Interoperable Connectivity

National V2X Deployment Plan Supplement

www.its.dot.gov/index.htm

Final Report – December 2024
FHWA-JPO-24-140

U.S. Department of Transportation

Produced by Noblis, Inc.
U.S. Department of Transportation
Office of the Assistant Secretary for Research and Technology
Intelligent Transportation Systems (ITS) Joint Program Office (JPO)

Notice

Non-Binding Contents

Except for the statutes and regulations cited, the contents of this document do not have the force and effect of law and are not meant to bind the States or the public in any way. This document is intended only to provide information regarding existing requirements under the law or agency policies.

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

The U.S. Government does not endorse products or manufacturers. Trademarks or manufacturers' names appear in this document only because they are considered essential to the objective of the document. They are included for informational purposes only and are not intended to reflect a preference, approval, or endorsement of any one product or entity.

Technical Report Documentation Page

1. Report No. **FHWA-JPO-24-140**	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle Interoperable Connectivity – National V2X Deployment Plan Supplement		**5. Report Date** December 2024 **6. Performing Organization Code**
7. Author(s) James Chang, S. Gregory Hatcher, Eapen Kuruvilla, Kelly Bare, Mohammed Zaatari, Carl Kain, Ian McManus, Anand Seshadri, Kathy Thompson		**8. Performing Organization Report No.**
9. Performing Organization Name and Address Noblis, Inc. 500 L'Enfant Plaza, S.W., Suite 900 Washington, D.C. 20024		**10. Work Unit No. (TRAIS)** **11. Contract or Grant No.** 693JJ321D000021
12. Sponsoring Agency Name and Address Intelligent Transportation Systems (ITS) Joint Program Office (JPO) 1200 New Jersey Avenue, S.E., Washington, DC 20590		**13. Type of Report and Period Covered** Final Report **14. Sponsoring Agency Code** HOIT-1
15. Supplementary Notes Work Performed for: Govind Vadakpat (ITS JPO; TOCOR)		
16. Abstract This companion document to the *National V2X Deployment Plan* provides additional supporting information for a comparatively more technical audience to gain a more detailed understanding of considerations for planning and deploying interoperable vehicle-to-everything (V2X) technologies. Its intended audience is for technical staff, including program/project managers and their teams, with limited experience with V2X deployments. The supplement provides an overview with information and potential considerations for both technical and institutional enabling elements, and highlights information to build an understanding of benefits and available technical support resources.		
17. Keywords V2X, Interoperable Connectivity, Deployment Planning	**18. Distribution Statement**	
19. Security Classif. (of this report)	**20. Security Classif. (of this page)**	**21. No. of Pages** **38** **22. Price**

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

Acknowledgements

The authors would like to thank the U.S. Department of Transportation (USDOT) Intelligent Transportation Systems (ITS) Joint Program Office (JPO) for sponsoring this work. Specifically, the authors would like to thank Govind Vadakpat (ITS JPO, Government Task Order Manager), and John Harding (FHWA) for their support and feedback. The authors gratefully acknowledge the support and input provided by JD Schneeberger, Faisal Saleem, Justin Anderson, Ed Fok, Usman Ali, Abdul Zineddin, Norah Ocel, Marcia Pincus. Kingsley Azubike, Kate Hartman, Brian Cronin and others in developing this supplement to the *National V2X Deployment Plan*.

The authors express particular appreciation for the detailed review and feedback by members of the Cooperative Automated Transportation (CAT) Coalition V2X Subject Matter Expert Group (SME-G) from industry, associations, research organizations, and transportation agencies, and facilitated by ITS America staff. Members contributed essential stakeholder insights and constructive comments, which were critical to completing this document. The specific feedback provided by Jim Misener, Blaine Leonard, Robert Gee, Kristine Guzak, Brad Stertz, and others was greatly appreciated. Additionally, the feedback from the deployment community, through participation at the summit events as well as through specific comments on the draft deployment plan, were also helpful in the development of the supplement.

Table of Contents

List of Figures

List of Tables

1 Introduction

This companion document to the *National V2X Deployment Plan* provides additional supporting information for a comparatively more technical audience to gain a more detailed understanding of considerations for planning and deploying interoperable vehicle-to-everything (V2X) technologies. Its intended audience is for technical staff, including program/project managers and their teams, with limited experience with V2X deployments. More technical and in-depth resources will be available through the *V2X Deployer Resource* document along with other related documents and resources on the U.S. Department of Transportation's (USDOT) Smart Community Resource Center Interoperable Connectivity page: https://www.its.dot.gov/scrc/index.html#/ic. All stakeholders in the V2X deployment community are encouraged to stay engaged with the community dialogues and resources to stay informed, and to support effective planning, decisions, and implementation. Some organizations have led the charge forward in actively participating in working groups and standards activities. The expectation is that these efforts will continue to advance the maturity of V2X resulting in interoperable, secure, and impactful deployments. However, it is the intent of USDOT that those who may be reluctant to deploy at large scale or have more limited deployment experience should not be left behind, and this supplement and the *V2X Deployer Resource* document collectively aim to inform and support the entire V2X deployment community.

1.1 How the Deployment Community Takes Action – *Together*

The USDOT has long supported research and development of communications-based transportation technologies and emphasizes the need to deploy interoperable connectivity to save lives and reduce serious injuries. Recent development and decisions, and stakeholder inputs have underscored the need to accelerate deployment now in a more coordinated fashion and USDOT is facilitating and coordinating across stakeholders and providing funding and technical support for deployment. The 30 megahertz (MHz) allocated to Intelligent Transportation Systems (ITS) is a valuable asset and enables interoperable connectivity deployments focused on transportation safety, but realizing the full value relies on increasing deployment scale, to allow devices to cost-effectively benefit from a broad ecosystem with many users and use cases. Early work has shown promise for using V2X communications to support a variety of use cases in the 5.9 gigahertz (GHz) spectrum. While this band will not support every envisioned application, initial real-world deployments using this band to improve safety applications for all road users are essential. These initial deployments are expected to:

- Demonstrate commitment from key deployer entities within a cooperative environment.

- Build critical momentum that realizes gains from network effects (economies of scale from increasing deployed number of users) where other applications are developed to leverage a growing ecosystem.
- Encourage other deployments, through showing and quantifying benefits, costs, and lessons from deployment experience.
- Begin to achieve real-world benefits in safety, mobility, and environmental performance.
- Establish foundational organization capacity within transportation agencies to deploy, operate, and maintain emerging technologies.

At the same time, other connectivity outside the 5.9 GHz band has the potential to enable a much broader set of transportation applications beyond direct V2X use cases. For these cases, there are also current motivations to address interoperability, particularly across public agencies, for emerging technologies where national scale would rely upon interoperable connectivity. By establishing interoperability at critical interfaces within an overall modular ITS architecture, future transportation applications can benefit public agencies, enable seamless travel by the public, and leverage private-sector innovation.

There are also expected synergies in that deployers / applications can use the licensed ITS spectrum and other communications. For example, sensors, components, and data generated or collected for one purpose can often support other uses. It is important to emphasize that the underlying foundation to achieving these envisioned deployments will be **architectural, technical, and organizational support for interoperability** across the nation and within diverse stakeholder groups.

Actions taken by deployer stakeholders in a coordinated and informed manner are more likely to realize interoperability in the ecosystem, and the associated positive feedback benefits from increased scale. No one group is able to enable deployment by itself. By learning, engaging, and participating in working groups and other stakeholder-based dialogues, entities will be able to understand the plans, progress, and results for other deploying entities and make more informed decisions as a result. For example, using a standalone message implementation might achieve a project-based outcome, but would miss out on a wider set of participating entities and benefits resulting from a standards-based approach leveraging a deeper market of suppliers. Standards-based interoperability can enable efficiencies of scale by reducing the level of custom development work needed across implementations for different deployments and allow maintenance costs, such as analysis and updates for cybersecurity, to be distributed over a nationwide deployed user base. Active engagement also contributes to improvements to the standards over time through shared implementation experience and development of best practices.

The *National V2X Deployment Plan* identifies examples of potential actions that various stakeholder groups could take toward interoperable V2X deployment. For example, public sector agencies may collaborate with local partners and national standards working groups to deploy V2X technology using standards that address agency priorities for safety and other transportation system needs. The vendor and service provider community, by implementing and supporting interoperable solutions, can provide the capabilities needed in not just a single community, but in many jurisdictions facing similar needs. Within the V2X ecosystem, information sharing, in both institutional and technical forums, can be of significant value in building consensus across key focus areas that enable interoperable and cybersecure V2X deployments, ranging from systems engineering to benefits assessment.

1.2 Interoperable Connectivity Background

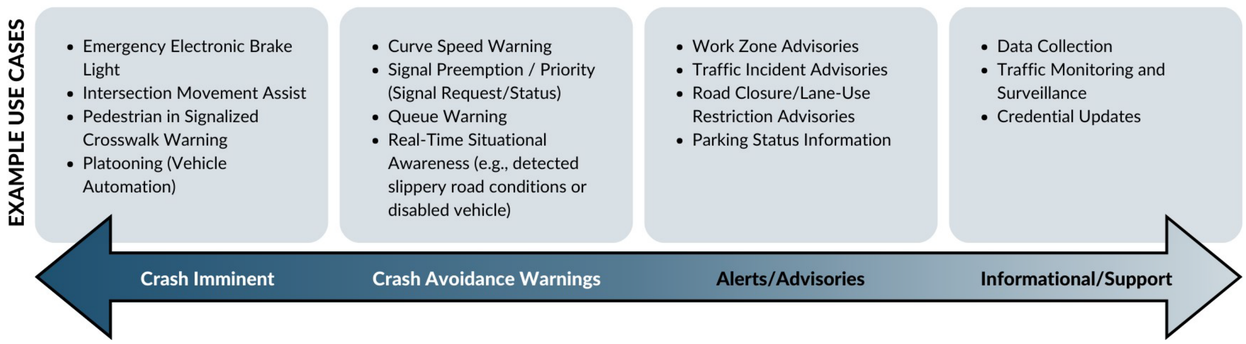
USDOT and stakeholders have conducted research on connected vehicle technologies using licensed Dedicated Short Range Communications (DSRC) spectrum, including piloting both vehicle-to-vehicle (V2V) centered crash avoidance safety applications (Safety Pilot Model Deployment in Ann Arbor, Michigan) and a broader set of prototype V2V and vehicle-to-infrastructure (V2I) applications (Connected Vehicle Pilot Deployment Programs in New York City, Tampa, and Wyoming) over the past decade. These efforts provided a foundation showing the feasibility of a wireless technology platform for communications-based applications across vehicles, infrastructure, and pedestrians, and necessary technical and institutional elements for deployment. For example, site teams collaborated to clarify ambiguities in standards interpretations, and planned and demonstrated cross-site interoperability in a 2018 test with applications using trusted security certificates. Although pilot deployments and assessments were adversely affected by the pandemic, results from the Connected Vehicle (CV) Pilot sites' performance measurement activities and independent evaluators are highlighted in a 2024 Executive Briefing. It is important for deployers to note that collecting data and assessing and documenting results will greatly assist other deployers to better understand the technologies and applications and inform local decision-making. USDOT has collected available information on connected vehicle deployment benefits and created summaries in a Spotlight on Connected Vehicle Deployments in an effort to widely disseminate information to the community. Complete results and findings from the CV Pilot Deployers are documented in publications available on the CV Pilot Deployment Program website.

More recent deployments have demonstrated innovations through using the 5.9 GHz band for applications such as transit signal priority for buses and preemption for snowplow operations. For example, in Utah, applying conditional signal priority when buses are behind schedule led to an increase in schedule reliability from 88% to 94%. Utah Department of Transportation (DOT) also estimated an 8% reduction in crashes as a result of more efficient snowplow operations enabled by the snowplow preemption application and fewer interactions with passing vehicles. Importantly, Utah DOT observed that the previous investments including staff experiences with early-stage equipment and investments in signals and software development were enabling elements to realize the deployment benefits and ability to scale up with additional deployment areas. In addition to Utah, Colorado, Wyoming, Maricopa County (Arizona) and Texas A&M Transportation Institute are deployment sites under USDOT's recently awarded *Saving Lives with Connectivity: Accelerating V2X Deployment* program, which aims to build national models to accelerate and spur new V2X deployments. Significant efforts are also underway in other states using other USDOT discretionary grants or agency resources to leverage the safety band and other technologies, Groups have been formed to share information among deployers and advance the state of practice, including the Accelerating V2X Cohort and Connected Vehicle (and planned successor V2X) Pooled Fund Study. Monitoring current activities and engaging with peer agencies to learn about their recent results and deployment experiences represent a key support for deployment decisions and planning. Making documented evaluation results available publicly in a timely fashion is an important mechanism to support progress through building upon deployment experiences, and enables other deployers to benefit through nationwide resources such as the ITS JPO's ITS Deployment Evaluation website.

1.3 Shifting to a New Spectrum Landscape

Dedicated wireless communications spectrum allocated by the Federal Communications Commission (FCC) is important to realizing the potential benefits of V2X especially for safety use cases relying on direct low-latency communications. As a result of rule changes the FCC formalized in 2021, the spectrum available for direct ITS communications has been changed to a 30 MHz band prioritizing low-latency safety and requiring use of a different communications technology, "Cellular V2X" (C-V2X) in the remaining 5.9 GHz band (5.895-5.925 GHz). While C-V2X has been interpreted in varying ways by different stakeholders, this supplement considers the C-V2X term in the scope of the original FCC first report and order, reflecting the required direct communications technology in the 5.9 GHz ITS spectrum ("direct V2X"). Although FCC did not specify a specific cellular standard in its Second Report and Order, direct long-term evolution (LTE)-V2X (LTE-V2X sidelink, 3GPP Release 14, PC5 Mode 4) is used here to refer to the current expected direct V2X usage (where recent activities have primarily focused on a 20 MHz channel from 5.905-5.925 GHz), as referenced in the SAE International J3161 standard. The recent Second Report and Order reflects the official rules and guidance for implementation and compliance in the 5.9 GHz band going forward, including a transition timeline for DSRC infrastructure (ceasing operations in the band by December 13, 2026), but relies upon industry and the V2X community to realize specific paths for cellular technology interoperability and channel utilization strategies. Deployers can observe how peers and other V2X ecosystem participants have been selecting strategies that rely upon consensus-based standards to realize interoperability and plan deployments.

While past spectrum changes caused disruptions and uncertainty in V2X deployment, the community has now largely shifted to both a focused strategy for deploying using standards-based messages, using the remaining allocated 30 MHz in the 5.9 GHz band for use cases **benefitting from ad hoc direct V2X communication**, and also using a broader approach to apply **other communications spectrum** for other transportation use cases. Communications outside the allocated 5.9 GHz spectrum can be used to send and receive V2X messages using commercial licensed cellular networks (through mobile network operators), satellite, or new and emerging communications technologies such as multi-access edge computing (MEC). These communications methods may support other interoperable connectivity use cases ("network V2X") that do not require direct communication or have sensitivity to higher latency. For example, efforts are currently underway to examine network-based solutions for freight vehicle signal optimization with the North Central Texas Council of Governments. However, work remains to define interoperability and data exchanges that will allow for broader deployment of these types of connectivity applications where multiple options exist to support a range from crash imminent to informational use cases (as illustrated in Figure 1).



Source: USDOT

Figure 1: Use Cases for a Range of Communications Latencies

(Note: examples for illustration – see stakeholder technical documents such as 5G Automotive Association (5GAA) and Connected Transportation Interoperability (CTI) for suggested use case latency and reliability details)

The use cases depicted above are only intended to illustrate some possibilities supported by wireless communications with varying latencies. Stakeholders and working groups represented in 5GAA, ITS America, Connected Vehicle Pooled Fund Study, SAE International, CTI technical committee (multi-organization), American Association of State Highway and Transportation Officials (AASHTO), Institute of Transportation Engineers (ITE), and National Electrical Manufacturers Association (NEMA), among others, have been working to define envisioned near and longer term V2X deployment use cases and associated messages, in light of the new spectrum landscape. Documentation and resources from these groups documenting priorities, and importantly, leading toward V2X deployments and planned deployment commitments, are essential to understand what is likely to be available within the current V2X ecosystem. Collectively, these represent a range from safety-critical 5.9 GHz V2V and V2I applications to traveler information dissemination through multiple communication media. The companion *V2X Deployer Resource* document provides a summary of use case information and considerations in selecting and implementing V2X technologies to meet regional transportation user needs. While many communications-based applications are widely deployed, achieving the vision of broad nationwide interoperable V2X deployment relies on mechanisms to enable interoperability not only in the 5.9 GHz band, where application interoperability has long been understood as the goal, but across other communications methods where interoperability may currently exist at the network layer but where application interoperability can be more uncertain.

Current activities within the V2X standards and architecture communities and transportation data exchanges such as Work Zone Data Exchange (WZDx), are making significant progress, and deployers are encouraged to understand and engage with these efforts to support broader interoperability for their deployment. **Table 1** highlights some examples mentioned in various stakeholder working groups, but deployers should not necessarily consider these as a single solution set covering all needs, but rather an indication of focus areas among key stakeholders.

Table 1: Use Case Examples from Stakeholder Working Groups

Working Group	Examples of Messages / Use Cases Mentioned
Connected Transportation Interoperability (CTI)	• Non-proprietary, communications-agnostic, industry consensus Roadside Unit (RSU) Standard (CTI 4001) • Connected Intersection Guide (CTI 4501) harmonizing Signal Phase and Timing (SPaT), MAP, Radio Technical Commission for Maritime Services (RTCM) broadcast with an initial focus on Red Light Violation Warning including associated security, but also with applicability to other intersection use cases (SAE J4501 is planned update as recommended practice/standard)
CV Pooled Fund Study	• Creation and Verification of MAP message • Monitoring SPaT and MAP consistency with Basic Safety Messages (BSMs) • Connected Signalized Intersections with Vehicle Trust • Connected Work Zones
ITS America	• BSM • SPaT • MAP • RTCM • Traveler Information Message (TIM) • Signal Request Message (SRM) • Signal Status Message (SSM) • Road Safety Message (RSM) • Probe Vehicle Data (PVD)

Working Group	Examples of Messages / Use Cases Mentioned
5GAA	• BSM • SPaT • MAP Data • RTCM corrections • TIM • RSM • WAVE Service Advertisement (WSA) • Security Credentials • SRM / SSM (limited vehicle use) • Toll Advertisement Message / Toll Usage Message / Toll Usage Message Acknowledgement (limited vehicle use)

Source: Summarized from [CTI], [CV PFS], [ITS America], [5GAA] (not in any order)

The *National V2X Deployment Plan* articulates and synthesizes the feedback received to establish a plan to collectively take significant actions toward deployment of interoperable connectivity. The deployment community recognizes the importance of those who have already taken initial steps to deploy a platform in the 5.9 GHz ITS spectrum under the interim FCC waivers, while other supporting elements and broader interoperable connectivity efforts beyond 5.9 GHz are also included, with additional needs being investigated. From the history of prior research and development and pilot deployments in this area, it is anticipated that an incremental approach, with increasing scale of nationwide deployment over time, will better fit the nature of a **connected ecosystem** involving many stakeholders with varying views and interests, but cooperatively utilizing interoperable technology as a foundational platform.

Through efforts such as the development of the *National V2X Deployment Plan*, stakeholder engagements, and continuing development and deployment support efforts, USDOT aims to support and accelerate deployment of interoperable connectivity to enable the greater realization of benefits to agencies and the traveling public. Recognizing that the nation's transportation system crosses boundaries of state, regional, and local agencies, multiple transportation modes and vehicle manufacturers, and a wide-ranging vehicle and infrastructure supplier and support community, USDOT is focusing on achieving interoperability so that economies of scale and efficient and effective connectivity applications can be implemented. Without national leadership, connectivity deployments could be limited and piecemeal, which could diminish benefits and could discourage deployment and adoption of technologies that have great potential. At the same time, the strength of state and regional infrastructure owner/operators (IOO) relationships among peers and with existing relationships such as Federal Highway Administration (FHWA) Division and Resource Center staff and Federal Transit Administration (FTA) region offices should be leveraged to ensure that the understanding of local processes and constraints are incorporated into the planning, design, and implementation context. As with other Federal-Aid programs, the USDOT headquarters and field teams provide not only funding and stewardship, but also help local public agencies and state partners to successfully manage and administer ITS projects and will similarly support agencies with interoperable connectivity deployments.

1.4 Interoperable Connectivity Deployment Principles

Several key principles are useful to consider in developing a consistent understanding among stakeholders of the context of deployment of cooperative interoperable connectivity systems, which differ from deployment of standalone ITS systems. These principles include:

- USDOT Role – USDOT has a central role to convene and coordinate standards and deployment efforts (especially for infrastructure owners) to realize national interoperability, in particular relating to safety – and supports but does not directly deploy/operate the transportation network. USDOT released a stakeholder informed National V2X Deployment Plan and continues to engage with the stakeholder community.
- Deployer Role – Interoperable connectivity deployers, including IOOs, vehicle original equipment manufacturers (OEMs), and associated supplier communities, are collectively deciding the nature and pace of V2X deployment, and realize (including through customers/users) the resulting benefits. Deployers often make decisions independently but must engage collaboratively for interoperability to be realized, and supporting elements such as standards and trust must meet deployer needs to be implemented at national scale.
- Transparency – Public-sector agencies have an expectation that proprietary interests in infrastructure connectivity and potential vendor lock-in risks are taken into consideration.
- Open Standards-based Architecture – Interoperability should rely on open ITS standards setting process and modular architecture as a key foundation. A competitive supplier base for components and subsystems is encouraged but V2X-enabled interfaces need to be open and standards-based for widespread adoption across the nation thereby supporting cost-effective deployment and maintenance. Current and new applications developed in the future will leverage the foundational platform through standards.
- Deployer Motivation – Deployment may be accelerated through current federal funding and V2X grants, but fundamentally will rely on organic growth, building on successful deployer experiences and deployers' views of benefits and costs.
- Technological Evolution – Technology has increased the pace of innovation which enables new components and applications but makes modularity a more significant deployer consideration for interoperable connectivity. A sound systems engineering approach remains important to recognize and plan for areas where benefits of future innovations can be incorporated without excessive disruption to deployed systems and interoperability.

- Operating Entities – Key groups such as vehicle manufacturers and infrastructure owners are expected to lead deployment in their domains. Consortia can enable efficient dialogue, but deployment relies on individual entities' decisions.
- Spectrum – FCC is the responsible federal agency on spectrum allocation and use decisions. USDOT did facilitate progress toward the second report and order through providing supporting information and feedback via regular discussions with the National Telecommunications and Information Administration (NTIA).
- Real-World Implementation – Fielded and operational systems, as compared to plans and forecasts, have significant weight in encouraging peers. Results from early deployments are essential to further define benefits and costs needed for wider scale investments.
- Accelerated Deployment – Early phases of interoperable connectivity deployment that demonstrate the benefits and capabilities would generate public awareness and encourage support by decision-makers for a quicker deployment pace.

1.5 Focus on Interoperability

The following definition of **Interoperable Connectivity** was presented by USDOT at the second V2X Summit:

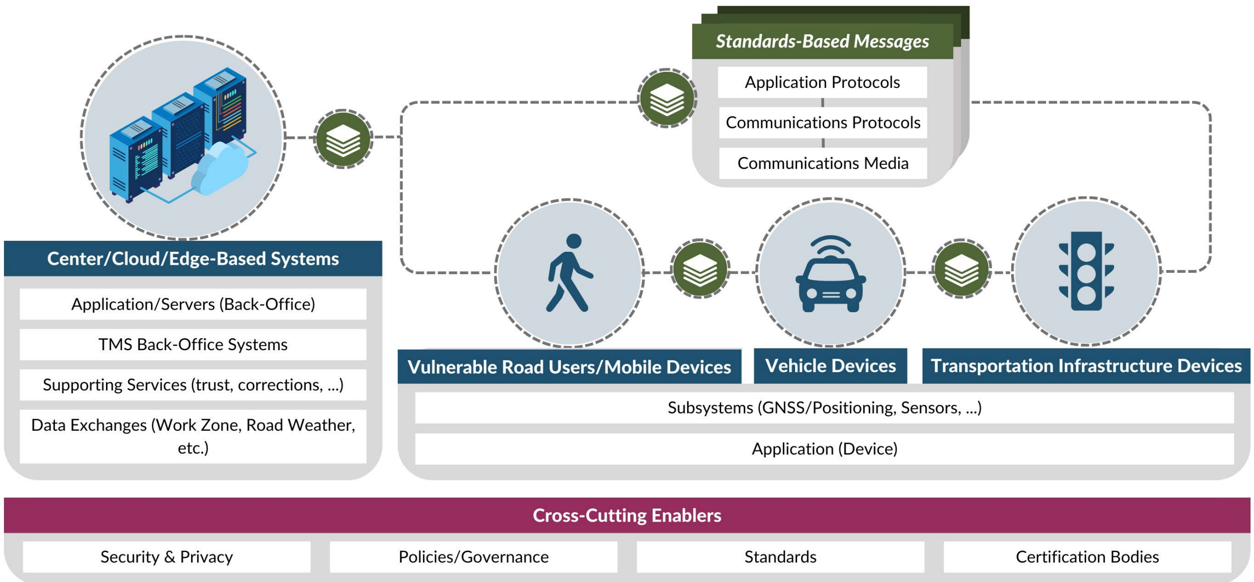
> Interoperable Connectivity refers to the capability of various elements of the transportation system (personal, transit, and freight vehicles, pedestrians, bicyclists, roadside infrastructure, transportation management centers, etc.) to:
>
> - Effectively connect and communicate the safety, system efficiency, mobility, equity, and environmental messages in a secure, trusted, privacy-protected, and coordinated manner.
> - Effectively utilize all available spectrum in the local/regional area to communicate these messages.
> - Effectively identify the appropriate spectrum—dedicated, commercial, or other—based on the requirements of the applications or support functions.

Interoperable connectivity between and among vehicles, infrastructure, and other road users and supporting systems enables a range of applications that utilize data within standards-based messages and communications to improve safety (e.g., warn distracted drivers of a traffic signal turning red), mobility (e.g., provide approaching travelers with real-time incident information), agency operations (i.e., enable more reliable transit and more efficient road maintenance), and environmental impacts (e.g., cooperatively merge while minimizing sudden acceleration/deceleration).

Collectively, these interoperable connectivity interactions may be termed "V2X" or vehicle-to-everything to encompass vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and variations where interoperable wireless communications using standards-based messages is the enabling element. As mentioned above, these may use spectrum such as the 5.9 GHz dedicated spectrum reserved by the FCC for direct ad hoc transportation communications using direct V2X technology, or other communications media where those better support use case requirements and tradeoffs.

Direct communications-based applications have the potential to achieve additional safety benefits beyond individual vehicle or infrastructure systems by enabling real-time multi-vehicle crash avoidance applications beyond sensor range (such as warning of sudden braking many vehicles ahead), as well as improving application performance in conjunction with sensor-based components. At the same time, interoperable connectivity also includes the use of a wide range of communications for safety and other use cases that may not require direct low latency communications. Interoperable connectivity is not a static technology, but should be viewed as a dynamic platform that should not only support today's applications but also new innovations as they are developed.

With connectivity as the starting point, it is critical to underscore the importance of interoperability for deployments to both support deployers participating in a broader ecosystem (see Figure 2) and to achieve anticipated benefits. Standards-based messages, transmitted directly on roadways, or with the support of center, cloud, or edge-based systems, can utilize multiple communications media to support use cases based upon defined protocols, messages, and standards (e.g., SAE J2735, SAE J3161/1), to realize interoperability. Additionally, interoperable connectivity deployments require support from other cross-cutting enablers such as security and privacy measures, governance policies and associated certifications to ensure trust, and a common interpretation of standards. Architectural resources such as Architecture Reference for Cooperative and Intelligent Transportation (ARC-IT) can provide a valuable foundational starting point, but additional testing and clarifications of standards and specifications will be important for deployers to collaborate on and collectively document to realize interoperability, as in resources such as CTI 4501, Connected Intersections Implementation Guide.



Source: USDOT

Figure 2: Illustration of V2X Ecosystem Components

The **interoperability** envisioned in the *National V2X Deployment Plan* includes **the ability to realize full end to end application functionality and integrity across varying communicating components in vehicles, infrastructure, and devices in the transportation system**. Just as dialing a phone number lets one talk with another person speaking the same language whether they are using a landline, voice-over-IP on a laptop, or mobile phone from any carrier or brand, with a vision of nationwide V2X interoperability, a vehicle traveling from Maine to California could receive consistent roadway advisories across jurisdictional boundaries and warn its driver of conflicts with vehicles from other manufacturers. When traveling on city streets, the same vehicle could be warned of pedestrians crossing or the need to stop for a light turning red, while also enabling more efficient traffic operations. Realizing and maintaining interoperability over time is also an important theme in the transportation system where vehicle and infrastructure components need to consider the evolution of technological developments and the many vendors and suppliers in the ecosystem.

For development and deployment of Interoperable Connectivity in the transportation system with a variety of actors and systems, achieving the vision of interoperability depends not only on the technical interoperability of communications which may naturally come to mind, but also process and organizational interoperability[1] which may rely upon policies and written agreements (and technical features that support these). In an Interoperable Connectivity context, examples of these levels may include elements such as:

Table 2: Supporting Elements for Interoperability

Interoperability Supporting Element	Description (and illustrative example)
Wireless protocols (Communications Media & Protocols)	Specifications to enable communication over radio spectrum with devices in range and to access center/cloud/edge-based systems (e.g., "device can transmit/receive encoded data over the air from another device") with suitable reliability, availability, and performance
Message Structure	Agreed-upon format of messages transmitted from one device to another (e.g., "device can process transmitted data to understand that it consists of a compliant SAE J2735 Signal Phase and Timing Message")
Data Elements	Agreed meaning and interpretation of individual data within a message (e.g., "device can process the message to extract the timestamp field as representing the number of minutes elapsed in the current year")
Semantics	Specifications stating the dialogue of messages among communicating entities (e.g., "Signal Status Message reflects response to Signal Request Message")
Application	Collective set of processes and upper layer protocols using communications and data to achieve a result (e.g., "signal controller extends green interval in response to Signal Request Message satisfying established criteria") Innovation will continue to yield additional applications leveraging the underlying V2X foundational layers

[1] Cureton, K. (2022) *Interoperability Evaluation in Systems and Systems-of-Systems*, presentation to International Council on Systems Engineering (INCOSE) San Diego, California Chapter, August 2022.

Interoperability Supporting Element	Description (and illustrative example)
Supporting Trust Processes and V2X Security Services	Provides security services and management (using e.g., Institute of Electrical and Electronics Engineers (IEEE) 1609.2 standard, and governance elements to enable automated verification of trust in data and messages received (e.g., "RSU verifies that Signal Request Message is associated with an identity certificate matching a pre-authorized list")
Supporting Institutional Policies and Relationships	Supporting policies and agreements to define necessary relationships for all elements needed for applications to be deployed and function (e.g., "Neighboring jurisdictions define a memorandum of understanding to specify requirements and conditions under which signal priority can be granted to regional transit buses")

As interoperable connectivity is being deployed into an existing transportation system, which will continue to evolve over time, it should be noted that interfaces with existing systems such as Transportation Management Systems (TMS) are of particular interest. Existing data systems, and standards such as National Transportation Communications for ITS Protocol (NTCIP), will need to be incorporated in an efficient manner. While in the longer-term connectivity within legacy systems will also evolve, deployers should be mindful of opportunities to connect to existing systems as appropriate and practical without extensive modification. Therefore, interoperable connectivity should not be viewed as throwing out all existing ITS to deploy a single new set of components, but rather a strategy to enable more advanced applications and interactions with a broader group of transportation system users and devices. For example, Wyoming DOT utilized its existing Road Weather Information System (RWIS) including sensors, supplemented by fleet and county agency road condition information, to collect, manage, and distribute a consistent set of data on road closures via a standards-based data exchange. This allows the same content to reach travelers and fleet managers in a timely manner, whether they are using an in-vehicle device, commercial navigation service, or web portal.

2 Enabling Elements for Interoperable Connectivity

This section provides an overview of several key elements that enable sustainable deployment of Interoperable Connectivity. By presenting considerations that deployers should take into account, investment decisions can be planned and executed in the short term with a holistic long-term view.

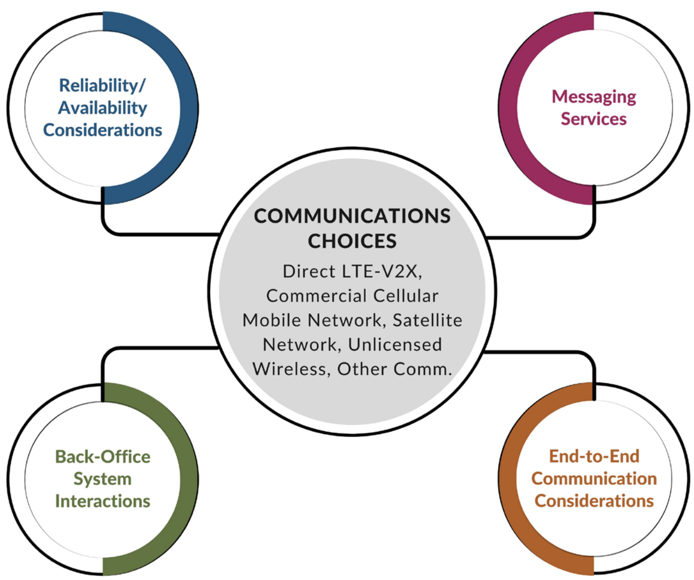
2.1 Systems Engineering Processes

Following long-standing ITS deployment principles and FHWA policies and procedures based on 23 CFR 940 ("Rule 940") for ITS systems engineering, the use of an appropriate systems engineering approach is an important factor in realizing successful interoperable connectivity deployment. FHWA recently updated the Systems Engineering for Intelligent Transportation Systems handbook, which conveys the importance of following a Systems Engineering process to manage risks, ensure the right system is being developed to meet transportation needs, and critically, to support interoperability. The USDOT Smart Community Resource Center maintains an organized set of systems engineering resources and tools, and example documents from projects such as the CV Pilot Deployments. While there is not a one-size-fits-all strategy, to achieve broader interoperability it becomes valuable to view the interoperable connectivity ecosystem as a system of systems (as highlighted in USDOT's Research, Development, and Technology Strategic Plan) when planning and developing deployments, rather than an isolated project. To realize the ecosystem benefits, interoperable connectivity deployments will need to interface with external systems including existing ITS systems as well as external supporting systems and V2X systems. Communications approaches can be selected based on underlying application requirements, such as low latency, but also other broader suitability factors including acceptance, availability, and adoption in the interoperable connectivity ecosystem. Development approaches may vary by project scale and complexity but should give interoperability significant consideration at all stages. This is particularly important to achieve anticipated benefits from safety applications which need to function effectively based on interoperable communications from other devices potentially operated by other entities.

2.2 Wireless Technologies

The Interoperable Connectivity ecosystem relies upon a variety of communications technologies to connect vehicles, infrastructure systems, and other transportation system users. The range of technologies utilize both licensed spectrum such as the 30 MHz in the 5.9 GHz ITS band dedicated to safety, commercially licensed spectrum such as cellular and satellite, and license-exempt spectrum using standards like IEEE 802.11. As communications technologies continue to innovate over time, deployers and developers of interoperable connectivity will use current spectrum and technologies to deploy today, but will need to be aware of future advancements that enable further use cases and capabilities.

Figure 3 illustrates some of the types of considerations that should be included when assessing and selecting candidate technologies and protocols. End-to-end communications considerations include not only wireless latency but communications availability and capacity, cybersecurity, cost, and privacy factors. Critical use cases may need support for high reliability, through protected licensed spectrum, quality-of-service capabilities, or prioritization, while others may be suited to best effort or occasional communications through opportunistic connections. Some use cases may interact with back-office system in real-time while others are based on direct device-to-device interactions. Needs for messaging services can range from local devices broadcasting to other devices in range, sharing messages through edge systems, to support for geofencing or publish/subscribe models. It is also important to keep in mind that deployment architecture choices should not only look at individual use cases currently being deployed, but also expectations and plans for the future, as part of an overall ITS architecture that leverages communications to provide benefits across multiple V2X use cases.



Source: USDOT

Figure 3: End-to-End Communications and Related Considerations

Each technology has a unique life cycle, and is expected to be upgraded over time. Deployers should be mindful to plan for both operating and maintenance costs as well as long-term costs for updates/upgrades. Historically, transportation infrastructure has been oriented toward long life cycles, but with the increasing use of information and communications technologies (ICT) in the transportation system, any one specific wireless technology should not be viewed as a permanent feature. Rather, the high-level architecture includes communications between and among transportation system users and infrastructure, with specific standards and technologies that will evolve over time. These include both direct broadcast wireless communications as well as communications that are routed through center/cloud/edge systems and wired and wireless networks, which will need to support overall required performance (such as speed/capacity, latency, reliability).

It is envisioned that communications media within the V2X ecosystem will not be selected based on an “either 5.9 GHz or non-5.9 GHz” decision, but rather through a systems engineering process based on requirements and tradeoffs. For example, devices equipped with 5.9 GHz direct LTE-V2X communications could still use other unlicensed wireless communications for non-time sensitive uploads and downloads for supporting functions when in range of an access point.

2.3 Standards & Architecture

To realize interoperability, ITS standards apply a development process that is consensus-based, open, and voluntary. Interoperable connectivity deployments in the 5.9 GHz band may need to rely upon some additional non-ITS standards. Deployers using other spectrum should consider the value of consensus-based standards, developed with inputs from all affected stakeholders, which have demonstrated support for long-term sustainability, adoption and innovation. Because the interoperable connectivity community as a whole relies upon standards but may not individually participate in standardization, standards should represent an industry-based consensus which allows for competition but defines necessary interfaces for interoperability clearly and unambiguously. For national interoperability, the level of standardization has varied across different industry standards working groups and architectural elements, but it is essential that working groups ultimately reflect the needs of deployer stakeholders. Future growth is supported by the presence of multiple suppliers and defined standards such that an individual supplier leaving the market would not adversely affect a deployment site.

Given that connectivity applications rely upon machine-to-machine communication prior to human engagement, the protocols for transmitting and processing messages needs to be defined clearly and with documented specifications, such that software from multiple vendors can be written to function with interoperability following a defined ITS architecture. Use of standardized data formats and protocols, and identification of corresponding tools for data analytics and reporting, can facilitate both data sharing and interoperability. Adoption of open architecture principles also maximizes the ability for infrastructure owners to procure and update equipment over time without vendor lock-in. It is essential that deployers look beyond an individual deployment as a single application, and instead consider early in the design phase how the deployed technology would be updated and expanded over time with additional applications and capabilities that may not yet be commercially available, and interactions with additional transportation system users.

In addition to published standards documents, interoperability will rely upon consistency in how wireless technologies interact with existing and future transportation system elements such as Traffic Management Systems, Traffic Signal Controllers, and ITS equipment,. For example, the CTI 4501 Connected Intersections Implementation Guide includes interpretations for accuracy of nodes and reference points to support consistency in MAP messages, based on both vehicle and infrastructure stakeholders. For a seamless experience to be realized, it is likely that additional coordination will be regularly needed across public sector agencies and other V2X deployers to harmonize interfaces, practices, and processes so that the interoperable connectivity ecosystem can benefit from implementations in the transportation system infrastructure and devices that serve a wide user base. It is envisioned that current, agencies that have been playing a leading role in deployment will continue to work through stakeholder-led groups like the CTI Committee and Connected Vehicle Pooled Fund Study (CV PFS) to collaborate and collectively define common practices based on successful deployment experience. Also, collaboration and integration with existing ITS standards such as NTCIP should be included so that the industry will benefit from already-developed standards and knowledge within the ITS community, where practical. Additional technical details on interoperable connectivity standards will also be discussed in the upcoming *V2X Deployer Resource* document.

2.4 Transportation System Cybersecurity

Connectivity to infrastructure systems will enable a variety of applications and associated benefits but will also increase the exposure of ITS systems and connected devices to external cybersecurity threats, due to the introduction of additional interfaces. Design, implementation, and operation of interoperable connectivity components need to incorporate specific cybersecurity needs and processes and verify and monitor operations. Deployment of interoperable connectivity infrastructure will also simultaneously necessitate review and potential updates to agency information technology (IT) security practices and processes. For example, the USDOT has created resources on how to use the National Institute of Standards and Technology (NIST) Cybersecurity Framework including a Profile for Connected Vehicle Environments, which provides a mechanism for an agency to assess, and strengthen cybersecurity measures and enhance intra- and inter-agency communication related to cybersecurity activities. The USDOT has also created an ITS Cybersecurity Framework Profile, which provides a voluntary, risk-based approach for managing cybersecurity activities and reducing cyber risk to the ITS ecosystem. The ITS Security Control Set for Traffic Signal Controllers developed by the USDOT is intended to be used by system and service managers/owners, system integrators system engineers, and system component manufacturers to derive security requirements for the traffic signal controller. The USDOT is supporting the development of Cybersecurity for the Advanced Transportation Controller (ATC) Standards which builds a design for security for the ATC family that is deployable and sustainable nationwide. Improvements to agency cybersecurity practices will not only support interoperable connectivity-based applications that rely upon trusted data but will strengthen operational technologies such as traditional ITS systems and operations. Agencies are encouraged to engage in dialogue with departments responsible for enterprise systems and with other peer agencies to understand their current cybersecurity posture and develop, implement, and maintain a cybersecurity profile that enables the agency's planned interoperable connectivity deployment, to protect both connected devices as well as transportation operations systems. For example, Information Sharing and Analysis Centers (ISACs) support forums to address cyber threats and information relevant to specific critical infrastructure groups, such as state and local governments participating in the Multi-State ISAC. Working groups such as task forces within the CTI committee are also taking a broader view of V2X security including for example security considerations related to messages generated elsewhere, such as within traffic management centers. On the traveler side, device suppliers similarly need to apply best practices for cybersecurity including considering other components and communications subsystems that are connected to interoperable connectivity systems. More details on cybersecurity resources related to V2X communication and ITS can be found at the ITS Cybersecurity Research Program web site.

3 Institutional / Governance Related Supporting Elements

The following sections discuss several important supporting elements that relate to institutional, policy, and governance-related topics.

3.1 Interoperable Connectivity Security Credential Management System

Interoperable connectivity often relies upon broadcast communications, or communications between entities that may not be previously known to each other. For applications to utilize the underlying data being sent, some degree of trust is required, which may vary upon the nature of the application (e.g., a warning application may have a policy requirement for a high level of confidence that the signal phase data matches the current traffic signal indication, while a traveler information advisory application may not have such stringent requirements). Trust may not be interpreted the same way in all uses, and therefore at least basic signing should be a minimum applied to all messages, rather than simply transmitting unsigned messages. An application may otherwise reject messages since they cannot be verified. For applications requiring authorization, such as priority and preemption, messages need a mechanism to ensure that the transmitter is properly authorized, based on defined criteria. All of these situations lead to the need for security credentials for cryptographically signing messages, which can then be verified in an automated fashion by the receiver according to a tailored set of criteria to support policy needs, such as the need to rely on message data that is sufficiently accurate and reliable. Examples of potential trust needs within the ecosystem include:

- Basic trust – signed message matches the credential provided with message, enabling verification that the message is authentic
- Ecosystem trust – credential is chainable (cryptographically verified as linked) back to a trusted root(s) on the device's Certificate Trust List (CTL) indicating accepted certificate and security policies, and has not been identified on a Certificate Revocation List (CRL) of problem devices (e.g., flagged as malfunctioning or having sent erroneous or invalid data)
- Policy trust – credential is chainable back to a certification entity's criteria, such as verified standards conformance or performance criteria for a service category
- Service Authorization trust – credential is chainable back to a set of authorization permissions for a given service, should permissions be granted by category
- Identity trust – credential is chainable back to a known pre-determined identity, should permissions for a service be granted only on identity

USDOT had supported development of strategies to support trust in early connected vehicle projects, but as technologies and processes have matured, the use of a coordinated multi-entity Security Credential Management System (SCMS) supporting the interoperable connectivity ecosystem has emerged as a likely need. To ensure a resilient ecosystem with interoperability, trust and competition desired by stakeholders, it is envisioned that multiple vendors participating in a SCMS, with corresponding governance and management processes, will be commercially available to provide security credentials servicing one or more of the above, or other trust criteria. However, to enable broader interoperability, the security credential providers will need to have a technical and governance mechanism to allow for cross-party trust, which is currently being pursued based on the IEEE 1609.2.1 technical standard.

A set of industry actors has used USDOT research to create a consortium called the SCMS manager, but it is not yet clear how the broader set of stakeholders will resolve the underlying needs for security certificates and the associated compliance and policy/governance processes, which will likely need to reflect a diverse set of needs across the deployer and certificate provider community. For example, the need to rely on valid data in messages is clear, but determination of criteria for securing devices and identifying and reporting misbehavior or problem devices, and processes for revoking or restricting credentials, remains an active work area. As the policy and governance needs have not been entirely defined or agreed upon for the V2X ecosystem, this remains an area of active development, and deployers should be active in understanding the state of practice, and engaging, including with security credential providers to inquire how they interact with multiple other providers, and explore how future deployed vehicles would interact with the deployment ecosystem.

Another aspect deployers should be mindful of is the historical focus of SCMS activities around direct V2X communications between devices, and the need for governance processes that address broader V2X needs. Experience with applying these trust mechanisms for the broader range of communications has been limited; however as an example the Wyoming DOT signs their TIMs when sending through other broader distribution methods, such as satellite broadcast.

3.2 V2X Certification

One significant supporting process for interoperable connectivity is V2X equipment certification, in which device suppliers submit products for independent third-party technical testing of conformance to key industry standards, requirements, and functionality. This is in addition to any lower level certification required by FCC for equipment authorization of radio frequency devices. A certification provider (supporting criteria established with industry) manages and maintains a list of devices that were tested and found to satisfy key interoperable connectivity criteria, such as direct LTE-V2X initial conformance and interoperability for OBUs and RSUs. For certain types of trust relationships, the linking of successful certification testing with issuance of security credentials and/or linked permissions assurances assures that a received message was generated by a device that was tested to meet certain performance criteria, such as location accuracy, which in turn can support reliance on the message content for application functionality. By utilizing an objective certification process, based on community-established needs and criteria, interoperability is enhanced without necessitating individual entity-by-entity or identity-based trust relationships which are impractical for most use cases, and may instead utilize a connection between certain SCMS credentials or permissions and issued certifications.

Stakeholders should be mindful that certification does not exist as a one-size-fits-all testing regime, but follows specific test specifications; progress in certification testing had largely focused on on board units (OBUs) in support of V2V safety applications, but has expanded to other devices such as roadside units (RSUs) for conformance/interoperability. For example, within the Connected Transportation Interoperability (CTI) Committee effort, automotive and transportation infrastructure stakeholders have been working toward consensus definitions and verification processes for intersections broadcasting SPaT and MAP messages such that vehicles can act upon the received messages. This effort relies upon necessary dialogue across stakeholder groups to understand both needs from the receiving device as well as capabilities and practicality of meeting those needs. One specific effort to verify reliability of message content over time is being conducted within the CV Pooled Fund Study Connected Intersection Message Monitoring Systems (CIMMS) project. This supporting capability aims to facilitate trust for applications that use intersection messages, by enabling a vehicle to check that message data is from an intersection with adequate monitoring for accuracy and consistency in SPaT and MAP data (e.g., CTI 4501).

3.3 Policies

Interoperable connectivity is not envisioned to be a monolithic, static, uniform system, but instead an ecosystem focused on interoperability to achieve desired transportation system benefits and outcomes between and among diverse transportation system users and entities. As such, overall policies are primarily defined by the organizations with roles and responsibilities in supporting the sustainable governance of the ecosystem and are likely to evolve over time based on the use cases that are deployed. For example, authorization policies and protocols for traffic signal priority and preemption are defined by the local signal operator in conjunction with the applicable fleet vehicle operator (if different). There are also areas in which stakeholders have already established capabilities supporting policy measures such as protections for individual vehicle privacy through use of non-permanent randomized identifiers in the Basic Safety Message. Furthermore, the requirement for cybersecurity and protecting user privacy in V2X communications was reiterated in the FCC’s final rule. More broadly, data management and governance planning for V2X deployments should account for the various types of data including from vehicles, infrastructure and other sources. Data management plans should consider ownership, policies, and corresponding needs. such as storage, backup, security within a project. In particular, deployments can plan and implement data management strategies to support usability of open data while ensuring that sensitive data is not inadvertently collected, and that data are protected with appropriate cybersecurity measures (e.g., confidentiality, integrity, availability). Examples of general policies within the interoperable connectivity ecosystem commonly include:

- Open Standards-Based Architecture / Evolution of spectrum over time
- Privacy by Design
- Data governance policies for interoperable connectivity
- Actions/Warnings Decided by the User-Facing Device
- Communications Priority for Safety
- Safety Information Sharing
- Processes for accurate geographic referencing/positioning and message content reliability to enable trusted use
- Utilization of a SCMS to support message verification/reporting and trust chains

3.4 Spectrum Governance

Wireless communications spectrum is a managed resource, due to the potential for interference from differing RF transmissions and capacity limitations. In late 2024, the FCC completed its rulemaking for defining the rules for the remaining 5.9 GHz ITS band (5895-5925 MHz). Even in advance of the publication of the final rule, USDOT has been supporting state and local agency deployers by facilitating knowledge on suitable FCC mechanisms to begin deployment activities through short-term experimental licenses, special temporary authority licensing (STA), as well as the more forward-looking direct C-V2X waiver process. In April 2023, 2 agencies and 12 OEMs/suppliers/other entities received waivers to enable interim deployment using a 20 MHz (5905-5925 MHz) channel and direct C-V2X sidelink technology with certain operating parameters. These waivers specified that deployers will need to modify operations as needed to conform to the rules (within the timeframe specified) when the FCC's second report and order becomes effective. As of September 2024, an additional 24 agencies and 15 other entities had been granted waivers by the FCC under the same conditions. In the final rules, FCC indicated that those who have already deployed devices using the waiver process have the ability to continue operations as they transition to license-based operation, since the waiver-based power limits fall within those defined in the final rules. RSU deployers will still need to plan and manage power levels for effective coverage within their deployment area while minimizing potential for interference with nearby RSUs. The final rules also establish the expectation that industry consensus will establish channel utilization practices and standards for the band, and implement any future evolution of communications protocols in this band in a manner that is interoperable, forward and backward compatible.

Beyond the licensed ITS band, communications for interoperable connectivity may include a variety of options which are governed differently. Also, development of additional messages such as sensor sharing (SAE J3224) continues with the expectation of a supportive future spectrum landscape. Current options may range from unlicensed wireless spectrum that is not protected from interference, which might be used for supporting uploads and downloads, to commercial mobile operator spectrum available to paid subscribers, such as typically used for smartphones. While applications exist in these other spectrum options, the *National V2X Deployment Plan* envisions a future where broader interoperability is realized through data exchange standards at a higher level, and not necessarily through identical wireless technologies. For example, the same SPaT messages generated for direct V2X broadcast may also be sent through other communications and backhaul networks at a lower rate to support applications that are not latency-sensitive.

3.5 Outcome / Benefit Framework

As interoperable connectivity often operates as a cooperative system between and among vehicles, infrastructure, and other road users, a variety of use cases are expected to build upon a base platform of connectivity. Cost efficiency is gained through this use of a standards-based interoperable platform for a nationwide user base, instead of many individual applications relying upon separately maintained technology stacks. Therefore, formal assessment of benefits and costs are not expected to be as straightforward as a standalone technology deployed by an individual entity. Rather, once connectivity is deployed, with required supporting elements to enable use cases, an assessment of interoperability should be considered to verify the deployed system's ability to successfully interact with other deployment elements, such as through the successful initial deployments of agency operations applications. By doing so, the anticipated benefits may not only accrue directly to the deployed transportation system users, but as fleet and infrastructure penetration increase, the aggregate estimated benefits can often increase due to a higher number of entities for potential interaction. For example, if an intersection is equipped with the capability to transmit SPaT/MAP, vehicles can use that information for both safety applications such as red-light violation warning as well as other use cases like transit signal priority or green light optimal speed advisory, for mobility, operations, or environment.

The scaling of benefits with the increasing number of vehicles and other entities participating in the interoperable connectivity ecosystem is a significant characteristic owing to the network effect, but critically, depends on achieving interoperable connectivity. Development costs for applications can largely scale to high volume without significant added marginal costs but initial efforts can be substantial. As a result, collective realization of adequate scale is a critical factor for advantageous benefit/cost ratios. For the ecosystem to grow, a critical element will be the awareness and sharing of early deployer experiences and outcomes, which are expected to inform and support additional deployers through the network effect and the technology adoption life cycle.

To deploy and sustain interoperable connectivity over time, suggested considerations related to evaluation include:

- Take a full life-cycle approach to evaluation. Start early to understand the differences in assessing a cooperative technology platform that participates in a larger interoperable connectivity ecosystem, as compared to a standalone ITS deployment. Evaluations should consider the timing of both benefits realized and costs expended in the life cycle (including long-term maintenance and upgrades/replacements) and assess uncertainties through confidence levels or sensitivity analyses.

- Review existing benefits and costs information and analyses from previous and current deployments, through resources such as the USDOT ITS Deployment Evaluation website and results shared by peer deployers.
- In the planning stage, take the necessary time to develop clear objectives and measures (both for applications and the overall deployment) and identify and develop the methods required to gather supporting data and conduct evaluation analyses. Attempting to conduct evaluations without the requisite planning is likely to be infeasible or ineffective in yielding the desired understanding of deployment impacts.
- Consider defining key performance indicators (KPIs) directly tied to the primary strategic intent and objectives of the deployment to review progress over time and guide adjustments. KPIs for a small-scale pilot focusing on applications using an agency's fleet vehicles are likely to differ from those for a regionwide deployment aiming for significant interactions with multiple external stakeholder groups. Selected KPIs should be meaningful for agreed-upon objective(s) while balancing the practicality of data collection.
- Discuss the role and importance to return-on-investment (ROI) and benefit-cost analysis (BCA) to get buy-in from leadership. Utilize supporting resources such as the USDOT's ROI Best Practice Guide.
- Plan for workforce development and maintenance policies that may differ from existing expectations and need new monitoring and assessment strategies to meet the needs for interoperable connectivity. Leverage training and other resources from the ITS Professional Capacity Building program and Smart Community Resource Center.
- Collaborate with other deployers and establish and refine frameworks and performance measures that are suitable for assessing benefits from cooperative platform technologies like interoperable connectivity. Capture both quantitative and qualitative results and share with other deployer groups to enable more rapid leveraging of deployment experiences for future projects.

Further discussion and suggested practices in designing evaluation plans are included in the *Deployer Resource* document.

3.6 Support for New Deployers

Agency deployers vary in their experience and familiarity with interoperable connectivity and have different resources and constraints, but most agencies have at least some experience with applying advancements in technology to their transportation systems. The *National V2X Deployment Plan* aims to inform potential deployers of practical strategies to make tangible deployment progress, starting today. Agencies at different levels of experience may approach their priorities differently. However, deployers should generally begin by **identifying the**

transportation problems that are most pressing in their operating environment as an initial step and aim to start with a plan corresponding to level of experience and resources.

Challenges and priorities for a large metropolitan area vary based on their focus and the communities they serve and may not be necessarily the same as a small rural focused agency or a state agency with responsibilities for urban, suburban, and rural facilities. While there may be some overlap in priorities among these agencies, one must tailor the selected approach to best serve the specific needs of the community or jurisdiction. Existing regional processes and studies/plans, such as Transportation System Management and Operations (TSMO) plans and performance management processes and data, are likely to be useful resources in identifying significant problem areas. The National ITS Architecture and updates to regional ITS architectures are likely an informative tool in understanding the current state of use cases applicable to various transportation problem areas, and benefit/cost resources should be reviewed at an early stage to inform planning efforts. As stated earlier, peer entities can be a helpful resource as they may experience similar transportation problem areas and have similarities in constraints. Deployers should be mindful of expected roles of IOOs and OEMs in reviewing prospective strategies, but potential examples relevant to interoperable connectivity include:

- Intersection crashes – V2I applications such as Red Light Violation Warning and V2V crash avoidance applications like Intersection Movement Assist / Left Turn Assist Warning
- Agency fleet efficiency – V2I applications such as snowplow preemption
- Schedule reliability for bus transit – V2I applications such as Transit Signal Priority
- Weather related crashes – V2I applications such as road weather advisories and warnings
- Work zone related crashes – V2I and V2P applications such as Work Zone worker advisories and warnings
- Vulnerable Road User road crossings – V2I applications such as Pedestrian in Signalized Crosswalk

The *V2X Deployer Resource* will include a more detailed review of use cases and transportation system challenges related to interoperable connectivity technologies. Deployers should also include gathering information about messages and application maturity and other deployers' experiences at the early stages. Establishing relationships with other entities at similar phases can also be beneficial to share information and discuss potential collaboration and coordination in deployment activities, such as testing and interoperability.

For agencies without prior experience, efforts in the near term should start small but meaningfully and aim to build further while progressing on the learning curve. A low-risk way to get started is to review the existing state of foundational systems such as backhaul communications and power, traffic signal controllers and other ITS equipment, and back-office systems, cybersecurity plans and measures, and include interoperable connectivity considerations when planning update/upgrades and equipment refresh cycles. Activities to get started also include non-technical areas such as reviewing procurement processes, establishing partnerships with peer agencies, and participating in training and professional capacity building efforts.

Those who have had prior experience but without active deployments should refresh their understanding based on the developments over the last several years, knowing that skills and knowledge gained in the past can mostly be applied to the current technology. Trainings such as USDOT's new V2X Foundational Training and other planned modules will help both people new to V2X and those who want a refresher to learn about current V2X technologies Finally, those deployments who have been actively building and operating initial applications should take advantage of their experience to both scale up their own deployment environments as well as take a leadership position in advancing successful deployments by sharing technical knowledge and specifications. It is reasonable to expect that deployment projects may experience problems and setbacks before outcomes are achieved. However, by viewing the results and lessons with an audience of the broader interoperable connectivity community, successes can more rapidly multiply while project components found to be lacking can be left for potential work within the research and development community and not a repeat lesson for other deployers. By coordinating and supporting the deployer community through efforts such as developing the *National V2X Deployment Plan*, sharing resources through the Smart Community Resource Center, and facilitating interactions among peer deployers through early deployer cohort programs such as the Accelerating V2X Cohort and planned V2X Pooled Fund Study, USDOT aims to more effectively and rapidly enable fielded interoperable connectivity deployments to accrue and realize transportation system benefits, particularly in the area of safety.

3.7 Needs Status

The *National V2X Deployment Plan* reflects the information available as of August 2024, but USDOT recognizes that a static document is only a starting point. Continued engagement within the stakeholder community will support more sustained deployment efforts, with a V2X summit held in October 2023 and additional meetings at industry events such as the Transportation Research Board (TRB) Annual Meeting in January 2024 and the ITS America Annual Meeting in April 2024. USDOT also plans continued structured engagements with key stakeholder associations such as AASHTO, ITS America, ITE, and the Alliance for Automotive Innovation. As mentioned earlier in the document, to support deployers and prospective deployers, USDOT is developing the *V2X Deployer Resource* document that discusses technical needs and provides more detailed technical considerations for agency technical staff and supporting consultants. Example topics include:

- Fundamentals of V2X Connectivity (including V2X messages and use cases)
- Key V2X Concepts and Topics (including communications technologies, data exchange, standards and trust)
- Strategies to Enable V2X Deployment (from a technical and project view)

- V2X Systems Considerations (in the Project Development Process)
- Information to Understand Federal Funding Categories and Eligibility Factors

Resources will also be developed, made available, and updated over time through the Interoperable Connectivity page of the USDOT Smart Community Resource Center. Deployers are encouraged to engage within working groups such as the Connected Transportation Infrastructure (CTI) program, public agencies participating in the Accelerating V2X Cohort, CV Pooled Fund Study, standards development organizations, and transportation and ITS trade associations. Staying connected with ongoing developments and progress will ultimately help deployers to be more successful and maintain perspective on the future direction of interoperable connectivity. Additionally, the forthcoming *V2X Deployer Resource* will include a more current review of funding categories related to Interoperable Connectivity deployment.

4 Understanding Expected Benefits/Outcomes

To sustain efforts toward interoperable connectivity, the deployment community should keep in mind the expected outcomes and benefits toward transportation systems and users and sharing results from well-planned evaluations, rather than pursuing technology deployments as an end in itself. This supplement differs from prior approaches in advocating a more deployer-led focus with more nimble strategies to achieve transportation system benefits under a continued dynamic environment. Indeed, one expected outcome from interoperable connectivity deployment is a change in mindset within public agencies to evolve practices and processes to realize greater compatibility with a technology life cycle that moves more quickly than traditional ITS. V2X builds upon ITS and the use of interoperable connectivity and data to address safety and other challenges and improve performance, across a variety of supporting communications media but with a focus on standards-based interoperability, is envisioned as a significant functionality of the transportation system going forward. This shift does come with risks, which need to be managed primarily through building agency capacity and knowledge; however, it must also be recognized that there are underlying opportunity costs in not taking actions to potentially save lives and improve transportation system operations.

4.1 Safety

Interoperable connectivity at scale can enable a wide variety of crash avoidance applications such as V2V alerts for emergency braking and conflicting traffic at intersections. Initially, a subset of applications that do not depend on high market penetration will likely provide nearer-term safety benefits. For example, drivers that are notified of upcoming slowed or stopped traffic through the use of real-time data and analytics can be more prepared and decelerate more gradually, reducing the probability of chain-reaction and secondary incident-related crashes. Weather and other hazards on roadways and work zone areas requiring additional driver attention and speed reduction can be identified more quickly and advisories disseminated more widely with interoperable connectivity, including informing the growing number of vehicles with higher levels of driving automation. Equipping emergency vehicles and traffic signals with interoperable connectivity can not only facilitate faster response times to life-threatening emergencies, but also reduce the risks posed to emergency responders driving to incidents from other drivers and even other emergency vehicles responding from other directions. The potential to use both advanced sensing technologies (including sensor sharing) and smart devices to identify and communicate potential conflicts and provide warnings can begin to counteract the trend toward higher crashes involving vulnerable road users and wrong-way driving, leading to both safer vehicles, safer speeds, and safer people.

4.2 Mobility & Environment

The efficiency of the transportation system can also be improved with interoperable connectivity deployment. The future may hold promise for vehicle automation using interoperable connectivity to optimize real-time trajectories and reduce energy consumption through platoons and ad-hoc car following strategies that smooth traffic flow. With early-stage interoperable connectivity deployment, more widespread real-time data and analytics can inform travelers and agencies of incidents and mitigate resulting congestion to improve travel time and reliability. Agencies can provide more rapid and widespread information on road closures and advisories to travelers, fleet managers, and logistics systems through consistent and interoperable connectivity. The real-time data enabled by interoperable connectivity will also allow the transportation system to respond more dynamically to events and improve recovery and build resiliency.

4.3 Agency Operations

Interoperable connectivity can contribute to more efficient and effective agency operations more broadly, including transit vehicles and DOT fleets. For example, equipping transit and fleet vehicles with interoperable connectivity allows agencies starting with intersection deployment to begin with deployments within their control and gain early value through applications such as transit signal priority and snowplow preemption, which can improve agency operations. Adding connectivity to agency fleet vehicles is also a natural fit for enabling a variety of use cases, such as gathering road condition data, monitoring and coordinating incident response, and transit operations without needing a separate platform for each application. Significantly, interoperable connectivity deployments that improve agency operations are likely to provide more immediately realizable benefits including potential efficiency savings that can offset agency deployment and operations costs.

4.4 Continued Innovation Mindset

While the above categories of benefits serve as motivations for transportation system outcomes enable by interoperable connectivity deployment, the broader impacts should also be considered in deployment planning and decisions. An agency's experience with active deployment and operation of these technologies will help to build internal capability and knowledge which will be of benefit in other ITS and operational challenges, such as effectively managing transportation data. Interoperable connectivity deployment also broadens the agency's relationship with other agencies and potentially less familiar entities such as automakers, which can result in improved understanding of transportation problems and operations from a cross-domain perspective, leading to more effective solutions. USDOT is supporting these cross-agency and cross-entity relationships by facilitating the development of reference implementations that others can build from to progress from individual deployments toward the national-level, and will be coordinating activities to facilitate interoperable connectivity interfaces and data exchange standards across jurisdictions. While these impacts can be harder to quantify, it is envisioned that these benefits will be shown in more successful deployment experience and outcomes which in turn will lead to more rapid and greater scaling of deployment at a national level, which can be quantified – in terms of growth rate, participation in interoperable connectivity ecosystem, or aggregate measures of change in transportation outcomes over time.

.

5 Technical Assistance and Support

USDOT aims to facilitate and support the interoperable connectivity community to realize the benefits of deployed applications. Through the development of the *National V2X Deployment Plan*, stakeholders from a variety of groups, experience levels, and organizational capabilities can better understand potential roles and expectations and identify meaningful opportunities to plan and deploy interoperable connectivity. Resources and information will be made easily discoverable through USDOT's Smart Community Resource Center and professional capacity building activities such as foundational training on V2X with additional training modules planned. USDOT also plans to regularly engage with stakeholders for key interoperable connectivity supporting elements, such as spectrum, standards, certification, and security. Regular engagements supported by USDOT, such as stakeholder meetings and technical workshops, will provide an additional mechanism to validate stakeholder inputs and needs, and to facilitate sharing development progress within the community.

USDOT will continue with strong coordination and facilitation activities and provision of technical support and funding. State and local infrastructure owners and supporting vendors, automotive OEMs, application/device suppliers, and other supporting components will be the driving force in enabling and deploying in the field, and will need to deploy, operate, and maintain interoperable connectivity components from the developer and supplier community and supported by interoperable standards.

The Intelligent Transportation Systems Professional Capacity Building (ITS PCB) program and other related activities are envisioned to help facilitate the exchange of knowledge and best practices, as well as lessons learned from those entities that have deployed safety related technology and have learned the need for interoperable connectivity in their systems. USDOT can help showcase early deployer experiences to inform and support future deployers at a suitable level of readiness, whether implementing supporting infrastructure like fiber communications backbones, building cybersecurity maturity within agencies, or deploying smaller-scope applications. Examples of USDOT-sponsored support capabilities that have been recently developed or enhanced include:

- Frequent delivery of a new foundational V2X training with additional modules planned
- Establishment of a new Accelerating V2X Cohort, with over 40 public agency members (so far)
- Continued enhancements and added capabilities in USDOT open source V2X tools
- Organization of V2X information and resources as part of the Smart Community Resource Center
- Current V2X equipment available for loan along with supporting help desk
- Deployment map and tracking resource being developed to visualize progress
- Outreach and education materials to support agencies planning V2X deployments

5.1 Highlighted Deployer Resources

To support leading deployer agencies to increase deployment scale and enable other deployers to have a smoother path in getting started or taking next steps, several deployer resources for interoperable connectivity are highlighted in **Table 3**. USDOT is actively preparing multiple products and avenues of technical assistance, training, and other support to facilitate successful deployment, but also seeks to highlight broader efforts in the V2X stakeholder community. Agencies and others in the deployment community are encouraged to build their awareness and knowledge, including in the areas of technology, standards, implementation, operations, and maintenance, and to engage with peers, working groups, and community efforts to share experiences and inquire and collectively contribute to innovation.

Table 3: Potential Resources and Engagement Opportunities for V2X Deployers

Resource	Description	Location
V2X Deployer Resource	This technically-oriented compendium offers a single source of information, recommendations, and pointers to additional resources for prospective and experienced V2X systems deployers.	Forthcoming
Cooperative Automated Transportation Coalition	AASHTO, ITE, and ITS America group collaborating to further Cooperative and Automated Transportation implementation.	https://transportationops.org/CATCoalition
Connected Transportation Interoperability	AASHTO, ITE, NEMA, SAE group supporting cross-industry collaboration to define necessary elements and standards to achieve interoperability between vehicles and infrastructure.	https://www.ite.org/technical-resources/standards/connected-intersections/
SAE V2X Committees	Standards groups developing and maintaining V2X standards	https://standardsworks.sae.org/standards-committees/v2x-vehicular-applications-technical-committee

Resource	Description	Location
Connected Vehicle Pooled Fund Study and planned successor Vehicle to Everything (V2X) Pooled Fund Study	Public sector transportation agencies conducting research and development for infrastructure V2X.	https://engineering.virginia.edu/labs-groups/cvpfs and https://www.pooledfund.org/Details/Solicitation/1615
Trainings and Supporting Materials – PCB program	The ITS JPO Professional Capacity Building program develops and supports trainings and webinars on a variety of ITS including interoperable connectivity.	https://www.its.dot.gov/pcb/
Smart Community Resource Center – Interoperable Connectivity portal	The Smart Community Resource Center connects communities with resources that can be used to develop ITS and smart community initiatives including interoperable connectivity deployments.	https://www.its.dot.gov/scrc/index.html#/ic
USDOT Spectrum Team	USDOT coordinates transportation-related spectrum with NTIA/FCC and deployers. Conveys V2X deployers' need for spectrum commitment and clarity.	https://www.its.dot.gov/research_areas/emerging_tech/htm/Next_Landing.htm and via email to 5.9GHzSpectrum@dot.gov
Accelerating V2X Cohort	Documents and shares early deployment experiences and best practices through a recently established V2X focused cohort and companion resource documents.	Materials will be shared through the SCRC: https://www.its.dot.gov/scrc/#/
Standards	ITS standards development and maintenance, including interoperable connectivity standards activities, are tracked and supported by the ITS JPO's ITS Standards Program.	https://www.standards.its.dot.gov/

Resource	Description	Location
Technical Assistance	USDOT offers a connected vehicle help desk service that offers technical support to deployers including open source tools such as MAP and TIM creation tools and equipment loans.	https://www.its.dot.gov/pcb/documents/EquipmentLoan_HelpDesk_Primer.pdf and https://www.its.dot.gov/scrc/#/ic
Public Outreach and Engagement	USDOT has convened stakeholder forums such as the V2X Summits in August 2022, April and October 2023, and at transportation conferences and events to share information, share user stories online, and collaborate with a wide range of stakeholder groups.	https://www.its.dot.gov/research_areas/emerging_tech/htm/ITS_V2X_CommunicationSummit.htm

U.S. Department of Transportation
ITS Joint Program Office – HOIT
1200 New Jersey Avenue, SE
Washington, DC 20590

Toll-Free “Help Line” 866-367-7487

www.its.dot.gov

FHWA-JPO-24-140

U.S. Department of Transportation