-sized installation (more than 200 units but less than 1000), including projects in low- to moderate-density urban areas, regional initiatives, and corridor projects.
  - **$4.0 million** is estimated for sites with less than 50 units including areas covering rural areas; however, with the recent request by the American Trucking Association (ATA) to install DSRC radios in fleets that traverse rural States such as Wyoming, rural costs are likely to increase.
  - **$360,000** is estimated for smaller installations of 20 or fewer devices.

- In total, it will take more than **$645 million** in infrastructure costs to State and local DOTs to remove and replace existing equipment at 57 operational sites, and to either replace or re-engineer equipment at the 66 sites currently in the planning, installation, or testing phases (see table below).

Table 4: Replacement Costs

Cost Item	Number of Sites	Total
Operational sites	57	$408,886,995
Sites in planning, construction, or testing phases (see note)	66	$236,724,050
Total	**123**	$645,611,045
Note: For the 66 sites in planning, construction, or testing phases, the site is estimated at an average of 50 percent of the operational replacement cost because some sites will need full replacement, other sites will need re-engineering only, and some sites a combination of replacement and re-engineering.		

- Lengthy timelines (estimated from 2 to 5 years) to resubmit all station licensing; prepare cross-jurisdiction MOUs; and procure, test, install, and integrate new technologies into existing operational systems. During this time, any ongoing or imminent V2V/V2I installations would be suspended.
  - If LTE-CV2X becomes the prevailing technology, the delays would be considerable, likely 3–5 years (due to satisfactory evaluation and testing, and supply and manufacturing limitations).
  - If the existing channel assignment changes and existing equipment retained, the delays may be shorter (2–3 years) but would still require an interim suspension while existing equipment and operations are reprogrammed or modified.
  - We further note that with the complexities of RSU positioning and GPS corrections, additional testing is critical, and changes could lead to increased risks of failure.[81]

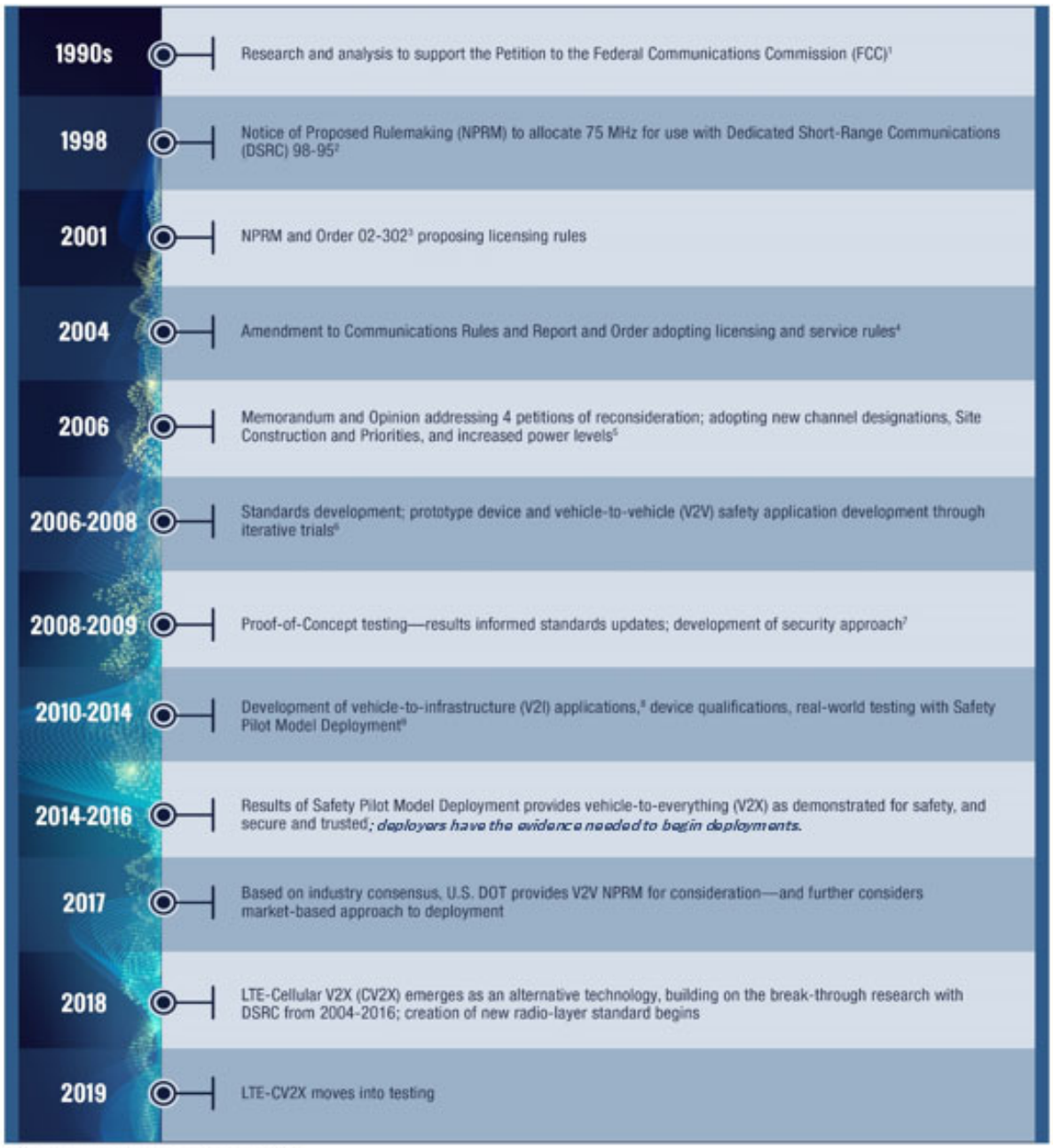
[81] The underlying assumptions and constraints of this analysis includes:
- The information is an assessment that asks the question about how changes to the band plan might affect the Connected Vehicle (CV) pilot sites. In the assessment, we assume that any change results in the same level of service or better as is currently in place for the CV pilots.

In addition to these direct costs, this lost time will also reduce the benefits for deployments. As noted above, operational sites that have deployed and continue to expand their V2X footprint recommend that they may need up to five years to make such significant changes. During such time, these localities will no longer be able to advance the safety and mobility benefits of the deployments. Further, delays due to the need to test new V2X technologies will also postpone any new deployments and the benefits that could have been gained had those deployments occurred sooner.

V. The Need for Adequate Testing to Support any Change to the Band Plan

After the FCC made the initial allocation of the 5.9 GHz band in 1999, US DOT, in collaboration with industry and State and local governments, advanced the development of V2X communications. The significant iterative research and development, standards development, and testing occurred from 2006, with the FCC's Amendment that detailed channel designations, to 2014, with the completion of real-world testing that delivered demonstrated effective, spectrally efficient, secure, and trusted devices and applications for safety-critical conditions. The breadth of reports and analyses that underpin this work shows the time and effort needed to develop a break-through technology that can address critical life-safety challenges in an ever-changing and rapidly moving environment. Collectively, the results of this testing demonstrate that these technologies operate safely and can deliver greater safety to travelers. The key milestones in this process included:

- We assume:
  - That the changes will allow the operational systems to work at a level that makes operations safe and cost efficient.
  - That all standards are completed/updated to implement band plan changes. We recognize that only through testing under real-world conditions can the standards be completed; the sites will need to provide feedback to those standards as part of the change.
  - That vendors are willing to update their equipment to meet new requirements and standards.
  - Costs and time durations are additive to the current CV pilot site operations, availability of funds, and schedules.
  - Labor costs for added staffing to make changes are pulled from current GSA schedule. For specialty labor areas like system and network engineers, costs are pulled from CV Pilot sites and averaged.
  - That any CV operations are maintained during the transition; this will be dependent upon whether the FCC's changes allow for continued use of the channels during transition.
  - That system engineering methods will be used to implement changes including taking steps to appropriately redesign, install, test, refine (if needed), and retest (if needed). The costs include the planning, procurement, and documentation that system engineering best practices require; and that were followed in the CV Pilot and other deployments around the Nation. (Systems engineering is not only a part of the ITS installation process, but results in a higher success rate of integrated and interoperable systems working in the first or first set of efforts.)



[1] Original filing: https://www.fcc.gov/ecfs/filing/183641
[2] https://transition.fcc.gov/Bureaus/Engineering_Technology/Notices/1998/fcc98119.pdf
[3] https://ecfsapi.fcc.gov/file/6513402453.pdf
[4] https://docs.fcc.gov/public/attachments/FCC-03-324A1.pdf
[5] https://docs.fcc.gov/public/attachments/FCC-06-110A1.pdf
[6] https://www.nhtsa.gov/technology-innovation/vehicle-vehicle-communication#resources and https://www.camplic.org/publications/
[7] Id.
[8] https://www.its.dot.gov/ and https://www.its.dot.gov/research_archives/safety/v2i_comm_safety.htm and https://www.its.dot.gov/research_archives/dma/index.htm
[9] Id.
[10] Id.
[11] https://www.regulations.gov/docketBrowser?rpp=25&so=DESC&sb=commentDueDate&po=0&dct=SR&D=NHTSA-2014-0022

Figure 6: Timeline of Key V2X Development Milestones

The purpose here is not to show that the testing of any new V2X technology, such as LTE-CV2X, or new band plan, such as that included in the FCC NPRM, will take the exact same amount of time. In fact, due to the significant work done to test and develop DSRC, we believe

that future testing will be able to move more quickly, as LTE-CV2X may be able to incorporate many of the upper-layer standards and V2V/V2I applications into the device and have the device perform cooperative-ITS communications. Testing is underway to understand this potential.

Instead, the work done to develop DSRC under the existing allocation makes clear that moving from an idea to a band plan and technology suitable for safety-of-life communications is a complex process that takes considerable effort. These complications arise from both the unique aspects of V2X communications and the importance of having confidence that V2X technologies can perform critical safety-of-life applications without challenges from harmful interference, and with the assurance that priority is given to safety communications and that testing results show that all the technologies can actually co-exist within the band. These all underscore that V2X is complicated and that all of these factors must be addressed in any effective band plan.

FCC should, therefore, pause any decision to dramatically alter the 5.9 GHz band until these issues have been addressed through thorough testing in both laboratories and the field. In particular, testing is needed to inform how to set appropriate power levels and out-of-band-emissions filters, as well as to understand antenna positions and directionality. US DOT has already begun testing LTE-CV2X and has performed limited testing (and is continuing to perform quick-turnaround testing) on how the proposed band plan could affect both DSRC and LTE-CV2X. US DOT remains ready to continue working with FCC and other interested agencies to perform the testing to produce the data and evidence needed to support a more comprehensive decision-making process about the most effective use of the 5.9 GHz band.

a. V2X technologies are different from consumer electronics

First, to achieve the reliable connectivity needed to enable safety-of-life communications, V2X must grapple with factors that are, in some respects, more complex than consumer electronic communications. Notably, there is a range of environmental effects on communications when the technology or device is moving rapidly, as discussed above, which make it challenging to keep a steady connection. V2X technology and application development had to address these environmental effects to prove safe and effective performance. Many of these effects are obvious only through real-world conditions testing. They include:

- Doppler spread;
- Multipath propagation;
- Variable Path Loss;
- Ground reflection;
- Non-line-of-sight (NLOS) conditions;
- Atmospheric and weather conditions;
- Terrain contours, vegetation, foliage and other environment features;
- Effects of variable antenna heights;
- Distance between the transmitter and receivers;

- RF shadowing or signal reflectivity due to the presence of large commercial vehicles within the system;[82]
- Hidden node problems; and
- Reflectivity, refraction, diffraction, absorption, or other environmental effects.

In addition, there are key timing and operational performance metrics that were measured, tested and analyzed. The key performance measures from a rapidly moving vehicle perspective include: Packet error rate or packet completion rate; Information Age; Inter packet gap; Latency; Channel busy ratio; and Inter-transmit time, among others.

Moreover, the analysis must take into account different types of interference. US DOT employs at least three types of tests for interference, which include looking not only at the channel in which the V2X exchanges are occurring, but also in the adjacent channels (known as "first adjacent," "second adjacent," and others ("n-adjacent") to measure the energy leakage or "emissions"):

- Ensuring that each device can transmit in a timely manner—that no device is suppressed;
- Ensuring that the message transmission is not corrupted; and
- Ensuring that the receiving devices can "hear" the non-corrupted incoming messages and that the safety-critical messages are prioritized over the less-critical messages.

b. V2X communications require an established ecosystem

In addition, as with any new radio technology, the radio and device itself are but one element to be considered as part of mature technology that performs in an effective and safe manner. The following illustration describes the additional factors at play:

[82] *See* Summary of NHTSA Heavy-Vehicle Vehicle-to-Vehicle Safety Communications Research DOT HS 812 300 at: https://one.nhtsa.gov/DOT/NHTSA/NVS/Crash%20Avoidance/Technical%20Publications/2016/812300.pdf, page 3.

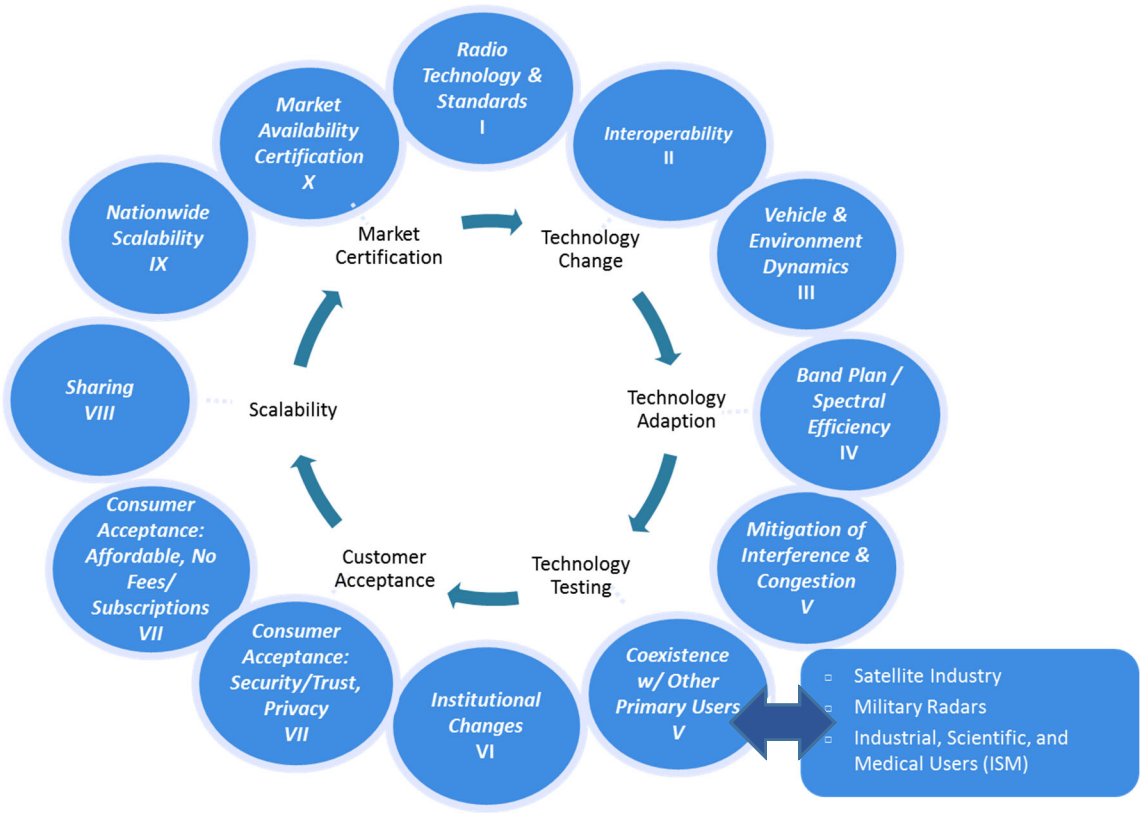


Figure 7: V2X Communications Eco-System

The first V2X communication technology to complete comprehensive testing and with an established eco-system is based on Wi-Fi (IEEE 802.11p) and is commonly referred to as DSRC. Devices and related equipment are available on the market now; they have been certified for safety, performance, and interoperability through a market-based certification solution that emerged in 2017;[83] and these V2X devices with applications are in use, as discussed above.

Throughout the research and development cycle of DSRC, iterative testing was performed to validate that the concept worked in practice, worked with the crash applications and, further, worked with the safety-of-life applications in real-world rapidly moving, highly dynamic conditions (edge use cases).

V2X-DSRC testing spanned from 2008 through 2014 along the lines of this general research and testing framework:

[83] The V2X certification program began as a public-private partnership between the US DOT and certification laboratories. The program eventually became an industry-led certification program run by the OmniAir Consortium, which launched the first DSRC-based certification in 2017. At this time, OmniAir is developing LTE-CV2X test certification procedures and will be performing the first LTE-CV2X radio testing at their April 2020 Plugfest. See: https://omniair.org/news/omniair-preparing-launch-v2x-device-certification/ and https://omniair.org/events/.

- Assessment of the ability of V2X-DSRC devices to operate consistently in highly varied environment and in different conditions, including complex "edge use" cases;[84]
- Measurement of the ability of V2X-DSRC devices to withstand interference from other types of communications near the band or naturally occurring in the environment (interference testing);[85]
- Analysis of the interoperability among different makes/models of V2X-DSRC devices and chipsets (interoperability testing);
- Analysis of V2X-DSRC device ability to perform reliably in the presences of hundreds (and over 1000) nearby devices (scalability) and not congest the spectrum channels such that either the applications stopped working or prevented other devices from transmitting (congestion testing); and
- Testing of devices with real-world drivers (naturalistic testing).

c. V2X can be accomplished in a technology-neutral—not outcome-neutral—environment

At US DOT, we are actively engaged in supporting the deployment of V2X communication technologies that will provide tremendous safety and efficiency benefits. Because transportation communications technologies continue to improve, we continue testing the performance of both emerging (LTE-CV2X) and established (DSRC) communications technologies as they evolve and become more sophisticated.

In the Department's view, being technology-neutral is not the same as being outcome-neutral in determining the appropriate technology to be used for V2X communications, especially those related to critical safety-of-life applications. That is, the Department is supportive of any and all communication technologies that could be used for V2X, but these technologies must be proven to meet safety performance requirements before they can be deployed. Reaching this level of reliability means that these safety technologies require thorough testing under varying and edge-case conditions. It is with this type of test data that the most appropriate basic technical rules—such as safety-of-life priority parameters, device power limits or antenna parameters, spectral limits for OOBE, channel sizes, and other rules—are best set, which will influence any market or policy decisions.

Through recent testing, LTE-CV2X technologies appear to offer similar capabilities in the laboratory, and we support the continued development and testing of the technology. The decision to put LTE-CV2X into use, though, must be balanced against the comparative maturity and public deployment of DSRC in any change to the allocation. The Department has sought public input on this issue both in a late 2018 Request for Comment (RFC),[86] which elicited 171 responses and at a June 3, 2019 listening session that was attended by over 150 government and industry representatives. These outreach efforts identified that (a) there is a divide within

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[84] *See* the NHTSA-CAMP research documents and results at https://www.nhtsa.gov/technology-innovation/vehicle-vehicle-communication and at https://www.campllc.org/publications/.
[85] *See* US DOT's Interference Test Results at https://www.transportation.gov/research-and-technology/safety-band-testing-plans-and-technical-info.
[86] *See* https://www.regulations.gov/docket?D=DOT-OST-2018-0210.

industry over which technology is preferable, and (b) there are a range of questions concerning LTE-CV2X performance.[87] To address these questions, US DOT has developed a test plan designed to provide similar, rigorous, and independent testing, as was performed for DSRC. Key questions addressed by the test plan include:

1) Does LTE-CV2X conclusively support crash-imminent safety applications in non-network connected V2V mode?
2) What is required to prevent interference within and between LTE-CV2X channels?
3) What is required to prevent interference between LTE-CV2X and DSRC channels?
4) Are there LTE-CV2X performance gaps in high device density scenarios?
5) At what level is interoperability at all possible between LTE-CV2X and DSRC (potentially through immediate translation as conceptualized in "dual-mode" devices)? Alternatively, among devices from different vendors?
6) Are the industry LTE-CV2X laboratory results able to be validated through field-testing?

d. V2X Requires dedicated spectrum free from harmful interference

Earlier in this document, the Department discussed the list of key communications requirements for V2X. Two of these requirements are most severely impacted by the NPRM's proposed band plan:

- The requirement for spectrum to be free from harmful interference; and
- The priority of the safety message.

Because the proposal presents significant concerns relating to both these requirements, we provide the additional discussion below.

i. Understanding interference through testing

A crash can occur in less than three seconds. As FCC noted in its Report and Order from 2003, "it is paramount that such communications be protected from interference given the consequences to the traveling public should any one of the safety applications fail due to unacceptable error rates or delay."[88] For a cooperative ITS environment, US DOT defines interference to cooperative communications in three ways:

- Transmission of the V2X message is suppressed—the device senses that the spectrum is in use and it cannot broadcast a message. For DSRC, the device "listens," and if it can hear other uses, it will suppress the messaging. For LTE-CV2X, the device may not schedule its resource blocks in which to transit but, more likely, it may schedule the block to transmit over the block with the weakest signal.
- The V2X message is corrupted upon reception – two or more messages arrive at the receiver, overlapping and causing errors in demodulation and packets.

[87] *See* the US DOT's 2018-2019 V2X Communications Request for Comment (RFC) and responses at https://www.regulations.gov/docket?D=DOT-OST-2018-0210.
[88] *See* FCC 03-324 REPORT AND ORDER, December 2003, ET Docket No. 98-95. https://docs.fcc.gov/public/attachments/FCC-03-324A1.pdf

- The receiving devices cannot "hear" the incoming messages and/or the safety-critical messages are not prioritized over the less-critical messages.

The scenario that is most concerning is that of a building with high Wi-Fi usage located next to busy arterial streets and intersections in dense urban settings. From a road use perspective, configurations such as this can present "edge-case" conditions for transportation:

- Intersections can be complex, with some vehicles moving rapidly while other vehicles are stopped but still employing the V2V/V2I broadcasts.
- Nearby buildings can block line-of-sight identification of vehicles traversing side streets that might also violate stop signs or traffic signals.
- Pedestrians and vulnerable road users (*i.e.*, bicyclists, scooters, blind people, or disabled travelers) tend to be part of the scenario, including passengers alighting from buses.
- A scenario like this can include a critical number of vehicles all transmitting within a 300-meter radius.

US DOT field-testing has taken these types of set-ups and conditions into account when analyzing the collected data. When adding this scenario and its access point for unlicensed Wi-Fi users, potentially streaming video or downloading data, adjacent channel interference becomes a factor in the ability for cooperative V2X communications to properly support safety-critical applications—both V2V and V2I signals being sent to prevent crashes.

The Department has addressed these issues through testing during the development of V2X technology, which can be organized into four time periods, each with a specific focus and some being performed in parallel.

The first period occurred as part of, and shortly after, the initial 1999 allocation while the original band plan rules were being defined and ran until approximately 2012. This testing considered the potential for interference below and above the 5.9 GHz band, which determined that the 5 MHz guard band at 5850-5855 MHz and spatial offset offered enough protection to alleviate the concerns with interference below the band, while the high-powered nature of channel 184, which allowed public safety to "talk over" other transmissions, addressed this need in the upper portion of the band.[89] Testing during this phase also looked into the potential for self-interference (co-channel or adjacent channel interference) caused by DSRC devices operating within the band, which informed the band plan concept that offered a control channel to assist DSRC devices in identifying and using available spectrum addresses these issues.[90] Finally, this initial testing analyzed interference from or affecting co-primary users such as Defense radars, satellite uplinks, or indoor Industrial, Scientific, and Medical (ISM) uses. Studies were performed in the 2000's that identified that interference either would not be a problem for DSRC devices or that DSRC devices would need to cease operations momentarily (on the order of a few microseconds) when in the presence of an established co-primary user

[89] *See* FCC 03-324 Report and Order, December 2003, ET Docket No. 98-95 at https://docs.fcc.gov/public/attachments/FCC-03-324A1.pdf. *See also* Amendment of the Commission's Rules Regarding Dedicated Short-Range Communication Services in the 5.850-5.925 GHz Band (5.9 GHz Band) at https://docs.fcc.gov/public/attachments/FCC-06-110A1.pdf.
[90] Id.

such as military radars. A separate study identified that V2X is unlikely to affect satellite users.[91]

The second period focused on assessing the magnitude and effect of unlicensed Wi-Fi sharing in the 5.9 GHz band with DSRC devices, based on the approached suggested in FCC's 2013 NPRM. Notably, allowing sharing into this band was based on new (at that time) UNII-4 concepts that proposed new ways to mitigate interference and enable sharing. Interference testing during this period focused on baselining the effects of UNII-3 devices on DSRC as a measure of understanding the issue and creating greater certainty for the automotive manufacturers and infrastructure owner/operators who were just beginning investments. This work has culminated in the following reports (summary details are provided in Appendix A):

1. *Impairing Traffic Safety from Changes in the 5.9 GHz band: Introduction of Interference from Unlicensed Users.*[92] This analysis looked specifically at the re-channelization approach. Using measured data from field tests, we can conclude that there will be significant, negative degradation of V2X communications due to the move of critical V2X messaging into three channels at the upper end of the band. With such a move, we can see the effects of the UNII transmissions on the ability to send and receive basic safety messages. We anticipate that the effect will apply to LTE-CV2X exchanges as well.
2. *Analysis of 2016 Proposed Changes to Existing Out of Band Emissions (OOBE) Rules.*[93] This analysis identified that the FCC's amended rules increase the permissible OOBE levels of UNII devices, thus raising the risk of adjacent channel interference into the 5.9 GHz band. While the report focuses on interference from UNII devices operating up to 5850 MHz, this same effect can be expected with this new proposed band plan that will allow UNII-3 devices to operate up to 5895 MHz.
3. *Preliminary Technical Assessment of Out-of-Channel Interference (Out-of-Band Emissions).*[94] US DOT performed this analysis with the Crash Avoidance Metrics Partnership (CAMP) to understand the feasibility of sharing. The tests are laboratory-based and conclude that unlicensed Wi-Fi operating in the lower 45 MHz will interfere with DSRC operations. We can anticipate seeing similar interference from unlicensed operations above the 5.9 GHz band.
4. *US DOT Spectrum Sharing Test Report.* US DOT and its partners conducted tests to measure and understand interference to DSRC by Wi-Fi transmitters in the same and

[91] *See DSRC/FSS Earth Station Spectrum Sharing Protocol*, submitted to FCC in February 18, 2008.
[92] *See Impairing Traffic Safety from Changes in the 5.9 GHz band: Introduction of Interference from Unlicensed Users.* Additional information can be found at https://www.transportation.gov/research-and-technology/impairing-traffic-safety-changes-safety-band-introduction-interference.
[93] *See Analysis of 2016 Proposed Changes to Existing Out of Band Emissions (OOBE) Rules*. Additional information may be found at https://www.transportation.gov/research-and-technology/analysis-2016-proposed-changes-existing-out-band-emissions-oobe-rules
[94] *See Vehicle-to-Vehicle Communications Research Project (V2V-CR) DSRC and Wi-Fi Baseline Cross-channel Interference Test and Measurement Report -Pre-Final Version*, December 2019. At: https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/v2v-cr_dsrc_wifi_baseline_cross-channel_interference_test_report_pre_final_dec_2019-121219-v1-tag.pdf.

adjacent channels under a wide range of laboratory and field conditions and scenarios.[95] The most significant finding noted in the draft report[96] is that Wi-Fi access points (UNII-3) cause critical interference to DSRC communications when located 100 meters or more away. Co-channel sharing with Wi-Fi or any unlicensed radio service with similar power and duty cycles will not be possible without a robust and reliable sharing mechanism that defers to the priority safety messages. It is also significant that now a dataset exists that:

- Informs us about interference expectations under a wide variety of environmental conditions that moving vehicles experience.
- Illustrates the effects of UNII-3 devices that used the same parameters as found in the proposed band plan in the FCC's NPRM.
- Establishes a foundation for testing the UNII-4 devices in the field under similar real-world conditions and edge-condition cases.

US DOT testing during this phase also involved working with FCC to test prototype UNII-4 devices that had been delivered to the FCC in Fall of 2016, as part of the "Phase 1 testing" that had begun through the coordination of the Department, FCC, and the National Telecommunications and Information Administration (NTIA).[97] The testing focused on two types of UNII-4 devices: (1) re-channelization devices that offer a mitigation based on the ability to sense DSRC messages and give DSRC message priority; and (2) detect-and-vacate devices that will leave the 5.9 GHz band when they hear DSRC devices in use. The FCC's report was published in late 2018. While FCC and US DOT saw some promising aspects of the UNII-4 mitigations, certain results and measurements clearly illustrate interference that would be detrimental to V2X communications. As this testing was performed only in a laboratory, "Phase 2" of joint testing plan was envisioned to understand the performance of UNII-4 devices with vehicles in motion by moving the prototypes to US DOT laboratory and field settings. The operational re-channelization device was provided in Fall 2019 and the detect-and-vacate device was received in February 2020. Testing is underway to answer open questions about whether these types of devices can share the band with DSRC. Phase 3 of the joint testing plan, which has not yet begun, is expected to involve testing the performance of these technologies in on-road setting on actual vehicles.

In parallel to the DSRC-UNII sharing testing, the Department has launched additional testing, which involves assessing the newest technology to emerge—LTE-CV2X—to assess its capabilities.[98] With the emergence of prototype devices in Summer 2019, US DOT acquired devices for testing. The initial testing focus is on validating the industry's test and simulation results, work that has been underway since September 2019 in US DOT's partner laboratories.

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[95] US DOT Spectrum Sharing Analysis Plan: Effects of Unlicensed-National Information Infrastructure (U-NII) Devices on Dedicated Short-Range Communications (DSRC.) at. https://www.its.dot.gov/research_archives/connected_vehicle/dsrc_testplan.htm.

[96] US DOT Spectrum Sharing Test Report: Effects of Unlicensed-National Information Infrastructure-3 (U-NII-3) Devices on Dedicated Short-Range Communications (DSRC), *see* Additional information may be found at https://www.transportation.gov/research-and-technology/us-dot-spectrum-sharing-test-report-effects-unlicensed-national-information.

[97] As noted in the joint agency letter to Congress, located at: https://docs.fcc.gov/public/attachments/DOC-337251A1.pdf.

[98] As noted on slide 9 at this schedule at https://www.transportation.gov/sites/dot.gov/files/docs/research-and-technology/363111/arnold-slides-v3-19nov2019-update.pdf.

With an announcement soliciting hundreds of devices,[99] US DOT is preparing to put LTE-CV2X devices into test under the more challenging real-world conditions and edge-condition cases. By acquiring hundreds of devices, we will be able to test and resolve questions about scalability, channel congestion, and interoperability. Essentially, the same testing performed on DSRC will be applied to LTE-CV2X in a much-compressed timescale, which is possible by leveraging the knowledge gained in the testing of DSRC.[100]

Finally, the fourth and most recently launched phase of the Department's testing on interference has been its assessment of the magnitude and effect of the proposed band plan in the current FCC NPRM. As part of this testing, which has attempted to determine the probabilities of interference that could result from the FCC's NPRM, the Department took UNII -3, DSRC, and LTE-CV2X devices into a laboratory to look at each device's emissions profile to understand whether we can anticipate interference in adjacent channels. With this preliminary work, the Department found that the three devices cannot co-exist in the same band and presented the results in a white paper titled, *Preliminary Technical Assessment of Out-of-Channel Interference Out-of-Band Emissions.*[101]

As part of this preliminary report, the Department also performed analysis using FCC's Phase 1 results to illustrate the expected interference. Results show that the proposed band plan does not provide for enough isolation—frequency isolation or spatial isolation—to protect either DSRC or LTE-CV2X from UNII transmissions. Table 5 shows these results.[102] We note that the 5GAA filing on the FCC docket on January 24, 2020 appears to support these conclusions, noting from their analysis that, "[t]his leaves at least 33.7 dB of additional necessary suppression, which would reduce the OOBE level from -27 dBm/MHz to more than -60 dBm/MHz," and suggesting that FCC adopt a tighter OOBE limit to achieve OOBE suppression to -60 dBm/MHz into the 5.9 GHz band.[103]

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[99] Solicitation at https://beta.sam.gov/opp/0678d5124e52475cbc03f6c8800c10e3/view.
[100] The planned test schedule is located at https://www.transportation.gov/sites/dot.gov/files/docs/research-and-technology/363111/arnold-slides-v3-19nov2019-update.pdf, slide 11.
[101] This white paper, *Preliminary Technical Assessment of Out-of-Channel Interference (Out-of-Band Emissions)* is located at https://www.transportation.gov/research-and-technology/preliminary-technical-assessment-out-channel-interference-out-band-emissions.
[102] The full analysis is located in this working white paper, *Analysis of FCC Phase I Sharing Report: Out of Band Emissions for UNII Adjacent and Next Adjacent Channel Power* at https://www.transportation.gov/research-and-technology/analysis-fcc-phase-i-sharing-report-out-band-emissions-unii-adjacent-and.
[103] The filing is located at https://ecfsapi.fcc.gov/file/101242472530463/5GAA%206%20GHz%20Ex%20Parte%2001.24.20.pdf, *see* pages 1-2.

Table 5: Effects of FCC's OOBE Changes

	Energy in DSRC Channel 180	**Energy in LTE-CV2X Channel 183**
20 MHz U-NII below proposed new 5.9 GHz band	-14.25	-31.31
20 MHz U-NII above proposed new 5.9 GHz band	-38.98	-16.19
40 MHz U-NII below proposed new 5.9 GHz band	-13.88	-18.97
40 MHz U-NII above proposed new 5.9 GHz band	-27.37	-15.95
80 MHz U-NII below proposed new 5.9 GHz band	-18.95	-23.33
80 MHz U-NII above proposed new 5.9 GHz band	-29.99	-18.78

Based on these analyses, the Department is greatly concerned that the band plan included in the NPRM would, if finalized, have a significant risk of harmful interference that would either degrade or make unusable the 30 MHz that would remain allocated for V2X, especially for safety applications. These analyses also highlight that the proposed device parameters in the NPRM require further analysis and testing.

From this work, we also understand that, with the limitation of a total 30 MHz allocation, neither of the two existing V2X technologies—DSRC or LTE-CV2X—will be able to use the 30 MHz allocation effectively, nor can their operations be accommodated together in the band due to the likelihood of unlicensed inference.

The issues associated with energy bleed and adjacent channel interference can be summarized as:

- V2X-DSRC in channel 180 cannot coexist next to UNII: UNII operations in 160 MHz channels up to 5.895 GHz are expected to bleed energy into channel 180 (5.895-5.905 GHz), causing interference to the proposed V2X-DSRC channel.
- UNII will likely effect LTE-CV2X below channel 183: In preliminary testing, results suggest that unlicensed transmissions up to 5.895 GHz will likely affect LTE-CV2X in a similar manner—unlicensed Wi-Fi will emit interference into the upper 30 MHz and destabilize or suppress LTE-CV2X transmissions. Testing is ongoing to understand the magnitude of the effect.
- V2X DSRC and LTE-CV2X in adjacent channels: Preliminary measurements indicate significant energy leakage into the adjacent channel by both technologies, making them unusable in the same location. In addition, energy from V2X DSRC and LTE-CV2X has not been measured into channel 178, but there is no reason to expect the energy not to effect U-NII operations.
- UNII will likely affect LTE-CV2X from above channel 183: Given that the FCC is planning unlicensed Wi-Fi uses from 5.925-7.125, US DOT expects similar issues to

affect channel 184 (which is expected for use in LTE-CV2X operations as part of channel 183).

FCC's NPRM did not provide any alternative data or results showing that the three technologies can coexist in the proposed band plan. Thus, users of both technologies would need guard bands or buffers, which the proposed band plan does not include. This means that the "45-30" split included in the NPRM would actually provide significantly less spectrum for V2X, as guard bands would need to exist between: (1) UNII and DSRC; (2) DSRC and LTE-CV2X; and (3) LTE-CV2X and UNII. More testing will be needed to determine the magnitude and impact of that interference on devices performing safety-critical exchanges in a rapidly moving and a highly dynamic vehicular environment.

ii. Priority of the safety message

Finally, a crucial aspect of preventing interference is that priority be given for basic safety messaging, which has been removed in the FCC NPRM without explanation. In this respect, the proposed band plan is likely to be unworkable even if other interference concerns are addressed:

- By fully removing 95.3159 in the OBU section and parts (d) and (e) of 90.377 in the RSU section, the FCC negates the purpose of the ITS crash-imminent, safety-of-life communications. Removing this language has the effect of requiring that, in densely congested areas, priority safety-of-life messages wait for other users to finish transmitting, during which time, a crash can occur (we note that a crash set-up and occurrence can happen in under three seconds).
- Further, by removing this language, FCC undercuts the public safety use of this spectrum, thereby allowing commercial uses (with an expectation of larger, longer message exchanges) that will interfere with the basic safety messages, suppress V2X transmissions, or create delays that will result in crashes.

Even were the safety priority to be restored, the band plan in the NPRM would likely result in harmful interference that would jeopardize V2X communications for safety-of-life purposes. Without test data specific to the conditions and parameters as stated in Appendix B of the FCC's NPRM, it cannot be determined whether this proposed band plan will work for transportation safety.

Appendix A: Recent US DOT Testing on Interference and other Spectrum Matters

A.1 Analysis of FCC Phase 1 Sharing Report to Examine Out-of-Band Emissions for UNII Adjacent and Next Adjacent Channel Power in the NPRM's Proposed New Band Plan

Analysis of FCC's Phase 1 Results Illustrate the Expected Interference[104]

Prior to the NPRM, we conducted testing using the U-NII channel bandwidths that were presented in the FCC's Phase I sharing report to examine potential OOBE interference into the adjacent 10 MHz and 20 MHz channels that the FCC has suggested could serve all transportation low-latency, high availability needs. For this analysis, US DOT looked at the power leakage into DSRC channel 180 and LTE-CV2X channel 183 from a U-NII "interferer" both above and below these two bands. Since we know the energy in the 20 MHz below channel 177, we used that as the basis to determine the process for calculating the power present.

Results illustrate that FCC's proposed band plan in Appendix B of the NPRM does not provide for enough isolation—frequency isolation or spatial isolation—to protect either DSRC or LTE-CV2X from UNII transmissions. The FCC's 2016 changes in the OOBE laws result in the high probability of problematic or harmful interference. The Table below provides the analysis results.

Table 6: Out-of-Band Emission into Proposed Transportation Channels

	Energy in DSRC Channel 180	**Energy in LTE-CV2X Channel 183**
20 MHz U-NII below proposed new 5.9 GHz band	-14.25	-31.31
20 MHz U-NII above proposed new 5.9 GHz band	-38.98	-16.19
40 MHz U-NII below proposed new 5.9 GHz band	-13.88	-18.97
40 MHz U-NII above proposed new 5.9 GHz band	-27.37	-15.95
80 MHz U-NII below proposed new 5.9 GHz band	-18.95	-23.33
80 MHz U-NII above proposed new 5.9 GHz band	-29.99	-18.78

We note that the 5GAA filing on the FCC docket on January 24, 2020 appears to support these conclusions, noting from their analysis that, "[t]his leaves at least 33.7 dB of additional

[104] This is the same working white paper as noted in footnote 102. It can be found at https://www.transportation.gov/research-and-technology/analysis-fcc-phase-i-sharing-report-out-band-emissions-unii-adjacent-and Note that to achieve these results, we used a discrete integration technique to complete a Riemann summation to estimate a discrete integration such that the analysis approaches a true integral definition.

necessary suppression, which would reduce the OOBE level from -27 dBm/MHz to more than -60 dBm/MHz," and suggesting that FCC adopt a tighter OOBE limit to achieve OOBE suppression to -60 dBm/MHz into the 5.9 GHz band.[105]

US DOT concludes that the full impact will not be known unless a rigorous technical assessment is completed.

A.2 US DOT Analysis: Results from November 2019 Testing of the Basic NPRM Premise of Three Technologies Coexisting in the 5.9 GHz Band

US DOT Analysis of Adjacent Channel Interference—US DOT Testing: Preliminary Results on Out-of-Channel Interference (Out-of-Band Emissions) [106]

To inform our understanding of the revised 5.9 GHz band allocations in the FCC's proposal, US DOT went into the laboratory to investigate the ramifications of the new proposed rules. In considering the proposed changes to the band plan, in November 2019, US DOT took LTE-CV2X devices into a laboratory where testing was ongoing with DSRC and UNII devices to assess the feasibility of spectrum sharing (Phase 2 of the FCC-US DOT-NTIA spectrum sharing test plan). This analysis for the first time, brought LTE-CV2X, UNII-3, and V2X-DSRC devices together to examine the probability for adjacent channel interference from any of the devices to interfere with the basic safety message.

In our analysis, we compared all three technologies in a similar plot to illustrate the out-of-band emissions (OOBE). In doing so, we observed that OOBE extends beyond the channels with varying ranges of energy extending outside of the designated channel:

- Energy from the LTE-CV2X, only 17dB down, leaks into the adjacent channel;
- Energy from the UNII, only 20 dB down, leaks into the adjacent channel; and
- Energy from the DSRC, at 40 dB down, leaks into the adjacent channel.

While additional testing is needed to determine the level of interference from one device to another, it is apparent from this analysis that the basic framework in the NPRM will result in interference. These results raise the question of the reliability of V2X communications in this configuration. Without a high level of reliability, transportation safety cannot be assured. These preliminary results also suggest that the rules and the division of spectrum, as described in the NPRM, may result in significant adjacent channel interference between the different radio services and should be examined further. These results can also be found on the Department's 5.9 GHz band website.

[105] The filing is located at https://ecfsapi.fcc.gov/file/101242472530463/5GAA%206%20GHz%20Ex%20Parte%2001.24.20.pdf, *see* pages 1-2.

[106] This technical assessment is the same as the one referenced in footnote 102. It can be found at https://www.transportation.gov/research-and-technology/preliminary-technical-assessment-fcc-59-ghz-nprm.

A.3 Impairing Traffic Safety from Changes in the 5.9 GHz band: Introduction of Interference from Unlicensed Users

Impairing Traffic Safety from Changes in the Safety Band: Introduction of Interference from Unlicensed Users[107]

US DOT and its test partner, NTIA's Institute of Telecommunications Sciences in Boulder, Colorado (NTIA-ITS Boulder), developed this analysis to examine the effects of re-channelization, as it was proposed by industry in 2016. Using measured data from field tests, this analysis presents a structured, technical analysis of re-channelization, as proposed in the FCC docket by U-NII vendors. The analysis of the re-channelization approach concludes that there will be a significant, negative degradation of transportation safety communications and the ability to support the range of V2V, V2I, and public safety functions as currently in operation in with the 5.9 GHz band plan. This effect is due to the self-interference and adjacent channel interference experienced when moving the three V2X channels next to each other in the upper band without any isolation from the U-NII transmissions. Re-channelization will significantly affect the ability to transmit and receive the broadcast basic safety messages (BSMs) and similar messages such as emergency vehicle messages, signal phase and timing (SPaT) information, and other critical safety and security information. Similar to the first report, this type of interference is anticipated to affect LTE-CV2X exchanges as well.

A.4 Analysis of 2016 Proposed Changes to Existing Out of Band Emissions (OOBE) Rules

Analysis of 2016 Proposed Changes to Existing Out of Band Emissions (OOBE) Rules: Adjacent Channel Interference from Unlicensed National Information Infrastructure (UNII) Transmissions into the 5.9 GHz[108]

In its earlier 2013 NPRM, FCC proposed amending Part 15 of its rules governing operation of U-NII devices in the 5 GHz band; in particular, for devices operating in the spectrum directly below the 5.9 GHz band. The amended rules increase the permissible OOBE levels of U-NII devices, thus raising the risk of adjacent channel interference into the 5.9 GHz band. US DOT's analysis concludes that, while the increase in OOBE identified in Part 15.407 (issued March 1, 2016) represents an improvement over the OOBE limits allowed for digitally modulated devices in Part 15.247, the new OOBE limits described in Part 15.407 are above the previous levels allowed for U-NII devices, and the level of potential interference has significant potential to disrupt 5.9 GHz band device access to the safety-of-life channel.

[107] This report is the same analysis referenced in footnote 92 and can be found at https://www.transportation.gov/research-and-technology/impairing-traffic-safety-changes-safety-band-introduction-interference.

[108] This report is the same analysis referenced in footnote 93 and can be found at https://www.transportation.gov/research-and-technology/analysis-2016-proposed-changes-existing-out-band-emissions-oobe-rules.

A.5 DSRC and Wi-Fi Baseline Cross-channel Interference Test and Measurement Report

Vehicle-to-Vehicle Communications Research Project (V2V-CR) DSRC and Wi-Fi Baseline Cross-channel Interference Test and Measurement Report[109]

US DOT performed this analysis through a partnership with the Crash Avoidance Metrics Partnership (CAMP, which represents automotive manufacturing research organizations). The partnership performed laboratory testing from 2016-2018. The report concludes that unlicensed Wi-Fi operating solely in the lower 45 MHz of the 5.9 GHz band (5.850-5.895 MHz) will interfere with DSRC when DSRC is pushed to operate in the upper 30 MHz (5.895-9.25 MHz) of the 5.9 GHz band. These cross-channel emissions were measured during field tests that replicated basic (not highly dynamic or complex) transportation movements. As unlicensed Wi-Fi use grows, we can conclude that the probability for greater amounts of harmful interference to V2X communications will also grow. While the report used DSRC as the V2X communications technology, it is anticipated that operations of LTE-CV2X devices seeking to operate in the uppermost 20 MHz (5.905-5.925 MHz) of the 5.9 GHz band will also be subject to interference from unlicensed Wi-Fi. The interference is expected from both the lower 45 MHz as well as from spectrum in use above the 5.9 GHz band (5.925-7.125 MHz) that is being repurposed for unlicensed operations. US DOT has posted this report on the 5.9 GHz band website.

A.6 US DOT Additional Analytical Results on Adjacent Channel Interference under Real-World Conditions

US DOT Spectrum Sharing Test Report: Effects of Unlicensed-National Information Infrastructure Device Transmissions in the Third Band (U-NII-3) on Dedicated Short-Range Communications (DSRC) (DRAFT report)[110]

In parallel with the FCC's Phase 1 laboratory testing to determine the performance of UNII-4 devices and their sharing capabilities, US DOT performed field-testing to understand the magnitude of UNII-3 transmissions on V2X communications. The report describes the testing that the US DOT conducted to measure and understand the ability for unlicensed Wi-Fi to share the 5.9 GHz band with V2X DSRC. It also investigated the level and impact of interference to V2X-DSRC by Wi-Fi transmitters in the same channel and in an adjacent channel. US DOT tested a wide range of conditions and scenarios, which generated numerous results. The most significant finding from these tests is that Wi-Fi access points cause significant interference to DSRC communications when located 100 meters or more away, even if operating an access point inside a building or on an adjacent channel or with a moderate traffic load. This represents a significant impact to safety given that DSRC was designed to provide situational awareness in a safety zone defined by a 300 m radius around a vehicle. Co-channel sharing with Wi-Fi or any unlicensed radio service with similar power and duty cycle as Wi-Fi will not be possible without a robust and reliable sharing mechanism that defers to the high priority safety messages.

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[109] This report is the same analysis referenced in footnote 94 and can be found at https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/v2v-cr_dsrc_wifi_baseline_cross-channel_interference_test_report_pre_final_dec_2019-121219-v1-tag.pdf.

[110] The draft is located at https://www.transportation.gov/research-and-technology/us-dot-spectrum-sharing-test-report-effects-unlicensed-national-information.

Similarly, a reallocation of channels would need to provide guard bands to protect both radio services from adjacent channel interference from the other.

US DOT testing focused mostly on co-channel radio performance; however, testing also revealed some preliminary findings on adjacent channel interference. USDOT's Phase 2 testing will build on these initial results to better understand the impacts of reallocating the band to place DSRC/ITS and unlicensed devices in adjacent channels.

Outcomes: The desired outcomes of the Phase 1 testing were:

1. Generate experimental data from individual devices for models of potential interference at deployment scale (hundreds to thousands of devices in range).
2. Define bounding cases where no sharing may be possible, where unrestricted sharing may be possible, and exploring any zone in between where design choices and regulation impact the potential for sharing.
3. Understand interference mechanisms well enough to shed light on possible ways to mitigate them.
4. Create the technical grounding for USDOT policy related to spectrum sharing.

Key findings:

- **Co-channel interference** from a <u>weak</u> outdoor Wi-Fi access point with minimal power (50 times less than the DSRC power) and a light traffic load (10%) caused untenable interference as far as 300 m from the access point.
    - Putting the weak access point inside a wooden building reduced the interference but it was still untenable 100 m from the building.
    - Putting the weak access point inside a brick or filled-cinderblock building mitigated the interference.
    - If the building had windows, the interference when the vehicle was exposed to the access point through a window as it drove by was the same as if the access point was outside, that is, untenable.
- **Co-channel interference** from a <u>strong</u> outdoor Wi-Fi access point at high power (EIRP=36 dBm), highly loaded (70%) opposite DSRC running at four times higher power than would be deployed (EIRP=25 dBm) caused untenable interference at least 800 m from the access point.
    - Putting the strong access point in a wooden building made no difference. It was untenable at all ranges.
    - Putting the strong access point in a brick or filled-cinderblock building reduced interference but it was still untenable to at least 200 m and significant to 800 m.
- Interference was far more sensitive to the traffic load transmitted by the Wi-Fi than the power level. As noted above, even the weakest power level was enough to cause interference, so the number of Wi-Fi packets in the air and the space between them, which is determined by the loading, is what mattered most.
- A regular periodic distribution of Wi-Fi traffic caused about 10-20% more packet errors than a more random Poisson distribution. We provide data that can be used to scale

between tests using easier to control periodic Wi-Fi traffic and those using more realistic Poisson traffic.

- Actual interference during deployment would be bounded by these high power-high load, and low power-low load cases. That means real-world interference will be something in between these particular measurements. It is unlikely to be less or more than the extent described here.
- **Adjacent channel interference** from a Wi-Fi access point at high power (EIRP=36 dBm) but moderate traffic load (15%) caused significant interference 200 m from DSRC.
- Interference from Wi-Fi in an adjacent channel typically resulted in significant packet errors 200-350 m away for traffic loads of 15% and higher. This interference included gaps in the DSRC traffic greater than half of a second, which may be safety critical. For traffic loads less than 15%, the packet errors were more likely to cluster in gaps of missing BSMs less than half of a second long. Those may, or may not, be safety critical depending on the sensitivity of the safety application and level of channel congestion.

One example is the measured data that shows a packet error rate (PER) at 30 percent for DSRC with the UNII transmitting at a moderate load of about 15 percent. (Wi-Fi in adjacent channel EIRP is 36 dBm). This PER can climb to as high as 80 percent within a 200 meter range. The graph below illustrates these results—the blue lines are for each BSM and the red line represents the 0.5-second rolling average (which illustrates the PER). The roadside unit is located at 0 meters, the UNII device at 160 meters, and the vehicle is driving between 0 and 2000 meters before turning around.

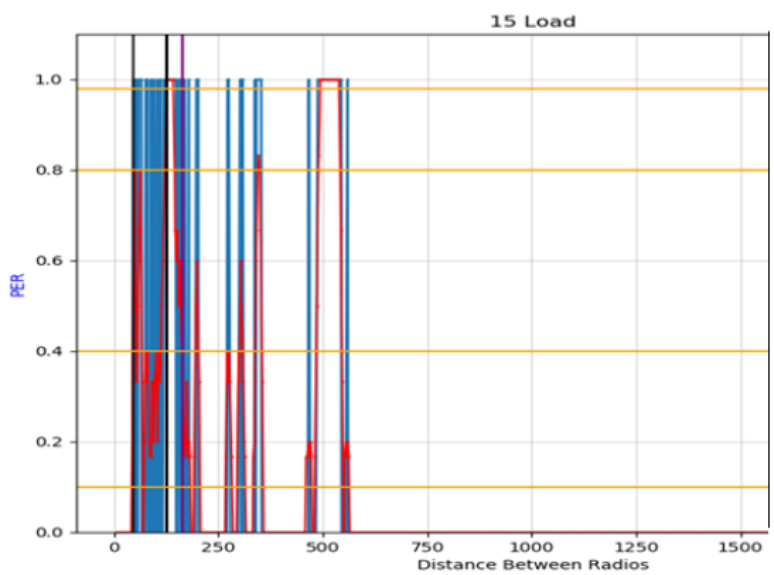


Figure 8: UNII-3 Interference with DSRC at 15 percent Load

Even in an adjacent channel, one radio service can interfere with another service 100 to 200 meters away. The report provides additional, similar results that represent a significant impact to safety given that V2X-DSRC was designed to provide situational awareness in a safety zone defined by a 300 m radius around a vehicle. Co-channel sharing with U-NII-3 Wi-Fi or any unlicensed radio service with similar power and duty cycle as Wi-Fi will not be possible without a robust and reliable sharing mechanism that defers to the high priority safety messages. Similarly, a reallocation of channels would need to provide guard bands to protect both radio services from adjacent channel interference from the other.

- DSRC was designed to provide situational awareness in a safety zone defined by a 300 m radius around a vehicle. Even operating an access point in a building or on an adjacent channel still causes interference 100 m or more away so would have a significant impact on safety. Co-channel sharing with Wi-Fi or any unlicensed radio service with similar power and duty cycle as Wi-Fi will not be possible without a robust and reliable sharing mechanism that defers to the high priority safety messages. Similarly, a reallocation of channels would need to provide guard bands to protect both radio services from adjacent channel interference from the other.
- The DSRC receiver is more susceptible to interference from Wi-Fi than the DSRC transmitter. Most of the interference measured, especially at the long ranges was due to packets corrupted at the receiver.
- Suppression of DSRC transmissions happened only at much shorter ranges (25-75 m) and was far less than interference to a receiver at the same distance from the Wi-Fi. Because the 10 MHz DSRC and the 20 MHz Wi-Fi radios do not recognize each other's packets, their clear channel access mechanisms only kick in at the much less sensitive energy-detect threshold.
- Suppression of DSRC transmissions might be more significant if DSRC was operating in the 20 MHz channels. Both DSRC and Wi-Fi are based on the same 802.11 protocols so they could detect each other's symbols. That detection has a more sensitive detection threshold. In that case, they would be likely to suppress each other's transmissions at a much further distance.

THE SECRETARY OF TRANSPORTATION
WASHINGTON, DC 20590

November 20, 2019

The Honorable Ajit Pai
Chairman
Federal Communications Commission
445 12th Street, SW
Washington, D.C. 20554

Re: Draft of Notice of Proposed Rulemaking
In the Matter of Use of the 5.850-5.925 GHz Band

Dear Chairman Pai:

Thank you for your transmittal on Friday, November 8, 2019 of the Commission's draft of a Notice of Proposed Rulemaking (NPRM) relating to the use of the 5.850-5.925 GHz spectrum band (the Safety Band or the 5.9 GHz Band). The Department of Transportation (Department or DOT) is pleased to respond and to provide comments.

DOT appreciates FCC's continued consideration of the important issues raised in this proceeding. Nonetheless, DOT has significant concerns with the Commission's proposal, which represents a major shift in the FCC's regulation of the 5.9 GHz Band and jeopardizes the significant transportation safety benefits that the allocation of this Band was meant to foster.

During 2017, there were over 6 million police-reported vehicle crashes in the U.S. that resulted in 37,133 lives lost, as well as 2,746,000 injuries. These crashes also resulted in economic harm of approximately $250 billion in direct costs and over $800 billion when the loss of life, injuries, and other quality of life factors are put into dollars. Further, traffic congestion costs are estimated at over $140 billion annually and continue to increase.

Due to the significant potential vehicle-to-everything (V2X) technologies have to reduce these societal crises, it is imperative to the Department that the full 75 MHz of the 5.9 GHz Band is preserved for its existing purposes, including transportation safety and other intelligent transportation purposes. To that end, the Department would support a proposed revision to the existing band plan from specifying Dedicated Short Range Communications (DSRC) to a technology-neutral approach that preserves the entire band for its existing purposes, but allows the market, and not the Federal government, to determine the specific communication technology that will best achieve these purposes. Further, if spectrum-sharing technology is proven feasible after completing Phases 2 and 3 of DOT's spectrum sharing research plan, the band plan could be further modified to allow

for such sharing—thereby maximizing the utilization of this valuable spectrum for all stakeholders.

Contrary to the FCC's proposal, this spectrum band is already being actively used by industry and by a variety of additional private and public sector stakeholders, and continues to hold even greater promise in the very near future. In addition, Canada and Mexico also have dedicated the same 75 MHz to transportation, which positions North America to have a single standard for vehicles produced in the United States and exported and, importantly, to keep connected vehicle capabilities from failing as vehicles move across our borders.

The Department would like to continue its dialogue with the Commission and with other interested agencies on these concerns before the proposal is issued. This would permit a more robust and meaningful public comment period, and would also reaffirm the agencies' interests in conducting testing on spectrum interference and the other complex issues raised by the proposal. However, to the extent that the FCC deems it necessary and appropriate to proceed with a proposal at this time, the Department is offering comments aimed at ensuring that the NPRM is accurate and balanced, and that it reflects the Administration's commitment to improving traffic safety and mobility for all Americans.

To assist the Commission in that endeavor, the Department is providing comments in a memorandum summarizing our concerns with the NPRM as well as notations to the draft NPRM. As explained in those comments, DOT agrees with FCC's decision to remove the "all unlicensed" option that it had previously considered in an earlier draft. Notwithstanding that change, there are a number of critical issues that should be more fully considered and discussed in the interest of protecting adequate spectrum for transportation safety and mobility use, including the following:

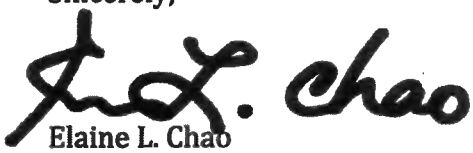
- The transfer of 45 MHz out of 75 MHz of transportation safety spectrum for unlicensed Wi-Fi;
- The apparent removal of the priority for safety messages in the remaining 30 MHz for transportation;
- The overreliance on particular forms of technology, rather than promoting a technology-neutral approach to address transportation safety;
- The lost potential of this spectrum to provide the well-identified public benefits of reduced traffic deaths and intelligent transportation systems, consistent with Congress's will, such as:
    - A substantial reduction of public safety benefits for the Nation, with thousands more deaths annually on the road and millions more injuries than would be the case otherwise;
    - A significant effect on current users of this spectrum and traveling citizens; and
    - A limitation on future transportation technology evolution and innovations for automation, putting the United States at a competitive disadvantage;

- The discontinuation of a thorough testing endeavor involving both laboratory and real-world scenarios, which the agencies have been conducting to ensure that the Commission's decisions are fully grounded in the best available science;
- An absence of cost-benefit analyses on which to base decision making for the Nation, including the omission of a novel approach to broadband Wi-Fi that recently emerged on the market—802.11ax—that has the potential to change the nature of the broadband industry's needs for this spectrum;
- Mistaken assumptions about deployment advances and current and expected use of the spectrum for transportation safety; including assumptions about technology evolution for DSRC, C-V2X and 5G related to backwards compatibility and interoperability;
- The rationale for dividing the 75 MHz allocation to produce faster Internet streaming for infotainment is not commensurate with the significant National transportation public safety benefits that are being realized in the real world;
- The recognition that all or some combination of the three communications media may not be able to operate properly in the same band.

In light of these concerns, the Department's view is that the NPRM, and the substantial shift in direction that it represents, is insufficiently grounded.

DOT looks forward to a more extended discussion with the FCC and other stakeholders on the path forward for the 5.9 GHz Band, including the opportunity to partner in testing, to produce a more rigorous and objective analysis for a new band plan, and to reformulate the Commission's proposal. In the meantime, it is DOT's view that the proposal should be withheld from public issuance, and that in all events, any proposal that the Commission issues be refined further to address these concerns.

Sincerely,



Elaine L. Chao

Critical Discussion Items

This memorandum describes the Department of Transportation's (the Department or DOT's) concerns and recommendations relating to the Federal Communications Commission's (FCC's) November 8, 2019 draft of a proposed rulemaking relating to the use of the 5.850-5.925 GHz spectrum band. These points are made with greater specificity within the accompanying draft NPRM mark-up. DOT would like to meet with FCC and other interested agencies to discuss these concerns before the issuance of an NPRM.

Reduction in spectrum for traffic safety

This draft NPRM presents a dramatic shift in the current rules and the spectrum allocation for transportation use. This shift would result in the loss of 45 MHz of the allocation for transportation safety—limiting transportation to 20 MHz of usable spectrum given highly probable interference issues in adjacent channels and the need for a "guard band" between Wi-Fi and ITS operations. DOT has produced analysis that illustrates that this is not enough spectrum to result in the broad and significant safety and mobility benefits that were intended by the allocation of this band and the subsequent investments in it, let alone to provide the spectrum needed to accommodate future connected and automated vehicle (CAV) applications (such as management of automated platoons, greater situational awareness for automated vehicles, coordinated intersection movement, and others).

An allocation of just 20 MHz of useable spectrum results in a significant loss for transportation safety, including:

- An inability to embrace a wide range of vehicle-to-infrastructure (V2I) or infrastructure to vehicle (I2V) applications, such as system efficiency, road weather, transit and freight logistics, and public safety applications as part of V2X communications;
- A significant cost to those currently deploying and operating in this band for transportation safety, or those investing in it;
- A curtailing of new connected automation applications, just at the point in time when these and other important edge-computing, machine-to-machine, and artificial intelligence innovations are emerging. These include an expected cessation of truck platooning at the point when private sector testing is turning this into commercial uses. This is an important application for freight logistics (among other uses).

With the limitation of a 30 MHz allocation, we note that neither of the two technologies in discussion—Dedicated Short-Range Communications (DSRC) or 4G long-term evolution cellular V2X communications (LTE-CV2X)—will be able to effectively use the 30 MHz allocation nor can their operations be accommodated together in the band (see Appendix A for more details and Appendix F for preliminary test results):

- If a 20 MHz channel is allocated for LTE-CV2X, DSRC would not be expected to operate as intended in the remaining 10 MHz due to expected adjacent channel interference from LTE-V2X.[1]
- If DSRC is allocated the 30 MHz, US DOT test results (as documented in a draft white paper seen by and commented on by the FCC), identify the need for a buffer on either side from unlicensed broadband in the lower 45 MHz as well as above the band with the new plan for 5.925-7.125 GHz. Even if the buffer is limited to 5 MHz channels on each side, DSRC cannot operate in two adjacent 10 MHz channels and still perform collision avoidance and other priority public safety applications.
- It is likely that LTE-CV2X will also need a similar buffer from unlicensed broadband. (See Appendix F.)

Overreliance on specific technologies rather than a technology-neutral approach

DOT cares deeply about safety outcomes and seeks to ensure that a communications technology works in the dynamic and complex transportation scenarios that are the cause of crashes.

When taking the limitations of LTE-CV2X and DSRC in 30 MHz into account, the default technology (as per the stated intention of this draft NPRM) becomes LTE-CV2X. This technology is still unproven and has yet to be demonstrated in a manner that can assure the Nation that the technology is appropriate for collision avoidance (particularly in complex and dynamic scenarios where the risk of an accident increases). In the Department's view, it is appropriate to approach the proposal from a perspective that is more technology neutral, and that allows innovation to inform decision making about transportation safety and spectrum use.

Additionally, the technology design and its standards are not yet complete. The one draft SAE J3161 standard for the upper protocol layers for vehicle safety received only a 29 percent approval by the participating industry members, and the standard has been evolving.[2] From both a device performance and a safety performance perspective, DOT understands that there is a considerable amount of technical work still to be completed (pp. 15, 16) yet the FCC defers to industry claims that have not been validated (para. 43 in the draft NPRM). Please see Appendix B for details on the maturity of this technology.

A policy shift of this nature should be based upon independent and objective analysis that includes not only the spectral performance of the technology, but also the safety performance, given that it will be applied to safety-of-life applications. This is the foundation of the test program that the Department and the Commission have sought to foster, and it would be appropriate to ensure that any proposal the Commission issues can be informed by such rigorous scientific testing and analysis.

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[1] The DOT technical team has seen the energy emissions from LTE-CV2X devices from preliminary testing, and the industry manufacturer has verbally confirmed the emissions. More work is needed to gauge the magnitude of the interference.

[2] For instance, in the current draft of the standard, there are inconsistent power level parameters (23 dBm versus 21 dBm because the manufacturers and industry are still working on defining where (within the device) the power levels should be measured. We note that the FCC's text in this draft NPRM appears to reference power levels (and other parameters) from older documents and does not acknowledge that this in one of the issues in flux.

Removal of the safety message priority and public safety use of the spectrum

In Appendix B of the draft NPRM, DOT notes two major changes that could effectively render as useless the cooperative-Intelligent Transportation Systems (ITS) collision avoidance applications.

- By fully removing 95.3159 in the OBU section and parts (d) and (e) 90.377 in the RSU section, the FCC undermines the purpose of the ITS crash-imminent, safety-of-life communications. Removing this language has the effect of requiring that, in densely congested areas, priority basic safety messages wait for other users to finish transmitting, during which time a crash could occur (we note that a crash set-up and occurrence can happen in under 3 seconds, as per the video we previously reviewed with FCC staff).
- Further, by removing this language, FCC fundamentally removes the public safety use of this spectrum, thereby allowing commercial uses (with an expectation of larger, longer message exchanges) that will interfere with the basic safety messages, suppress V2X transmissions, or create delays that will result in crashes.
- We note one further concern with Appendix B, which is the ambiguous 3GPP[3] references with relation to the LTE-CV2X devices. We note that Release 14 is comprised of thousands of references that address a wide range of device capabilities, including the PC5 Mode 4 (LTE-CV2X) capability but also networking interfaces (for instance, the Uu interface), network infrastructure and end user equipment specifications, and specification for other modes. The reference in section 95.3189 appears to predominantly discuss the Service and System Aspects (SA) as opposed to the radio aspects (from the Radio Access Network or RAN elements of Release 14). This ambiguity could allow any type of Release 14 uses into the 20 MHz channel and raises the risk that different LTE-CV2X manufacturers may develop devices that are not interoperable. Which again (as noted above), negates the purpose of public safety benefit, collision avoidance messaging.

Profound effects on Transportation

Loss of V2I-I2V capabilities

To date, the LTE-CV2X device and standard development has been focused on vehicle-to-vehicle (V2V) messaging; it has not addressed Signal Phase and Timing (SPaT) or MAP capabilities that are critical for V2I intersection safety. When the Notice does begin to address V2I, there is no indication of whether the technical team expects that one 20 MHz channel can accommodate all V2V/V2I for safety *and* the breadth of other V2I applications. DOT anticipates that the breadth of V2I applications cannot be accommodated in one 20 MHz channel.

Appendix C describes an exercise that demonstrates how an urban/suburban area with a built-out Connected Vehicle environment will use the available spectrum. It is dependent upon which applications are chosen. We included applications and their message sizes/data rates that mimic the applications being put into use at CV deployment sites. It is a scenario that can be expected during rush hour or peak delivery hours. The results are that channel 172 is predominantly utilized by V2V crash avoidance applications with a small set of V2I safety at intersection (SPaT, MAP) in support of collision avoidance; and the remaining channels are used by V2I applications. Channel 184 is in

[3] The Third Generation Partnership Project, which advances telecommunications standards.

use for regular V2I, but a large amount of it is reserved for public safety uses when needed. Similar to Defense industry requirements, when a crisis is imminent, availability of the spectrum is critical.

We do not anticipate that all 75 MHz of the spectrum will be in constant use across the Nation. But an analysis performed by industry experts (Car-to-Car Consortium) demonstrates that an individual vehicle will use between 42-73 MHz of spectrum each day. If thousands of vehicles are transmitting during rush hour as well as throughout the day, and using a broad range of V2I applications, this analysis finds that a 20 or 30 MHz allocation will not be enough. In particular, we are curious as to how LTE-CV2X will accommodate these needs given that they employ a duplication of each V2X message sent (hybrid automatic repeat request or HARQ).

We have not yet seen enough simulation results from either industry or our own testing to understand fully the capacity of a channel configured for 20 MHz LTE-CV2X (which includes HARQ on). To date, the LTE-CV2X industry suggests the use of cellular networked communications, but they have not yet demonstrated how this works and still preserves the safety, security, and privacy protection of the V2X communications. Further, they have not provided the information on how the V2I/V2X public benefits can remain subscription-free, as they are now.

If the approach taken in this draft NPRM is enacted, it will produce a critical loss for State, regional, and local agencies to employ vehicle-to-infrastructure (V2I) applications at a time when V2X installations are beginning to show results such as:

- **V2I road-weather applications** that can address 25% of crashes on freeways due to winter weather;
- **V2I system efficiency applications** that can reduce speed and variability on freeway segments by 18%-58% and within freeway segments by 10%-47%, resulting in fewer rear-end crashes;
- **V2I system efficiency applications** that can address reduction in travel time on arterial corridors by 6% to 27% when combined multimodal traffic signal systems are implemented;
- **V2I transit signal priority applications** that can reduce travel time for transit vehicles by up to 10% (Utah DOT is reporting 12%);
- **V2I Public Safety/Emergency Response applications** that can reduce travel time by up to 23% and number of stops by up to 15% for emergency vehicles;
- **V2I work zone applications** that can reduce network-wide delay of up to 14% due to alerts to incident zone workers;
- **V2I energy applications** that can produce a fuel savings of 2%-22% when signal operations and freeway lane management are optimized, also resulting in annual fuel savings of 323,000-981,000 gallons with an integrated corridor management decision support system.

Adverse impact upon deployment, operations, and investments in transportation safety

In addition to the loss of benefits, if enacted, this shift could cost DOT and the transportation community over $500 Million and hamper accident reduction well into the future. Needless deaths and injuries that can be prevented with intelligent transportation systems and cooperative, connected vehicles results in a cost of trillions of dollars. These costs result from the time needed for all operational sites to “rip and replace”—these changes can take up to 5 years, pausing the

progress made over the last few years just as deployment sites have begun operations. If enacted into rule, the arrangement in this NPRM leaves existing deployers with few options:

- One is to remove existing installations and forego V2X communications fully. There is no guarantee that deployers will continue with V2X implementations if they were required to remove infrastructure and equipped vehicles that are already tested and working.
- A second is to completely replace them with LTE-CV2X, an option that will take a significant amount of funding—**we estimate over $500 Million** (see Appendix D)—and will delay V2X applications being put into use by at least another 2 years (if not more).

In our experience, deployers are cautious with taxpayer funding and they are unlikely to transition to a different technology before the standard(s) is stable and proven. Please see Appendix D for cost estimations.

The FCC suggests that the same V2X benefits can be provided through other technologies, citing Waze and current-day sensor suites as examples. In the analyses done by the US DOT,[4] we note that sensors and Waze are not complete responses to these problems:

- Sensor suites and cameras require direct line of sight and thus cannot provide a 360-degree awareness for the driver/vehicle within a 300-1000 meter range, including when buildings, foliage and other blockers (say a truck blocking a car) are in the way. V2X applications by comparison, are capable of providing warnings in several scenarios where vehicle-based sensors and cameras cannot (e.g., vehicles approaching each other at intersections).[5] Stated differently, NHTSA's analysis shows intersections crashes are not well-served by conventional vehicle sensors (radar, camera) yet intersection crashes are consistently the number one crash type in terms of annual economic cost and human harm measures. Intersection crashes are exactly the type of crash scenario that V2V is particularly well-suited to address.
- The Waze application is a voluntary, crowd-based traffic app that is not in use by all people driving at the same time; in which case, it cannot consistently offer collision-avoidance capabilities. Furthermore, Waze is not interoperable with data from other navigation systems and applications people use at this time.[6] This results in the data generated by these applications being silo'ed and only available to those that use one or another app. Notably, both Waze and infotainment systems are not as secure as critical vehicle-based safety

[4] Please see: https://www.govinfo.gov/content/pkg/FR-2017-01-12/pdf/2016-31059.pdf, which is one of a number of publicly available sources. US DOT is happy to provide additional resources for FCC, if needed.

[5] In this same reference in the above footnote, industry makes the following observations about V2V capabilities to provide warnings in several scenarios where vehicle-based sensors and cameras cannot (e.g., vehicles approaching each other at intersections):

- Honda Motor Col, Ltd commented that ''. . . the ability of vehicles to directly communicate with one another will greatly assist in the ability to safety and effectively deploy'' higher-level driver assistance and automated technologies
- Along similar lines, Meritor WABCO and the Automotive Safety Council both mentioned that V2V safety applications with warning capability would enhance current active safety systems.
- Systems Research Associates, Inc. stated that ''it is irrefutable that V2V, V2I, and V2P communications will be absolutely critical to the successful development of self-driving vehicles that can avoid collisions, navigate responsibly, and achieve a transport objective efficiently and in a timely manner.''
- Similarly, IEEE USA commented that V2V provides the trusted map data and situation awareness messages necessary for innovative safety functions, and support the flow of traffic with self-driving cars.

[6] With the exception of Google Maps, which recently bought Waze.

systems, and that critical coverage gaps remain in the cellular network throughout the U.S. outside of major urban centers.

Further, we note and have documented that interoperability plays a critical role in collision avoidance. At this date, interoperability is only available through V2V, V2I, and V2X applications and cooperative ITS systems that are based on the existing standards.

Limitations on future (and near-term) innovations, including Automation

With this draft NPRM, the FCC is severely curtailing access to spectrum to support connected-automated-vehicle (CAV) application requirements. The development of automated driving systems (ADS) hold the promise to revolutionize transportation choices for all citizens. While connected vehicle technology is not an absolute requirement for ADS technology, virtually every automotive manufacturer has acknowledged the important role that V2X communications can play in enhancing safety, extending operational design domain, and improving interactions with other vehicles and the infrastructure.[7] For example, V2X can allow ADS vehicles to easily and reliably communicate with emergency response vehicles (ERVs), with traffic signals, and with other infrastructure messaging (such as location of work zones, temporary lane closures, and numerous other messages that can help an ADS vehicle navigate along its intended path). Additionally, V2X messaging is an absolute requirement to support coordinated vehicle movements such as platooning applications. By limiting available bandwidth to 20 MHz, the FCC proposal effectively halts innovation in the connected-automated-vehicle area and threatens U.S. leadership in advancing automated vehicle development. Appendix E offers additional details on the automation efforts that are enhanced by V2X communications.

Furthermore, by selecting a 30 MHz band size, the FCC is jeopardizing the U.S. leadership in Automation. Currently, the U.S. has the lead in the automated technologies market, which includes both automated vehicles and infrastructure technologies and strategies that benefit from automation. If enacted, this draft NPRM removes the opportunity for this type of leading-edge research and technology development to continue. See Appendix E on the advancements coming through FHWA and industry research—all activities rely upon access to the 5.9 GHz band outside of the V2V channel 172.

Discontinuation of testing

In the NPRM, the FCC appears to abandon its joint endeavor with DOT and other agencies to continue testing of this spectrum band with respect to interference and the impact of unlicensed Wi-Fi devices. This action has the effect of dismissing Congress's direction in the Transportation Equity Act for the 21st Century to consult with DOT on spectrum needs for ITS.

Furthermore, the FCC appears to have made a decision on what technology is most appropriate for transportation safety without having yet obtained independent or objective results on the technology through rigorous scientific testing. As the FCC is aware, DOT has worked with FCC on a phased test approach to produce such results, and we invite the FCC to continue with us in

[7] https://www.govinfo.gov/content/pkg/FR-2017-01-12/pdf/2016-31059.pdf.

that endeavor. We estimate that by early May 2020, DOT should have compelling evidence about this technology to inform FCC's proposal.

If a change in technology is warranted, as noted above, there are a number of critical steps that will require a transition period. Having a solid base of data acts both as a means to refine the technology and standards quickly; and as a means of providing deployers with a trusted and transparent rationale for making changes. These steps will need to include:

- The FCC will need time to finalize a new rule and band plan, noting that the DSRC experience took 4-6 years (the allocation came in 1999, the first report and order in 2004, and the last amendment that completed the band plan rules in 2006).
- Industry will need to complete the V2V standard, develop the V2I standards (including a re-write of the roadside unit specification), complete certification test procedures (based on the standards), and validate that it has an appropriate certification process. All LTE-CV2X vendors will have to go through the certification process.
- DOT will need to develop guidance for deployers on how to transition to LTE-CV2X.
- There is only one OEM (Ford) that is committed to LTE-CV2X. If the NPRM is enacted, other OEMs face two optional paths—transition to LTE-CV2X or decline to put V2X applications into use. DOT will need time to work with the other OEMs to determine whether they will make the transition.

LTE-CV2X is not a new technology. Notably, LTE-CV2X will remain based on an old technology—LTE 4G is 14 years old (approximately the age of DSRC) and unlikely to evolve much once the telecommunications industry focuses on 5G. While LTE-CV2X is marketed as being a pathway to 5G, to date we note that it is simply incorporated to support basic safety use cases and is unlikely to evolve to support more advanced V2X use cases. 5G V2X is more likely to emerge as an adjunct to, or replacement of, LTE-CV2X technology, rather than an evolution from LTE-CV2X, since these technologies cannot coexist on the same channel. DOT and the industry will need to develop a plan for how the LTE-CV2X standards and technologies will be sustained until 5G V2X use cases are developed and tested. 5G devices will require modification to meet transportation safety requirements, and a 5G small cell infrastructure capability is deployed significantly around the Nation, if 5G V2X will need to rely upon it.

In short, CV2X appears to be a technology with no evolutionary path to 5G, nor an evolutionary path that would continue to update and improve the performance of the 4G LTE-based technology. It is based on a technology that is essentially stagnant. In contrast, the IEEE 802.11 committee that oversees DSRC standards has a plan in place (and a commitment from industry participants) to develop "next generation" DSRC (also referred to as 802.11 b/d)—and to ensure that future enhancements to DSRC maintain backwards compatibility.[8] To be clear, USDOT remains technology neutral with regard to what communications technology will best serve the needs of the transportation industry—and we are not advocating for DSRC over CV2X. We are simply pointing out that there are several important factors that the market (and FCC) will need to consider—including technology evolutionary paths that will allow for continued product improvements while addressing backward compatibility and interoperability issues.

[8] See PAR at https://mentor.ieee.org/802.11/dcn/18/11-18-0861-08-0ngv-ieee-802-11-ngv-sg-proposed-par.docx.

Absence of a cost-benefit analysis

Such a momentous shift in policy should be accompanied by a consideration of the relevant costs and benefits, as Chairman Pai has called for in the past.[9] In this case, such consideration should include the following:

- A rigorous analysis of the benefits to the Nation of:
  - Retaining the entire spectrum for transportation safety;
  - Dividing the spectrum between unlicensed Wi-Fi and giving transportation safety a limited allocation; and
- Consideration of alternatives analysis, including:
  - A thorough review of other technologies that may be capable of achieving the Wi-Fi broadband business models goals; and
  - A determination of the most efficient use of the spectrum.
  - A thorough examination of the spectral efficiencies of the various technology alternatives given the intended use-cases and applications—including if and how spectrum sharing technologies may impact the overall spectral efficiency of any given proposal.

Benefits of retaining the band for transportation safety

Please see Appendix C for an understanding of the magnitude of the public safety benefits. Each year that the FCC or others create a "pause" on V2X implementations, the Nation incurs significant ongoing losses due to crashes that V2X technologies can address and resolve.

Dividing the band

In the text in this draft NPRM, we find that FCC is reallocating 60 percent of the band for the Wi-Fi industry. A good portion of the rationale for this decision appears to be come from the FCC's reliance on a RAND study that both overstates the economic benefits reallocation and does not address in any way the transportation public safety costs and benefits, and thus offers a precarious analysis that this draft NPRM treats as given. The analysis leads the reader to believe that benefits from use of the 45 MHz for unlicensed Wi-Fi exceed those for transportation safety. Our work in Appendix C provides a more holistic understanding of the public safety benefit and suggests that a more rigorous approach can benefit all in the decision-making process.

In the text in the NPRM devoted to unlicensed Wi-Fi and the proposed 45 MHz allocation discussion, the FCC references RAND's dubious estimates in terms of consumer surplus and revenue growth (the same as GDP, fn. 96) but does not mention RAND's market value estimate. At $17.7 billion for 75 MHz, this estimate is much smaller and by implication smaller still for 45 MHz at $10.6 billion ($17.7 billion x 0.6). The NPRM does not adjust any of the estimates down for 45 MHz.

The NPRM does not make clear that the broadband industry can charge subscription fees for the services on the valuable spectrum that the FCC proposes to allocate to the industry for free. This same spectrum could otherwise deliver transportation safety enhancements worth billions of

[9] https://www.multichannel.com/news/fcc-gets-ok-for-new-economic-analysis-office.

dollars in savings from collision avoidance, greater mobility and system efficiency, greater fuel savings, and faster responses to public safety situations.

There should also be a risk assessment performed that C-V2X may not work in the remaining 20 MHz-30 MHz.[10] (See Appendix F, which suggests potential interference from unlicensed Wi-Fi—we expect that to be a problem both below and above the 20 MHz channel.) In appearing to unnecessarily favor a particular technology in this draft NPRM¸ the FCC will need to calculate this and other economic effects to provide a basis for why a particular technology is preferred.[11] If enacted, the new draft rules will deny market access to a competitive existing technology. There are DSRC industry firms that will fail and/or require financial support to shift to the LTE-CV2X technology (if it is proven to work).

Last, we note that this policy change could tend to hinder competition—at this time, there is only one U.S.-based chip manufacturer, which raises questions about interoperability with other manufacturers should they decide to enter the market. This could set up a barrier to market entry.

Omission of an Alternatives Analysis that includes 802.11ax capabilities to serve the broadband industry's needs

Additionally, alternative analyses are an important part of determining the best outcome for the Nation's citizens as well as various (and often competing) industry actors.

One of the key omissions is the discussion of Wi-Fi 6 based on 802.11ax. While the FCC notes the emergence of 802.11ax, the FCC does not include the information that this new Wi-Fi innovation has the ability to aggregate non-contiguous bandwidth to produce larger channels—up to 160 MHz channels. With the introduction of these technologies on the market, the DOT questions the industry's insistence that unlicensed broadband requires large swaths of mid-band spectrum that will be taken away from current licensed users which results in a critical impact to their lives, their operations, and their business models.

Assumptions about the fastest path to deployment and use of the spectrum

In the FCC's assumptions about the paths to deployment, DOT finds that the FCC omitted the existing deployment sites and their progress. The FCC notes that the sites are in existence, but does not take into effect the magnitude of the installations across the Nation. As noted on previous pages and in Appendix C, the labor and equipment costs to replace with a different technology will be over $500 Million. DOT therefore asks how the FCC would propose to assist State and local agencies to cover these costs, and to address the concerns of DSRC manufacturers and firms facing the sudden loss of a market.

[10] We note that FCC's proposal may result in the loss of 40 percent of the band if LTE-CV2X does not work in highly congested and dynamic transportation scenarios to produce the collision avoidance safety benefits along with other public safety efficiencies.

[11] FCC does not appear to express any concern about any failure of DSRC on technical grounds, nor does it indicate that any particular regulatory targets, goals, or milestones were not met. FCC should therefore offer additional consideration of DSRC's current state and its potential in light of continuing investments and deployment.

Additionally, Canada and Mexico also have dedicated the same 75 MHz to transportation, which positions North America to have a single standard for vehicles produced in the United States and exported. Importantly, achieving cross-border interoperability keeps connected vehicle capabilities from failing as vehicles move across our borders. This assures U.S. citizens and transit and freight carriers that their safety is preserved as they travel across borders and that there will be a system that works consistently for them when they arrive. It also assures our citizens that Canadian and Mexican drivers will participate in our safety systems as they journey through the United States.

Last, if enacted, this draft NPRM will result in a serious deployment pause or full stoppage of V2X operations, and it will take the Nation a longer time to realize collision-avoidance and other important public benefits described in Appendix C.

Assumptions about coexistence among the three communications media (or various combinations)

In 2017, the US DOT provided the FCC with two white papers. One measured the effects of placing two high-powered, public safety and V2V channels next to each other; the other white paper demonstrated the out-of-band emissions (OOBE) of unlicensed Wi-Fi (UNII-3) using the new rules proposed by the FCC at that time. Additionally, at the in-person meeting on September 27th, the US DOT, FCC, and NTIA technical staff discussed the adjacent channel energy emissions observed with the LTE-CV2X devices.

Given the knowledge of these types of adjacent channel interference opportunities, the US DOT seeks a more sufficient grounding for how the FCC concluded that the three media (or some combination) can occupy the band without challenges. We note, in looking at the proposed rules in Appendix B, that the FCC allows for the UNII-3 rules to become operational in the lower 45 MHz of the band, including the current OOBE levels and filter requirements. We also note that the FCC used the industry device parameters that are evolving.

To support more grounded discussion, the US DOT took all devices into a lab to measure the adjacent channel emissions. The preliminary results are included in Appendix F. While more testing is needed to measure the magnitude of the emissions, Appendix F illustrates the likelihood of significant adjacent channel interference between the different radio services; and thus the proposed rules may need significant reconsideration.

Appendix A: Effects of Limiting V2X Technologies to 30 MHz

- **Limitations if using DSRC:**
  - UNII operations in 160 MHz channels up to 5.895 GHz are expected to bleed energy into channel 180 (5.895-5.905), causing interference to at least DSRC V2V messages. Thus, we anticipate that channel 180 will be used as a buffer. (See Appendix F for preliminary test results.)
  - Given that the FCC is planning unlicensed Wi-Fi uses from 5.925-7.125, we expect similar issues about channel 184, thus anticipating that channel 184 will be used as a buffer. (Again, see Appendix F.)
  - USDOT did an analysis on the unlicensed Wi-Fi emissions parameters and pointed this out to the FCC in a draft white paper; and has recently set up these technologies in a lab to look at their emissions (Appendix F).
  - Even if 180 and 184 are not used as buffers (if we assume that the unlicensed devices employ better filters that go beyond the current FCC emission parameters), the critical DSRC functions cannot operate in three 10 MHz channels—the USDOT did an analysis on this and provided it to the FCC as a draft white paper on numerous occasions. If LTE-CV2X needed two 20 MHz channels, we expect that they could not be adjacent to each other (but would test that to confirm).
  - This limits DSRC to one 10 MHz channel—182.
  - In the most densely urban areas, DSRC V2V transmissions can fill the 10 MHz channel, requiring a congestion mitigation algorithm to be put into use. This precludes use of most if not all V2I applications. We anticipate that State and local agencies would not see the benefit in investing in roadside units that are underutilized.

- **Limitations if using LTE-CV2X:**
  - We anticipate that unlicensed transmissions up to 5.895 will likely affect LTE-CV2X in a similar manner with regard to channel 180 (the effect of unlicensed transmissions on LTE-CV2X have not yet been measured). Since LTE-CV2X is transmitting in channel 183, this leaves channel 180 and part of channel 182 as a buffer.
  - However, in preliminary measurements, we note that LTE-CV2X emits energy into channel 180, thus making it unusable. If there is additional bleed into channel 178 by LTE-CV2X, this is a significant impact to the proposed FCC plan and may affect LTE-CV2X operations.
  - LTE-CV2X uses the full 20 MHz channel to replicate what DSRC does in one 10 MHz channel. This is due to their need to duplicate each transmission in order to gain more message accuracy in the receiving vehicles. In addition to this being spectrally inefficient, there is little room to accommodate V2I applications.

Appendix B: The Overreliance on Particular Forms of Technology

- If LTE-CV2X is the chosen technology, the rules will have to be redesigned for LTE-CV2X. These rules are not yet known—FCC is including potential parameters based on a small amount of companies that are trialing LTE-CV2X.
- LTE-CV2X is still in development and not yet mature:
  - The standard still in development and is changing with new testing—we note that with the last draft, the device power levels shifted from 23 dBm to 21 dBm; the FCC draft NPRM is citing the older parameter and we advised them to look into the draft standard.
  - It took over 5 years for the first DSRC standards to be approved and published (Nov 2004-July 2010) and another six years of refinement through testing (current standards are from 2016). While LTE-V2X can build on DSRC lessons learned, as well as incorporate parts of the DSRC standards, the LTE-CV2X standard will (a) still take time; and (b) is currently only focused on a V2V profile. More work will be needed to expand the profile if the 20 MHz is to include the small V2I transmission set related to intersection safety, which uses the roadside unit (another specification being altered for LTE-CV2X).
- Deployers are unlikely to transition to LTE-CV2X before the standard is stable and proven.
- There is only one current manufacturer of LTE-CV2X chipsets, setting up a monopoly, at least in the near-term, and raising questions of interoperability with other manufacturers should they decide to enter the market. This could set up a barrier to market entry. DSRC has many manufacturers and vendors.
- Notably, LTE-CV2X is a 14-year-old technology. The one manufacturer has not made a public commitment to sustaining the technology for the longer-term or when the transportation industry decides to transition out of LTE-CV2X.

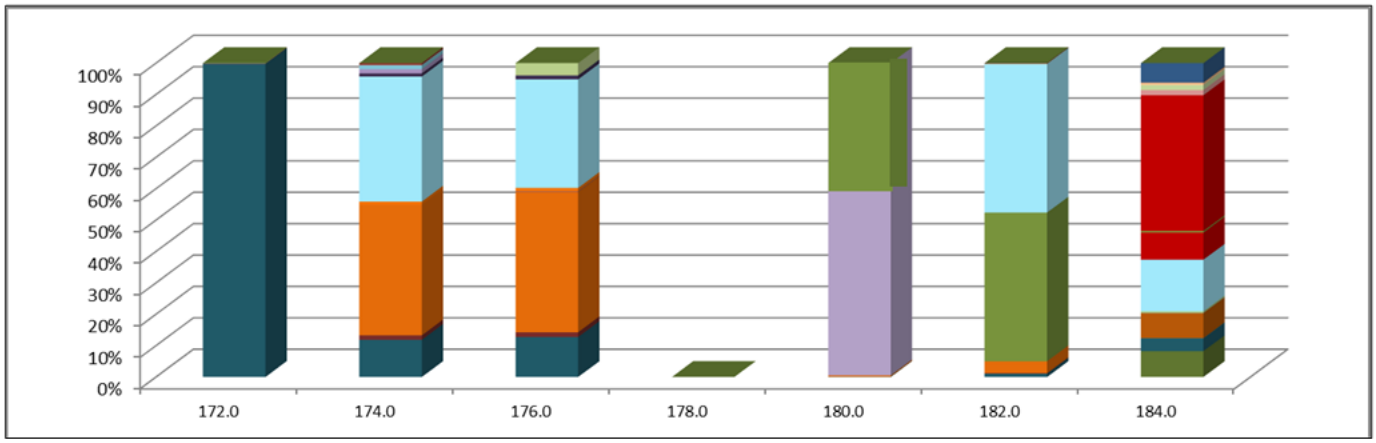
Appendix C: Loss of Benefits –More than 30 MHz needed to achieve V2I and Other V2X Benefits—And Noting the Significant Under-estimation of Benefits by the FCC and Other Organizations (RAND)

V2X application usage of the spectrum is dynamic for the following reasons (among others):

- V2X devices can adjust their power levels and/or data rates in times when accidents are forming to send more frequent messages to those vehicles that could potentially be involved in a crash
- V2X devices can adjust based on spectrum congestion in dense urban areas
- V2X use is not as dense in urban areas but address more devastating crash types as well as facilitate more immediate emergency response
- V2X applications have a wide range of message sizes
- Traffic conditions vary widely on a moment-to-moment basis, particularly in inclement weather.

The spectrum and deployment teams are developing an internal analysis to estimate the potential benefits loss for the Nation if the spectrum were to be divided and a portion given away to unlicensed broadband. Key points are the following:

- The following graphic offers an illustration of an urban/suburban area's spectrum use based on assumptions about a built-out Connected Vehicle environment. A good portion of the spectrum will be utilized. The illustration depicts a scenario during rush hour or peak delivery/logistics hours.
- Note that channel 172 is predominantly utilized by V2V crash avoidance applications with a small set of V2I safety at intersection (SPaT, MAP) in use to support V2V interactions. See the chart on the next page.



Collision Avoidance Applications such as Left Turn Against Traffic, Signal Phase and Timing (SPaT), or Railroad Crossing Violation Warning, Pedestrian in Crosswalk	**Emergency Response/Public Safety Applications** such as Emergency Communications and Evacuation, Emergency Vehicle Priority and Preemption, Reduced Speed/Work Zone warning, Incident Scene Pre-Arrival Staging Guidance for Emergency Responders
System Efficiency Applications such as Cooperative Adaptive Cruise Control or Platooning, Advanced Automated Crash Notification Relay	**Traffic Efficiency Applications** such as Freight Signal Priority, Dynamic Transit Operations
Traffic Signal Efficiency Applications such as Transit Signal Priority, Stop Sign Gap Assist, Adaptive Traffic Signal Systems in Integrated Corridors, Traffic Congestion Alerts	**V2I Safety Applications** such as Control Loss Warning, Curve Speed Warning, Roadside Alerts, Spot Weather Impact Warnings, Stop Sign Gap Assist, Low Bridge Warning

- Limiting the spectrum to 20 MHz can be expected to preclude use of the:
  - **V2I road-weather applications** that can address 25% of crashes on freeways due to winter weather
  - **V2I system efficiency applications** that can reduce speed and variability on freeway segments by 18%-58% and within freeway segments by 10%-47%, resulting in fewer rear-end crashes
  - **V2I system efficiency applications** that can address reduction in travel time on arterial corridors by 6% to 27% when combined multimodal traffic signal system is implemented
  - **V2I transit signal priority applications** that can reduce travel time for transit vehicles by up to 10% (Utah is reporting 12%)
  - **V2I Public Safety/Emergency Response applications** that can reduce travel time by up to 23% and number of stops by up to 15% for emergency vehicles
  - **V2I work zone applications** that can reduce network-wide delay of up to 14% due to alerts to incident zone workers
  - **V2I energy applications** that can produce a fuel savings of 2%-22% when signal operations and freeway lane management are optimized, also resulting in annual fuel savings of 323,000-981,000 gallons when an integrated corridor management decision support system is integrated.

These application opportunities will be lost based on this draft NPRM's plan to move V2X operations into channels 180-184 (30 MHz from @ 5.895-5.925 GHz) and based on the physical limitations of spectrum, as described in Appendix A.

- While not an exact comparison, ITS experts produced a 2019 analysis that estimated that an individual vehicle would need between 42 – 73 MHz of spectrum each day. If thousands of vehicles are transmitting during rush hour and using different applications (and in complex rural situations), this peak usage might look something similar to the graphic above. This analysis was provided to the US DOT in the 2018 Request for Comment (offered by the Car-to-Car Consortium[12]). A CV deployment site used the analysis framework with their own assumptions and found similar spectrum use results. Below is table 2 from the submission.

				challenging situations	
message type / environment	**urban**	**suburban**	**Rural** (Highway) light traffic, high speed	urban square in addition to **urban**	truck parking area/ toll station, very dense truck penetration in addition to **Rural**
CAM cooperative awareness message	6,21	6,98	9,70		
DENM decentralized environmental notification message	3,32	1,87	1,04		
SPAT, MAP traffic light	0,12	0,06	0,15		
PCM platooning control message	1,45	2,91	7,27		14,55
PSM personal safety message	4,24	0,17	neglectable	34,87	
Geolocation enhancement message (similar to DENM)	3,32	1,87	1,04		
CPM collective perception message	10,86	12,22	16,97		
MCM maneuver coordination message 400 Byte	6,21	6,98	9,70		
MCM maneuver coordination message add. Resource for 800 Byte	6,21	6,98	9,70		
total spectrum needs in MHz	**42**	**40**	**56**		
total for challenging situations Urban and Rural in MHz				**73**	**70**

- These scenarios result in important loss of VX benefits to the Nation. FCC significantly understates these benefits in the draft NPRM due to their reliance upon benefit statements from the RAND Corporation's analysis in 2018, which was paid for by the unlicensed Wi-Fi industry. The NPRM cites the potential for economic gains of $59.8-$96.8 billion that they expect to accrue to the Nation with an addition of only 45 MHz of bandwidth—an incredible conclusion given that the entire Wi-Fi industry appears to be valued at about $93B in 2018[13] with an estimated 660 MHz in use in the 2.4 GHz and 5 GHz bands.
- The OST-R's economic analysis team identified significant flaws with the RAND study, including a deeply non-credible estimate of the value of V2X benefits at $6.2 million.

Using the NHTSA NPRM analysis (based on OMB parameters), just four V2X collision-avoidance applications reduce the taxpayer burden by $109-$319 Billion and results in over 7,000 lives saved, 1.8 Million injuries avoided and a reduction in damages of 4.7 Million

[12] https://www.car-2-car.org/fileadmin/documents/General_Documents/C2CCC_TR_2050_Spectrum_Needs.pdf.
[13] This is estimate is on the higher end in viewing analyses from market growth reports such as marketing for this report: https://www.marketresearchreports.com/wifi

vehicles and other property. When looking holistically at the total crash population that could be resolved by V2V applications, NHTSA estimates a savings of $721 Billion (in 2014 dollars). These costs accrue to the Nation each year at current crash levels. Despite a recent reduction (3.4% in the first six months of 2019[14]), the levels and types of crashes remain high. V2X communications in use as a powerful 360-degree sensor of threats and hazards forming in the roadway is an innovation and break-through that by industry to move toward zero crashes. Further, there is a strong expectation that V2X communications can enhance the introduction of automation into use with non-automated vehicles and continue to prevent collisions.

Last, we can report benefits that will be lost from existing deployment sites:

- Utah—UDOT has been deploying DSRC for four years and currently has 127 intersections and 82 fleet vehicles with DSRC equipment installed and operating. A DSRC corridor in Utah improves transit reliability by 12 percent, reduces late bus arrivals by 40 percent. Utah is giving signal preemption priority to snow plows during inclement weather this winter.
- Arizona reported that with four signal control applications deployed in coordination (including freight and transit signal priority) reduced vehicle travel time 6-27%.
- Washington State—An application to apply variable speed limits during unsafe weather reduced (VSL) system on I-90 in Washington showed that the system reduced average speed by up to 13%.
- Sequential, dynamic curve warning guidance systems can reduce reported crashes by up to 77 percent.
- Truck platooning technology can reduce travel times by up to 13 seconds per vehicle on a five-mile section of I-85 in Alabama. See additional results in Appendix E based on the Federal Highway Administration's research.
- Truck platooning demonstration in Texas observes upper ranges of fuel-savings of 40 percent for the follower vehicle and 20 percent for the leader vehicle.
- Public safety applications have the ability to reduce average network-wide delay by up to 14% during a major incident response. Other V2V/V2I applications can potentially reduce the emergency vehicles' travel time by up to 23% and their number of stops by up to 15%.

[14] https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812824

Appendix D: Costs Associated with Band Plan Changes—over $500 million

The spectrum team has been working with the CV Pilot team to assess the steps taken in procuring, receiving and testing, installing and testing (which includes enacting cross-jurisdictional Memoranda of Understanding or MOUs), and turning the radios into operational technologies. These steps are similar steps to what deployment sites expect to do with any new cooperative technology that will be employed for collision avoidance and other safety and system efficiency uses.

The assessment across the three sites reveals that to shut down each DSRC installation and either make a change due to band plan changes (i.e., retune and retest radios based on new channels) or to replace with a new radio (i.e., LTE-CV2X), will accrue significant expenses and require significant amounts of time to make the changes. The numbers are preliminary but conservatively speaking, are anticipated to include:

- Between $3M - $12M in labor, testing, and reinstallation costs
  - We note that the $12M is more representative of densely installed areas
  - An average urban area estimate is around $7M
  - A rural area can be estimated at $4M due to fewer installations along corridors across the State, but with recent request for inclusion of trucking companies by the American Trucking Association (ATA) to install the DSRC radios and increase V2I participation, the costs are likely to grow.
- 24-60 months to redo all licensing, MOUs, procurements, testing, and installation and integration into the operational system during which time, any V2V/V2I installations would have to cease if LTE-CV2X becomes the chosen technology (longer time) or if the channel assignment changes (shorter but still includes a pause).
- In extrapolating out to 53 existing operational sites plus 23 sites moving from the planning to operational stages, the following calculations can be offered:
  - Using an average of $5.5M for a deployment site but keeping 1 current site the cost for the one densely installed site separate:52 operational sites @$5.5M + $12M for the dense installation = $298M
  - 23 planned sites @ $5.5M = $126.5M
  - Total = $424.5M
- Note that if transition to LTE-CV2X is the path, this does not include procurement of new technologies, which at the moment are based on US DOT costs to procure devices range from $2K - $5K. With the noted 21,521 devices in operational status and 4,068 in planning as per our deployment map (25,589 in total), this would add an additional an approximate $52K - $128K to the total for a range of cost replacement at: $476.5 – $552.5K
- This estimate does not include the sunk costs to research and implementation to date which the ITS JPO has estimated at $700M, including funding provided by US DOT to implementers.

We further note that with the complexities of RSU positioning and GPS corrections, additional testing is critical and changes lead to increased risks of failure.[15]

An additional set of costs that will accrue to the Nation is the cost of ongoing crashes and accidents due to the amount of time needed to transition to a different band plan. This time could be as long as 5 years, which would result in hundreds of thousands of additional deaths, injuries, and property damage as well as congestion due to crashes, but also no relief from regular recurring mobility. In addition, as V2X communications are proving effective in reducing the time for public safety and emergency responders to reach their destinations (either to the scene of a crash or other emergency or to hospitals, for instance). This benefit will be lost in for those State and local areas already employing these applications.

[15] The underlying assumptions and constraints of this analysis includes:

- The information is an assessment that asks the question about how changes to the band plan might affect the CV pilot sites. In the assessment, we assume that any change results in the same level of service or better as is currently in place for the CV pilots.
- We assume that the changes will allow the operational systems to work at a level that makes operations safe and cost efficient
- We assume that all standards are completed/updated to implement band plan changes. We recognize that only through testing under real-world conditions can the standards be completed; the sites will need to provide feedback to those standards as part of the change.
- We assume that vendors are willing to update their equipment to meet new requirements and standards
- Costs and time durations are additive to the current CV pilot site operations, availability of funds, and schedules.
- Labor costs for added staffing to make changes are pulled from current GSA schedule. For specialty labor areas like system and network engineers, costs are pulled from CV Pilot sites and averaged.
- We assume that any CV operations are maintained during the transition; this will be dependent upon whether the FCC's changes allow for continued use of the channels during transition.

We assume that system engineering methods will be used to implement changes including taking steps to appropriately redesign, install, test, refine (if needed), and retest (if needed). The costs include the planning, procurement, and documentation that system engineering best practices require; and that were followed in the CV Pilot and other deployments around the Nation. (Systems engineering is not only a part of the ITS installation process, but results in a higher success rate of integrated and interoperable systems working in the first or first set of efforts.)

Appendix E: Loss of Spectrum for Automation

In addition to the NHTSA research on the benefits of V2X communications with automated vehicles, the Federal Highway Administration (FHWA) has produced analyses that show transformative transportation impact and benefit. These critical impacts include:

- Vehicle platoons that safely double the capacity of the highway;
- Commercial truck platoons that improve safety, reducing fuel consumption by 7-10 percent, and reducing the stress on drivers
- Vehicle platooning benefits from cooperation with infrastructure along signalized corridors to improve safety and efficiency by optimizing vehicle flow and smooth traffic.

As noted previously in the memo, Automated Driving Systems (ADS) have performance limitations navigating dynamic roadway situations such as work zones, incidents, weather, and traffic signals. With the infrastructure sharing real-time data through connectivity, the ADS have better situational awareness and can operate safer and more efficiently. The safety band is the critical link to obtaining these safety, efficiency, and economic benefits through vehicle connectivity and cooperation with other vehicles and the infrastructure.

Three important initiatives will be impacted by this draft NPRM shift:

- The Cooperative Automation Research Mobility Applications (CARMA) open source platform that is accelerating automation research and enabling Automated Driving Systems (ADS) to facilitate tactical maneuvers in complex transportation scenarios
- Traffic optimization on signalized corridors that is delivering smoother traffic flow especially at higher market penetration rates and network level benefits in mobility in terms of total delay, stopped delay and total travel time
- Cooperative Automated Truck Platooning that results in substantial fuel savings
- Cooperative Automated Integrated Highways that include technologies that extend ADS performance limitations to improve system performance and safety
- Participation in an SAE International standards-setting effort to define cooperative communications in support of ADS.

CARMA

To support advancement of the technologies and acceleration into use, FHWA developed the innovative CARMA open source research platform to demonstrate the safety, efficiency, and economic benefits of vehicles connected and cooperating with each other and the infrastructure using the safety band. The unique open source platform was created to be vehicle and technology agnostic. CARMA enables the research and development (R&D) of cooperative automated driving system (CADS) capabilities to improve transportation system performance known as TSMO. CARMA is resulting in work with implementers (OEMs and deploying/operating agencies) on a concept of operations for various TSMO strategies, such as work zones, Traffic Incident Management (TIM), and weather scenarios that provide new strategies for operators and first responders interacting with ADS.

Beyond reducing traffic congestion and improving transportation safety, the CARMA research platform results in support to industry collaboration and R&D to expand on existing automation capabilities, reduce R&D time, and advance cooperative automated driving technology.[16]

Traffic Optimization on Signalized Corridors

Traffic Optimization on Signalized Corridors (TOSCo) enables sharing of traffic signal timing and phasing information with vehicles using the safety band in order for the vehicles to maximize the system-wide benefits by improved mobility and fuel economy. Without the connectivity provided by the Safety Band, these economic, safety, and performance benefits could not be achieved.

By combining vehicle automation with traffic signal information shared over-the-air via V2X communications, FHWA finds that we are able to increase the safety and efficiency of the transportation system by stacking vehicles in strings as they approach the signal and launch them in a coordinated fashion at the start of green, thereby reducing the number of stops. This has been demonstration through a joint cooperative automation field test between ITS JPO, FHWA, state DOTs in the Connected Vehicle Pooled Fund Study, and light vehicle original equipment manufacturers (OEMs) in the CAMP Consortium. TOSCo results are demonstrating:

- Smoother traffic flow especially at higher market penetration rates
- Network level benefits in mobility in terms of total delay, stopped delay and total travel time.

The next steps are to field these technologies along SH 105 in Conroe, TX.

Cooperative Automated Truck Platooning

FHWA has demonstrated automated truck platooning fuel saving benefits of 7-10% at 30-50 feet following distances depending upon speed and position in the platoon that incorporates vehicle-to-vehicle (V2V) communication through V2X communications. Human factors studies have indicated truck drivers are comfortable at these following distances. Without the connectivity provided by the Safety Band, these economic, safety, and performance benefits could not be achieved.

Truck platooning technology builds on adaptive cruise control systems to automatically control the truck's brakes and throttle allowing trucks to form close following platoons. Close following for trucks reduces aerodynamic drag (e.g., similar to NASCAR drivers) and results in fuel savings and reductions in emissions. Recent studies have shown that fuel savings estimates are in the 7-10% range for platooning trucks. Truck platooning technology builds upon today's truck safety systems (e.g., automatic emergency braking (AEB), air-disc brakes, etc.) and combines V2V communications for quicker reaction times and the potential for improved safety. Closer following distances between trucks could save space on the highway, thus increasing traffic throughput for heavily travelled truck corridors. Through the automated brake and throttle control, the truck driver's workload is reduced, resulting in less stress for the truck driver.[17]

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[16] Additional details are available at: https://highways.dot.gov/research/research-programs/operations/CARMA.
[17] Additional details at: https://www.fhwa.dot.gov/publications/research/ear/17045/index.cfm.

In addition, vehicle platoons combined with Cooperative Adaptive Cruise Control double the capacity of the highway. In simulation and modeling, FHWA has shown V2X communications allow for vehicle strings or platoons on a highway at 80-100 percent saturation can safely double the performance and efficiency of the roadway. For example, with an intra-platoon headway of 0.8 seconds and an inter-platoon headway of at least 1.3 seconds, lanes will have the potential to reach a capacity exceeding 4200 vehicles per hour per lane at 100% market penetration.[18]

Cooperative Automation Integrated Highways

The Federal Highway Administration (FHWA) recognizes the potential value of combining the use of V2X communications with automated control systems into a cooperative automated driving system (ADS) technology to increase the capacity and improve safety on the transportation infrastructure. ADS have performance limitations navigating dynamic roadway situations. FHWA demonstrated in a field test how connectivity and cooperation can together extend ADS performance limitations to improve system performance and safety on the transportation.

Cooperative Communications

SAE International, with the participation of industry organizations, is currently engaged in a standards-setting effort to define cooperative communications as they apply to driving automation and on-road motor vehicles, under the project title, "Taxonomy and Definitions for Terms Related to Cooperative Driving Automation for On-Road Motor Vehicles J3216."[19].

As described by SAE International:

> This document describes machine-to-machine (M2M) communication to enable cooperation between a subject vehicle and other participants. The cooperation supports or enables performance of the Dynamic Driving Task (DDT) for a subject vehicle with driving automation feature(s) engaged. Other participants may include other vehicles with driving automation feature(s) engaged, shared road users (e.g., manually operated vehicles or personal devices) or infrastructure owners and operators (e.g., traffic signals, work zones). Cooperative driving automation (CDA) aims to improve the flow of traffic and/or facilitate road operations by coordinating the movement of multiple vehicles in proximity to one another. This is accomplished by, for example, sharing information that can be used to influence (directly or indirectly) the dynamic driving task. Cooperation among multiple participants and perspectives in traffic can improve safety, mobility, situational awareness and operations. Cooperative strategies may be enabled by the sharing of information in a way that meets the needs of a given application. The needs may be expressed in terms of performance characteristics, such as latency, transmission mode (e.g., one-way, two-way), range, privacy, and information content and quality. There are several potential technologies for communicating information between the subject vehicle and other participants.

[18] Additional details at: https://www.fhwa.dot.gov/publications/research/operations/19006/19006.pdf.

[19] Link for SAE J3216: https://www.sae.org/standards/content/j3216/

Appendix F: *Preliminary Testing:* Out-of-Channel Interference

1. Introduction

To inform the concerns that the US DOT has with the FCC's draft NPRM, the US DOT went into the lab to investigate the ramifications of the new proposed rules. Specifically, we looked at the performance of three media in operation—DSRC, LTE-CV2X, and unlicensed Wi-Fi (UNII) when positioned in adjacent channels. The proposal includes allowing UNII to expand up to channel 177 (incorporating 5850-5895 MHz), DSRC in channel 180 (5895-5905 MHz), and LTE-CV2X in channel 183 (5905-5925). This paper examines this proposed scenario.

2. Process

The process described here is to illustrate the potential for adjacent channel interference. Establishing the level of interference will require additional testing. All three technologies were set up individually in a laboratory environment and configured to transmit such that they would pass significant data from the transmitter to the receiver. Figure 1 illustrates the test configuration.

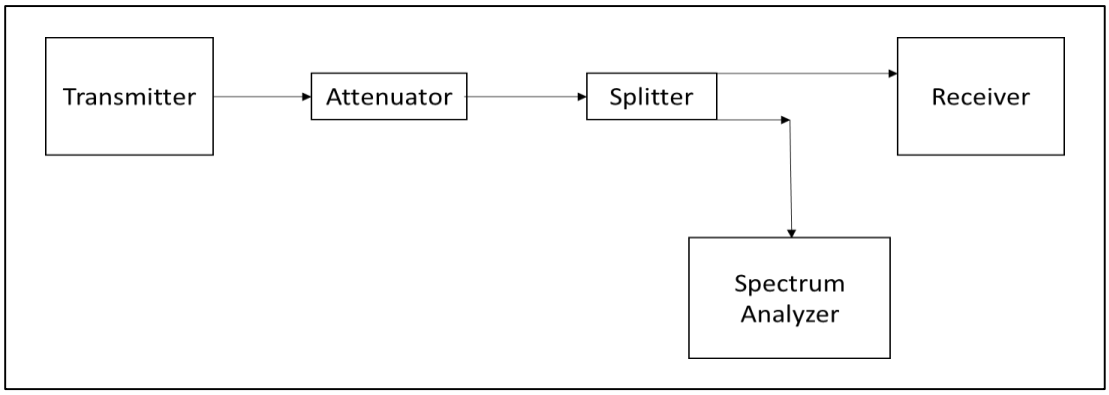

Figure 1. Equipment Configuration

Due to the quick turnaround, this preliminary investigation focused on emissions in the adjacent channels. The spectrum analyzer was set to compare all three technologies in a similar plot.

3. Spectrum Plots

Starting at the top of the 5.9 GHz Safety Band, a plot of the LTE C-V2X is shown in Figure 2. This was a max hold plot and illustrates the out-of-band emissions (OOBE). This plot is centered at 5915 MHz and a span of 50 MHz. While the main channel is in the 20 MHz designated for this technology, we can see that OOBE extends another 20 MHz to either side with considerable energy. Again, this data is to indicate potential interference to adjacent channels. More testing is needed to quantify the level of interference. Figure 3 and 4 are similar plots for DSRC and UNII devices.

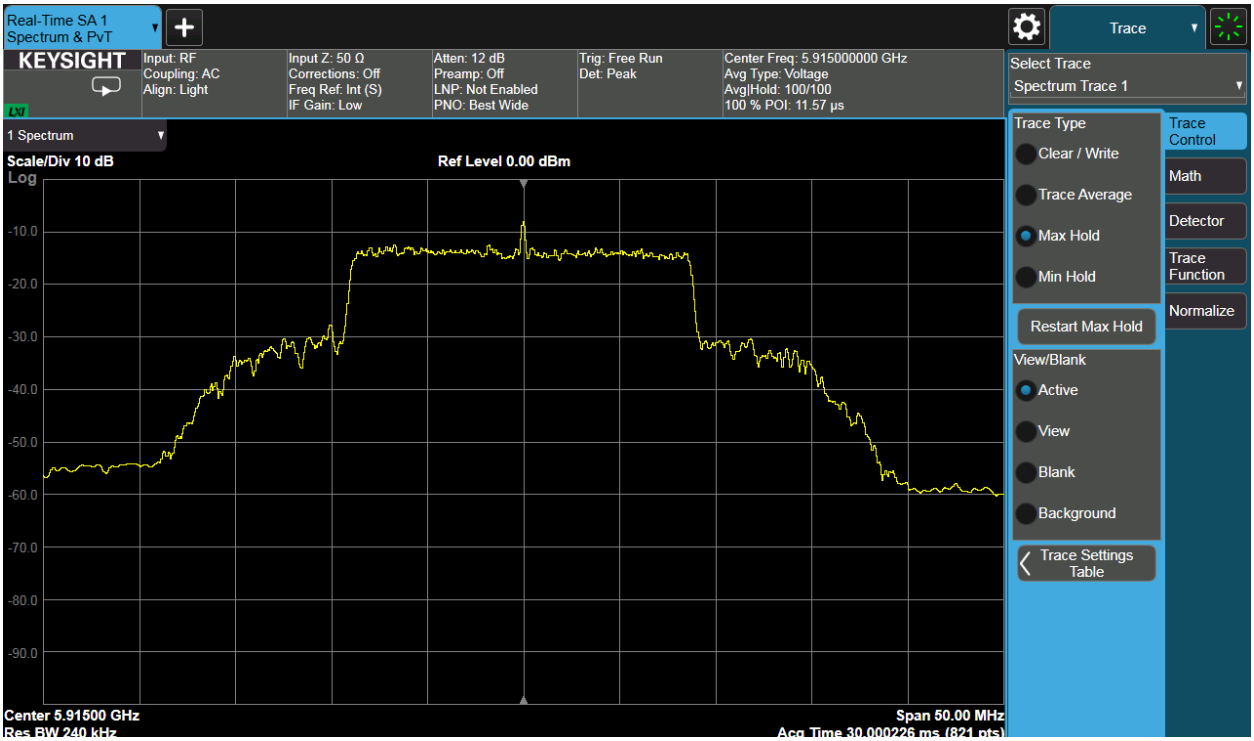

Figure 2. LTE C-V2X spectrum plot

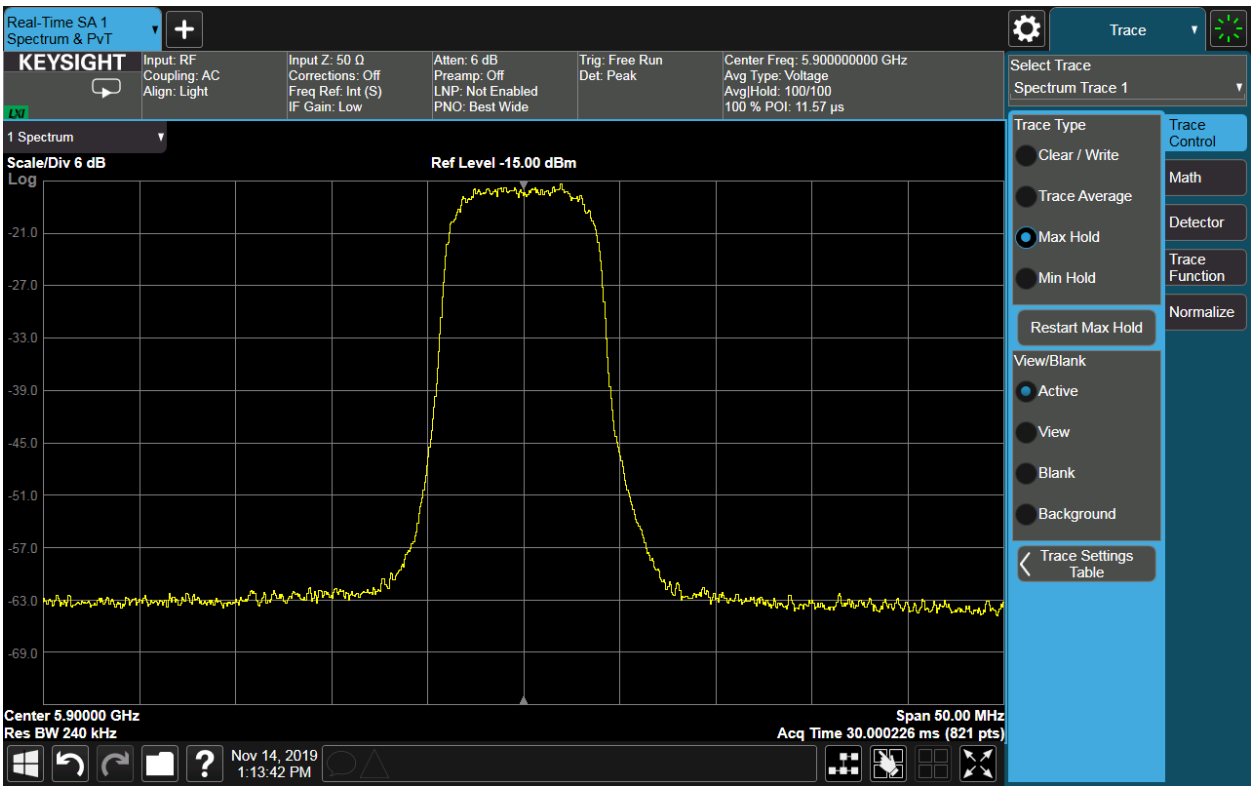

Figure 3. DSRC spectrum plot

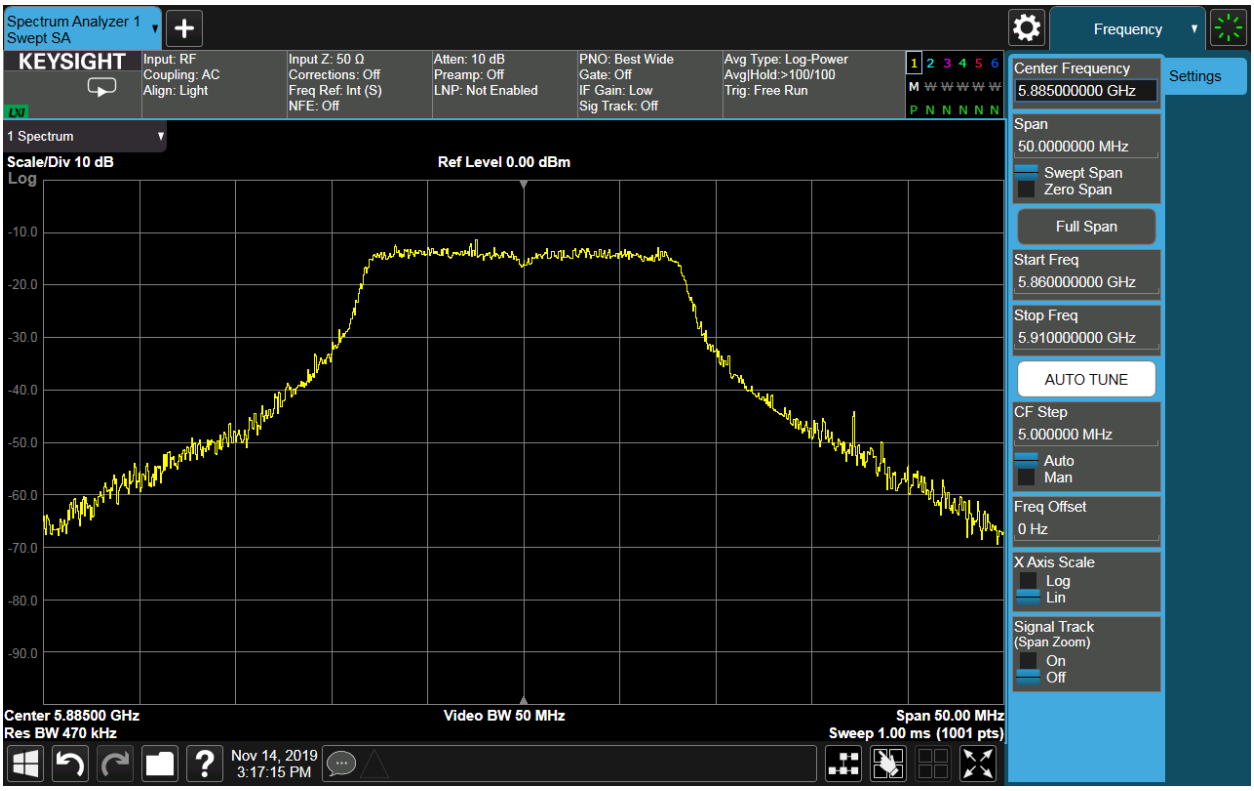

Figure 4. UNII spectrum plot

In addition to these figures, we were able to capture "waterfall" plots across the 5875 to 5925 MHz spectrum. Again starting at the top with LTE C-V2X in figure 5, the top half of the chart is an instantaneous capture of the spectrum. The lower half is spectrum occupancy over time. The color-coding reflects the energy in dBm in a narrowly quantized portion of the band. Red represents the highest power at roughly -20 dBm. The dark blue represents the noise floor of the spectrum analyzer at roughly -72 dBm.

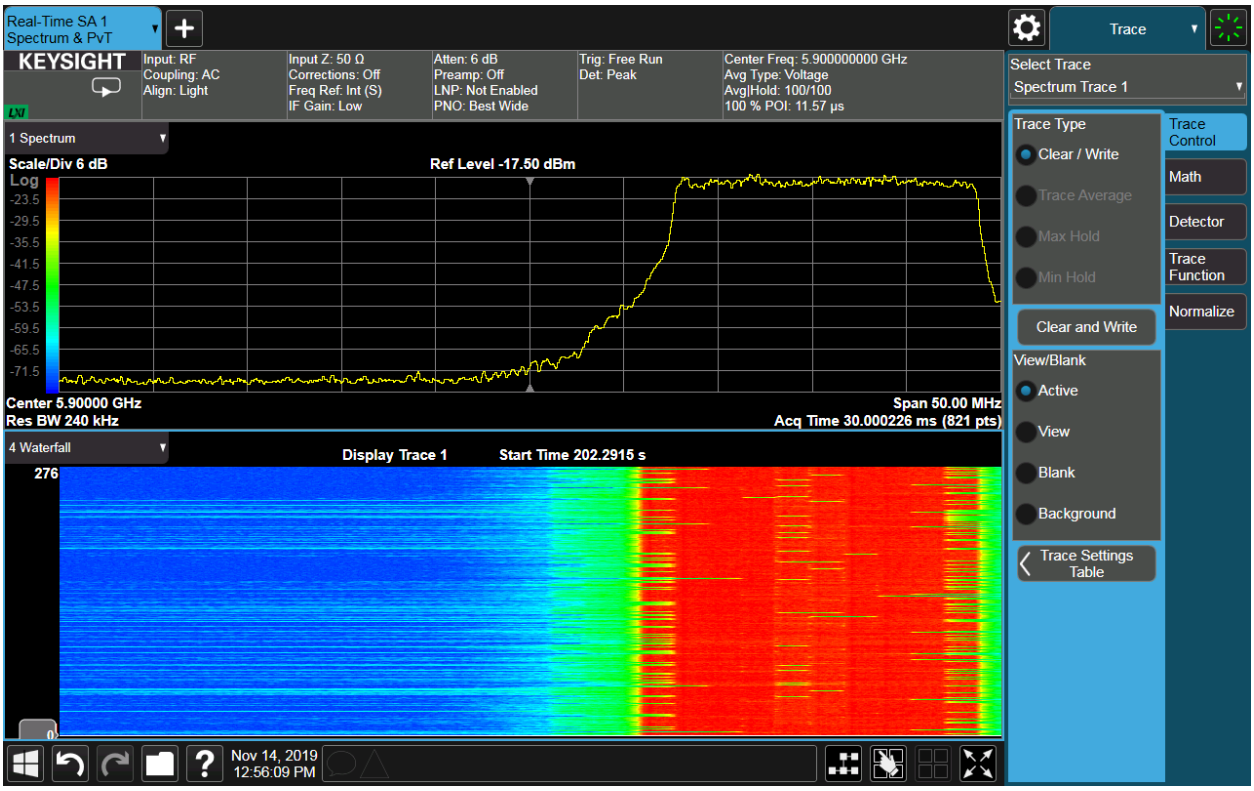

Figure 5. LTE C-V2X in the 5875 to 5925 MHz spectrum with Waterfall plot

Figures 6 and 7 are similar plots for DSRC and UNII.

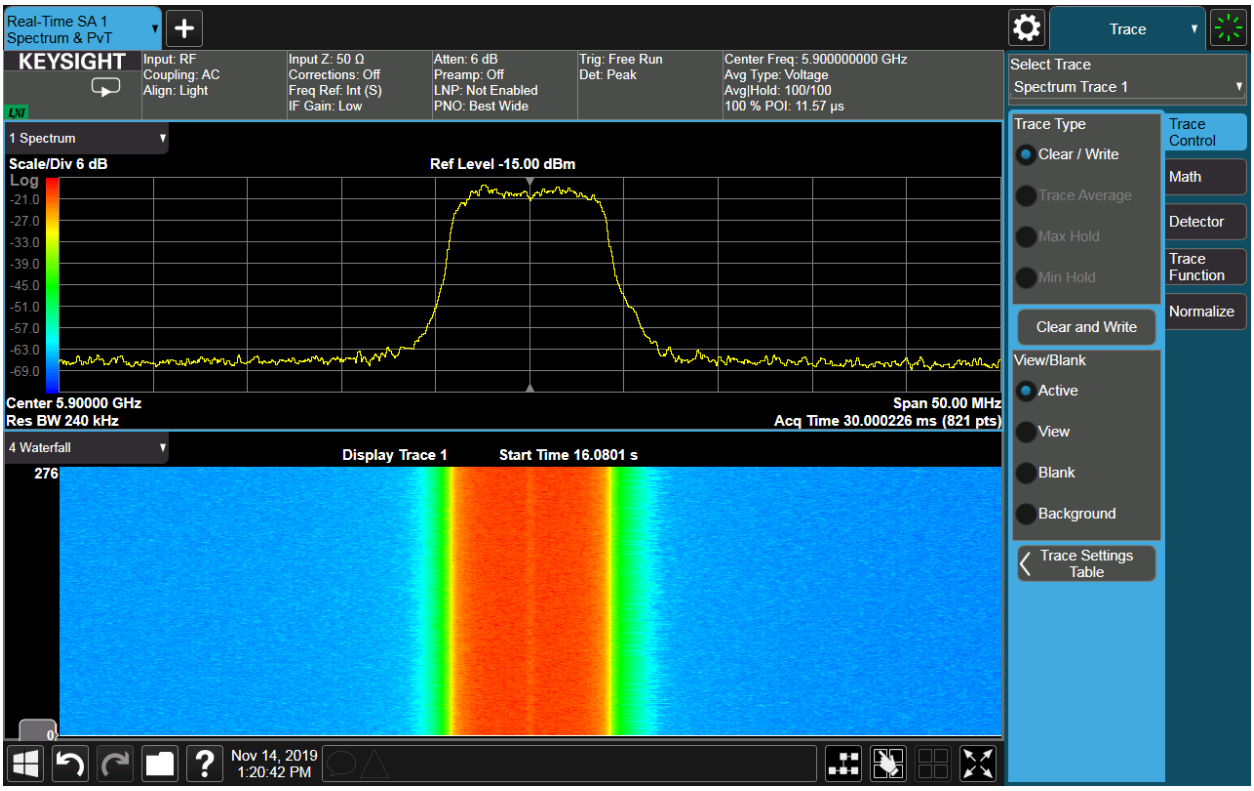

Figure 6. DSRC in the 5875 to 5925 MHz spectrum with Waterfall plot

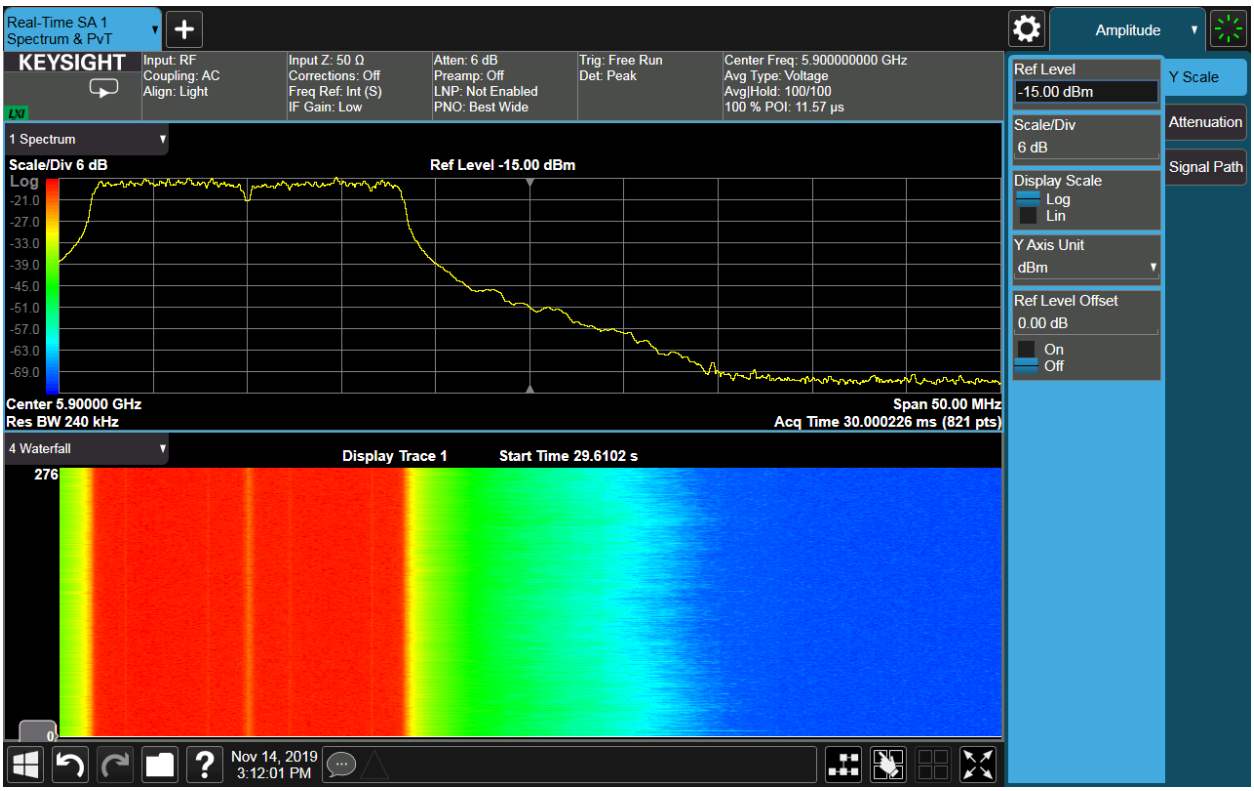

Figure 7. UNII in the 5875 to 5925 MHz spectrum with Waterfall plot

In all three, energy extends outside of the designated channel:

- Energy from the LTE-CV2X, only 17dB down, leaks into the adjacent channel.
- Energy from the UNII, only 20 dB down, leaks into the adjacent channel.
- Energy from the DSRC, at 40 dB down, leaks into the adjacent channel.

4. Conclusion.

While additional testing is needed to determine the level of interference from one device to another, it is clear that interference will occur, raising the question of the reliability of V2X communications in this configuration. Without a high level of reliability, transportation safety will be impacted. These draft results also suggest that the rules and the division of spectrum, as described in the draft NPRM, may result in significant adjacent channel interference between the different radio services and thus may need reconsideration.