Infrastructure and V2X Mapping Needs Assessment and Development Support

Final Project Report

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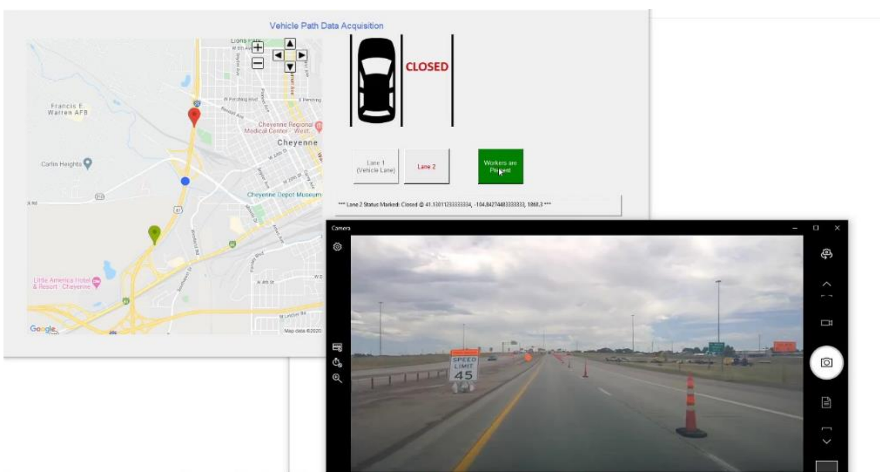

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16. Abstract

Sharing location-based information and positioning vehicles with respect to that information has been one of the fundamental challenges in intelligent transportation for over two decades. As Connected and Automated Vehicles (C/AVs) and related data-intensive transportation network management solutions start to emerge, this research project assesses *what map information is needed and how do we best communicate it to current and emerging Vehicle to Everything (V2X) devices to support safety and mobility applications?* In an effort to close the gap in knowledge in this field, USDOT is funding research to determine the core set of application needs and gaps in current map data standards and processes to support V2X applications. As part of this effort, this document provides a report on the five tasks on this project. It integrates all deliverables into a single compilation that shows the evolution of our understanding and provides detailed research and analysis results.

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Executive Summary

Introduction

For many years, the public sector has focused on building a *connected, cooperative* transportation system that allows vehicles to communicate with each other and the publicly owned infrastructure, including reception of both information and direction from traffic management centers. This concept has always assumed that there would be a human driver.

With the recent emergence of automated driving, however, the transportation system will now need to support both human and machine drivers (also known as *connected, automated vehicles*, or CAVs). More automated systems will make their way onto the market for adoption in a gradual fashion, and there will be a duration during which many different kinds of solutions will co-exist. In addition, there is not yet consensus on the overall business models for the public and private sectors for providing location-based data (such as maps) for CAVs.

This situation adds a new complexity to the already challenging task of sharing location-based information with travelers. Standardization becomes critically important, as machine drivers need much more consistent and descriptive information than human drivers do. For example, a human driver can see the words "work zone ahead" and will figure out how to navigate the situation. A machine driver needs much more detailed information about what has changed and where exactly the new navigable path is located. Further, this information needs to be interoperable nationally, as vehicle software will not be able to adjust every time it crosses a jurisdictional line.

The Research Question

The stated initial research question for this project is: *How do we best communicate map information from the infrastructure to vehicle-to-everything (V2X) devices?*

A subsequent framing of the problem stated the following:

- *How do we describe and connect CAV-Path data*[a] *to core road network data with required quality for use in a mixed CAV environment?*
- *What is the public sector role in providing location-based information to CAVs?*

[a] A real-time collection of data allows the vehicle to understand the basic road network and the current status of its *path* through that network.

Figure 1 illustrates this progression.

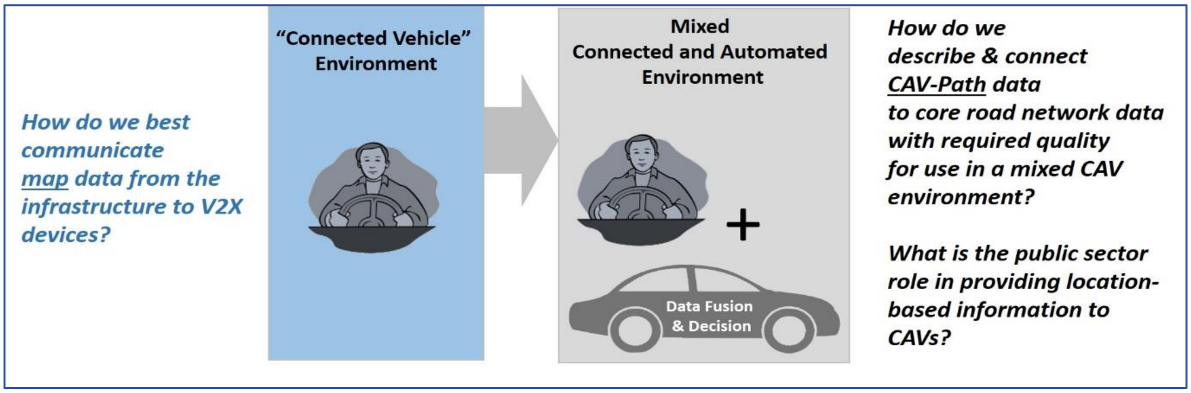

Figure 1. Progression From CV Environment to Mixed CAV Environment.
(Source: FHWA)

Project Outcomes

Activities included a state of the practice review, stakeholder needs review, concept synthesis & gap analysis, and a case study. Based on the input from a diverse group of public and private sector stakeholders, we synthesized a set of "key concepts," which helped provide context for the V2X mapping discussion; we developed a traceable set of standards needs; and we documented current and emerging standards activities. Stakeholder discussions and subsequent analysis identified implementation gaps documented in this report. In particular, findings from the project highlight the following:

Maps for automated vehicles are not the same as those used for traditional GIS or navigation. In particular, vehicles now need a combination of dynamic and static data that depict the driving environment. This new data must allow the vehicle to understand the basic road network and the current status of its path through that network, and it must be at a very high level of precision, accuracy and currency. As a result, map data now refers to a real-time collection of data composed of multiple layers and update streams. For the purposes of this document, this data is referred to as "CAV-Path data."[b]

The primary need is for standard content descriptions, as shown in Figure 2. Standard content must be able to consistently and accurately answer the following questions:

- *What is the event/object/structure?*
- *Where is it located?*
- *How good are these data?*

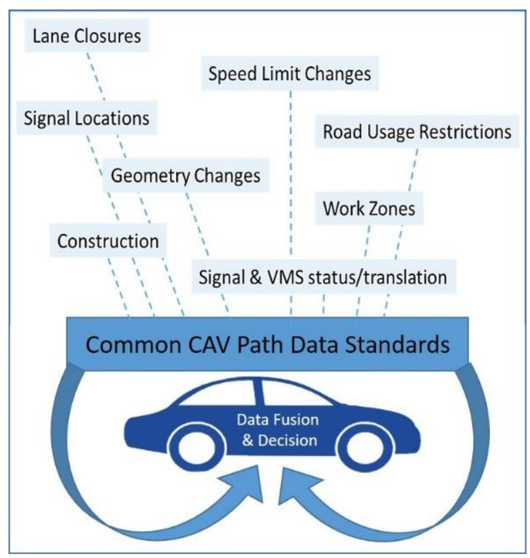

Figure 2. Need for standardized content.
(Source: USDOT)

[b] While there is no consistent industry name for this new definition: the term "High Definition (HD) map" is often used to describe high-accuracy road network data, but opinions vary as to the details. "Dynamic map" and "LiveMap" are other terms that have been put forward with similar implications.

Automated vehicles require *computable* data that will allow them to compare multiple sets of received information to other sensor inputs and make repeatable, effective decisions. The information must be consistently coded and quantified to allow this processing to occur.

Public sector agencies will be "one among many" types of entities making data available for AV use. Original equipment manufacturers (OEMs) and third-party data aggregators will likely also play a major role. In order to gain the maximum benefit from their investment, public sector agencies will need be quite selective in the types of data that they choose to provide. There is a focus on data that *clearly provides transportation safety and operational benefits* and that the public sector can most efficiently provide. For example, information about dynamic rules of the road and planned roadwork (work zones) might meet both criteria.

The primary standards challenge appears to be *"How do we select and implement the necessary standards to develop a nationally consistent set of public sector information to enable AVs?"* There is a great deal of standards development work underway globally to generate standards to meet AV requirements, including the extension and expansion of existing deployed standards. The stakeholder community will need to either select, harmonize or translate among the many competing and overlapping options.

Nationwide public sector deployment of standardized data suitable for CAVs is a major implementation challenge. There is a need to agree upon a minimum national data set; develop the necessary data collection and delivery capabilities; and work to ensure that infrastructure owner-operators (IOOs) are aware of, and able to effectively implement, the core suite of standards that corresponds to the minimum national data set.

Using work zones as a case study, the research team developed tools to demonstrate how a public agency might create data feed(s) that can be used to provide data for human and machine drivers based on existing and emerging standards. The end goal was to begin "connecting the dots" among existing programs and specification development efforts in support of common Work Zone Event Data for V2X and Cooperative automated driving systems (ADS) applications.

The research team divided this effort into two tasks:

- *Design and Development Activities to Address Standards Gaps,* which sought to research opportunities to leverage and evolve geospatial elements of Work Zone Data Exchange (WZDx) for advanced driver-assistance systems (ADAS) and AV use-cases for use by machines. We focused on an *in-depth review* of the spatial data standards identified in previous efforts to support the provision of *work zone data*. The results of this task provide specific input to both specification developers and data providers, especially on linking Work Zones to HD Maps (e.g., WZDx and WZDI work). They also contribute key insights toward a draft "national AV-ready spatial data set" that OEMs and IOOs can both usefully review.

- *Development and Testing of V2X Mapping Proof-of-Concept (POC) of Work Zone Mapping Toolset,* which sought to test how to attach data to different maps. The team developed and tested a POC system for efficiently capturing a digital map of a work zone and its features, including lane closures and workers present in the work zone. The team combined these data with other work zone configuration data to form a work zone map message that is published and disseminated to infrastructure owner-operators' (IOO) traveler information systems, third-party traveler information systems, and ADS.

Chapter 1. Introduction

Background

The United States Department of Transportation (USDOT) and its stakeholders have identified a wide range of potential vehicle-to-infrastructure (V2I) safety applications that can reduce the likelihood of crashes and improve the safety of work zone and first responder personnel on and near the roadside. Every V2I application has slightly different needs for map and location accuracy. However, sharing location-based information and positioning vehicles with respect to that information has been one of the fundamental challenges in intelligent transportation for over two decades.

Furthermore, the connected vehicle world is evolving – we must now consider "connected and automated vehicles" (CAV) in addition to simply "connected" ones. We expect that the more automated systems will make their way onto the market and be adopted in a gradual fashion, and that there will be a long period of time during which many different kinds of solutions will co-exist, as shown in Figure 3.

Figure 3. Graph. Mixed Transportation Environment *(Source: FHWA)*

Any new standards will need to handle the needs of the diverse users of this mixed transportation environment. In particular, location-based information is fundamental to:

- *Humans*, who will continue to drive vehicles and will sometimes receive assistance from machines (e.g., vehicles with "connected vehicle" application capabilities).
- *Machines*, which will begin to drive vehicles, and will sometimes receive assistance from humans (e.g., vehicles with automated functions and fully automated vehicles).

This new CAV environment is driving new needs, and maps are evolving to support them. Specifically, maps need to provide more than static, geographical information. Instead, they are now a basis for dynamic and equally critical information, such as traffic condition, weather, and road furniture – all tailored to each vehicle's location and type (e.g., passenger vs. commercial vehicle). They are no longer "maps" in the traditional sense; they are now a collection of "CAV-Path data" that we can use to help human and machine drivers navigate the road network. A good example of this extended map data set is work zone safety warnings. Useful warnings must do more than simply indicate the approximate location of a planned work zone. They need to clearly indicate the location and characteristics of lane closures in real time. The corresponding vehicle application needs to know vehicle position accurately enough to know whether it is in an affected lane or not and whether to warn the driver in time to take necessary action.

This means that we will need to address the following:

- Definition and sharing of static and dynamic geospatial and other driving environment data for use by *humans* (direct and machine-assisted). This is the traditional “connected vehicle” challenge.

- Definition and sharing of static and dynamic geospatial and other driving environment data for direct use by *machines*. This is the emerging “automated vehicle” challenge.

- *Positioning* of vehicles in relation to these data and to the real world in all these scenarios.

To properly design standards for the emerging mixed transportation environment, we need to consider the needs of both humans and machines so that the result is a properly integrated whole. For example, connected applications and automated functionality will both likely take advantage of initial connected vehicle data streams; and such data streams will likely evolve to better support automated vehicle functions. Further, data will not only be sent *to* vehicle-to-everything (V2X) devices but will also be shared *from* and used *within* those devices. The entire suite of standards, particularly logical models, will have to function in an interoperable manner.

Project Purpose and Objective

This project focuses on the sharing of CAV-Path data. We initially posed the research question as: *How do we best communicate map information*[c] *from the infrastructure to V2X devices?* However, as the project progressed, we learned that a better way to state the problem was: *How do we describe and connect CAV-Path data to core road network data with required quality for use in a mixed CAV environment?*

As shown in Figure 4, we considered deployment models and standards for the content and format of data sent from a variety of map sources to an even more diverse collection of V2X devices. In addition, we also considered system-level standards that support the effective deployment of all required data types (e.g., data quality).

The further exploration and refinement of this question and the standards necessary to answer it form the focus of this project. This discussion is of interest because of the diversity of stakeholders and associated perspectives involved in this space at this time.

[c] The term “map” here includes static and dynamic geospatial and other driving environment data.

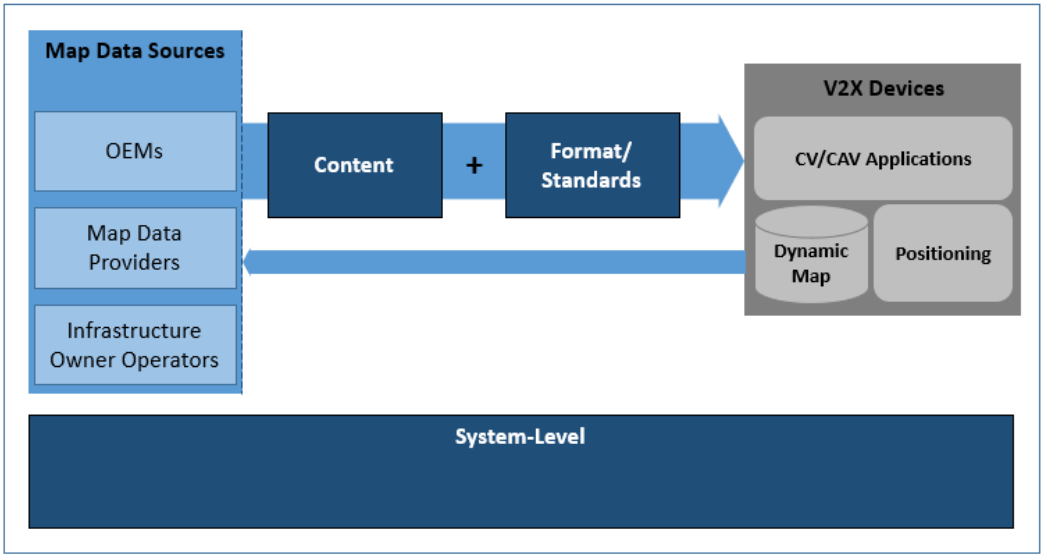

Figure 4. Graph. Mapping Architecture
(Source: FHWA)

Research Process Overview

This project included five major tasks:

1. *State of the Practice Review.* This exercise allowed us to look at the current status of the mapping industry from both the public and private sectors and review overall trends in the field and investigate positioning technology activities in both the public and private sectors. This also considered an initial review of applications with connectivity that rely on mapping on positioning information.

2. *Stakeholder Needs Review.* This portion of the program involved outreach to key stakeholder groups to investigate their perspectives on content and standards needs. We also did an initial review of existing standards activities.

3. *Concept Synthesis and Gap Analysis.* Based on the input from stakeholders, we synthesized a set of "key concepts" that help provide context for the V2X mapping discussion; developed a traceable set of standards needs; updated our understanding of current and emerging standards activities; and identified gaps. We also documented implementation gaps that emerged in our stakeholder discussions and subsequent analysis.

4. *Work Zone Case Study for CAV-Path Data.* This part of the project carried forward the idea of developing a CAV-Path data set to demonstrate how a public agency might provide data for drivers, using existing/emerging standards to create data feeds that will be computable by a machine (e.g., an autonomous vehicle).

5. *Proof of Concept Toolset.* This task developed and tested a proof of concept (POC) system for efficiently capturing a digital map of a work zone and its features, including lane closures and workers present in the work zone.

Document Purpose

This document provides a report on the five key tasks on this project. It integrates all deliverables into a single document that shows the evolution of the project and provides detailed research and analysis results. We considered the following topics:

- What are the trends in map data collection and distribution?
- What are the advances and trends in positioning technology?
- What key global tests and trials have been performed in this area?
- What is the priority stakeholder needs and issues?
- What is the status of the formal and de facto standards efforts in this space?
- What are the key standards issues that have emerged to date?
- What are the standards and implementation gaps?
- How do we make all shared data computable for use by machines (including quality data)?
- How do we attach data to different maps?

Document Structure

The document includes the following chapters:

- Chapter 1 provides the background of this project and document, specifically the objective and purpose.
- Chapter 2 summarizes the findings from the state of the practice review.
- Chapter 3 details the results of the stakeholder needs review.
- Chapter 4 synthesizes the key concepts, details the gaps analysis, and provides recommendations for next steps.
- Chapter 5 discusses using work zone data as a case study.
- Chapter 6 describes the Proof of Concept developed as part of this study.
- The Glossary and References provide a list of acronyms and references.
- Appendices A through D provide supplemental information.

Chapter 2. State of the Practice Review

The first step in this project was a review of the existing state of the practice conducted in the fourth quarter of 2017. This chapter provides the following information:

- An update of the mapping industry from both the public and private sectors and highlights overall trends in this field.
- An update of positioning technology activities in both the public and private sectors.
- A framework for considering the *applications with connectivity* that use mapping and positioning information.

See Appendix A: Global Tests and Trials for a summary of global tests and trials.

Mapping Industry Update

This section will lay out trends from both public and private sector perspectives. It considers the question: *What are the trends in map data collection and distribution?*

Public Sector Activities and Trends

To date, the public sector focus has been on building a *connected, cooperative* system that allows vehicles to communicate with each other and the publicly owned infrastructure, including reception of both information and direction from traffic management centers. The intent of this system is to enable more efficient and effective transportation overall. Figure 5 shows a sample context diagram. The emphasis is on interaction with public sector equipment (e.g., roadside equipment [RSEs], traffic lights), and often with public sector communications infrastructure (e.g., Dedicated Short Range Communications [DSRC]/C-V2X and/or a Security Credential Management System [SCMS]) and information (e.g., Traveler Information [TIM] and Road Safety Message [RSM], and eventual cooperative driving).

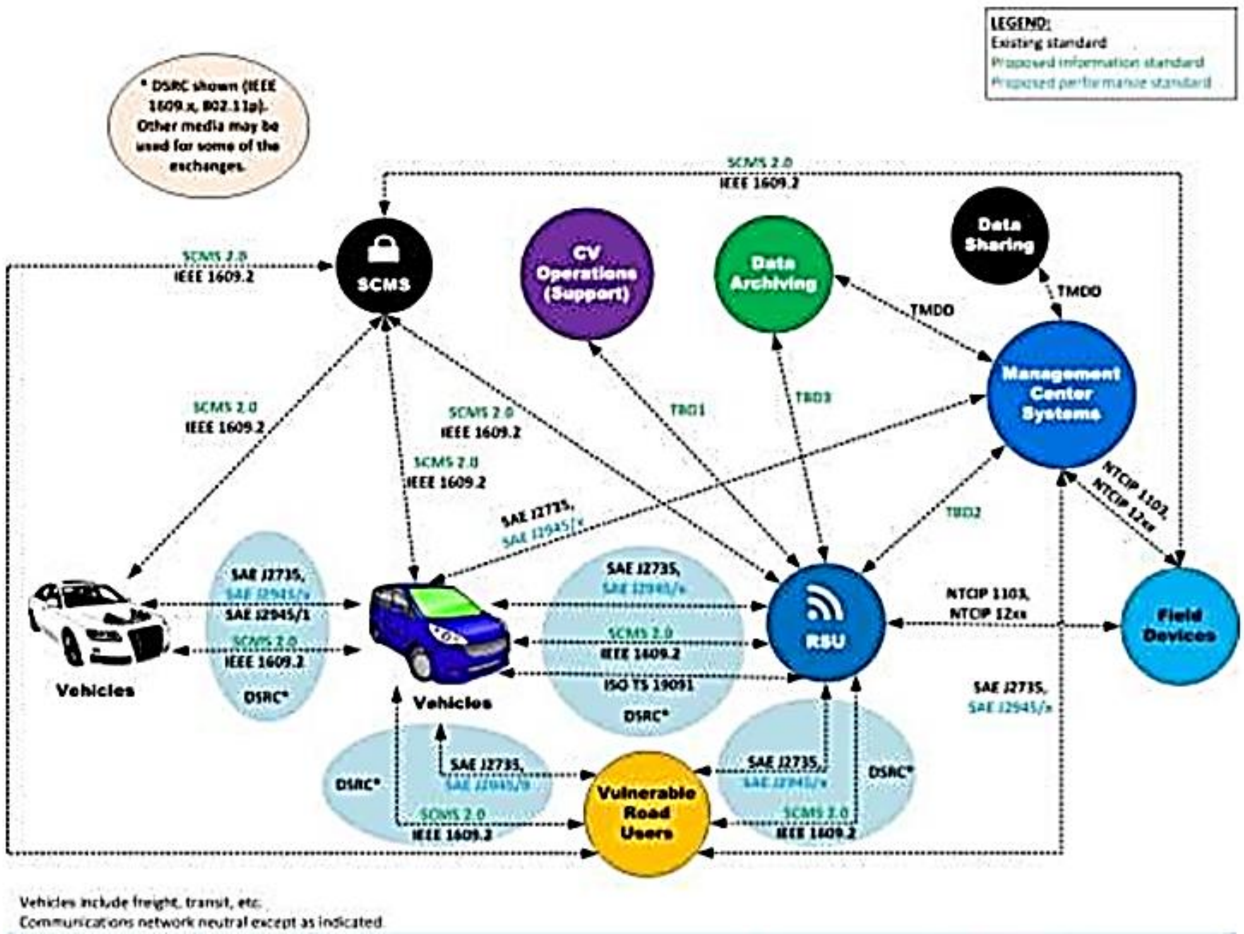

Figure 5. Graph. V2I Standards Context Diagram
(Source: V2I Deployment Coalition, 2017)

To deliver such a system, a great deal of research has been carried out and is still underway. There are also ongoing efforts that, while not specifically focused on connected vehicles, may yield results that add value to that system. Below are two key mapping-related activity areas:

- *Geospatial data collection.* This has ranged from very specific connected vehicle activities, such as the Intersection Signal Design (ISD) Message Creator Tool[55] designed to allow the creation of intersection maps necessary to provide Map (MAP) and Signal Phase and Timing (SPaT) information, to broader efforts to generate State and national-level maps at various accuracies (e.g., the Michigan and Texas LiDAR mapping efforts; and the national Highway Performance Monitoring System (HPMS) and All Road Network of Linear Referenced Data (ARNOLD))[17]. A related activity is the Federal Spatial Data Infrastructure (SDI) program, an effort to drive more efficient management of spatial data across the Federal government overall.

- *Development and testing of Connected Vehicle applications.* These activities have included a broad range of applications over time, as State and national governments have sought to understand functionality, feasibility, and deployment questions. Location-based data has been a foundational component of this work, and a substantial sub-group has focused on freight and logistics solutions.

It is important to note that the bulk of the public sector focus has so far been on *interactions with human travelers*, as opposed to automated vehicle functions. In this context, a “map” is a static collection of geospatial information. Travelers may further benefit from access to additional streams of data, such as weather, traffic, and work zones, which humans may use directly or in warning-type in-vehicle applications that help human drivers make better decisions. Linkage of this information with the map is of course useful, but road segment-level accuracies are often sufficient for this effort. A current example of this viewpoint is included in the HTG7 Harmonized Architecture Reference for Technical Standards (HARTS) work shown in Figure 6.[56]

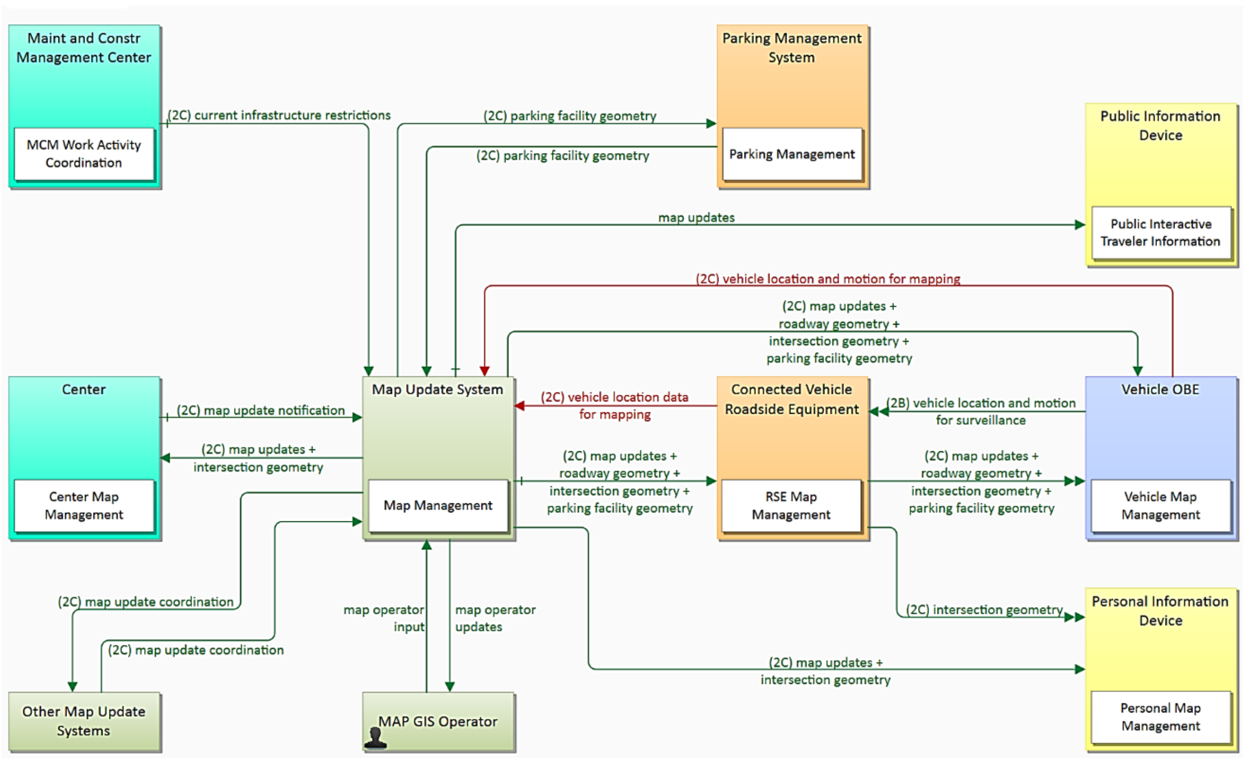

Figure 6. Graph. HTG7 HARTS Mapping Architecture
(Source: USDOT)

Lessons Learned

The primary lessons learned from the public sector activities in this area that are of note to this project include:

- *Cost of collecting and maintaining geospatial data.* The up-front and ongoing expense of collecting and updating location-based data has been a substantial challenge for public sector activities in this area. Further complicating this challenge is the need to manage very specific types of data attributes which cannot be collected by standard mapping technologies (e.g., intersection lane numbering) and to upgrade to centimeter-level accurate maps. For example, the Multi-Modal Intelligent Traffic Signal Systems (MMITSS) program had to create a MAP description file for each of the intersections in their testbed using Google Earth tools to collect the coordinates of the intersection reference points and lane nodes.[59]

- *Interoperability in multi-map environment.* Geospatial data exists in many forms to meet many needs at public agencies, and in some cases, private providers are the source. The result is a mix of different accuracies, attributes, and metadata. Combining such data from multiple sources and attaching dynamic data to it from still further sources is an ongoing challenge.

Private Sector Activities and Trends

The primary private sector focus in mapping today is support for automated driving, which is generating an evolving set of much more stringent requirements than previously existed in this space. In particular:

1. *A need for high precision and high accuracy.* Automated vehicle functions need lane-level information, with accuracies of a few centimeters within those lanes.[d] This contrasts with previous work, which was often done at the road segment-level, with accuracies of a few meters.

2. *A need for real-time geospatial data updates.* For an automated vehicle to make its way through the road network, it needs to know about any and all changes to that network as immediately as possible. This is particularly important in the case of physical changes, such as construction, lane closures, and lane shifts. Today's automated vehicle functions use this information to turn control back over to the driver, but tomorrow's systems will need to navigate such situations on their own.

3. *A need for real-time driving environment updates.* Automated vehicles can also benefit significantly from additional information about the upcoming driving environment along the vehicle's path, such as road weather, and rolling traffic queues.

4. *A need for validated or certified data quality.* Where mapping and related content become part of the overall automated vehicle control system, serving as a "sensor" input, the quality of that information becomes critical. As with any other sensor, the vehicle must be able to apply confidence levels and other quality frameworks to the input it receives.

5. *Intense competition within the private industry* to lead with their "mapping" solutions for their industry and the overall industry.

The combination of points two and three has led to the concept of "e-horizon" or the "live" or "dynamic map," in which vehicles have access to both static and dynamic data that allow them to understand the road ahead. Figure 7 shows one view of this technology. This concept is causing a major change in the approach to collecting and distributing map data in general. In the new model, instead of static databases with limited updates, a flow of structured "live" map data will be collected, integrated, and made available to end users. These data will not only be updated in near real time, but will include both spatial data and

[d] It should be noted that some prior accuracy categorizations distinguish between "lane" and "with-in lane" accuracy. The terminology used here reflects our understanding of current industry language, which is concerned with referencing (to the lane vs. to the segment), and further describes the metrics to be used within that framework (centimeter or meter). This is an area for further exploration and consideration in this project.

dynamic event data, which have been considered external to the map until now (e.g., a lane blockage caused by an obstacle would be integrated as an update to the map data flow).

Figure 8 shows a typical architecture for this model.[60] Vehicles maintain a wireless link with their manufacturer, which in turn shares data with a backend system that may be run by that Original Equipment Manufacturer (OEM) or by partners such as map providers. The relationship with public sector data is still evolving, but there is recognition that certain key types of information (e.g., signal phase and timing, roadworks and construction) will likely be sourced at some level from the IOOs who manage those functions. However, at this point, the information linkage is typically between the IOOs and third-party map providers rather than OEMs directly.

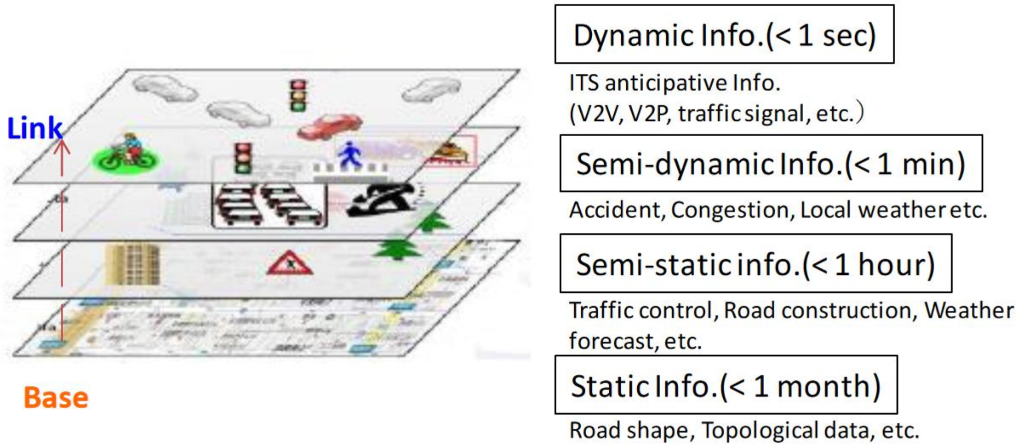

Figure 7. Graph. Dynamic Map Concept From SIP-Adus Program
(Source: Sugimoto, 2017)

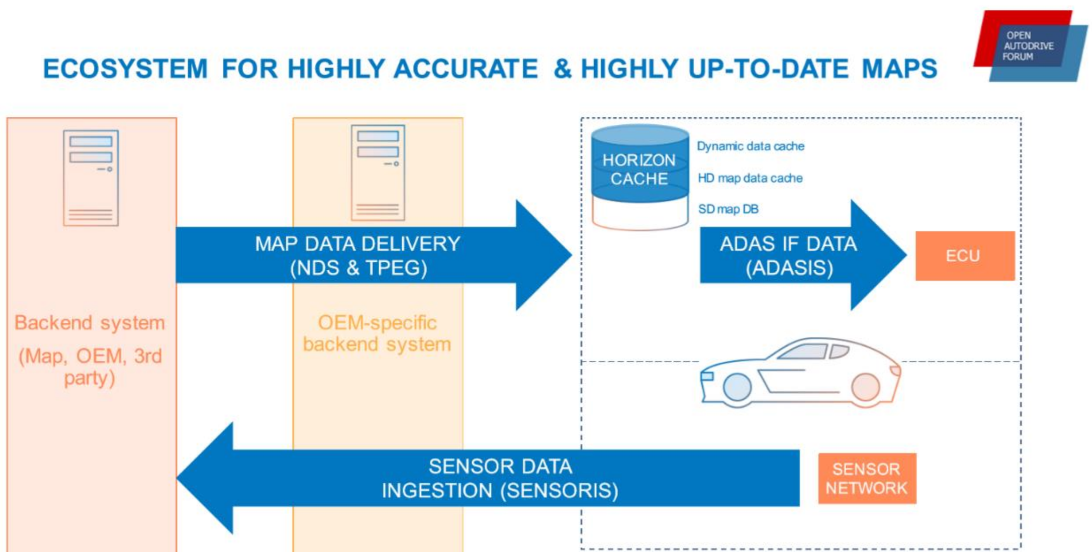

Figure 8. Graph. OADF "Live Map Delivery Chain"
(Source: OADAF, 2017)

The need for highly accurate mapping has generated a variety of different commercial activities. Companies are working to:

- *Collect high definition (HD) geospatial data.* This effort began by using LiDAR and other sensors on dedicated mapping vehicles to collect the centimeter-level data needed to support automated driving. The latest trend is the use of less expensive sensors like cameras and radar for data collection, which opens the possibility of faster deployment to non-dedicated vehicles (crowdsourcing) and a significant reduction in the cost of ongoing maintenance, both of which are critical needs. Other data collection technologies, such as satellite, are also being progressed. Traditional map companies, such as HERE Technologies and TomTom; technology companies such as Google, Intel/Mobileye, Uber; and startups like Civil Maps, DeepMap, Waymo, and Carmera are all engaged in this work. A recent media article provides a non-exhaustive summary of private sector activities in this area.[61]

- *Establish new map delivery systems.* Solutions for providing large quantities of static map data are of limited utility in the expected automated vehicle environment. Instead, private sector firms are pioneering various solutions for distributing live streams of geospatial and other driving environment data.

- *Develop standards for data collection, sharing, and exchange.* Original Equipment Manufacturers (OEM) and map providers have realized that they need mechanisms for sharing geospatial data through the data delivery chain to and from the vehicle, as well as within the vehicle. They are also increasingly recognizing that they need standards for integrating additional data types into this system and ensuring quality and have begun that work as well.

Overall Trends

The industry is rapidly developing the ability to better communicate critical information about the road network to vehicles and travelers. There are two very different perspectives in play, with the public sector tending to a cooperative model in which vehicles interact directly with the public infrastructure, and the private sector considering a model in which vehicles interact most closely with their manufacturers and the suppliers to those manufacturers using a private infrastructure.

The demands of automated vehicles, however, will certainly play a part in any future system, and it seems clear that highly precise maps optimized for machine-to-machine use will be necessary going forward. Similarly, the development and sharing of additional driving environment data, such as work zone locations, will also be important, whether it is provided as separate streams or as part of an overall dynamic map.

What final deployments will look like is less clear. We might categorize a sampling of future alternatives as shown in Figure 9. There will likely be multiple scenarios in the marketplace for the foreseeable future, which will also include solutions that are non-automated and/or non-connected as well. We have yet to define the map data requirements of each scenario and the various automation levels and operational design domains.

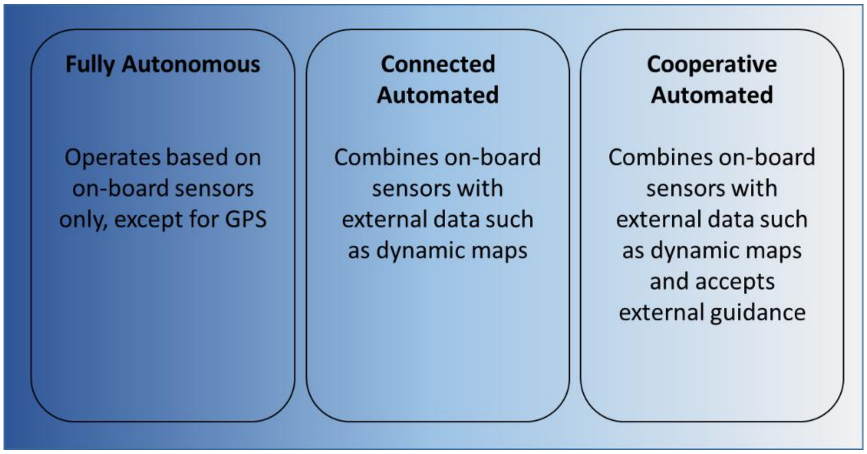

Figure 9. Graph. Automation/Connectivity Model Scenarios
(Source: FHWA)

From a public sector perspective, the three different options have an interesting set of implications. In particular, the role of the IOOs might be very different in each case. Figure 10 lists some possible outcomes for IOO roles.

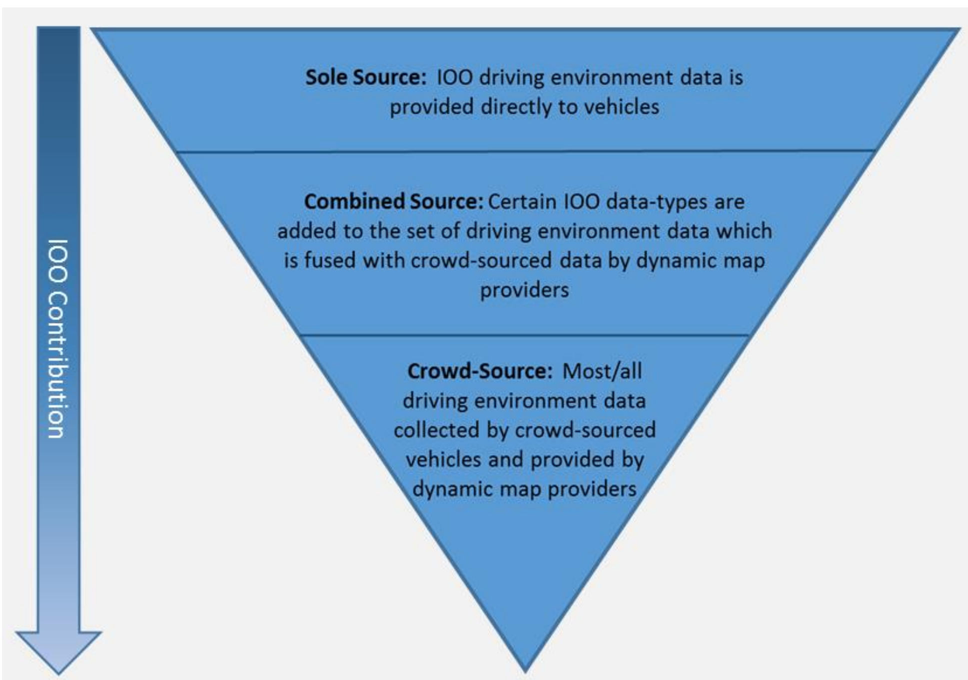

Figure 10. Graph. Potential Public Sector Data Provision Roles
(Source: FHWA)

Another alternative is for IOOs to manage the crowd-sourcing process and return information directly to vehicles. However, the deep integration required between this data and safety-critical vehicle control functions appears to make it likely that OEMs will want only mediated data to be used in their vehicles.

Positioning Technology Update

This section addresses the question: *What are the advances and trends in positioning technology?* Positioning technology is intricately linked with mapping, and advances in the field of positioning can significantly impact the requirements for the mapping technology and vice versa.

Public Sector Activities and Trends

Positioning accuracy is fundamental to the successful implementation of connected vehicles. The three current CV Pilots (2015–present), V2I Safety Applications, INFLO, and RESCUME projects all feature connected vehicle testing at varying degrees of positioning accuracy, including lane and sub-lane-level. Specifics focus areas of these and other public sector activities include:

- *DGPS augmentation.* For example, the RESCUME project required lane-level accuracy for applications that warned drivers who were entering incident or work zones. The project achieved this accuracy by using the Differential Global Positioning System (DGPS).[22] The INFLO project used similar strategies.[21,] The New York CV Pilot is also planning to explore means of augmenting its GPS location information with methods such as dead reckoning algorithms.[23]

- *Data fusion.* For example, the European Union's InLane program fused multiple data sources, such as satellite systems, internal measurements, static maps, and vision signals to improve accuracy[11]. U.S. Exploratory Advanced Research (EAR) funded projects also sought to achieve improved positioning accuracy through a data source fusion approach[16].

- *Ongoing technology assessments.* For example, the European Cooperation in Science and Technology (COST) Action on Satellite Positioning Performance Assessment for Road Transport (SaPPART) assessed positioning terminals[10].

Lessons Learned

Reviewing the published results of the above programs provides a variety of lessons learned, including:

- *A need for multiple position sensor inputs.* The EAR research found that "no single independent sensor technology is capable of simultaneously attaining the accuracy, integrity, and availability specifications for lane-level positioning"[16]. Overall, the research found that GPS satellites offer high accuracy in open areas, but less so in urban settings, and that internal systems are accurate in all settings, but drift over time.

- *A need for higher accuracy positioning for some applications.* New York and the Transit Retrofit program both found that GPS was not sufficient to support applications that required accuracies of less than a meter, such as pedestrian crossing warning (PCW) applications and vehicle turning right in front of bus (VTRW).[58]

- *The importance of mapping to positioning accuracy.* EAR-sponsored research that assessed different data fusion techniques for positioning found that certain integration techniques were effective but were limited by mapping and survey accuracy. Further, the same research noted the importance of mapped features that LIDAR and RADAR sensing can recognize[16].

- *Certification challenges.* The SaPPART project team noted that one of the largest challenges to integration of cameras and global navigation systems was the difficulty of obtaining test data sufficient for certification, since only field testing could meet the necessary criteria[26].

- *A need for effective ways to assess GPS accuracy for moving vehicles.* Drift over time and multiple satellites make this difficult. Additionally, GPS accuracy is reported in terms of CPS statistical probability of being right. This appears to be a static answer and does not provide information on effectiveness of performance at 70 mph.

Private Sector Activities and Trends

In the private sector, the industry is working on more accurate sensors and on additional integration of sensors and vehicle systems to allow more accuracy overall.

Current systems using GPS/GNSS have location challenges in dense urban environments, tunnels, parking structures, and multi-level interchanges. These are all areas where open sky visibility is not available for the antenna or where multipath propagation occurs. Manufacturers are integrating Inertial Measurement Units (IMUs) as well as wheel speed sensors to help with this challenge. These sensors help but are also imperfect as they drift over time and temperature. A sampling of new technologies that are becoming available to address these issues include the bullets below. The cost per unit remains a challenge to deployment in the mass vehicle market.

- *U-blox 3D Automotive Dead Reckoning with the UBX-M8030-Kx-DR chip set*[49]. This technology augments traditional satellite-based location services with individual wheel speed and heading and vertical displacement when satellite signals are partially or completely blocked. This can assist with navigation through tunnels and urban canyons. The chip integrates gyro and accelerometers with vehicle wheel speed sensors to combat satellite signal loss. These sensors provide several kilometers of range without satellite correction.

- *Furuno dead reckoning integration with GPS/GNSS*[50]. This solution also supports dead reckoning integration with GPS/GNSS. The Furuno system uses speed sensors on the non-turning wheels with gyro sensors and accelerometers to achieve better accuracy in urban environments and tunnels.

- *Broadcom BCM47755 chip*[51]. A new smartphone chip is promising significant improvements, with a claimed accuracy of 30 centimeters. We also expect it to handle concrete city canyons with a more moderate power consumption than current chips. This technology is currently available but still working through software problems to show full accuracy. Its dual frequency chip is still not widely available in devices.

The other major area of activity is sensor fusion. Today's DSRC-based connected vehicles are working well with GPS, other vehicles, infrastructure communications, and integrated IMUs but have limited access to data from internal vehicle systems. Today's automated vehicles have strong integration with the vehicle's Controller Area Network (CAN) bus and other internal systems (i.e., dynamic maps, cameras, LiDAR, radar, and wheel sensors) but do not have DSRC-chip positioning support. In the next few years, we expect that connected vehicle technology such as C-V2X or DSRC will be added to vehicles with automated control systems, which will offer significantly improved solutions: we can leverage dynamic map updates with wheel sensors to create a fusion algorithm with the GPS and IMU that will improve location awareness.

Snapshot of Applications

This section summarizes the categories of applications that include V2X mapping. As noted in previous sections, there is a need to prepare for the emerging mixed transportation environment. From the application perspective, this means taking a fresh look at the needs of the collected set of *applications with connectivity,* which will serve both human and machine drivers, so that we can generate systems and standards that meet the integrated needs of both.

Table 1 organizes an example set of these applications into three categories: mobility, safety warning, and safety control. The examples here are not all-inclusive and are meant only to provide a sense of what applications might fit into each category. We expect that we will review and refine these categories as needed during the stakeholder discussions conducted later in this project. This table also provides a few examples of map data that might be useful to each category. We will provide further detail and expand this information later in this project to include both human and machine perspectives.

Table 1. Applications With Connectivity Examples

Mobility	Safety Warning	Safety Control
Apps that provide mobility-related information	Apps that provide safety-related warnings	Apps that take control of a vehicle function
Examples		
• Traffic updates • Eco-driving • Dynamic speed harmonization • Fuel-saving assist	• Spot weather impact warning • SPaT • Legal driving support (speed limit warning, IV-VMS, etc.) • Oversize vehicle warning • Work zone warning • Freight-specific warnings • Transit vehicle at stop/station warnings	• Adaptive cruise control • Stop & go drive assist • Lane-keeping assist
Map Data Needs		
• Meter-level • Segment-level	• Polygon and event within polygon • Geo-fencing	• Centimeter-level • Lane-level

When thinking about an integrated system, it is also useful to consider the additional range of location-based data that may be of assistance to automated systems. Content and concepts that allow consistent linking of this data to maps (e.g., lane models and location referencing) is critical to enabling the entire system. Table 2 shows one example of this.[62] [e]

[e] We did not make any operational assumptions about where the dynamic map information is hosted or how the application handles that information. This is an evolving area in the industry at this time.

Table 2. Potential Dynamic Data-Augmented Automation

	Crash	Road-work	Adverse Weather	Obstacle	Extreme Weather	Visibility	Slow Vehicle	Wide Moving Jam	Wrong Way Driver
Adaptive Cruise Control	✓	✓	✓	✓	✓	–	✓	✓	✓
Blind Spot Detection	–	–	–	✓	–	✓	✓	–	✓
Curve Warning	–	–	✓	–	✓	✓	✓	✓	✓
Electronic Stability Control	–	–	✓	–	✓	–	–	–	–
Forward/Side Collision Warning	✓	✓	–	✓	–	–	✓	✓	✓
Green Driving	✓	✓	✓	–	✓	–	✓	✓	✓
Lane Departure Warning	–	✓	✓	–	–	–	–	–	–
Lane Keeping Assistant	–	✓	✓	–	–	–	–	–	–
Lane Change Assistant	✓	✓	✓	✓	–	–	✓	✓	✓
Overtake Assistant	✓	✓	✓	✓	–	✓	✓	✓	✓
Powertrain Efficiency	✓	✓	✓	–	✓	–	✓	–	–
Speed Advisory	✓	✓	✓	✓	✓	✓	✓	✓	✓
Stoplight and Stop Sign Warning	–	✓	–	–	–	–	–	–	–

Chapter 3. Stakeholder Needs Review

This chapter describes the stakeholder outreach efforts conducted as part of the project, including:

- The stakeholder interview and follow-up process.
- The specific questions asked of stakeholders.
- A high-level summary of the stakeholder responses. A more formal and detailed breakdown of these needs is in Chapter 4.

Stakeholder Interview Process

The working team interviewed 17 industry stakeholders from three key stakeholder groups, as illustrated in Figure 11. We organized these groupings by perspective, with the various types of suppliers (e.g., T1s) grouped with their customers (e.g., OEMs).

- OEMs and T1s – This group included representatives from major automotive manufacturers and their T1 suppliers.
- Map Providers – This group was a mix of established and start-up private sector map providers.
- IOOs/Suppliers – This group included representatives from infrastructure owner operators and their technology suppliers.

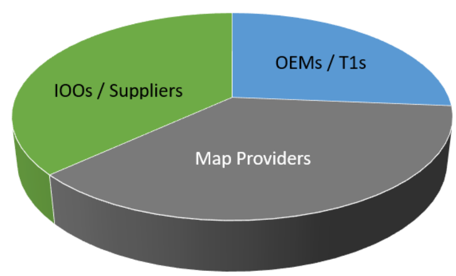

Figure 11. Graph. Distribution of Interviewees by Stakeholder Group
(Source: FHWA)

The team conducted phone or in-person interviews. In addition, we held a follow-on web meeting with a group of additional stakeholders from all three groups to further validate the results of the individual interviews. This discussion resulted in refinement of several key concepts.

Research Questions

We decomposed the overall research question into a questionnaire that we used for the stakeholder interviews. These questions included:

- What are the near-term priority **applications**? (5 years)
- What are the unmet mapping **content needs** for these applications?
- What are the **system-level needs** to support the priority applications?
- What are the **gaps in current standards** for priority application needs?
- What are the current and future **roles/responsibilities** for various parties?

Stakeholder Needs Summary

This section provides a high-level summary of the needs and other insights that stakeholders shared. Stakeholders generally provided quite consistent feedback. This section is therefore a combined summary, rather than a description of separate group perspectives. We note where differences of opinion did occur.

Priority Applications

We asked respondents the question: *What are the near-term (5 years) priority applications?* The resulting answers proved to be quite consistent and to apply to both driving scenarios that human and machine users perform. Stakeholder responses focused on the need to enable data users to address three key topics:

- Where am I relative to my environment?
- What are the rules of the road that apply to my path?
- What has changed from what I already know?

For all three topics, stakeholders noted that data relating to the entire journey is of interest, both what is true at any given time and place, and what is coming up. Responses also showed the expected evolution toward dynamic data-augmented automation identified in our prior State of the Practice review. For example, stakeholders mentioned autonomous emergency braking (AEB) with V2X information, weather responsive variable speed limits, etc.

Content Needs

We asked respondents the question: *What are the unmet mapping content needs for these applications?* Answers fell into four major categories:

- Road geometry. Information about the basic structure of the road network.
- Road furniture. Information about the location of roadside objects such as traffic signals and guard rails.
- Rules of the road ("legal path"). Information about long- and short-term laws and directives from road authorities. This includes both overall legal constraints (e.g., "no heavy trucks") and traffic management instructions (e.g., "hard shoulder open from 7A-9:30A"), as well as help translating visual instructions (e.g., which traffic signal applies to me; what does that complicated road sign mean for me right now).
- Recent/temporary changes. Information about any aspect of the driving environment that may have recently changed (e.g., "Eastbound lane shifted 3 meters to the right starting at point A and ending at point B"). This area saw the greatest expansion from the traditional definition of "map," as stakeholders focused on anything that impacted the vehicle *path*. This category overlaps with the "rules of the road" category in some cases, where rules are dynamic (e.g., variable speed limits).

Overall, content *quality* was another major priority area for stakeholders. For data to support automated vehicle functions, it must be highly accurate, complete, and current. Metrics provided included spatial accuracy (the consensus seemed to be that the required accuracy was 20 cm or below) and various types of latency (end to end, communications, data retrieval).

System-Level Needs

We asked respondents the question: *What are the system-level needs to support the priority applications?* System-level needs apply across the entire V2X ecosystem, regardless of interface. Responses fell into four main categories of standards:

- *Map definition* – Several stakeholders commented on the fact that map definitions are changing and that we need to have a clearer industry view on this topic. Some called for a standard that supported an overall content description that would allow users to know what was in the map.

- *Common models* – Stakeholders noted that CAV-Path data must share a common frame of reference if they are to be updated from multiple sources in real time. Lane models are a typical example: We need a standard way of describing a lane that applies across providers and jurisdictions.

- *Cross-map location referencing* – Similarly, location referencing (specific description of absolute and/or relative position) is critical to enabling the overall set of CAV-Path data, as it allows the same location to be accurately described no matter which map a vehicle or other device may be using. The accuracy and precision of maps vary greatly, and this becomes increasingly significant at the high levels of correctness that automated vehicle tasks need.

- *Quality and trust metrics and metadata* – The issue of data quality and trust was very high on the stakeholder needs list. Stakeholders seemed to agree that it would be difficult to set minimum quality standards at this time, but that it was imperative to include metadata that allowed a common understanding of how good/trustworthy the data were at a given time. “Just tell us how good it is so we can decide what to do with it” was a frequent comment.

Standards Needs

We asked respondents the question: *What are the gaps in current standards for priority application needs?* Some stakeholders indicated a need for specific standards, while others expressed concern that it is too early to set standards without risking innovation. Overall, however, it became clear that there was a need to enable nationwide automated vehicle operation by creating a consistent “data product” for use by OEMs and others.

Put simply, this means that data providers would need to agree and adopt a core set of system-level specifications that could consistently govern the exchange of V2X data. Note that this is not a standard implementation or set of required data feeds, but rather a key set of standards that ensures that any data shared are intelligible and usable by human and machine users. These specifications need to address three questions:

- What is the event/object/structure being described? Examples include common CAV-Path terminology, data models, and data dictionaries.

- Where is it located? Examples include common location referencing schemes (which may vary by data type).
- How good are the data? Examples include metadata specifications for quality items such as confidence and timeliness.

Stakeholders noted that standards work is underway in many of these areas, but that the overall set of required specifications is very far from full implementation. In particular, they noted that the area of quality descriptions needs more attention.

Chapter 4. Concept Synthesis and Gap Assessment

The stakeholder input obtained in this project provided important updates to our understanding of how the industry currently conceives spatial data, including new perspectives on how machine users will interact with this data. This chapter documents our synthesis of those key concepts. It also includes a more formal description of stakeholder needs, the current state of map-related standards efforts, and the gaps that still exist in this area. Stakeholders also provided insight on larger questions, such as the public sector role in this evolving environment, and key implementation gaps that we must close for the public sector to provide usable data to automated vehicles.

Key Concepts

This section describes several evolving definitions that are fundamental to the V2X mapping discussion. Efforts are underway to standardize these definitions; this section is a snapshot of current industry perspectives based on the interviewees' responses and the authors' industry knowledge. This is a very fast-moving area, and these concepts are evolving quite quickly.

Human & Machine Users

The original research question for this project was driven by challenges facing the "connected vehicle" space, which focuses on vehicles driven by humans. Traditional connected vehicle applications are designed to enable safer human driving by sharing information such as forward-collision warnings and signal timing status with drivers, who can then take appropriate action.

However, the last few years have made it quite clear that there is now a new user to consider as well: the automated vehicle. Initial predictions of an "all-automated" fleet in the very near future no longer seem realistic, but this has not slowed the significant global private sector investment in delivering the most automated vehicles possible as quickly as is safely feasible. The industry is making progress, as evidenced by recent announcements about transit and taxi-type services which function in limited environments.

As a result, we must broaden the discussion about V2X mapping to include both human and machine users. These two types of users have an overlapping, but not identical, set of needs. This means that we must review a number of core assumptions about the information traditionally provided to users and how users will consume that information. The sections below provide additional detail on this topic.

The AV User (Machine) Perspective

Automated vehicles rely on a complex set of sensors, computing, and decision-making that is designed to replicate (and where possible, improve upon) human capabilities. From a map data perspective, this creates several key differences from human users, including:

- Tasks vs. applications
- Map data vs. path data

- Human-readable vs computable data

Applications vs. Tasks

The initial vocabulary defining this project was drawn from the "connected vehicle" community, which uses the term *application* to describe the software which handles a specific set of functions (e.g., red light warning). These applications may be bundled into a series of consumer-facing *features* (e.g., forward collision warning). Chapter 2 shows examples of this in the "Snapshot of Applications" section.

However, the "automated vehicle" community typically focuses on *tasks* that the vehicle must perform to carry out the overall set of driving activities necessary to complete a trip. These include:

- *Perception* – Detect obstacles and features affecting vehicle path.[f]
- *Localization* – Determine vehicle location with respect to road geometry, furniture, and any other features affecting vehicle path.
- *Planning* – Determine route, maneuvers, and trajectories necessary to navigation to destination.
- *Control* – Execute steering, acceleration, and braking to traverse path.

These varying definitions represent a key conceptual change that can be viewed as an evolutionary spectrum, and may be mapped across the five levels of automation as shown in Figure 12.

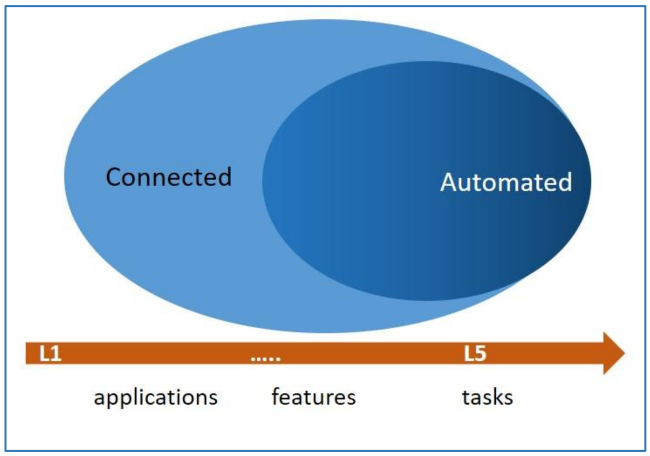

Figure 12. Graph. Applications/Task Spectrum *(Source:FHWA)*

Another way to look at the relationship between connected vehicle "applications" and automated vehicle "tasks" vocabulary is shown in Table 3. The same set of tasks is necessary to execute both traditional connected vehicle activities (e.g., Basic Safety applications) and automated vehicle activities (e.g., AV Level 5). The implementation of those tasks may be quite different – traditional connected vehicle applications largely focus on advising the driver rather than fully controlling the vehicle – but the key tasks that must be addressed (e.g., localization) are the same. For the purposes of this document, we will use the "task" vocabulary to be more consistent with the combined CAV perspective shown at the right side of Figure 12.

[f] Formal industry definitions of "obstacle" and "feature" vary and are evolving. For the purposes of this document, an obstacle is anything which may obstruct vehicle progress; a feature is a generic term for a lower-level path data element.

Table 3. Task/Application Example *(Source: FHWA)*

Task	Task Detail	V2V Basic Safety (FCW, BSW/LCW, IMA, EEBL, CLW, LTA)	AV Level 5
Perception	• What am I looking for? • Where should I look to see it? • How much can I trust what I am being told?	X	X
Localization	• Where am I? • Where is the object/geometry/event that may be affecting my path? • Where am I relative to that object/geometry/event?	X	X
Planning	• What is that is affecting my path? • Where is it along my path? • How much can I trust what I am being told?	X	X
Control	• Advise drier of possible necessary control action • Implement specific control action to avoid problem (e.g., braking)	X (advise)	X (Implement)

"Map" Data vs. Path Data

The definition of a *map* is evolving in response to the emergence of automated vehicle technologies. Stakeholder interviews confirmed this perspective. Maps for automated vehicles are not the same as those used for traditional GIS or navigation. In particular:

- Vehicles now need a *combination of dynamic and static data* that depict the driving environment.
- These new data must allow the vehicle to understand the basic road network and the status of its *path* through that network.
- Data must be at a very high level of precision, accuracy, and currency.

As a result, *map data* now refers to a real-time collection of data composed of multiple layers and update streams, as shown in Figure 13. This means that when we are considering these data in the C/AV context, we must also consider how all the various types of real-time driving environment data will integrate with geospatial data. This integration would produce a stream of information that allows the vehicle not only to understand the basic road network, but the status of each path through that network. For example, lane shifts, closures, and slowdowns are all part of the new dynamic map but are only valuable if they are correctly communicated in relation to each other and the road network. For further detail and discussion of this topic, see Chapter 2.

There is no consistent industry name for this new definition: the term "High Definition (HD) map" is often used to describe high-accuracy road network data, but opinions vary as to the details. "Dynamic map" and "LiveMap" are other terms that have been put forward. For the purposes of this document, we will simply call it "CAV-Path data."

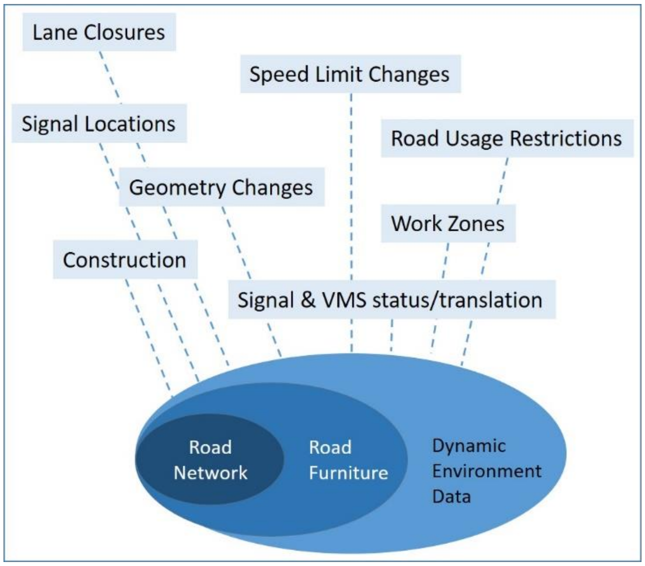

Figure 13. Graph. Example CAV-Path data
(Source: FHWA)

Human-readable vs. Computable Data

CAV-Path data today are provided to humans in many different forms, from static roadside signs to smartphone app updates. While there are some standards in place for encoding this information, a great deal of it is available in an analog fashion. Even event descriptions for apps may be described using non-standardized text strings, and their locations are often fairly high level. For example, “lane closed on highway 123 between Evergreen and Elm” might refer to a closure that is only a subset of the distance between the two cross-streets mentioned. Table 4 presents the evolution of functions and content descriptions.

Table 4. Evolution of Functions and Content Descriptions

	Human	Machine
Sample Application/Tasks	Navigation, Traveler Information	Localization, Path Planning
Standard Content Descriptions	Need to have data available and described for human use	Need to have all data effectively described for machine use

Similarly, the metadata about this information is often inferred or absent altogether. Humans are expected to make their own judgment calls about how current, precise, and reliable the information is. This is usually done based on the source of the data and the user’s own experience with the area.

AVs, on the other hand, require *computable data*. They need to know precisely what path data are being described, how to relate it to where they are and where they are going, and how trustworthy the information is, so that they can compare the incoming data to other sensor inputs and make repeatable, effective decisions. The information must be consistently coded and quantified to allow this processing to occur. Further, this consistency must exist at the national level, as vehicles may move throughout the continental U.S. and need to understand the information they receive the same way wherever they travel.[g]

Architectural Implications

Traditional connected vehicle architectures have been the subject of a great deal of collaborative research and development. They typically assume a specific type of standardized on-board unit (OBU) in the vehicle, communicating with other standardized in-vehicle OBUs and with standardized roadside units linked to a public-sector back-end infrastructure. Similarly, applications and message sets are standardized to allow consistent sharing of data across the fleet and with the infrastructure owner-operator (IOO) jurisdictions. This model is evolving rapidly, and the term “connected” is coming to mean *any* connection to the vehicle, regardless of technology or ownership.

In the automated vehicle space, ideas about the overall architecture are quite diverse, with many OEMs assuming that they or their designated intermediaries will be the ultimate link to the vehicle (rather than the public sector). On the data side, some providers are expecting vehicle sensors to handle primary data collection and updating directly (i.e., the vehicle builds its own map in real time),[h] while others are interested in various approaches to aggregating and communicating updates from a variety of on-board and off-board sources. In one widely considered model, public sector data would be made available to the OEM (or a third party) backend, aggregated with other input data (such as vehicle probe content), and communicated as a synthesized set of updates back out to the fleet.

For the purposes of this report and the project, we are taking a data-centric view only. We are not concerned with where the data are produced or how they are transmitted. We are focused on what the data content *is*, and how it needs to be *described* in a standardized way to support effective end user data fusion and decision-making. This is a particularly important distinction. With rapidly emerging sensor and vehicle configurations and capabilities, there is no way to predict which data sets are best collected on-board and which can be communicated remotely to the vehicle and under what circumstances. Instead, we need to ensure that consistent standards are available for use by any type of data provider, which seeks to offer data to the vehicle under any business model (“common CAV-Path data standards” as shown in Figure 14).

[g] The same data set might not be available in all locations. The data that are provided, however, should be provided in a standard fashion.
[h] Some versions of this are known as simultaneous location and mapping (SLAM).

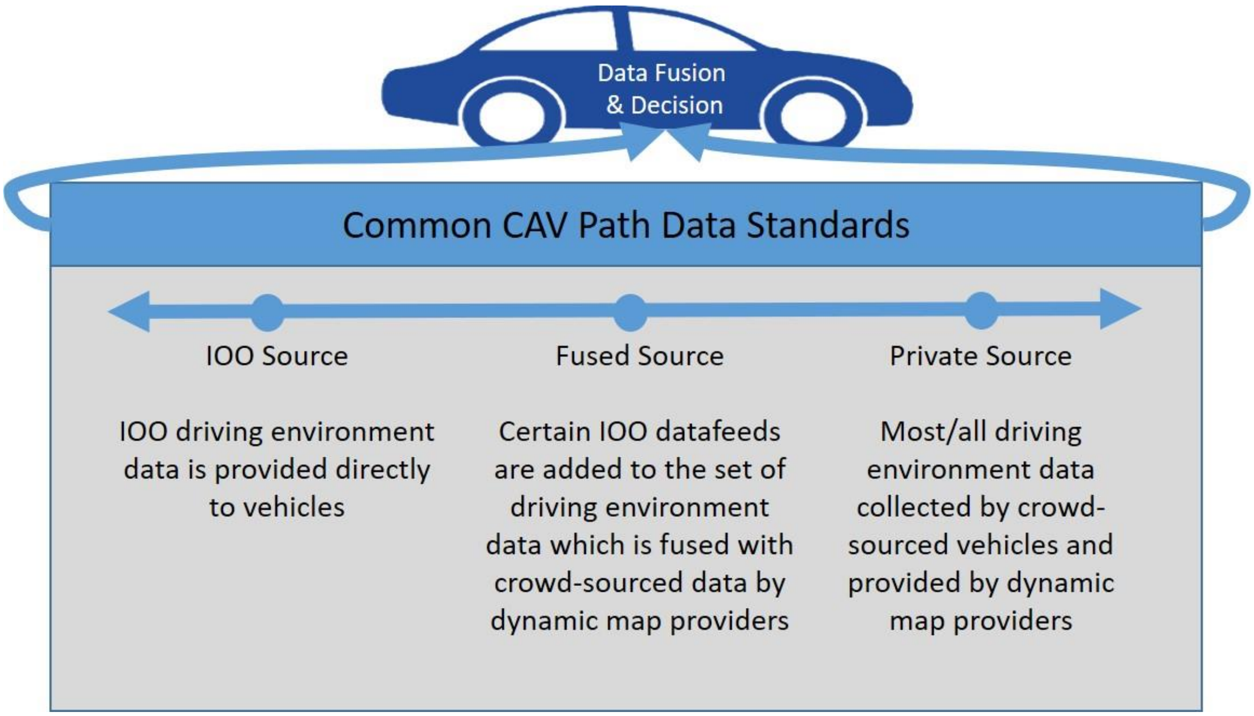

Figure 14. Graph. Data Fusion and Decision-Support Concept
(Source: FHWA)

Public Sector Roles

As noted above, standards are necessary to enable data exchange, but there is a lot more involved in establishing a viable transportation data ecosystem. One major open question is the role of the public sector. Our conclusion from this project to date is that:

- Public sector agencies will be "one among many" types of entities making data available for AV use. OEMs and third-party data aggregators will also play a major role, as noted above.
- To gain the maximum benefit from their investment, public sector agencies will need to be quite selective in the types of data that they choose to provide. There needs to be a focus on data which:
    - Clearly provides transportation safety and operational benefits.
    - Is most efficiently provided by the public sector.

Public sector agencies are likely best served by focusing on data that supports their key agency mission. For example, information about dynamic rules of the road and planned roadwork might meet both above criteria. For more about each of these content types, see the "Needs Summary" section.

Needs Summary

As described in the previous section, this report focuses on the combination of needs from human and machine users. This section describes the traceability from user tasks to required standards, as shown in Figure 15. Specifically:

- As noted in the "Key Concepts" section in this chapter, driving *tasks* must be performed in order to complete a trip, whether the driver is human or automated.
- A set of priority *task support questions* show the key questions which must be answered with content to support the driving tasks.
- The *task support content types* provide further detail on the specific content that is needed to answer the key task support questions.
- As noted in the "Key Concepts" section in this chapter, content for AVs must be described consistently and computably. The *standard content description needs* provide a high-level view of the standards needs for each content type.
- An analysis of the standard content description needs shows the *standards types* which are needed, by task support content type. Further review of this is in Section 0, which shows existing/emerging standards and gaps.

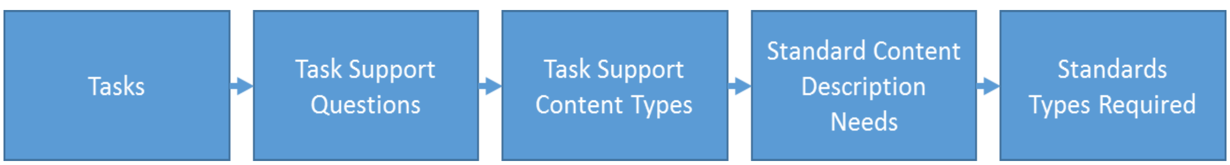

Figure 15. Graph. Tasks to Standards Traceability
(Source: FHWA)

Table 5 summarizes the responses to each of these categories. The sections below provide the details for each one.

Table 5. High-Level Needs Summary

Tasks	Task Support Questions	Task Support Content Types	Standard Content Description Needs	Standards Types Required
Perception Localization Planning Control	Where am I relative to my environment?	• Road geometry • Road furniture	Required for all content: • What is it? • Where is it? • How good is it?	• Terminology • Data models • Data dictionaries • Data registries • Cross map location referencing • Quality metadata
	What are the rules of the road that affect path?	• Rules of the road		
	What is changed from what I already know?	• Recent/ temporary changes		

Task Support Questions

When we reviewed the long list of applications, functions, and tasks that stakeholders provided, it became clear that three questions were a priority for both human and machine users:

- Where am I relative to my environment? Whether the user was a human interacting with a navigation application or an AV seeking to localize itself within its environment, “Where exactly am I?” was a critical question.
- What are the rules of the road that apply to my path? Quite a lot of today’s infrastructure is dedicated to helping humans answer this question (with not always perfect results). Automated vehicles need even more help in this area, as the human-focused information is often difficult or impossible for machines to translate; and a nationwide set of “local knowledge” which covers every road and driving situation is currently not available to programmers.
- What has changed from what I already know? This question is critical to both safety and efficient transportation network management for all users.

Task Support Needs

The priority task questions drive a set of content needs for both content types and content quality. The core need is to be able to *describe* this data in a *machine-usable* fashion which supports data fusion (*computable data*). This data is “interface-agnostic,” as it may be shared across any interface in the overall data ecosystem (see Chapter 4, “Architecture Implications,” for more on this).

The following sections provide more detail on each content type, including the standard content description needs for each one. There is also a discussion of content quality, an important component of the content description.

Content Types

Specific data requirements vary widely based on the user and the task at hand. We can capture these needs in four major content categories:

- Road geometry
- Road furniture
- Rules of the road (“legal path”)
- Recent/temporary changes

These categories are often represented as data layers, as shown in Figure 16, which provides one example of how we can name and organize these categories.

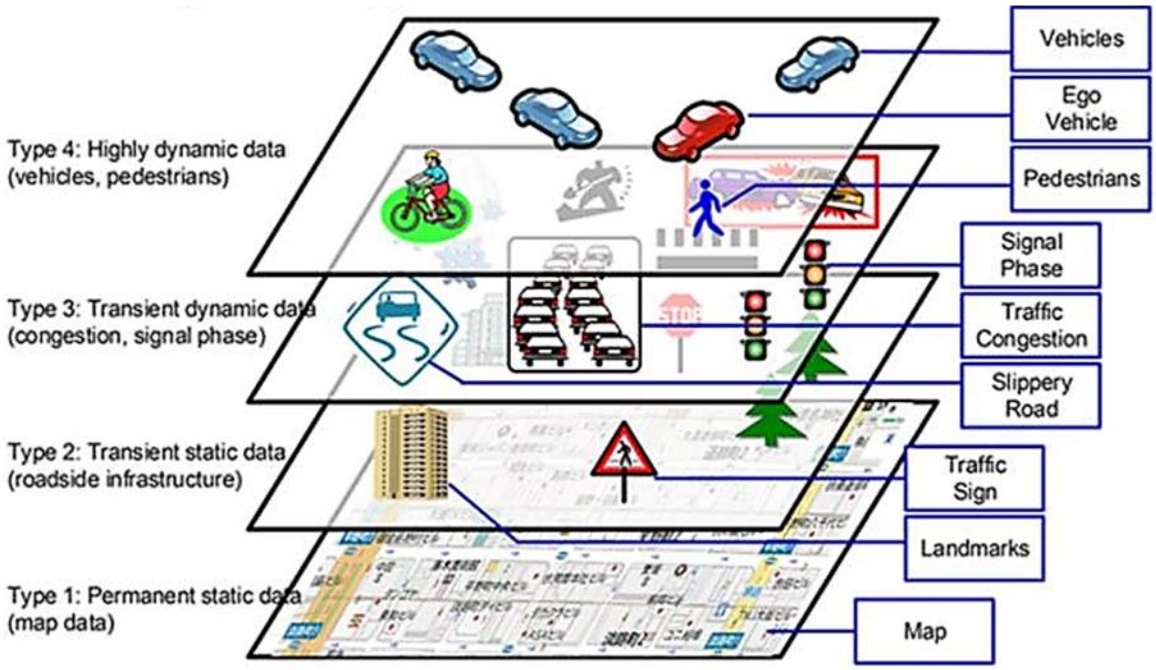

Figure 16. Graph. Sample Data Layer Diagram – EU inLane[63]

Stakeholders noted that data relating to the entire journey is of interest, both what is true at any given time and place, and what is coming up. In addition, stakeholders had diverging opinions about who should provide this data – further discussion on this is located in the "Key Concepts" section in this chapter.

Road Geometry

Description: Information about the basic structure of the road network in a consistent, computable format.

Geometric information of interest:

- Lane type (regular, managed, ramp, auxiliary, exit, etc.)
- Uniquely identified lane centers and markings
- Lane markings (including retro reflectivity)
- Speed bumps
- Road banking
- Crosswalks
- Bike boxes and lanes
- Internal storage lanes

- Lane suitability for emergency applications
- Vertical crest curvature
- Stopping sight distances

Standard content description needs:

- RG1 Need common definitions of road geometry elements (segments and segment attributes)
- RG2 Need a common model for describing relationships among elements (world and lane models)
- RG3 Need a way to consistently describe relative and absolute element location
- RG4 Need a way to indicate impact of road geometry attributes on each lane

Road Furniture

Description: Information about the location of roadside objects that have an impact on CAV-Path determination.

Examples highlighted by stakeholders:

- Guard rails
- Stop signs/other signage
- Bridges/clearance heights
- Mile markers
- Traffic signal locations/poles and consistent information on signal location on poles
- Impact barriers
- Toll booths

Standard content description needs:

- RF1 Need common definitions of road furniture items and attributes
- RF2 Need a common model for describing relationships of road furniture to road geometry
- RF3 Need a way to consistently describe relative and absolute road furniture location
- RF4 Need a way to indicate impact of road furniture attributes on each lane

Rules of the Road ("Legal Path")

Description: Information about long- and short-term laws and directives from road authorities. This includes both overall legal constraints and traffic management instructions, as well as help translating visual instructions.

Examples highlighted by stakeholders:

- Lane and road use restrictions (maximum height, weight, and width; vehicle type, vehicle occupancy, user type - local residents only; bus and bike lanes)
- Driving laws/policies/local practices
- Enforcement policies
- Signage impact on lane use, including off-road signs
- Speed limits (permanent)
- Reversible lanes
- Shoulder use for travel
- Parking restrictions

Standard Content Description Needs:

- RR1 Need common definitions of legal restrictions (both enforceable and advisories)
- RR2 Need a common model for describing relationships of legal restrictions to road geometry
- RR3 Need a way to consistently describe relative and absolute location of restriction application zone
- RR4 Need a way to indicate impact of restrictions on each lane by vehicle type

Recent/Temporary Changes

Description: Information about any aspect of the driving environment that may have recently changed. This includes anything that impacts vehicle *path*.

This category overlaps with the "rules of the road" category in some cases, where rules are dynamic (e.g., variable speed limits, traffic signals, reversible lanes, crosswalks with pedestrian activity, and temporary traffic control for work zones). These items are part of a continuum from temporary changes that are ephemeral to changes that are longer lasting. For example, ephemeral changes might be a short-term moving work zone or a stopped vehicle. More permanent changes may be long-term lane shifts for a major construction project. There is not yet industry consensus on precise demarcations along this continuum.

Examples highlighted by stakeholders:

- Road and lane/shoulder geometry changes
- Closures
- Temporary lane control sign information (for example, used in Active Traffic Management applications, lane/shoulder status [open/closed])
- Road friction/traction status
- Work zone driving restrictions
- Traffic signal and sign status (by lane)
- “Landmark uncertainty areas” where road furniture may have changed
- Obstacles and negative obstacles (pothole)
- Speed limit (variable)
- Path guidance (detours, lane re-location/shifts)

Standard content description needs:

- RC1 Need common definitions of recent or temporary changes
- RC2 Need a common model for describing relationships of changes to road geometry
- RC3 Need a way to consistently describe relative and absolute location of change
- RC4 Need a way to indicate impact of changes on each lane by vehicle type

Content Quality

Content quality needs to be applied to all the content types. Stakeholders noted the need for two aspects of quality:

- Quality levels
- Quality metadata

IOOs have been continuously working for many years to improve the quality of data available to human drivers. Automated vehicles (AVs) make this work an even greater priority, as safe AV operations require a substantially higher level of accuracy, currency, and completeness. Specific needs provided by stakeholders included:

- Spatial accuracy. The consensus appeared to be that locations needed to be accurate to about 20 cm. This is a dramatic shift from existing “road level” (e.g., I-95 northbound) and emerging “lane level” (e.g., I-95 northbound right-hand lane) accuracies to a “within lane” or “feature”-level focus.

- Latency. Similarly, AVs require a much tighter set of end-to-end latency metrics (time of change to time of vehicle awareness of change), which encompasses data collection, processing, communications, and retrieval periods.

For example, Table 6 shows some recent descriptions of desired content quality for typical AV functions. However, these are early indicators only. There does not appear to be a clear set of thresholds for these metrics available currently. Instead, the need is for quality metadata that will allow automated vehicles to make *informed judgments* about the data that they receive. This metadata will allow data providers to appropriately describe their information as quality improves over time.[i]

Standard content description needs:

- CQ1 Need common definitions of computable quality metrics for CAV-Path data
- CQ2 Need common metadata information about CAV-Path data

Table 6. Sample Content Quality for AV Functions *(Source: USDOT)*

Potential AV Needs for Map Data by Function and Accuracy		**Map and Position Accuracy**		
		Navigation Road Level Accuracy ±3.5m (J2945/2 Normal w/o Corrections)	**Local Route Guidance Lane Level Accuracy ±1.5m** (J2945/2 Normal)	**Local Trajectory Planning and Control Feature Level Accuracy ±10 cm**
AV Function	**Perception**	Does the map confirm my lat/long is: • On a mapped roadway? • Possibly on an unmapped new road? • Possibly in an unmapped construction zone?	Does the map confirm that my lat/long and/or sensor signal is: • The edge of the road? • The edge of the lane? • The intersection stop bar?	Does the map confirm that the sensor signal is: • A Jersey barrier? • A roadside sign? • A light pole? • A traffic signal?
	Localization	Which road am I on? Where am I on the road? Where am I relative to intersections and entrance/exit ramps? Where am I relative to my route?	Which lane am I in? Where I am I relative to upcoming lane maneuvers or turns?	Where am I within my lane? Where am I relative to perceived features and obstacles?
	Planning	Where am I relative to my destination? What are my route options?	Where am I relative to my next lane maneuver or turn? What are my lane options?	Where am I relative to my next steering, acceleration, or deceleration change?

[i] It is unlikely that there will ever be continuous availability of "perfect data"; instead, quality metadata should be captured and shared as part of the overall data governance and management process.

Potential AV Needs for Map Data by Function and Accuracy		Map and Position Accuracy		
		Navigation Road Level Accuracy ±3.5m (J2945/2 Normal w/o Corrections)	**Local Route Guidance Lane Level Accuracy ±1.5m** (J2945/2 Normal)	**Local Trajectory Planning and Control Feature Level Accuracy ±10 cm**
		What is my optimum route selection?	What is my optimum lane selection? What changes are required to achieve my optimum lane selection?	What are my steering, speed and accel/decel options? What is my optimum steering, speed, and accel/decel selection?
	Control	Iterative closed loop feedback using map to adjust route to achieve selection.	Iterative closed loop feedback using map to adjust lane to achieve selection.	Iterative closed loop feedback using map to adjust steering, speed and accel/decel to achieve selection.

Standard Content Description Needs Summary

Table 7 summarizes the content description needs.

Table 7. Standard Content Description Needs Summary

RG1	Need common definitions of road geometry elements (segments and segment attributes)
RG2	Need a common model for describing relationships among elements (world and lane models)
RG3	Need a way to consistently describe relative and absolute element location
RG4	Need a way to indicate impact of road geometry attributes on each lane
RF1	Need common definitions of road furniture items and attributes
RF2	Need a common model for describing relationships of road furniture to road geometry
RF3	Need a way to consistently describe relative and absolute road furniture location
RF4	Need a way to indicate impact of road furniture attributes on each lane
RR1	Need common definitions of legal restrictions (both enforceable and advisories)
RR2	Need a common model for describing relationships of legal restrictions to road geometry
RR3	Need a way to consistently describe relative and absolute location of restriction application zone
RR4	Need a way to indicate impact of restrictions on each lane by vehicle type
RC1	Need common definitions of recent or temporary changes
RC2	Need a common model for describing relationships of changes to road geometry
RC3	Need a way to consistently describe relative and absolute location of change
RC4	Need a way to indicate impact of changes on each lane by vehicle type
CQ1	Need common definitions of computable quality metrics for CAV-Path data
CQ2	Need common metadata about CAV-Path data

Standards Needs

Looking at the standard content description needs table: a clear pattern emerges. We can organize the three major components of the description for each data item as:

- What is it? What is the event/object/structure being described?
- Where is it? Where exactly is the event/object/structure located relatively and absolutely? And where does the vehicle have to be before it is made aware of event/object/structure?
- How good is it? What level of trust can be assigned to this information?

This organization yields a set of standards needs by category, as shown in Table 8.

Within these categories, stakeholders identified the need for specific types of standards that address the standard content description needs, as shown in Table 9. In particular, standards appear to be needed for:

- Terminology. Definitions for key CAV-Path data concepts.
- Data models. World models and lane models that allow us to understand how different features relate to each other.
- Data dictionaries. Collections of data elements relevant to specific task areas.
- Data registries. Central repositories for the data elements from multiple data dictionaries, with metadata and relational taxonomies to allow correct interpretation and re-use.

Table 8. Standard Content Description Needs by Category

Standard Content Description Needs by Category
What is it?
RG1 Need common definitions of road geometry elements (segments and segment attributes)
RG2 Need a common model for describing relationships among elements (world and lane models)
RF1 Need common definitions of road furniture items and attributes
RF2 Need a common model for describing relationships of road furniture to road geometry
RR1 Need common definitions of legal restrictions (both enforceable and advisories)
RR2 Need a common model for describing relationships of legal restrictions to road geometry
RC1 Need common definitions of recent or temporary changes
RC2 Need a common model for describing relationships of changes to road geometry
Where is it?
RG3 Need a way to consistently describe relative and absolute element location
RG4 Need a way to indicate impact of road geometry attributes on each lane
RF3 Need a way to consistently describe relative and absolute road furniture location
RF4 Need a way to indicate impact of road furniture attributes on each lane
RR3 Need a way to consistently describe relative and absolute location of restriction application zone
RC3 Need a way to consistently describe relative and absolute location of change
RR4 Need a way to indicate impact of restrictions on each lane by vehicle type
How good is it?
CQ1 Need common definitions of computable quality metrics for CAV-Path data
CQ2 Need common metadata about CAV-Path data

Table A in Appendix C shows the linkage between tasks, task support content needs, task support content types, and standard content description needs. Table B extends this traceability to standards description needs by category and standards types required.

Table 9. Standards Types Required by Category

Category	Standards Types Required
What is it?	• CAV-Path terminology • Data models (e.g., world models, lane models) • Data dictionaries • Data registries
Where is it?	• Cross-map location referencing (which may vary by data type)
How good is it?	• Quality metadata (e.g., confidence, timeliness)

Gap Analysis

At this point, it is useful to return to the core research question: *How do we best communicate map information from the infrastructure to V2X devices?* This chapter reviews the status of today's standards activities by standards need and identifies key gaps. In performing this analysis, it also became clear that there are other kinds of gaps which must be addressed in order to realize the public sector contribution to the data ecosystem needed to support AVs; in particular, implementation gaps. This chapter also provides some initial thoughts on these issues.

Table B in Appendix C provides a view of standard description needs by category to existing/emerging standards. Table C in Appendix C shows the linkage between standard content description needs, standards types required, standards status (summary), and gaps/priorities. Recommendations on how to address the listed gaps can be found in the "Standards Issues" section in this chapter.

Standards Review

This section reviews the existing and emerging standards work in the CAV-Path data area to help determine where needs are met and where gaps still exist. We developed:

- A snapshot of existing activities
- A review of standards focus by interface
- A review of standards by category

This section provides a high-level summary of each of these. Further detail is in Appendices A and B.

Snapshot of Relevant Organizations and Standards

We selected a set of standards activities for inclusion in this review based on our current understanding of the combined set of needs generated by the emerging suite of *applications with connectivity* at the V2X interface. In some cases, we also included C2C standards where they cover highly related subject matter (e.g., the exchange of map data between center and map provider). Table 10 provides a summary, and Appendix B. Standards Activity Review provides a more detailed description of these activities.

Table 10. Summary of Organizations and Standards

Organization	Standards
ADASIS	• ADASIS 2.0 • ADASIS 3.0 (in work)
CEN TC278 WG7	• Intelligent Transport Systems – Transport network Intelligent Transport Systems spatial data exchange framework (TN-ITS) (updates in work)
CEN TC278 WG17 [67]	• Intelligent Transport Systems – Location Referencing Harmonization for Urban-ITS – Part 1: State of the art and guidelines • Intelligent Transport Systems – Location Referencing Harmonization for Urban-ITS – Part 2: Translation methods • Intelligent Transport Systems – Electronic management of regulations and policies – Part 1: Basic concepts and architectures (METR) (in work)
ETSI TC ITS	• ETSI EN 302 895 V1.1.1 (2014-09) Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Local Dynamic Map (LDM) • ETSI EN 302 637-2 V1.3.1 Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 2: Specification of Cooperative Awareness Basic Service • ETSI EN 302 637-3 V1.2.1 Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 3: Specifications of Decentralized Environmental Notification Basic Service
ISO TC204 WG3	• ISO 17572 Series: Intelligent Transport Systems (ITS) – Location referencing for geographic databases • ISO 20524 Series: Intelligent Transport Systems – Geographic Data Files (GDF) 5.1 (in work; builds on prior ISO 14825 GDF standards) • ISO 14296:2016 (Ed. 1) Intelligent Transport Systems – Extension of map database specifications for applications of cooperative ITS • ISO 22726 Intelligent Transport Systems – Dynamic events and map database specifications for applications of automated driving systems, cooperative ITS, and advanced road/traffic management systems (proposed work item) • ISO TR 21718 – Intelligent Transport Systems – Spatio-temporal data dictionary for cooperative ITS and automated driving systems
ISO TC204 WG18	• TR 17424:2015: Intelligent Transport Systems -- Cooperative systems -- State of the art of Local Dynamic Maps concepts • TS 18750:2015: Intelligent Transport Systems -- Cooperative systems -- Definition of a global concept for Local Dynamic Maps (LDM) developed as ISO/DIS 18750: Intelligent Transport Systems -- Co-operative ITS -- Local dynamic map. • ISO/TS 19091:2017 Intelligent Transport Systems -- Cooperative ITS -- Using V2I and I2V communications for applications related to signalized intersections* *Includes harmonized MAP messages
ISO TC22 SC32	• ISO 26262 series: Road vehicles -- Functional safety (updates in work) • ISO 20078 series: Road vehicles -- Extended vehicle (ExVe) (updates in work)

Organization	Standards
ISO TC211	• ISO 19158:2012 Geographic information -- Quality assurance of data supply • ISO 19157:2013 Geographic information -- Data quality
NDS	• Open Lane Model • Full NDS specifications
OADF	• MBIL Task Force • Metadata Task Force
OGC	• OpenGIS® Location Services (OpenLS) Standards (Core Services and Navigation Service)* **References ISO 14825*
SAE	• J2735™: Dedicated Short Range Communications (DSRC) Message Set Dictionary (published) • J2945/10: Recommended Practices for MAP/SPaT Message Development (in work) • J2266™: Location Referencing Message Specification (LRMS) (published) • J2945/4: DSRC Messages for Traveler Information and Basic Information Delivery • 6857: Requirements for a Terrestrial Based Position, Navigation, and Timing (PNT) System (in work)
TISA	• TPEG 2.0* • TPEG 3.0 (in work) **Published by ISO TC 204 WG10 as TS 21219. Note Part 7 (Location referencing container) and planned Parts 20-22 (TMC, Geographic, and OpenLR Location referencing)*

Review of Focus by Interface

This section shows how each standard fits into the standards landscape by placing each of the relevant standards bodies at appropriate interfaces in a simple architecture, as shown in Figure 17. This figure is not intended to be exhaustive but instead to provide a representative sample of the variety of organizations at work throughout the architecture. The ordering of the chart bubbles does not imply any precedence.

To better show the integrated nature of the eventual full set of CAV-Path data, we also extended this picture beyond standards organizations who are focused on geospatial data as their primary activity to include a few of the activities which focus on the transfer of other types of driving environment data.

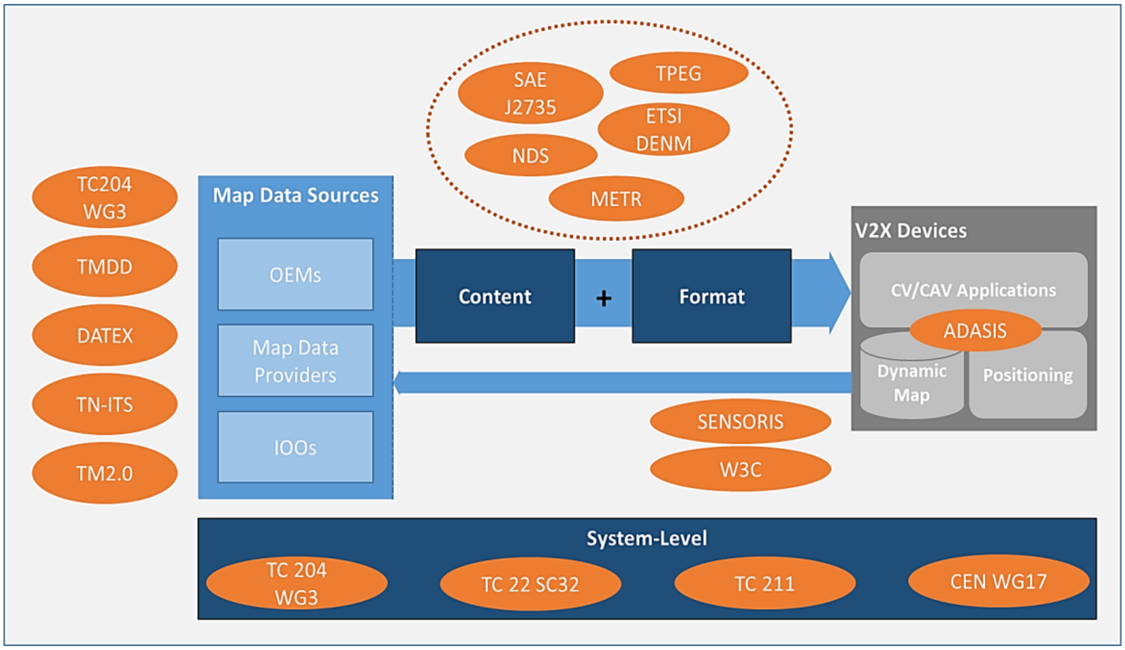

Figure 17. Graph. Standards Activity Landscape
(Source: FHWA)

Review of Standards by Category

As noted above, there were three basic categories of standard content description needs. There is a large body of existing and emerging standards in each needs category. In summary, the current status is:

- *What is it?* This is the largest area of active work, with a strong base of standards on *data models, dictionaries, and registries* developed at national and international levels, and a significant amount of work underway to update and extend these items. Standards like CEN's TN-ITS are available to facilitate the exchange of specific types of geographic data, and organizations such as CEN, ISO, OADF, SAE, and TISA are tackling the more dynamic data types. *Terminology* is also an active area – each standard typically contains a terminology section, but specific standards to help define industry vocabulary are also in progress.

- *Where is it?* Location referencing continues to be a challenge. Current standards efforts are focused on "cross-map" referencing at the levels of accuracy required for automated vehicles. There are several new approaches in development from organizations such as CEN, ISO, OADF and, most recently, the new SharedStreets[j] activity.

- *How good is it?* Some *quality* standards for geographic data exist, most notably ISO 19157. However, descriptions for other types of data are also in progress, as is an effort to describe data process quality (how good the data is at each point in the data chain. The EIP+ project has done some early work on this topic, and there are ongoing discussions in OADF.

[j] SharedStreets is a project of the World Bank's Open Transport Partnership, launched in partnership with NACTO. This effort is very new, and its exact activities are still emerging, but it is included here for completeness and as a potential key stakeholder forum.

Figure 18 provides an overview summary of these standards; Appendix C provides further detail on each one. It may be helpful to note that:

- This figure represents a large set of complex technical documents. It was not possible to review all of them in full technical detail for this report; we instead provide a summary here in high-level categories as a guide to further investigation.
- Standards that are in commercial use are more mature and have some level of industry adoption. This does not necessarily mean that they are optimal, but they do have some traction and real-world field exposure.
- Standards that were developed with U.S. content are primarily focused on U.S. needs (or at least have had significant U.S. input). This does not mean that international efforts may not also provide substantial value for U.S. use; it is merely one indicator of potential applicability. In fact, as the figure clearly shows, a great deal of work is taking place outside the U.S., and it is critical to understand and leverage those efforts where appropriate.

The standards space is extremely dynamic now, so this information should be a viewed as a snapshot which must be continuously updated to support any ongoing use.

Standards Issues

This section includes a high-level summary of known challenges. Key issues affecting standards include:

- *Evolution from human to machine use ("connected" to "connected-automated")*. Current maps and other location-based data are designed for use by humans, while we expect upcoming systems to have much heavier reliance on automated vehicle functions. There is significant work needed to understand exactly what this means for V2X communication of map information.
- *Pace of change*. The industry is evolving so rapidly that it is difficult for standards developers to deliver standards in time for them to be useful to implementers.
- *Deployment models.* The current variation in perspectives around the collection, processing, and delivery model for map and map-related data means that standards discussions must remain both strategic and flexible. The focus may best be on interfaces rather than entities, common frameworks rather than technologies, etc.

The other major challenge area is coordination among the standards bodies themselves. Many different organizations are working in parallel or on highly related portions of each interface. The scope of some of these work efforts is rapidly evolving, as each set of stakeholders seeks to respond to the expected needs of automated vehicles. All of these activities must interact successfully as part of an integrated whole. Data concepts, lane models, and location referencing must all be consistently harmonized or translated at each interface and eventually understandable by in-vehicle systems. This coordination is made more challenging due to:

- *Organizational diversity.* There is a great deal of standards activities going on in both traditional standards development organizations (SDOs) and in industry consortia. It may be the case that consortia carry out critical standards efforts and simply use the results as de facto standards without ever formalizing them in an SDO. This makes it vital to stay aware of the full range of standards activities and to encourage a focus on a truly interoperable end-to-end system wherever possible.

- *Business models.* In a related challenge, the business models of these standards organizations are not universally compatible. Some are funded by members or industry fora, while others rely on the sale of standards products. There are also other actors who do not participate in any industry standards discussions but who have still proven to be very effective promulgators of de facto standards (e.g., Google General Transit Feed Specification [GTFS]). Effective standards integration is difficult in this environment.

- *Standards adoption*. The wide, fragmented, and often confusing nature of the standards space can make it difficult for a standard to achieve critical mass. Deployers may simply be unaware of the existence of useful standards or may use proprietary solutions rather than navigate the maze of related and sometimes conflicting standards material.

The various standards actors are increasingly aware that all this is a challenge, and many different discussions and liaisons are now taking place between the various entities. Significant effort will be required to weld the outputs from all these activities into a coherent whole.

Standards Gaps

Upon reviewing both the content description needs and standards issues shared by the stakeholders, we identified a set of key gaps, which include:

1. *Standard Gap: Common data registry* – The need for a data registry, which will house the full suite of standard transportation data elements and their metadata; and enable consistent use and re-use of these elements by developers, is another well-recognized need. Without such a registry, it is very difficult to avoid unintentional standards overlap and conflict. Implementation, however, has been a major challenge. Recent developments in ISO and OADF may finally be making progress in this area, and it is important to maintain this momentum.

2. *Standard Gap: Location referencing solutions* – As noted in the "Needs Summary" section of this chapter, location referencing ("where is it?") is the critical glue which holds the CAV-Path data set together. At least three separate efforts are underway to develop improved solutions in this area. It is critical to monitor, support, and implement these new solutions in public sector data sets.

3. *Standard Gap: Quality description standards* – The need for map data quality standards is well recognized, and work has already been done in ISO for some kinds of data. However, standard metrics for dynamic types of data are not as well codified. Further work is required in this area.

4. *Standard Gap: Harmonization/translation of related/competing standards* – The ITS standards space is at an all-time high level of activity. Existing standards bodies are generating new work items and new standards groups are emerging constantly, and these represent a variety of stakeholder interests and standards development business models. There are ongoing efforts to harmonize key standards on a national and global basis, and this work is more important than ever at this time. An additional related option that is also under exploration is translation between data standards, to avoid the need for full harmonization. Outreach efforts to avoid the development of redundant standards is similarly critical.

5. *Standard Gap: Agreed upon set of CAV-Path data standards* – As shown in Figure 18, there is a great deal of standards development work underway to generate standards to meet AV requirements, including the extension and expansion of existing deployed standards. Figure 18 is not meant to be an exhaustive list and there is work still to do in that area. However, the primary public sector challenge appears to be not “how do we get the necessary standards *developed*?” but instead “how do we *select and implement* the necessary standards to develop a nationally consistent set of public sector information to enable AVs?”

Implementation Gaps

As noted above, public sector roles and focus are evolving area, but initial results from this project seem to indicate:

- Public sector agencies will be “one among many” types of entities making data available for AV use.
- Public sector agencies will need be quite selective in the types of data that they choose to provide in order to gain the maximum benefit from their investment.

These results give rise to the following implementation gaps:

1. *Implementation Gap: Agreed-upon minimum national data set* – IOOs are currently making decisions about what data to provide on an individual basis. To deliver a CAV-Path data set that can consistently support AV needs in coast-to-coast consumer and freight travel, there needs to be some agreement on a minimum data set which all relevant agencies can work to provide. As noted above, this set must be selected very carefully to ensure efficient use of public resources.

2. *Implementation Gap: Upgraded data collection and delivery capabilities* – IOO systems today, such as 511 and other traveler information solutions, have been developed to generate data for use by humans. Consistently collecting and delivering the types and quality of data needed to support AVs for real-time safety requires much higher level of capability. All aspects of the data lifecycle process, and the associated institutional, technical, and business implications, need to be reviewed and addressed as necessary.

3. *Implementation Gap: Standards implementation support* – Because the data provided by public agencies must be used by and fused with data from many other users across the ecosystem, that data must be contributed in a nationally consistent way that is as simple to use as possible. Multiple, inconsistently applied standards (or no standards at all) will cause major issues here. However, the standards landscape is complex and difficult to navigate. Work is needed to ensure that IOOs are aware of, and able to effectively implement, the core suite of standards noted in Standards Gap 5, which corresponds to the minimum national data set noted above in Implementation Gap 1. This is particularly important considering the dynamic nature of the space and agency resource constraints.

Models/Dictionaries/Registries

- **ISO 20524 Geographic Data Files (GDF)**
- **CEN TC278 WG 7 TN-ITS**
- **Navigation Data Standard (incl. Open Lane Model)**
- **OpenDRIVE 1.4**
- ADASIS 3.0
- ISO 14296:2016 Extension of map database specifications
- ISO TR 21718 Spatio-temporal data dictionary
- *SAE J2945/10 Recommended Practices for MAP/SPaT Message Development*

- *CEN METR*
- ISO/TS 19321:2015 IVI Data Dictionary
- ISO/TS 17425:2016 Data exchange specification for in-vehicle presentation of external road and traffic related data
- ISO 21219 TPEG 2
- ISO 18750:2018: Local dynamic map
- **CEN 16157-3 DATEX II Situation Publication**
- ETSI EN 302 637-3 V1.2.1 DENM
- ISO/TS 19091:2017 Using V2I and I2V for signalized intersections
- SAE J2735™
- ITE TMDD
- IEEE 1512
- *TISA TPEG 3.0*
- *J2945/4: DSRC Messages for TIM and BIM (RSM)*
- *FHWA WZDX*
- CIFS

- ISO 17419 Globally unique identification; *Management and operation of registries*

Terminology

- ISO 14812 Vocabulary
- SAE J3131 AD Reference Architecture

Location Referencing

- ISO 17572-1:2015 Location referencing for geographic databases
- **ISO 21219 - TPEG2 Parts 11, 20-22**
- **OpenLR v1.4.2**
- CEN EN 16157-2 DATEX II - Part 2: Location referencing
- OpenGIS® Location Services (OpenLS)
- J2266™: LRMS
- *CEN Location Referencing Harmonization for Urban-ITS*

Quality

- ISO 19157:2013, 2016 Geographic Information – Data quality
- ISO 19158:2012 Geographic Information – Quality assurance of data supply
- *OADF Highly Reliable Maps specifications*

Blue = developed in US or based on core US content
Italic = in draft
Bold = in commercial use

Figure 18. Graph. Existing/Emerging Standards by Category
***(Source: FHWA)*.**

Standards and Data Recommendations

Stakeholder outreach and state of the practice reviews have identified a major shift in how map-related information is viewed in the industry. A new user (the automated vehicle) has emerged, and for this user, requirements for map-related information are broader in terms of content type and quality. The needs and gaps identified in the previous sections for this user are significant and not expected to be solved by a single agency (Federal, State, local, or private). Rather, it requires a coordinated and cooperative approach to ensure that the next generation of vehicle systems is assured of high-quality content that is suitable for their functions/applications.

To that end, we offer the following recommendations for the next stage of this project as a starting point in the roadmap toward the goal of supporting AV deployment. They flow directly from the standards and implementation gaps and provide a cross-cutting approach to addressing a variety of the issues noted in the gap analysis discussion. The goals are to:

- Enable the process of determining how public agencies will consistently provide a nationally consistent, mission-appropriate set of automotive-grade content to CAVs by experimenting with the development, delivery, and use of specific data sets.
- Actively partner with related international activities to ensure that we end up with the best available solutions and avoid duplication of effort.

The recommendations noted here are a start that fit within the boundaries of the current project. Further efforts will be needed to address the remaining gap areas.

Recommendation #1 – Develop a sample CAV-Path data set

Dedicate the next stage of this project to demonstrating how a public agency might provide data in each of the core CAV Path data categories, using existing/emerging standards to create data feeds that will be computable by a machine. This activity would model what public agency CAV-Path data provision might look like. Some data types are relatively straightforward – there are already consistent public feeds available and the effort would be to convert them into standard data elements using existing standards. Other data types are more challenging – where a full set of public data is not already available or the data that is available is significantly divergent, we would need to assess what information is available (from a limited set of public agency partners) and determine how to make that data share-able. Several of the content types identified in the report would fall under this category.

The CAV-Path data set would also include consistent location referencing methods (and show the results on multiple, real maps) and quality metadata, using existing data quality specifications. The result of this effort would be a draft “national AV-ready data set” that OEMs and IOOs could both usefully review. The process and data could also be used as the basis for an ongoing data assessment and testing program for digital infrastructure. This recommendation provides an opportunity to tackle:

- Exactly what priority core data we think agencies should provide, based on their role as transportation network managers (e.g., changes to road network, road rules)
- How to make all shared data computable for use by machines (including quality data)
- How to attach data to different maps

Recommendation #2 – Test the utility of the CAV-Path data set for select use-cases at Turner-Fairbank Highway Research Center

Once the CAV-Path data is available, it is necessary to see it tested in a field setting. Demonstrating the ability of a vehicle to consume the CAV-Path data and make effective decisions for its driving tasks and applications is the key to this recommendation. For this activity, the team will develop sample use-cases that illustrate the value of CAV-Path data on AV operations. Included in this project are the tools necessary to validate and compute the CAV-Path data for applications and driving task.

Recommendation #3 – Engage in cooperative information-sharing around CAV-Path data standards and deployment internationally

The U.S. is not the only country facing the challenges of public sector data provision in this new environment. Europe has published Directives around “national access points,” which set out minimum data sets and standards, and is now in the very early stages of implementation. This initial activity was developed to support human users, but there are many lessons to be learned from both the Directives and the implementation process to date. Australia recently published a report that indicates their recognition of the need to tackle challenges quite similar to the gaps noted in this document and represents another opportunity to partner in addressing these issues.

One of the biggest challenges in this area is the diversity of stakeholders and complexity of the ecosystem. The only solution is constant communication of vision, status, plans, and research results. Regular promotion of the overall CAV-Path concept and information-sharing about program activities will help avoid re-work and accelerate adoption of these ideas. This is particularly important as individual IOOs pursue aggressive research programs that can add great value to the conversation if coordinated.

Chapter 5. Using Work Zone Data as a Case Study for CAV-Path Data Specifications

The recommendations of the initial tasks of the project called for further work on:

- Enabling the process of determining how public agencies will reliably provide a nationally consistent, mission-appropriate set of automotive-grade content to CAVs by experimenting with the development, delivery, and use of specific data sets.
- Actively partnering with related international activities to ensure that we end up with the best available solutions and avoid duplication of effort.

This part of the project carried these ideas forward, with a focus on the specific recommendation from the previous section: *Develop a CAV-Path data set to demonstrate how a public agency might provide data for drivers, using existing/emerging standards to create data feeds that will be computable by a machine (in this case, an automated vehicle).* This effort was intended to help us learn more about:

- How to make all shared data computable for use by machines (including quality data)
- How to attach data to different maps

This task included two sets of subtasks:

- Design and Development Activities to Address Standards Gaps
- Development and Demonstration of V2X Mapping Proof-of-Concept of Work Zone Mapping Toolset

The end goal was to begin “connecting the dots” among existing programs and specification development efforts in support of common Work Zone Event Data for V2X and Cooperative ADS applications.

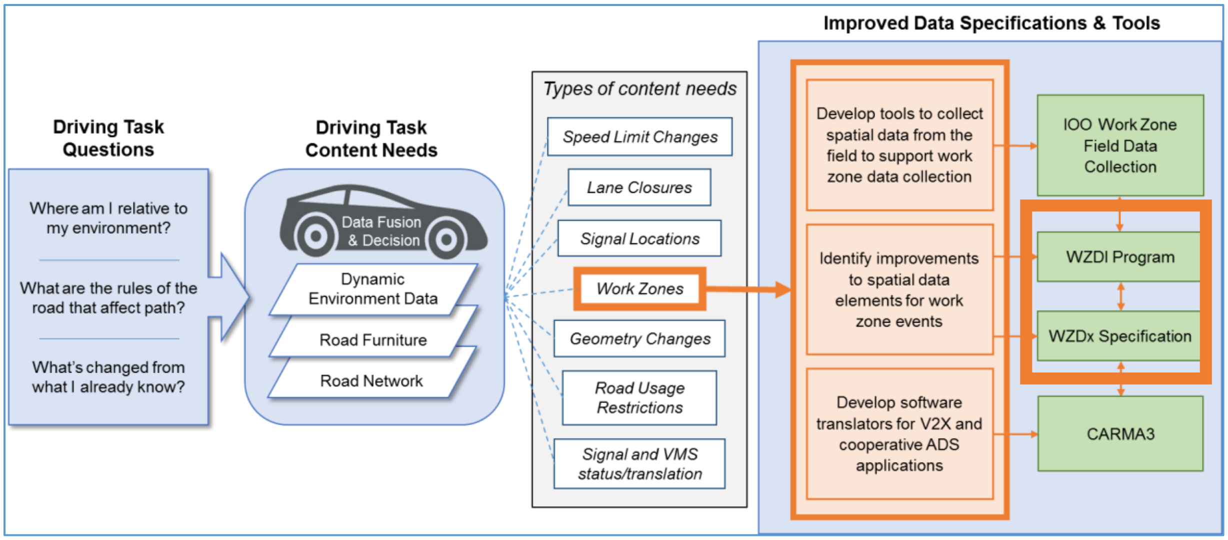

Figure 19. Review of WZ Data Specifications
(Source: FHWA)

Scope and Audience

The overall scope of this effort was: *research opportunities to leverage and evolve geospatial elements of WZDx for ADAS & AV use-cases.* We focused on an *in-depth review* of the spatial data standards identified in previous tasks to support the provision of *work zone data*. We conducted this work in close cooperation with existing work zone data efforts, including the WZDx and WZDI work within the USDOT.

Activities included:

- A more detailed look at specific spatial data element and associated data quality needs for work zones, e.g., start and end points, tapers
- Capture of identified standards gaps
- A review of existing spatial data elements, location referencing methods and quality metadata, using existing standards and specifications to support cross-map referencing
- Recommendations on use of existing standards
- Coordination with relevant standards bodies and research in this area to ensure efficiency, relevancy, and prompt leverage of results

The results are intended to provide specific input to both specification developers and data providers, including the software development and demonstration and the ongoing WZDx and WZDI work, especially on linking Work Zones to HD Maps. They are also meant to contribute key insights toward a draft “national AV-ready spatial data set” that OEMs and IOOs can both usefully review.

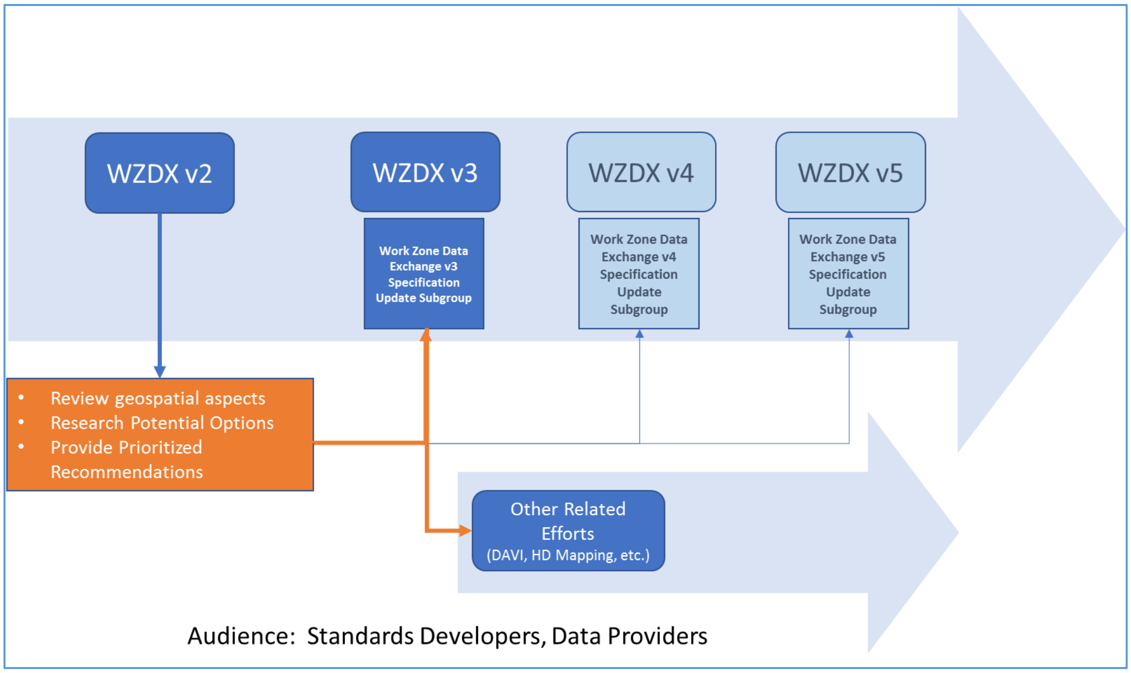

Figure 20. Scope and Audience for Work Zone Data Exchange Review
(Source: FHWA)

WZDX v2 review

The first step in this task was to review the existing material in the WZDX v2 specification with respect to the AV Applications and Content Needs developed in Task 3. The goal was to understand what adjustments might be needed to allow WZDx to support automated vehicles (machine users) in addition to the human users for whom it was initially designed. See Appendix D: WZDx v2 / AV Needs Review for a detailed analysis.

Table 11. AV Needs Summary

What is it?
RG1 Need common definitions of road geometry elements (segments and segment attributes)
RF1 Need common definitions of road furniture items and attributes
RR1 Need common definitions of legal restrictions (both enforceable and advisories)
RC1 Need common definitions of recent or temporary changes
RG2 Need a common model for describing relationships among elements (world and lane models)
RF2 Need a common model for describing relationships of road furniture to road geometry
RR2 Need a common model for describing relationships of legal restrictions to road geometry
RC2 Need a common model for describing relationships of changes to road geometry
Where is it?
RG3 Need a way to consistently describe relative and absolute element location
RG4 Need a way to indicate impact of road geometry attributes on each lane
RF3 Need a way to consistently describe relative and absolute road furniture location
RF4 Need a way to indicate impact of road furniture attributes on each lane

RR3 Need a way to consistently describe relative and absolute location of restriction application zone
RC3 Need a way to consistently describe relative and absolute location of change
RR4 Need a way to indicate impact of restrictions on each lane by vehicle type
How good is it?
CQ1 Need common definitions of computable quality metrics for CAV-Path data
CQ2 Need common metadata about CAV-Path data

Approach and Findings

We aligned each need with the relevant WZDx element, as shown in the example presented in Table 12. To ensure clarity, we also added industry best practice details to amplify the Need description. These best practices are drawn from the existing activities of nationwide data providers who supply both consumer and OEM partners.

Table 12. Analysis Example

What is it?	Best Practice/Need Detail	WZDx element	Required/ Optional	Enum values
RG1 Need common definitions of road geometry elements (segments and segment attributes)	Include full set of elements necessary to model real-world road network: • Geometry types • Geometries • Segment attributes • Description of re-location, re-routing of lanes (vs. lane-shift)	• geometry_ type • geometry • lane_type	r	MultiPoint LineString

In summary, we found that the WZDx specification was primarily oriented to providing alerts to the *presence* of a work zone. To fully support automated driving, it is important to provide additional detail to support *navigation* of a work zone.[k]

This distinction is perhaps best explained by considering a few example **Use Cases**, such as those shown in Table 13.[l] The content focus and metrics included in WZDx v2 are oriented to a Case A scenario. For example, WZDx v2 includes an optional “restrictions” element, with enumerated values including no-trucks, travel-peak-hours-only, and reduced width, height, length, and weight flags. However, this element is not required and does not include computable vehicle restrictions by vehicle, user, and lane type at lane level, which would be necessary for an AV to decide if it was allowed to traverse the work zone and determine an acceptable path. An AV in this situation would need to default to Case A, returning control to the human driver.

[k] This additional data would support, not replace, in-vehicle localization and path planning via sensors and onboard map.

[l] This is a simplified framework based on the Sample Content Quality for AV functions identified in Task 4.

Table 13. Sample AV Use Cases

	AV Work zone Response	Details	Metrics
Case A	AV returns control to human driver	• Need to be aware of work zone start point in sufficient time to warn driver and hand over control • Need to be aware of work zone end so that vehicle can safely offer to resume control (no premature takeover)	• Accurate to X meters on correct roadway
Case B	AV navigates simple work zone (lane closure)	• Need to be aware of work zone start & end point • Need to be aware of work zone activity status (workers present) • Need to be aware of lane close/open status by vehicle type	• Accurate to Y meters on correct lane/equivalent
Case C	AV navigates complex work zone	Stage Y elements +: • Need to be aware of full set of status and change details, e.g., lane shift/location	• Accurate to Z meters on correct lane/equivalent

Further refinement and extension of the specification will be necessary to support all the Use Cases for an AV user. Existing geospatial elements would benefit from a completed set of enumerated lists and business rules to enable computable data. The addition of new “navigation-support” elements will also be necessary to allow the provision of details about road geometry and road furniture changes.

As it is not feasible to accomplish this in a single new version, it is useful to leverage Use Cases such as those included here to provide context for prioritization of evolution over time.

Initial Recommendations

In order to support the refining exercise noted above, we identified specific adjustments pertaining to each Need, and provided a set of Initial Recommendations as to how the existing data elements and structures might best be adapted to support them, and where additional elements were needed. Where these changes appeared to be relatively straightforward to implement in the context of the existing WZDx specification and consistent with Use Case A, we highlighted them for near-term consideration in the WZDx v3 development effort.

Table 14 shows an example with near-term items highlighted in orange. Elevation is a useful tool for correctly describing specific locations in multi-layered expressway ramp configurations for both human and machine drivers. Appendix D: WZDx v2 / AV Needs Review shows the full set of initial recommendations.

Table 14. Sample Near-Term Recommendation

WZDx element	Initial Recommendations
• geometry_type • geometry • lane_type	• **Include elevation as a required geometry descriptor to support layered geometry types** • Add additional geometry types • Add segment attributes • Add ability to describe precise location/routing of geometry and lane changes

Detailed review of existing/emerging solutions

Some of the recommended changes will require significant evolution of the current WZDx specification. To avoid redundant work, we reviewed other existing and emerging standards to determine the best options to further evolve the specification. This effort included online research of existing standards and outreach to key standards development organizations to understand the status of ongoing efforts. Work continues to evolve in each of these areas, so the information and recommendations below should be regularly reviewed to identify and leverage improved solutions as they may emerge.

Focus Area Selection

As there were many recommendations, we conducted a prioritization exercise to determine the best candidates for further exploration. Based on our comparison of the existing specification and the AV Needs, we concluded that it was most useful to focus on two key areas that could provide the foundation for further evolution:

- Location referencing
- Quality

These areas align with specific needs identified in Task 3, as shown in Table 15.

Table 15. Selected Priority Needs

Where is it?	
RC3 Need a way to consistently describe relative and absolute location of change	Use location description which enables acceptably successful cross-map location referencing: • Ability to support base maps of varying accuracy • Business rules for all location data elements • Standardized enumerated values
RG3 Need a way to consistently describe relative and absolute element location	Use location description which enables acceptably successful cross-map location referencing (see RC3)
How good is it?	
CQ1 Need common definitions of computable quality metrics for CAV-Path data	Provide quality data with computable metrics and/or confidence measures to support multi-input decision-making

In addition, we considered the end-to-end **Data Use Chain,** which will be necessary to enable data to move from vehicles, through centralized processing of various types, and back to vehicles. Different specifications are tailored to support different points in the chain, as shown in Figure 21 below. These reflect the different requirements and limitations that apply at each stage. For example, the raw data sent by a vehicle over the air in real-time to a back-end data processor might be very different than the resulting data after input from the entire vehicle fleet is validated and aggregated. Similarly, the data which can be sent back to the vehicles over the air will need to be selected and formatted to allow efficient transmission and use. It is very important to consider consistency across all three stages wherever feasible to simplify usage.

With this in mind, we added a third area for detailed standards review:

- Vehicle Communications (Messaging)

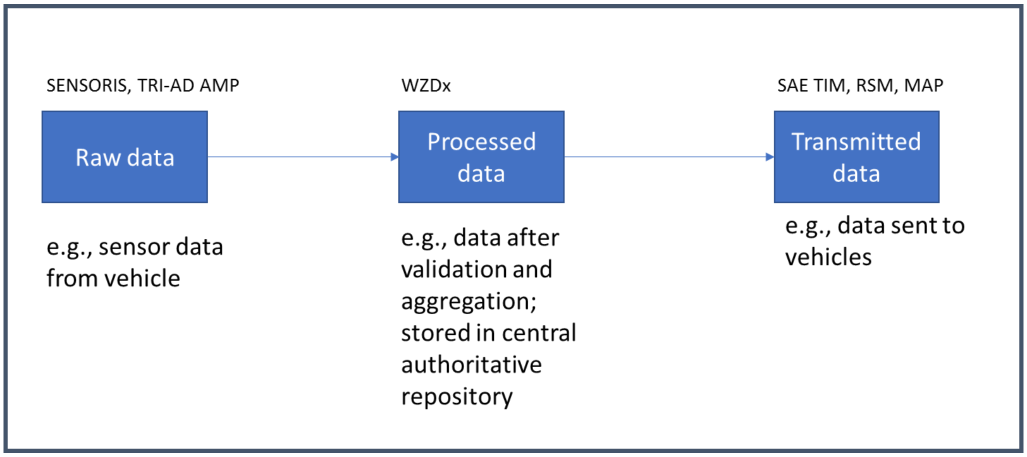

Figure 21. Sample Data Use Chain
(Source: FHWA)

Location Referencing (Where Is It?)

As noted in the earlier tasks of this project, location referencing is a particularly important and challenging area. Work zone data is sourced from a wide variety of public agencies which use a variety of maps. Each AV will also likely have its own internal map, which may well be updated by vehicle sensors in real time. Inevitably, there are quality variations among all these maps. As a result, any work zone location runs the risk of being incorrectly placed ("map-matched) on a given vehicle's map, and the more granular the information provided, the higher the risk of error.

Cross-map inaccuracy has historically been an issue for nationwide data aggregators and has the potential to create significant issues for AVs as they travel across jurisdictional boundaries as well. Especially for advanced use cases, AVs need significantly more accurate and detailed information than human drivers to enable safe execution of the driving task. For example, it is useful to share not only overall work zone location (which might support a simple use case such as hand-off to the human driver), but the new locations of new or reconfigured lanes (which might support a more complex use case, such as automated navigation of the work zone). The placement of major road furniture which may have been temporarily or permanently relocated is another key item, as AVs often use road furniture for localization.

There are several different types of location referencing schemes in use around the world, including:

- Pre-coded (e.g., ISO 19148; includes linear referencing and external codes)

- Dynamic (e.g., OpenLR, ISO 17572)
- Encoded geometry (e.g., ISO 19107)

Most recently, dynamic location referencing schemes have been the focus of increasing interest, as they can offer above 96% success rates at relatively high levels of precision without the need for pre-established location coding tables[52]. Solutions such as OpenLR, in particular, appear to be gaining traction because they combine the advantages of dynamic referencing with the availability of open-source. These standards have been successfully tested in a variety of markets and have been included as components of major activities, such as the European TN-ITS program and the related CEN/TS 17268:2018 standard.

In brief, this type of location referencing involves the combination of a specific set of location elements, each governed by clear business rules. This may include items such as:[m]

- Coordinate pair
- Functional Road Class
- Form of way
- Bearing
- Distance to next LR-point
- Lowest FRC to next LR-point
- Radius
- Number of columns/rows
- Offsets
- Side of road
- Orientation

The complete description of these elements and their use in successfully sharing location is included in the OpenLR specification. It is recommended that any standard or specification which seeks to supply location-based data to AVs carefully consider the inclusion of this type of dynamic referencing data to provide the best possible location resolution outcomes in a cross-map environment.

Quality (How Good Is It?)

AVs are expected to select from and integrate inputs from multiple sensors to make decisions. External work zone data acts as one of those sensor inputs. The vehicle must always have a high enough confidence in the externally supplied data to decide to include that data in its path planning process.

[m] Examples drawn from OpenLR v1.5 r2.

Further, if a vehicle sensor returns results which conflict with external AV data, the vehicle must decide which to trust. For example, the OADF Highly Reliable Maps project has identified several detailed AV use cases for consideration when reviewing quality data:[64]

- Sensor range extension
- Support for insufficient sensor performance
- Location-based information unavailable from sensors
- Localization

As a result, it is critical to ensure computable quality metrics, which will allow AVs to make good decisions about whether or not to rely on this data. There has been ongoing work to develop a standardized set of metrics for real-time transportation data. These address the need for "quality level" information identified by stakeholders in the earlier tasks of this project. The Iowa Automated Vehicle Project developed an initial set of metrics for data maturity, which were subsequently reviewed in a global industry workshop at the TRB Automated Vehicle Symposium.[65] These included:

- Presence (Availability, Geographic Coverage, Event Coverage)
- Timeliness (Start, Update, End, Reporting Period, Latency)
- Accuracy (Location, Reporting, Error Rate)
- Standards Compliance
- Data Quality Certification

These metrics were based on the EIP+ Quality Package for Real-Time and Safety-Related Traveler Information (RTTI and SRTI)[53]. A pan-European public and private sector experts' group developed and validated this Package to support the Commission Delegated Regulations regarding EU-wide real-time traffic and safety-related information services. The full Package includes Quality Criteria, Quality Requirements, and Quality Assessment methods to support national compliance with the associated Directives.

Table 16. Metrics for Quality

Level of Service	Geographical Coverage	Percentage of road network covered by the service
	Availability	Percentage of the time service is available
Level of Quality	Timeliness (start)	The time between the occurrence of an event and the acceptance of an event
	Reporting Period	The time interval for refreshing/updating the status reports
	Timeliness (update)	The time between the end or relevant change of condition and the acceptance of this change
		The average age of the sensor data used in the most recent reporting period

	Latency (content side)	The time between the acceptance of the event and its end or relevant change of condition and the moment the information is provided by the content access point
		The time between the calculation of the reporting data and the moment the information is provided by the content access point
	Location accuracy	The relative accuracy of the referenced location for the published event with respect to the actual location of the actual event
	Classification correctness	100% minus the percentage of published events which are known to be not correct concerning actual occurrence of this type/class
	Error rate	Percentage of published status reports which show excessive deviations of a reported quantity (e.g., speed or travel time) versus the actual value or otherwise determined to be erroneous
	Event coverage	Percentage of the events which are known to be correctly detected and published by type, class, time, and location
	Report coverage	The percentage of reporting locations for which a status report is received in any given reporting period

The AV stakeholders also noted a need for metadata standards. This is also an evolving area, but there are specific standards which include some of these metrics in metadata. ISO 19157 *Geographic information – Data quality* is an FGDC-endorsed standard, which includes[54]:

- Data quality schema (completeness; thematic accuracy; logical consistency; temporal quality; positional accuracy; usability element)
- Data quality element descriptors (measure reference; evaluation method; result)
- Metadata elements (confidence; representation; homogeneity)

Further work with respect to High Definition maps for AVs is also underway in the OADF and should be monitored for outcomes.

It is recommended that any specification seeking to support AVs make the inclusion of quality metrics and metadata a key priority. Both human and machine drivers can benefit from understanding the trustworthiness of the data. In both cases, drivers are more likely to comply with data that they recognize as higher quality.

Vehicle Communications (Messaging)

To be current enough to be useful, work zone data must be sent efficiently over the air in real-time to vehicles. It is important to avoid translation issues between the data, which is collected and aggregated by public and private back offices, and that which is transmitted to vehicles. The US standard designed to carry work zone data elements to connected vehicles is SAE J2945/4: Road Safety Applications, an evolving subset of SAE J2735.

At this time, there is not a perfect match between the data elements used by WZDx and those used by RSM, and a translator is necessary. The V2X Mapping project developed such a translator for the purposes of demonstrating a prototype data collection and use tool. Over time, however, we recommend that strong coordination be established between the two efforts to facilitate the most accurate and complete use of WZDx data by vehicles using the SAE standard. Depending on how the vehicle market evolves, it may become important to coordinate with other standards in this area as well, if they begin to gain significant US market traction. A list of those standards is included in prior tasks of this project.

Related Efforts to Consider

The European TN-ITS Go effort is a key related activity, supporting map information sharing between IOOs and third-party content suppliers. These information flows have been tested and deployed in at least seven different countries to date, with significant expansion funded and underway.

TN-ITS Services & Status

Country	Provider	Service Status	Coverage	Key Map Attributes	Location References	Data License	Update Frequency
Sweden	STA	Operational	All roads	Speed Limits, Restrictions, Roadinfo	OLR, INSP, GML	OpenData	Daily
Norway	NPRA	Operational	All roads	Speed Limits, Warning, Stop, Roadinfo	OLR, INSP, GML	OpenData	Daily
Finland	FTA	Operational	All roads	Speed Limits	OLR, INSP, GML	OpenData Attribution	Batch
Flanders	AWV/MOW	Pilot	Regional/ All roads	Speed Limits, Traf restrictions	OLR, GML	OpenData Attribution	Batch
France	IGN	Pilot	Regional/ All roads	FRC,FOW, LaneInfo,DTRF, AccessInfo	GML	Special License	Batch, daily, weekly
UK	DfT	Pilot	Regional/ All roads/TEN-T	Speed Limits, Restrictions	GML, INSP	Special License	Batch
Ireland	DTTaS Nium	Pilot	Regional/ TEN-T	FRC,FOW, SpeedLim., LanInfo	OLR, GML	OpenData Attribution	TBD

Figure 22. TN-ITS Status
(Source: ITS World Congress, S. T'Siobbel, 2019)

Chapter 6. Work Zone Data Collection Tool

Purpose of Toolset

Work zones are dynamic and change roadway characteristics frequently, affecting mobility and safety of traffic flow. Up-to-date information about dynamic conditions occurring on roads, such as construction events, is needed by both the traveling public and by CAVs to navigate work zones safely and efficiently. Mapping of work zones is particularly challenging because work zones vary widely with the type of construction they support, and because work zones change frequently to support the evolution of roadway construction projects.

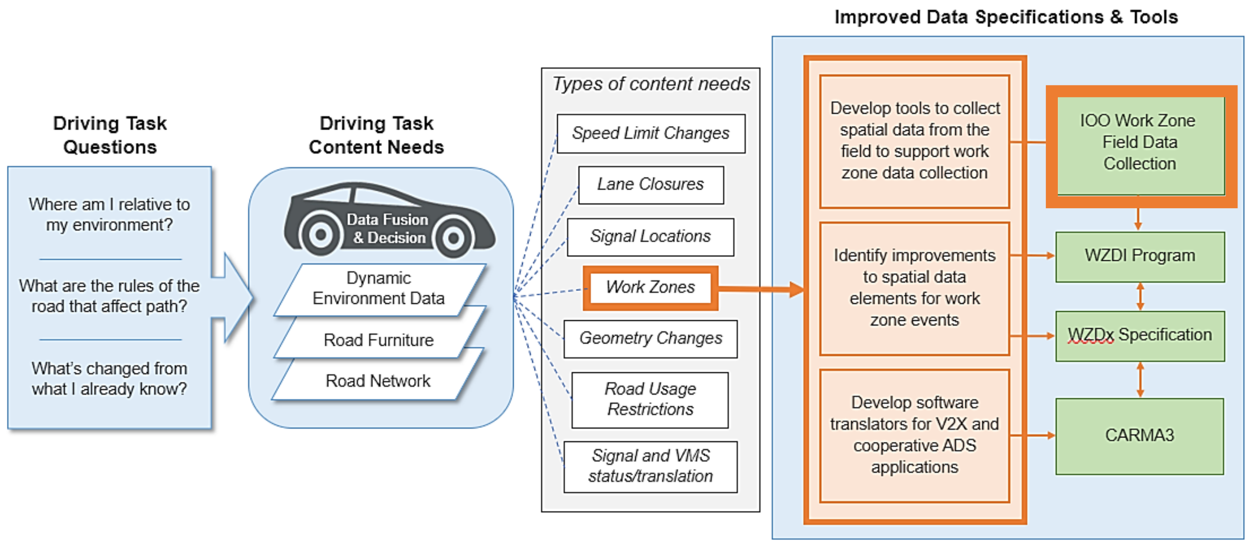

Figure 23. Tool Development for Utilizing Common Work Zone Event Data
(Source: ICF)

Multiple projects are currently in progress to help specify how to digitally describe and communicate these dynamic activities that take place on roads and highways. The FHWA launched the Work Zone Data Initiative to help systematize the collection and use of work zone event data, locally, regionally, and nationally. Furthermore, the FHWA and USDOT's Intelligent Transportation Systems Joint Program Office (ITS JPO) are co-leading the Work Zone Data Specification (WZDx) project to jumpstart the voluntary adoption of a basic work zone data specification through collaboration with data producers and data users.

While data specifications describe the "what" in terms of work zones, many infrastructure owners and operators (IOOs) have asked for more guidance and tools for "how" to collect work zone event data in these formats.

A rapid, cost-effective method of capturing high-accuracy work zone data from the roadside and digitally describe work zone configurations and travel path for various applications is the motivation behind the development of the toolset. The purpose of this Proof of Concept Work Zone (POC WZ) Toolset is to allow IOOs and construction managers to easily map work zones and generate standardized messages. These messages can then be distributed to relevant parties to enable connected and autonomous vehicles to more safely navigate work zones. The generated messages include the Work Zone Data Exchange message **(WZDx version 3.0)** as well as two versions of the Roadside Safety Message (RSM [in both XML and binary formats]).

This Toolset consists of a *website, cloud storage and a laptop/mobile application* running in a vehicle. The website allows IOOs to enter work zone information, edit and verify mapped work zones and publish verified messages for distribution to authorized parties. The cloud storage contains WZ configuration files as well as generated work zone map messages. The *laptop/mobile application* utilizes a GPS connection to collect path data of the moving vehicle and allows the user to mark feature locations (beginning and ending of lane closures as well as the presence of workers) as the user drives through the work zone. This path data is then combined with the WZ configuration file to allow standardized messages to be generated.

Toolset Capabilities

Core capabilities

The use case illustrated in Figure 24 describes the core capabilities of the toolset. The following text provides a step-by-step description of the process. Step numbers in the text correspond to numbers in the figure boxes.

[1] Following a substantial change in work zone configuration, IOO construction staff prepare to update the work zone map.

[2] IOO enter work zone information into online configuration creator.

[3] IOO staff use a laptop or other mobile computing device with a high-accuracy Global Positioning System (GPS) in a construction vehicle.

[4] Construction Manager initializes the device and work zone map toolset, loading the configuration file from the local machine or the cloud while they are connected to the back office.

[5] Staff position their vehicle in the through-lane prior to the work zone and begin traveling.

[6] When they enter the work zone, data collection automatically begins.

[6] Staff activate toggles in the toolset when the vehicle is adjacent to key work zone features to record their location. Examples of these features include beginning and end of lane closures and at the beginning and end of workers present.

[6] When they leave the work zone, data collection automatically ends, and the message builder runs.

[7] After capturing the work zone path and feature location data, staff exit the roadway and upload the collected path data and the work zone map messages are automatically generated in the cloud.

[8] Designated IOO staff inspect, edit and verify the generated work zone map.

[9] If approved, the message is posted in a designated location for access by authorized parties, such as third-party traveler information systems, connected vehicle communication systems, and cooperative driving automated vehicle systems.

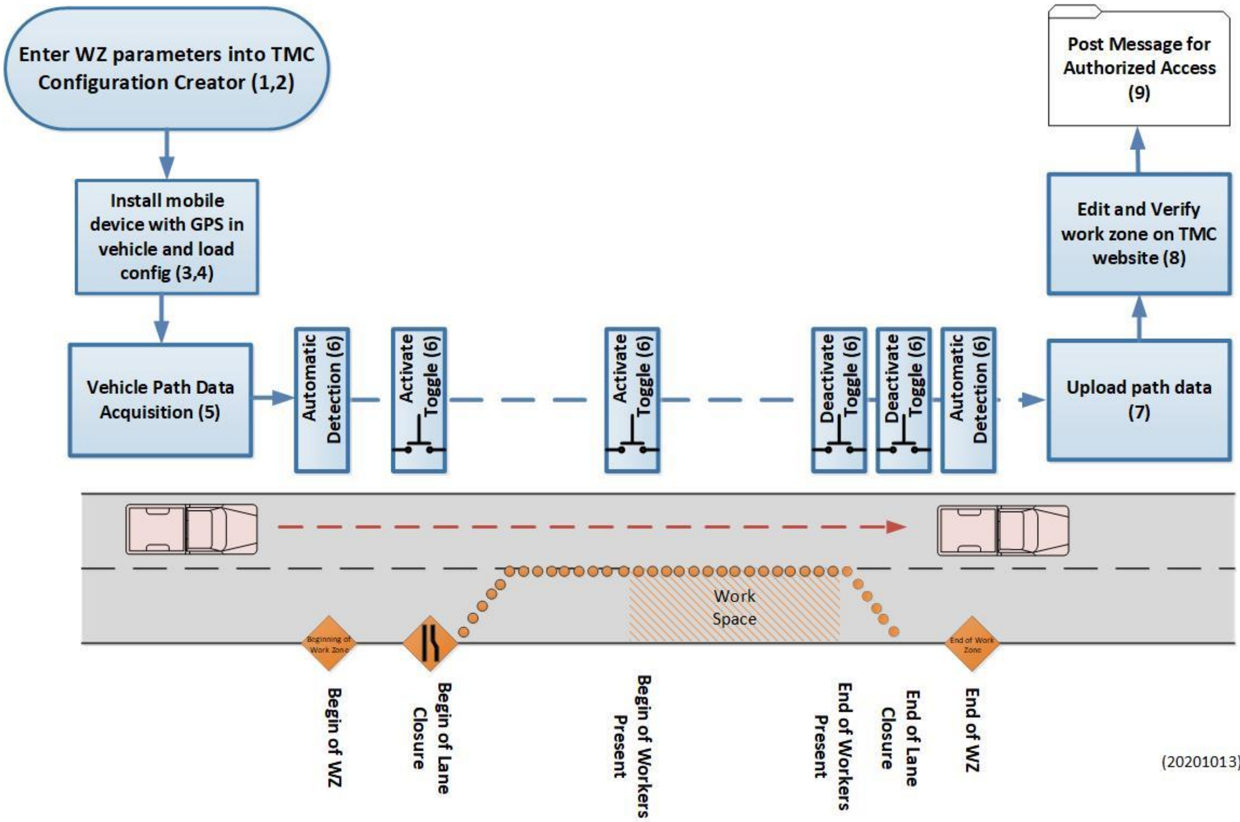

Figure 24. Illustration of WZ Mapping Toolset POC Use Case for Capturing WZ Path and Configuration Data
(Source: ICF)

System Overview

The physical view in Figure 25 represents the architecture diagram of the systems and interfaces (i.e., the interactions that occurs within and between the different entities), numbered for reference and furthered explained in Table 17.

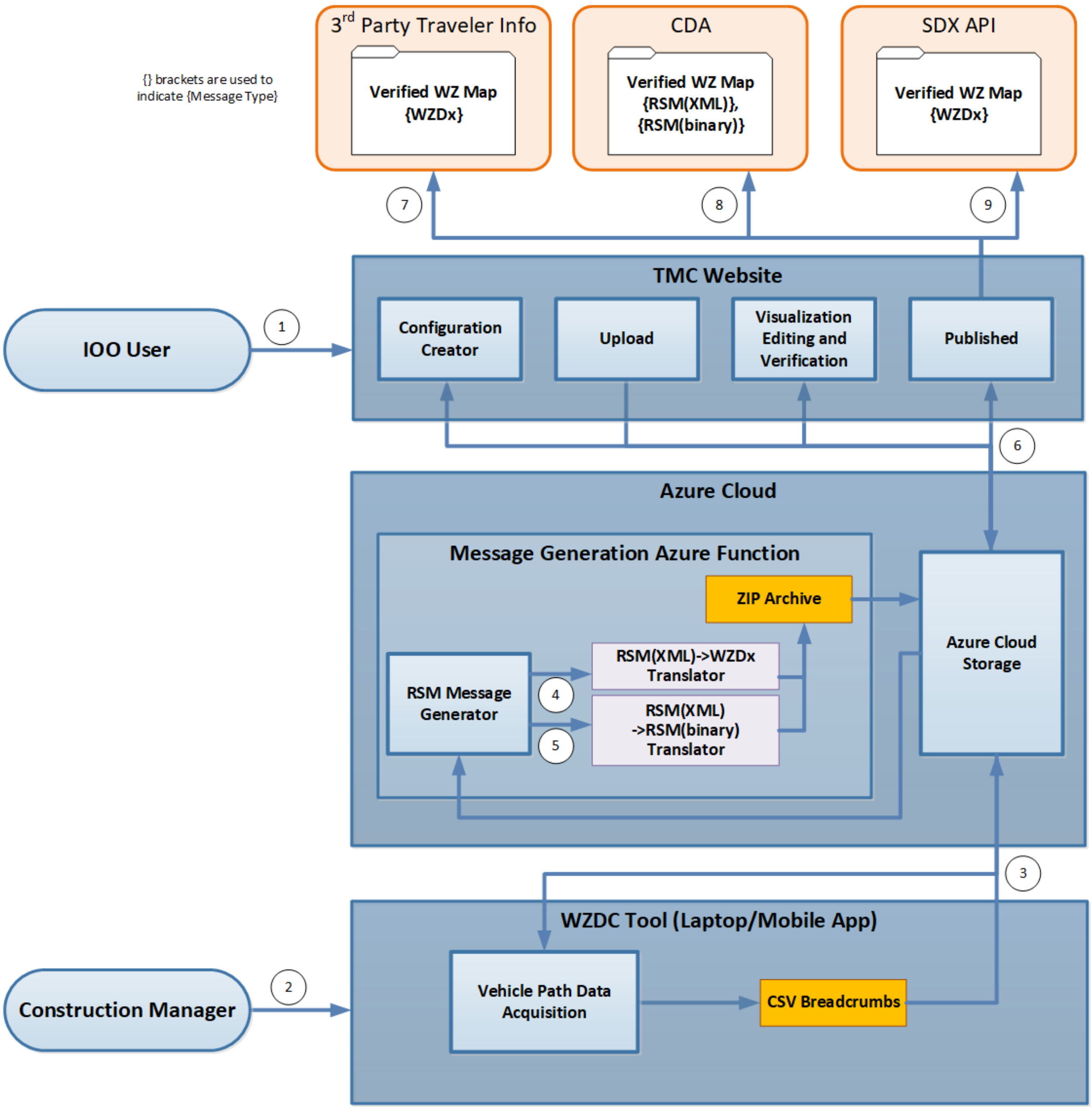

Figure 25. Physical View of System Architecture
(Source: ICF)

The following bullets describe the column headings used in Table 17:

- Interface Number: The interface number from Physical View (Figure 25)
- Source Element: The device which provides data for the flow
- Destination Element: The device which consumes the data for the flow
- Communication Profile: Communication protocol(s) used
- Application Information Standard: Key standard(s) governing this information exchange

Table 17. List of Interfaces

Interface #	Source Element	Destination Element	Communication Profile	Application Information Standard
1	IOO User	TMC Website	Human Web Interface WWW Browser	NA
2	Construction Manager	WZDC Tool	Human user Interface	NA
3	WZDC Tool	Azure Cloud Storage	CSV, JSON	Custom CSV, Custom JSON
4	WZDC Tool (Data Acquisition)	WZDC Tool (RSM XML to WZDx Translator)	XML, GeoJSON	XML RSM (J2735, J2945/4), WZDx GeoJSON
5	WZDC Tool (Data Acquisition)	WZDC Tool (RSM XML to WZDx Translator)	ASN.1, UPER, XML	J2735, J2945/4
6	Azure Cloud Storage	TMC Website	JSON, ZIP, CSV, UPER, XML, GeoJSON	Custom JSON, Custom ZIP archive, XML RSM (J2735, J2945/4), WZDx GeoJSON
7	TMC Website	3rd Party Traveler Info	GeoJSON	WZDx GeoJSON
8	TMC Website	CDA	UPER, XML	XML RSM (J2735, J2945/4)
9	TMC Website	Trihydro SDX	GeoJSON	WZDx GeoJSON

Testing

The POC WZ Toolset testing was conducted at the Archer complex in Cheyenne, WY. The testing was conducted on June 24th, 2020 on an artificial work zone, where a series of drive tests were recorded for presentation to FHWA and interested parties. This testing verified the functionality and performance of the POC toolset, verifying the accuracy and content of the generated work zone map messages.

Demonstration

A demonstration of the POC WZ Toolset was conducted on a live work zone in Cheyenne, WY, near the intersection of I-25 and I-80. The demonstration was conducted in partnership with Wyoming DOT on July 9th, 2020, in which all components of the toolset were demonstrated and explained, and the live work zone was mapped using the toolset.

Toolset Availability and Use

The current version of toolset and supporting documentation are available for use by IOOs and other stakeholders through the ITS Code Hub. (its.dot.gov/code). Supporting documentation available through the code hub include a user guide and videos of the tool as well as systems engineering documentation (interface control document, system engineering reports, and test case report).

Glossary

Table 18 provides a glossary of acronyms used in this document.

Table 18. Acronym List

Acronym/Abbreviation	Definition
ADAS	Advanced driver-assistance systems
ADS	Automated Driving System
AEB	Automatic Emergency Braking
AERIS	Applications for the Environment: Real-time Information Synthesis
ARNOLD	All Road Network of Linear Referenced Data
BIM	Basic Information Message
C/AVs or CAV	Connected and Automated Vehicles
CAMP	Crash Avoidance Metrics Partners
CAN Bus	Controller Area Network
cm	Centimeter
COST	Cooperation in Science and Technology
DGPS	Differential Global Positioning System
DSRC	Dedicated Short Range Communications
EAR	Exploratory Advanced Research
Eco-AT	European Corridor – Austrian Testbed for Cooperative Systems
EEBL	Emergency Electronic Brake Lights
EU METR	European Union Management of Electronic Traffic Regulations
ExVe	Extended vehicle
FSP	Freight Signal Priority
GDF	Geographic Data Files
GIS	Geographic Information System
GPS	Global Positioning System
GTFS	General Transit Feed Specification
HD	High Definition
HOV	High Occupancy Vehicle
HPMS	Highway Performance Monitoring System
I-SIG	Intelligent Traffic Signal Control
IMA	Intersection Movement Assist
IMU	Inertial Measurement Units
INFLO	Intelligent Network Flow Optimization
IOO	Infrastructure Owner-Operators
ITS	Intelligent Transportation Systems
LDM	Local Dynamic Map
m	Meter
MDSS	Maintenance Decision Support Systems
MMITS	Multi Modal Intelligent Traffic Signal System
MUTCD	Manual on Uniform Traffic Control Devices
NDS	Navigation Data Standard

Acronym/Abbreviation	Definition
OADF	Open AutoDrive Forum
OEM	Original Equipment Manufacturer
OGC	Open Geospatial Consortium
OpenLS	OpenGIS® Location Services
OTA	Over-the-Air
PCW	Pedestrian Crossing Warning
PED SIG	Pedestrian Signal System
PREEMPT	Emergency Vehicle Preemption
REL	Reversible Express Lanes
RESCUME	Response, Emergency Staging, Communications, Uniform Management, and Evacuation
RSE	Roadside Equipment
RWIS	Road Weather Information System
SaPPART	Satellite Positioning Performance Assessment for Road Transport
SCMS	Security Credential Management System
SDO	Standards Development Organizations
SIP-Adus	Strategic Innovation Promotion Program – Automated Driving Systems for Universal Service
SLAM	Simultaneous Localization and Mapping
SPaT	Signal Phase and Timing
T1	Tier One
TIM	Traveler Information Message
TISA	Traveler Information Services Association
TN ITS	Transport Network Intelligent Transportation Systems
TPEG	Transport Protocol Experts Group
TSP	Transit Signal Priority
TTI	Traffic and Travel Information
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything
VMS	Variable Message Sign
VTRW	Vehicle Turning Right Warning
WZDI	Work Zone Data Initiative
WZDx	Work Zone Data Exchange

References

Table 19 lists the documents, sources, and tools used and referenced to develop the concepts in this document.

Table 19. References

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Appendix A: Global Tests and Trials

This section provides high-level overview of the key global tests and trials currently underway or previously undertaken pertaining to CV deployment that have significant mapping and/or positioning components. The personnel and industry sectors involved in these activities are likely to be valuable sources of input to stakeholder discussions.

A.1 U.S. Field Trials

Mapping and positioning have been key elements in a number of the U.S. projects to date, as shown in Table 20. Each of these initiatives features connected vehicle testing involving varying degrees of positioning accuracy, often at the lane, level, or sub-lane-level.

Table 20. List of U.S. Field Trials

Location	Description
New York City CVP	Focuses on deploying a large fleet of CVs in a dense urban context with the aim of improving safety for pedestrians as well as motorists (FHWA JPO, 2015c). The NYC CVP deployment area encompasses three areas in the boroughs of Manhattan and Brooklyn, and is collectively expected to be the largest CV pilot deployment to date. Approximately 5,850 cabs, 1,200 transit buses, 500 commercial fleet delivery trucks, and 500 other city-owned vehicles that frequent the three project areas will be outfitted with DSRC equipment supporting CV applications (Galgano, et al., 2016). The deployment also includes 310 signalized intersections and RSUs along FDR Drive, a higher-speed corridor. To facilitate pedestrian crossing warning applications, pedestrians will also be equipped with personal devices.
Tampa-Hillsborough Expressway Authority CVP	Focuses on reducing urban congestion for commuters and improving safety by harnessing CV applications to improve the usage of the region's reversible express lanes (REL). The THEA CV Pilot will employ DSRC to enable transmissions among approximately 1,500 cars, 10 buses, 9 trolleys, 500 pedestrians with smartphone applications, and approximately 40 RSUs (Novosad, et al., 2016). Applications in the pilot include: slowed/stopped vehicle warnings, wrong way warnings, pedestrian crossing alerts at set crosswalks, transit signal priority for buses, and connections between transit vehicles and passenger cars (Novosad, et al., 2016).
Safety Pilot Model Deployment	Administered by NHTSA and the FHWA ITS JPO; was a one-year real-world deployment of DSRC applications on over 2,800 vehicles in 2012. This pilot sought to collect data supporting functional evaluation of V2V safety applications and to gain understanding of how to implement a V2V and V2I security system (Bezzina & Sayer, 2015). Overall, the deployment was considered successful in its core mission of testing the effectiveness of CV safety applications and led to the NHTSA proposed rulemaking on including V2V capability in all new light duty vehicles (Gay & Kniss, 2015).
Intelligent Network Flow Optimization (INFLO)	Prototype demonstrations focused on testing the functionality of end-to-end CV system applications involving DSRC connections between vehicles, RSUs, databases, and traffic management centers (Stephens, et al., 2015). In particular, the ability for systems to process CV data in a timely and reliable manner was tested. Example INFLO applications include the Speed Harmonization and Queue Warning applications.

Location	Description
RESCUME	Included a bundle of CV application tests focused on warning drivers that they were entering incident or work zones, which required lane-level accuracy. This accuracy was achieved using DGPS (FHWA-JPO, 2015b).
Transit Safety Retrofit Project	Outfitted three University of Michigan transit vehicles in 2013 with CV hardware capable of applications such as curve speed warning, collision warnings, pedestrian in crosswalk warning (PCW), and others. The project investigated the feasibility of CV systems in the context of public transit buses.
MMITSS	Focused on developing and testing five applications: Intelligent Traffic Signal Control (I-SIG), Transit Signal Priority (TSP), Mobile Accessible Pedestrian Signal System (PED SIG), Freight Signal Priority (FSP), and Emergency Vehicle Preemption (PREEMPT). Testing was carried out in Arizona and California.
AERIS (Applications for the Environment: Real-time Information Synthesis)	Developed green/environmentally-oriented technologies and applications with a focus on fuel efficiency and emissions reduction (AERIS Research Program , 2016). Included five operational scenarios and eighteen CV applications, including Eco-Signal Operations, Eco-Lanes, Low Emissions Zones, Eco-Traveler Information, and Eco-Integrated Corridor Management (Eco-ICM). All of these scenarios and applications depend on positioning and mapping to collect good quality information from the connected vehicles.
V2I Hub	A platform designed to enable DSRC-based CV applications (Battelle Memorial Institute, 2016). Program has included a collection of research efforts, including the *Mapping Technology Assessment for Connected Vehicle Highway Network Applications* project, which assessed the best current and anticipated geospatial technologies and mapping approaches to support intelligent transportation systems (FHWA, 2011).
Michigan	The State has designated CAV testing environments in Ann Arbor and Southeast Michigan that include portions of public roads, to allow for the testing of CAV applications in real-world contexts. Tested V2I applications in the State include signal phase timing (Michigan Department of Transportation, 2016). Michigan is also developing a Road Weather Information System (RWIS) to disseminate information on weather and road conditions, and a GPS and Maintenance Decision Support Systems (MDSS), which installed GPS and weather sensors on all 300 MDOT snowplow trucks and some maintenance vehicles, allowing fleet tracking and weather data reporting (Michigan Department of Transportation, 2016). The State is also working on LiDAR-based map data collection on dedicated vehicles and has developed a CAV/ITS Strategic Plan.[n]
Texas	Efforts include the Wrong Way Driving Detection and Management System, which is currently underway to design a proof of concept for a wrong way warning system.

It is useful to note that freight and logistics has been a key focus of many programs, including:

- Wyoming CVP. Covers approximately 400 miles along route I-80, a major freight corridor connecting the eastern and western centers of the country. System applications include weather alerts, accident alerts, parking notifications, and dynamic travel guidance using both DSRC and

[n] Plan is available at: http://www.michigan.gov/its

satellite communications (Gopalakrishna, et al., 2016). The vehicles are also capable of collecting and disseminating environmental data from onboard sensors.

- Michigan's work on the dissemination of truck parking availability information and border delay information (Michigan Department of Transportation, 2016).

- Texas efforts on commercial truck platooning, freight systems management tools, and safety warnings (Ma, 2016). Texas work also includes the development of an Overheight Warning System on key overpasses that pose safety concerns to large vehicles (Kozman & Stevens, 2015) and expansions to the Freight Advanced Traveler Information Systems to include work zone notifications, first with a cellular communication method, and later using DSRC (Poe, 2015).

Private sector fleets have also done a lot of research and deployment around mapping, positioning, and navigation to improve system efficiency. The UPS On-Road Integrated Optimization and Navigation program is one example of this.[o] These systems tend to be propriety and vertically integrated to support a single company or a vendor's customers.

A.2 EU Field Trials

There are a variety of field trials underway in Europe. A sampling of those which are looking at mapping and positioning in various ways includes:

- ECo-AT (European Corridor – Austrian Testbed for Cooperative Systems) is working to develop harmonized and standardized cooperative ITS applications in partnership with Germany and the Netherlands. This effort includes testing of MAP-SPAT messages, including the identification of lessons learned and proposed improvements.[p]

- Partnership Talking Traffic. This program is a collaboration between the Dutch Ministry of Infrastructure and the Environment, regional and local authorities, and national and international private companies. The focus is to accelerate development and deployment of traffic light data; to process and distribute a variety of data, including conversion into real-time and customized data sets; and to share this information with a wide variety of road users though smart devices and in-vehicle systems. This program has also tested existing MAP and SPaT standard messages and provided recommendations for improvements.[q]

- HIGHTS. This project aims to deliver positioning systems capable of 25 cm accuracy. It combines traditional satellite systems with on-board sensing and infrastructure-based wireless communication technologies (e.g., Wi-Fi, ITS-G5, UWB tracking, Zigbee, Bluetooth, and LTE).[r]

[o] https://sustainability.ups.com/media/UPS-ORION-Infographic.pdf
[p] Kasslatter, Fritz, ECo-AT (European ITS Corridor Austria) MAP and SPaT Message Generation Lessons Learned; June 13, 2017. See also http://www.eco-at.info/home-en.html.
[q] https://www.partnershiptalkingtraffic.com/
[r] http://hights.eu/

- Bavarian Digital Test Bed on A9. Audi is working to map two sections of the A9 to centimeter level accuracy, as well as roadway features such as bridges, signs, and road markings. This information is then fed into the HERE HD Live Map, and updated as needed.[s]

- Drive Me (Norway). Volvo Cars is working with TomTom's HD map as part of the Drive Me program, in which real drivers use autonomous driving in their daily lives on public roads.[t]

A.3 Japan Field Trials

Japanese activities in this area have coalesced around a major national R&D program: Cross-Ministerial Strategic Innovation Promotion Program – Automated Driving Systems for Universal Service (SIP-Adus). The focus of this five-year program is to a) achieve national transportation goals, including traffic accident reduction; b) deploy automated driving systems; and c) deploy next-generation public transport systems. This program was launched in 2014, and has led to the formation of the Dynamic Map Planning Company, a public-private partnership that is dedicated to generating dynamic maps as an advanced traffic information database for all vehicles. SIP-Adus has also been very active in promoting global conversation around these issues, hosting a series of major workshops.

The next phase of the SIP-Adus program is field operational testing, which is expected to launch in late 2017 and continue until 2019. Dynamic mapping is a key part of that effort, and will include work to validate 3D high resolution map data, data collection and distribution methods, and verify the utility of "semi-dynamic" information as shown in Figure 26.

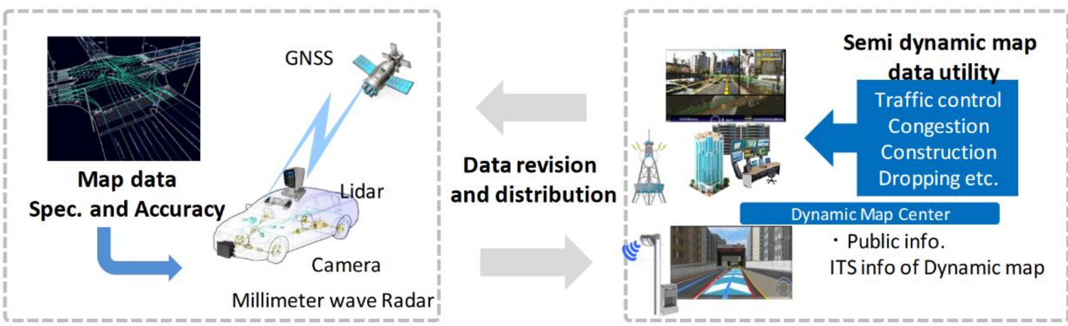

Figure 26. Graph. SIP-Adus FOT: Mapping Effort
(Source: Sugimoto, 2017)

[s]https://www.audi-mediacenter.com/en/press-releases/new-technologies-for-piloted-driving-audi-participating-in-digital-motorway-test-bed-6957
[t]http://www.automotive-fleet.com/channel/global-fleet/news/story/2017/03/volvo-and-tomtom-partner-on-autonomous-driving-program.aspx

Appendix B. Standards Activity Review

This review is intended to provide an overview of the existing and emerging standards as a basis for selection and (if necessary) profiling to establish an overall set of U.S. standards for use in this area. It includes:

- Relevant Organizations and Standards, including organizational descriptions for each standards body
- Standards by Needs Category, including more detailed descriptions of each relevant standard

B.1 Relevant Organizations and Standards

ADASIS

ADASIS is an industry consortium that has developed a standardized map data interface between stored map data and ADAS applications. ADASIS currently has 46 members, largely from the OEM, supplier, and map provider communities; and has also become part of the ERTICO Open AutoDrive Forum (OADF) in order to better collaborate with other consortia in this area.

This group has published a specification (ADASIS 2.0), which has been tested in European trials, and is now at work on an update, which is focused on support for automated driving. ADASIS 3.0 is currently scheduled to be available in Q4 2017, with additional updates planned.

CEN TC278

CEN is the European Committee for Standardization, and includes the participation of over 60,000 technical experts. CEN's TC278 is responsible for intelligent transport systems standards and has 33 national members who have produced approximately 152 standards to date. CEN's recent work has been directly responsive to European legislation which requests the development of standards solutions for specific EU-level challenges, in particular the Mandate M/546 on Urban ITS. Relevant CEN activities include:

- WG 7 (ITS Spatial Data), which has produced Intelligent Transport Systems – Transport network ITS spatial data exchange framework (TN-ITS)
- WG17 (Urban ITS), which has produced:
    - Intelligent Transport Systems - Location Referencing Harmonization for Urban-ITS - Part 1: State of the art and guidelines
    - Intelligent Transport Systems - Location Referencing Harmonization for Urban-ITS - Part 2: Translation methods
    - Intelligent Transport Systems - Electronic management of regulations and policies— Part 1: Basic concepts and architectures (METR) (in work)

ETSI TC ITS

ETSI TC ITS is a European standards development organization responsible for cooperative ITS standards. This group has developed many of the core “connected vehicle” messaging and testing standards which correspond to the DSRC messaging work being done in the U.S. Dialog between experts from both regions has resulted in partially but not fully harmonized concepts. Relevant ETSI standards include:

- ETSI EN 302 895 V1.1.1 (2014-09) Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Local Dynamic Map (LDM)
- ETSI EN 302 637-2 V1.3.1 Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 2: Specification of Cooperative Awareness Basic Service
- ETSI EN 302 637-3 V1.2.1 (Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 3: Specifications of Decentralized Environmental Notification Basic Service

ISO

ISO is an independent, non-governmental international standards development organization with a membership of 162 national standards bodies. It includes three Technical Committees that are relevant to this work: TC204, TC22, and TC211.

TC204

Technical Committee 204 is responsible for standardizing information, communication, and control systems for surface transportation. Its Working Group 3 (ITS database technology) handles mapping and positioning data elements, and related information. WG3 has the following published and in work items:

- *17572 Series: Intelligent Transport Systems (ITS) -- Location referencing for geographic databases* has four parts, Part 1: General requirements and conceptual model, Part 2: Pre-coded location references (pre-coded profile), and Part 3: Dynamic location references (dynamic profile) were all published on January 2016. Part 2 is currently under revision. Part 4: Lane-level location referencing is expected to be published by 2020.
- *20524 Series: Intelligent Transport Systems -- Geographic Data Files (GDF) GDF5.1* specifies the conceptual and logical data model and physical encoding formats for geographic databases for ITS. It has two parts, Part 1: Application independent map data shared between multiple sources, and Part 2: Map data used in automated driving systems, Cooperative ITS, and multi-modal transport. Both parts are under development, and are expected to be published by 2020 and 2019, respectively.
- ISO 14296:2016 (Ed. 1) Intelligent Transport Systems -- Extension of map database specifications for applications of cooperative ITS, provides the map-related functional requirements, data model (logical data model/logical data organization), and data elements for those applications for cooperative ITS that require information derived from map databases. The standard was published in April 2016.
- TR 21718 – Intelligent Transport Aystems — Spatio-temporal data dictionary for cooperative ITS and automated driving systems. Efforts are underway to generate a revised and expanded version of this document.

- 22726 Intelligent Transport Systems -- Dynamic events and map database specifications for applications of automated driving systems, cooperative ITS, and advanced road/traffic management systems, was accepted as a preliminary work item in October 2017. This document will then be expected to be further developed into a full standard within a set schedule.

TC 204's Working Group 18 has also done work in this area, including:[u]

- *TR 17424:2015: Intelligent Transport Systems -- Cooperative systems -- State of the art of Local Dynamic Maps concepts* surveys the current status of the Local Dynamic Mao (LDM), including architecture, implementation, and standardization. This technical report also reviews application needs and provides a standards gap analysis.

- *TS 18750:2015: Intelligent Transport Systems -- Cooperative systems -- Definition of a global concept for Local Dynamic Maps* specifies the functionality of a "Local Dynamic Map" (LDM) and provides an approach to creating a global LDM Data Dictionary which allows storing of information from new C-ITS message sets and legacy message sets. This document is being further developed as *ISO/DIS 18750: Intelligent Transport Systems -- Co-operative ITS -- Local dynamic map.*

- ISO/TS 19091:2017 Intelligent Transport Systems -- Cooperative ITS -- Using V2I and I2V communications for applications related to signalized intersections also includes map-related concepts, and is closely aligned with SAE's J2735. Discussions are now ongoing as to how to evolve this work in conjunction with CODECS IVI and ETSI DENM.

It should also be noted that other WGs have produced standards containing related content, e.g., WG 10 (Traveler Information). Efforts are now underway to begin assessing and further harmonizing the content of these standards.

TC22

ISO/TC 22 is responsible standards for evaluating the performance of road vehicles and their equipment. ISO/TC 22/SC 32 is responsible for electrical and electronic components and general system aspects.

- *26262 series: Road vehicles -- Functional safety* includes Part 1: Vocabulary, Part 2: Management of functional safety, Part 3: Concept phase, Part 4: Product development at the system level, Part 5: Product development at the hardware level, Part 6: Product development at the software level, Part 7: Production, operation, service, and decommissioning, Part 8: Supporting processes, Part 9: Automotive safety integrity level (ASIL)-oriented and safety-oriented analyses, Part 10: Guidelines on ISO 26262, Part 11: Guidelines on application of ISO 26262 to semiconductors, and Part 12: Adaptation for motorcycles. The series was initially published in 2011. It is under revision currently and all parts of the series are expected to be published by early 2018.

- *20078 series: Road vehicles -- Extended vehicle (ExVe)* includes Part I: 'web services' -- Part 1: ExVe content, Part 2: ExVe access, Part 3: ExVe security, and Part 4: ExVe control. The

[u] TC204/ WG18/SWG2 report Cooperative ITS— Gap/Overlap analysis from a road operator's point of view (Including contribution for outreach activity)

Extended Vehicle (ExVe) is intended to link in-vehicle telematics systems with offboard back-end systems. Publication of this series is planned for late 2018.

TC211

ISO/TC 211 (Geographic information/Geomatics) is responsible for digital geographic information standards. It has a formal liaison with ISO/TC 204. The TC's work includes:

- *TS 19158:2012 Geographic information -- Quality assurance of data supply* provides a framework for quality assurance specific to geographic information. It is based upon the quality principles (ISO 19113) and quality evaluation procedures (ISO 19114) of geographic information and will adopt general quality management principles (ISO9000:2005).

- *19157:2013 Geographic information -- Data quality* establishes the principles for describing the quality of geographic data. It defines components for describing data quality, specifies components and content structure of a register for data quality measures, describes general procedures for evaluating the quality of geographic data, and establishes principles for reporting data quality.

NDS

The Navigation Data Standard Association (NDS) is an industry consortium that includes 34 member companies, primarily from original equipment manufacturers (OEM), supplier and map provider communities. NDS was originally focused on standardizing map data for navigation applications, but is now looking at support for autonomous driving, including shared data and interfaces—see Table 21 for NDS's roadmap.[66] Its work is intended to enable interoperable handling of map data (Map As A Service). NDS standards are have been used in commercially available products since 2012. The NDS Open Lane model was made publicly available in 2016, but access to the complete set of standards for commercial use requires license agreements. NDS is now working to collaborate with other activities through the OADF.

Table 21. NDS Roadmap

Objectives	Short-term (until 2019)	Mid-term (until 2022)	Long-term (after 2022)
In line with the market	• AutoDrive: support for essential AutoDrive Use Cases • TBD > E-Mobility: support for essential E-Mobility Use Cases • Product readiness "NDS" solutions: built up representative development and validations platform	• Learning map: support for Car as Sensor • TBD > support for Car2Car Use Cases • TBD > support for Cas2X Use Cases	• Ongoing support of new innovative topics
Global Adaptation	• Global maturity: Focus: U.S. and Asia • Global visibility: Focus: U.S. • Extension for tool chain and software libraries (APIs)	• More parts of "NDS" as open source • More parts of "NDS" as software libraries	• Permanent requirement engineering with global stakeholders
Competitive User Experience	• Size and performance: optimize scalability especially for Entry Level Systems • Freshness of data: standardize update chain	• TBD > extended personalization • TBD >extended augmented reality	• TBD > user specific map enrichment

"NDS" Map as a Service	• Hybrid Reference Architecture • Service APIs for map content in the cloud • Reference implementation of "NDS" map services (for validation only)	• TBD > full streaming "NDS"	• Ongoing support of new topics for location based (map based) data on demand

OADF

OADF is an ERTICO-managed collaboration which includes ADASIS, NDS, SENSORIS, and TISA. OADF is working to integrate, harmonize, and promote the efforts of its component groups, which includes some cross-cutting task force efforts such as data quality and data registries.

Open Geospatial Consortium (OGC)

The OGC is an international standards organization which generates international standards for geospatial interoperability. It includes 525 member organizations and has published 48 open standards to date. OGC standards are intended to be used by software developers to build open interfaces (Percivall, 2017). OGC work relevant to this area includes:

- *OpenGIS® Location Services (OpenLS) Standards* (Open Geospatial Consortium Inc., 2008). Defines access to the GeoMobility Server, an open location services platform. This standard builds on ISO *17267:2007: Intelligent Transport Systems -- Navigation systems -- Application programming interface (API)*. Includes *Parts 1-5 Core Services* and *Part 6 Navigation Service*, which normatively references *ISO 14825 Geographic Data File (GDF)*.

OGC has recently established a Mobile Location Group to address cell phone location and map data standards. OGC also has a Moving Features standards activity which is working on standards related to probe data and data tracking.

SAE International

SAE International (SAE) develops standards for the automotive and aerospace industry via the collaboration of 128,000 engineers and technical experts. SAE's Dedicated Short Range Communications (DSRC) Technical Committee is responsible for developing and maintaining message set Standards, Recommended Practices, and Information Reports for use with short-to-medium-range wireless communication protocols specifically designed for road vehicle use. Standards developed by this TC include:

- *J2266™: Location Referencing Message Specification (LRMS)*: Standardizes location referencing for ITS applications that require the communication of spatial data references between databases. The LRMS is applicable to both homogeneous (same database) and mixed database environments that may be implemented on wireless or landline networks. Published in October 2004.

- *J2735™: Dedicated Short Range Communications (DSRC) Message Set Dictionary:* Defines a message set and its data frames and data elements for use by applications intended to utilize the 5.9 GHz Dedicated Short Range Communications for Wireless Access in Vehicular Environments and any other applicable wireless communications technologies. The most recent version of J2735 was published in March 2016.

- *J2945/10 WIP: Recommended Practices for MAP/SPaT Message Development.* This is work in progress to develop a best practices document outlining how to use the current MAP and SPaT message content found in J2735. There is also work underway to refine and extend current message content to better serve the needs of implementers.

- *J2945/4: DSRC Messages for Traveler Information and Basic Information Delivery.* This is a work in progress to define a new TIM/BIM message, with linkage to the MAP discussions.

- 6857: Requirements for a Terrestrial Based Position, Navigation, and Timing (PNT) System to Improve Navigation Solutions and Ensure Critical Infrastructure Security. This effort is intended as a complement to GNSS.

TISA

The Traveler Information Services Association (TISA) is an industry consortium focused on standards for traffic and travel information services and products.[v] This group is comprised of road operators, automotive OEMs, suppliers, and map providers. TISA works closely with ISO TC204 WG10, and has published some of its work as ISO standards. TISA is also part of OADF. A sampling of relevant work includes:

- TPEG 2.0. This standard is being published through ISO TC 204 WG10 as TS 21219 and includes 26 published and in work subparts. Of particular note are:
    - ISO/TS 21219-7:2017 Intelligent Transport Systems -- Traffic and travel information (TTI) via transport protocol experts group, generation 2 (TPEG2) -- Part 7: Location referencing container (TPEG2-LRC);
    - ISO/TS 21219-21 Intelligent Transport Systems -- Traffic and travel information via transport protocol experts group, generation 2 (TPEG2) -- Part 21: Geographic location referencing (TPEG-GLR) (in work);
    - ISO/TS 21219-22:2017 Intelligent Transport Systems -- Traffic and travel information (TTI) via transport protocol experts group, generation 2 (TPEG2) -- Part 22: OpenLR location referencing (TPEG2-OLR)

- TPEG 3.0 (in work). This standard is intended to include support for automated driving.

B.2 Standards Activity Descriptions

Survey Details

This section organizes the most relevant work based on the needs described in Section 0. Where possible, it also provides updates to the status of that work and adds additional relevant activities. Where

[v] http://ertico.com/projects/tisa/; https://www.iso.org/committee/54706/x/catalogue/

known active implementations exist, standards are reported as “in use.” Where information was not available on this point, standards are simply reported as “published.” The standards survey is organized by the different types listed below. For each one, we specify pertaining details, the actual standards, and their status.

- Terminology
- Data Models & Dictionaries
- Data Registries
- Location Referencing
- Map Data Quality

Standards Survey

Standards Type	Detail	Standards	Status (as of 12/2018)
CAV-Path terminology[w]	Terminology and taxonomy of CAV Path terms	ISO 14812 Intelligent Transport Systems – Vocabulary (https://github.com/k-vaughn/iso14812)	In draft
		SAE J3131 Automated Driving Reference Architecture Describes functional component taxonomy, related terms and definitions.	In draft
Data models & Data dictionaries	Road geometry Road furniture	ISO 20524 Intelligent Transport Systems -- Geographic Data Files (GDF) Part 1: Application independent map data shared between multiple sources (https://www.iso.org/obp/ui/#iso:std:iso:20524:-1:dis:ed-1:v1:en) Part 2: Map data used in automated driving systems, Cooperative ITS, and multi-modal transport Includes features, attributes, and relationships. Features include roads and ferries, admin areas, named areas, land cover and use, terrain elevation, structures, railways, waterways, road furniture, and public transport.	In use / in revision
		CEN - Intelligent Transport Systems – Transport network Intelligent Transport Systems spatial data exchange framework (TN-ITS) Original specification developed in ROSATTE project (http://tn-its.eu/documents/). Formal standardization work in progress. "Content specification for the exchange of road-related spatial data, and especially updates"[x]	Spec in Use / Standard to be published 10/2018 / In revision
		Navigation Data Standard (incl. Open Lane Model)	In use / in revision

[w] Most standards contain a terminology and definitions section. This section is focused on those standards which are dedicated primarily to this topic.

Standards Type	Detail	Standards	Status (as of 12/2018)
		(https://www.nds-association.org/index.html#home) Includes specification for road topology, link network, lane geometry, and markings, and localization landmarks (road furniture)	
		OpenDRIVE 1.4 (http://www.opendrive.org/index.html) "Open file format for the logical description of road networks," developed by simulation industry	In use
		ADASIS 3.0 Includes "a standardized data model to represent map data ahead of the vehicle (the ADAS horizon); data requirements for the creation or generation of the ADAS horizon."	Published
		ISO 14296:2016 Intelligent Transport Systems -- Extension of map database specifications for applications of cooperative ITS "Map-related functional requirements, data model (logical data model/logical data organization), and data elements for those applications of cooperative ITS that require information derived from map databases"	Published
		ISO TR 21718 – Intelligent Transport Systems — Spatio-temporal data dictionary for cooperative ITS and automated driving systems	Published
		SAE J2945/10 Recommended Practices for MAP/SPaT Message Development[y]	In draft
	Rules of the road (static)	Road geometry / road furniture standards such as GDF, TN-ITS, and NDS support basic restriction information in the form of road segment attributes (e.g., max height, max speed).	As above
		CEN - Intelligent Transport Systems - Electronic management of regulations and policies— Part 1: Basic concepts and architectures (METR)	In draft

[y] For the purposes of this document, the J2945/x series is listed in the data dictionary section because these standards include items which will be used to update J2735.

Standards Type	Detail	Standards	Status (as of 12/2018)
	Recent / Temporary changes (dynamic)[z]	ISO/TS 19321:2015 Intelligent Transport Systems — Cooperative ITS — Dictionary of in-vehicle information (IVI) data structures (https://www.iso.org/obp/ui/#iso:std:iso:ts:19321:ed-1:v1:en) “contextual speed, road works warnings, vehicle restrictions, lane restrictions, road hazards warnings, location-based services, re-routing”	Published
		ISO/TS 17425:2016 Intelligent Transport Systems - Cooperative systems - Data exchange specification for in-vehicle presentation of external road and traffic related data (https://www.iso.org/standard/59723.html) “Road and traffic conditions, qualified by road authorities/operators, in a consistent way with road authority's/operator's requirements, in the manner that is coherent with the information that would be displayed on a road sign or variable message sign (VMS)… defines the message structure, content, syntax, [and] atomic elements”	Published
		ISO 21219 - Intelligent Transport Systems — Traffic and travel information (TTI) via transport protocol experts group, generation 2 (TPEG2) Based on TISA TPEG standards. Part 15 deals with traffic events; Part 19 with weather information.	Published
		ISO 18750:2018**:** Intelligent Transport Systems - Co-operative ITS - Local dynamic map “specifies general characteristics of LDM Data Objects (LDM-DOs) that may be stored in an LDM, i.e. information on real objects such as vehicles, road works sections, slow traffic sections, special weather condition sections, etc. which are as a minimum requirement location-referenced and time-referenced”	Published

[z] Some of the standards in this section support a mix of static and dynamic data.

Standards Type	Detail	Standards	Status (as of 12/2018)
		CEN 16157-3 - Intelligent Transport Systems - DATEX II data exchange specifications for traffic management and information - Part 3: Situation Publication CEN 16157-7 **-** Intelligent Transport Systems - DATEX II data exchange specifications for traffic management and information - Part 7: Common data elements	In use / in revision
		ETSI EN 302 637-3 V1.2.1 (Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 3: Specifications of Decentralized Environmental Notification Basic Service	Published
		ISO/TS 19091:2017 Intelligent Transport Systems -- Cooperative ITS -- Using V2I and I2V communications for applications related to signalized intersections Includes MAP messages harmonized with SAE J2735.	Published / in revision
		J2735™: Dedicated Short Range Communications (DSRC) Message Set Dictionary	Published
		ITE TMDD	
		IEEE 1512	Published
		TISA TPEG 3.0 Designed specifically to support automated vehicles.	In draft
		J2945/4: DSRC Messages for Traveler Information and Basic Information Delivery	In draft
		ISO TC 22/SC 31 Remote Diagnostics and ExVeh Content	In draft
		FHWA Work Zone Data Exchange (WZDX) (https://www.transportation.gov/av/data)	In draft
Data Registries		ISO 17419 - Intelligent Transport Systems -- Cooperative systems -- Globally unique identification	Published
		Intelligent Transport Systems -- Identifiers – Part 2: Management and operation of registries	In draft

	Standards	Status
Location referencing	ISO 17572-1:2015 Intelligent Transport Systems (ITS) -- Location referencing for geographic databases -- Part 1: General requirements and conceptual model Includes ID, coordinate, grid, linear, cross street, and address referencing. This standard is referenced in a number of others, such as CEN TN-ITS, etc. It also includes references to a number of regionally developed standards such as AGORA-C and ALERT-C.	Published
	ISO 21219 - Intelligent Transport Systems — Traffic and travel information (TTI) via transport protocol experts group, generation 2 (TPEG2) Parts 11 and 20-22 deal with location referencing.	In draft / Published
	OpenLR v1.4.2 (http://www.openlr.org/) "Dynamic location referencing method which enables reliable data exchange and cross-referencing using digital maps of different vendors and versions."	In use
	CEN EN 16157-2 - Intelligent Transport Systems - DATEX II data exchange specifications for traffic management and information - Part 2: Location referencing "informational structures, relationships, roles, attributes and associated data types, for the implementation of the location referencing systems used in association with the different publications defined in the Datex II framework. It also defines a DATEX II publication for exchanging predefined locations."	In use / in revision
	OpenGIS® Location Services (OpenLS) Standards (Core Services and Navigation Service) References ISO 14825.	Published
	J2266™: Location Referencing Message Specification (LRMS)	Published
	CEN Intelligent Transport Systems - Location Referencing Harmonization for Urban-ITS - Part 1: State of the art and guidelines	In draft
	CEN Intelligent Transport Systems - Location Referencing Harmonization for Urban-ITS - Part 2: Translation methods	In draft
Map data quality	ISO 19157:2013, 2016 Geographic Information – Data quality	Published
	ISO 19158:2012 Geographic Information – Quality assurance of data supply	Published
	OADF Highly Reliable Maps specifications Includes map backend integrity and map quality attributes	In draft

Appendix C: Traceability Tables

This appendix contains tables that show the traceability from Tasks to standards Gaps / Priorities.

- Table A: Tasks to Standard Content Description Needs. Shows the linkage between Tasks, Task Support Content Needs, Task Support Content Types, and Standard Content Description Needs.
- Table B: Standard Description Needs by Category to Existing / Emerging Standards. Shows the linkage between Standards Description Needs by Category, Standards Types Required, and Existing/Emerging Standards
- Table C: Standard Content Description Needs By Category to Gaps / Priorities. Shows the linkage between Standard Content Description Needs, Standards Types Required, Standards Status (Summary), and Gaps / Priorities

Traceability Table Overview

Table A			
Tasks	Task Support Content Needs	Task Support Content Types	Standard Content Description Needs
Table B			
Standard Description Needs by Category	Standards Types Required	Existing/Emerging Standards	–
Table C			
Standard Description Needs by Category	Standards Types Required	Status Summary	Gaps / Priorities

C.1 Table A: Tasks to Standard Content Description Needs

Tasks	Task Support Content Needs
• Perception • Localization • Planning • Control	• Where am I relative to my environment? • What are the rules of the road that affect path? • What has changed from what I already know?

Task Support Content Types	Standard Content Description Needs
Road geometry	
• Lane type (regular, managed, ramp, auxiliary, exit, etc.) • Uniquely identified lane centers and markings • Lane markings (incl. retroreflectivity) • Speed bumps • Road banking • Crosswalks • Bike boxes and lanes • Internal storage lanes • Lane suitability for emergency applications • Vertical crest curvature • Stopping sight distances	RG1 Need common definitions of road geometry elements (segments and segment attributes) RG2 Need a common model for describing relationships among elements (world and lane models) RG3 Need a way to consistently describe relative and absolute element location RG4 Need a way to indicate impact of road geometry attributes on each lane
Road furniture	
• Guard rails • Stop signs / other signage • Bridges / clearance heights • Mile markers • Traffic signal locations / poles and consistent information on signal location on poles • Impact barriers • Toll booths	RF1 Need common definitions of road furniture items and attributes RF2 Need a common model for describing relationships of road furniture to road geometry RF3 Need a way to consistently describe relative and absolute road furniture location RF4 Need a way to indicate impact of road furniture attributes on each lane

Rules of the road	
• Lane and road use restrictions (maximum height, weight, and width; vehicle type, vehicle occupancy, user type - local residents only; bus and bike lanes) • Driving laws / policies / local practices • Enforcement policies • Signage impact on lane use, including off road signs • Speed limits (permanent) • Reversible lanes • Shoulder use for travel • Parking restrictions	RR1 Need common definitions of legal restrictions (both enforceable and advisories) RR2 Need a common model for describing relationships of legal restrictions to road geometry RR3 Need a way to consistently describe relative and absolute location of restriction application zone RR4 Need a way to indicate impact of restrictions on each lane by vehicle type
Recent / temporary changes	
• Road and lane / shoulder geometry changes • Closures • Temporary lane control signs information (for example, used in Active Traffic Management applications, lane / shoulder status (open/closed) • Road friction / traction status • Work zone driving restrictions • Traffic signal and sign status (by lane) • “Landmark uncertainty areas” where road furniture may have changed • Obstacles and negative obstacles (pothole) • Speed limit (variable) • Path guidance (detours, lane re-location/shifts)	RC1 Need common definitions of recent or temporary changes RC2 Need a common model for describing relationships of changes to road geometry RC3 Need a way to consistently describe relative and absolute location of change RC4 Need a way to indicate impact of changes on each lane by vehicle type

C.2 Table B: Standard Description Needs by Category to Existing / Emerging Standards

Further description and status of specific standards activities may be found in Appendix B.

Standard Description Needs by Category	Standards Types Required	Existing/Emerging Standards	
What is it?			
RG1 Need common definitions of road geometry elements (segments and segment attributes). RF1 Need common definitions of road furniture items and attributes. RR1 Need common definitions of legal restrictions (both enforceable and advisories). RC1 Need common definitions of recent or temporary changes. RG2 Need a common model for describing relationships among elements (world and lane models). RF2 Need a common model for describing relationships of road furniture to road geometry. RR2 Need a common model for describing relationships of legal restrictions to road geometry. RC2 Need a common model for describing relationships of changes to road geometry.	•Terminology •Data dictionaries •Data registries •Terminology •Data models (e.g., world models, lane models)	*Terminology* • ISO 14812 Vocabulary • SAE J3131 AD Reference Architecture *Data Models* • ISO 20524 Geographic Data Files (GDF) • OADF Data Catalogue • CEN TC278 WG 7 TN-ITS • Navigation Data Standard (incl. Open Lane Model) • OpenDRIVE 1.4 • ADASIS 3.0 • ISO 14296:2016 Extension of map database specifications • ISO TR 21718 Spatio-temporal data dictionary • SAE J2945/10 Recommended Practices for MAP/SPaT Message Development *Data Registries* • ISO 17419 Globally unique identification; Management and	*Data Dictionaries* • CEN METR • ISO/TS 19321:2015 IVI Data Dictionary • ISO/TS 17425:2016 Data exchange specification for in-vehicle presentation of external road and traffic related data • ISO 21219 TPEG 2 • ISO 18750:2018: Local dynamic map • CEN 16157-3 DATEX II Situation Publication • ETSI EN 302 637-3 V1.2.1 DENM • ISO/TS 19091:2017 Using V2I and I2V for signalized intersections • SAE J2735™ • ITE TMDD • IEEE 1512 • TISA TPEG 3.0 • J2945/4: DSRC Messages for TIM and BIM (RSM) • FHWA WZDX • CIFS

		operation of registries • OADF Data Catalogue	
Where is it?			
RG3 Need a way to consistently describe relative and absolute element location. RG4 Need a way to indicate impact of road geometry attributes on each lane. RF3 Need a way to consistently describe relative and absolute road furniture location. RF4 Need a way to indicate impact of road furniture attributes on each lane. RR3 Need a way to consistently describe relative and absolute location of restriction application zone. RC3 Need a way to consistently describe relative and absolute location of change. RR4 Need a way to indicate impact of restrictions on each lane by vehicle type.	•Cross map location referencing (which may vary by data type)	• ISO 17572-1:2015 Location referencing for geographic databases • ISO 21219 - TPEG2 Parts 11, 20-22 • OpenLR v1.4.2 • CEN EN 16157-2 DATEX II - Part 2: Location referencing • OpenGIS® Location Services (OpenLS) • J2266™: LRMS • CEN Location Referencing Harmonization for Urban-ITS	–
How good is it?			
CQ1 Need common definitions of computable quality metrics for CAV-Path data. CQ2 Need common metadata about CAV-Path data.	•Quality metadata (e.g., confidence, timeliness)	• ISO 19157:2013, 2016 Geographic Information – Data quality • ISO 19158:2012 Geographic Information – Quality assurance of data supply • OADF Highly Reliable Maps specifications	–

C.3 Table C: Standard Content Description Needs By Category and Gaps / Priorities

Further description and status of specific standards activities may be found in Appendix B.

Content Description Needs	Standards Types Required	Status Summary	Gaps / Priorities
What is it?			
RG1 Need common definitions of road geometry elements (segments and segment attributes) RF1 Need common definitions of road furniture items and attributes RR1 Need common definitions of legal restrictions (both enforceable and advisories) RC1 Need common definitions of recent or temporary changes	•Terminology •Data dictionaries •Data registries •Terminology •Data dictionaries •Data registries •Terminology •Data dictionaries •Data registries •Terminology •Data dictionaries •Data registries	There is a strong base of standards on data dictionaries and registries developed at national and international levels, and a significant amount of work underway to update and extend these items. Standards like CEN's TN-ITS are available to facilitate the exchange of specific types of geographic data, and organizations such as CEN, ISO, OADF, SAE and TISA are tackling the more dynamic data types.	**Common Data Registry** The need for a data registry, which will house the full suite of standard transportation data elements and their metadata; and enable consistent use and re-use of these elements by developers, is another well-recognized need. Without such a registry, it is very difficult to avoid unintentional standards overlap and conflict. Implementation, however, has been a major challenge. Recent developments in ISO and OADF may finally be making progress in this area, and it is important to maintain this momentum.
RG2 Need a common model for describing relationships among elements (world and lane models) RF2 Need a common model for describing relationships of road furniture to road geometry RR2 Need a common model for describing relationships of legal restrictions to road geometry	•Terminology •Data models (e.g., world models, lane models) •Terminology •Data models (e.g., world models, lane models) •Terminology •Data models (e.g., world models, lane models)	There is a strong base of standards on data models developed at national and international levels, and a significant amount of work underway to update and extend these items. Terminology is also an active area – each standard typically contains a terminology section, but specific standards to help define industry vocabulary are also in progress.	

Content Description Needs	Standards Types Required	Status Summary	Gaps / Priorities
RC2 Need a common model for describing relationships of changes to road geometry	•Terminology •Data models (e.g., world models, lane models)		
Where is it?			
RG3 Need a way to consistently describe relative and absolute element location RG4 Need a way to indicate impact of road geometry attributes on each lane RF3 Need a way to consistently describe relative and absolute road furniture location RF4 Need a way to indicate impact of road furniture attributes on each lane RR3 Need a way to consistently describe relative and absolute location of restriction application zone RC3 Need a way to consistently describe relative and absolute location of change RR4 Need a way to indicate impact of restrictions on each lane by vehicle type	•Cross map location referencing (which may vary by data type)	Location referencing continues to be a challenge. Current standards efforts are focused on "cross-map" referencing at the levels of accuracy required for automated vehicles. There are several new approaches in development from organizations such as CEN, ISO, OADF and, most recently, the new SharedStreets activity.	**Location Referencing solutions** Location referencing ("where is it?") is the critical glue which holds the CAV-Path data set together. At least three separate efforts are underway to develop improved solutions in this area. It is critical to monitor, support, and implement these new solutions in public sector data sets.
How good is it?			
CQ1 Need common definitions of computable quality metrics for CAV-Path data CQ2 Need common metadata about CAV-Path data	•Quality metadata (e.g., confidence, timeliness) •Quality metadata (e.g., confidence, timeliness)	Some quality standards for geographic data exist, most notably ISO 19157. However, descriptions for other types of data are also in the works, as is an effort to describe data process quality (how good the data is at each point in the data chain). Some early work on this topic has been	**Quality Description standards** The need for map data quality standards is well-recognized, and work has already been done in ISO for some kinds of data. However, standard metrics for dynamic types of data are not as well codified. Further work is required in this area.

Content Description Needs	Standards Types Required	Status Summary	Gaps / Priorities
		done by the EIP+ project, and there are ongoing discussions in OADF.	
Cross-Cutting (Applies to all Needs)			

Harmonization/Translation of related/competing standards

The ITS standards space is at an all-time high level of activity. Existing standards bodies are generating new work items and new standards groups are emerging constantly, and these represent a variety of stakeholder interests and standards development business models. There are ongoing efforts to harmonize key standards on a national and global basis, and this work is more important than ever at this time. Outreach efforts to avoid the development of redundant standards is similarly critical.

Agreed upon set of CAV-Path data standards

There is a great deal of standards development work underway to generate standards to meet AV requirements, including the extension and expansion of existing deployed standards. While there is work still to do in that area, the primary public sector challenge appears to be not "how do we get the necessary standards developed?," but instead "how do we understand and implement the necessary standards to develop a nationally-consistent set of public sector information to enable AVs?"

Appendix D: WZDx v2 / AV Needs Review

This table is a summary snapshot of the review of AV Needs vs WZDx v2 elements. Recommendations highlighted in orange are proposed for near term consideration. Those in dark green are proposed for medium- to long-term consideration. The complete analysis has been posted on the V2X Mapping website.

What is it?	Best Practice / Need Detail	WZDx element	Initial Recommendations*
RG1 Need common definitions of road geometry elements (segments and segment attributes)	Include full set of elements necessary to model real-world road network:	•geometry_type	•**Include altitude as a required geometry descriptor to support layered geometry types**
	•Geometry types	•geometry	•Add additional geometry types
	•Geometries	•lane_type	•Add segment attributes
	•Segment attributes	–	•Add ability to describe precise location/routing of geometry and lane changes
	•Description of re-location, re-routing of lanes (vs lane-shift)	–	–
RF1 Need common definitions of road furniture items and attributes	Include description of road furniture to support localization and path planning	–	•Add road furniture definitions
RR1 Need common definitions of legal restrictions (both enforceable and advisories)	•Communicate vehicle restrictions by vehicle, user, and lane type at lane level	•restrictions	•**Add restriction value as requirement to all restrictions**
	•Include computable restriction values for all restrictions	•restriction_type	•**Add additional restriction descriptors to support standard vehicle, user and lane types**
	–	•restriction_value	•Require restrictions descriptions that can be applied at lane level
	–	•restriction_units	
RC1 Need common definitions of recent or temporary changes	Link all change types to:	•type_name	•**Link reduced speed limit to vehicle type**
	•path impact/geometry change	•is_architectural_change	•Add path impact for work types

	•vehicle type	•workers_present	•Add ability to describe precise location of activity zones and geometry changes that impact path
	Provide change descriptions using computable metrics of an accuracy sufficient to support AV situation assessment and response	•reduced_speed_limit	•Add computable status data with refresh rate suitable to support AVs
	–	•start_date	–
	–	•end_date	–
	–	•creation_date	–
	–	•event_status	–
RG2 Need a common model for describing relationships among elements (world and lane models)	Include all lane-variants necessary to model real-world road network:	•total_num_lanes	•**Review existing standard lane models and include appropriate model by reference**
	•shoulders	•lane_edge_reference	•Add business rules to ensure interoperability
	•ramps	•lane_number	–
	•tapers (start location and count)	–	–
RF2 Need a common model for describing relationships of road furniture to road geometry	Include location of road furniture to support localization and path planning	–	•Add business rules for road furniture location description
RR2 Need a common model for describing relationships of legal restrictions to road geometry	Link all restrictions to road and lane level	–	•**Link restrictions to lanes**
RC2 Need a common model for describing relationships of changes to road geometry	Provide change descriptions using location descriptions of an accuracy sufficient to support AV situation assessment and response	–	•Add detailed change description approach at lane level

Where is it?	Best Practice / Need Detail	WZDx element	Initial Recommendations
RC3 Need a way to consistently describe relative and absolute location of change	Use location description which enables acceptably successful cross-map location referencing:	•wz_location_method	•**Add business rules for all location data elements**
	•Ability to support basemaps of varying accuracy	•lrs_type	•Multiple names
	•Business rules for all location data elements	•lrs_url	•“Publicly known” names (standard sources)
	•Standardized enumerated values	•road_name	•Jurisdiction definitions and designations
	–	•road_number	•Direction
	–	•direction	•**Add enum values & definitions to all location data elements**
	–	•beginning_cross_street	•**Review existing location referencing solutions and include appropriate solution by reference**
	–	•ending_cross_street	–
	–	•beginning_milepost	–
	–	•ending_milepost	–
RG3 Need a way to consistently describe relative and absolute element location	Use location description which enables acceptably successful cross-map location referencing (see RC3)	–	•**Review existing location referencing solutions and include appropriate solution by reference**
RG4 Need a way to indicate impact of road geometry attributes on each lane	Provide lane level road attribute change descriptions using computable metrics of an accuracy sufficient to support AV situation assessment and response	–	•Add detailed road attribute change description approach at lane level
RF3 Need a way to consistently describe relative and absolute road furniture location	Include location of road furniture to support localization and path planning	–	•Confirm that road furniture locations can be fully described with existing location elements at lane level •Add business rules for road furniture location description

RF4 Need a way to indicate impact of road furniture attributes on each lane	Provide lane level road furniture attribute change descriptions using computable metrics of an accuracy sufficient to support AV situation assessment and response	–	•Add detailed road furniture attribute change description at lane level
RR3 Need a way to consistently describe relative and absolute location of restriction application zone	Describe location of road restriction zone to support localization and path planning	–	•Confirm that road restriction zone locations can be fully described with existing location elements at lane level •Add business rules for restriction zone locations
RR4 Need a way to indicate impact of restrictions on each lane by vehicle type	Provide lane level restriction zone change descriptions using computable metrics of an accuracy sufficient to support AV situation assessment and response	•lane_status •vehicle_impact	•**Add vehicle type to existing data elements** •Add computable restriction zone impact description at lane level
How Good is it?	**Best Practice / Need Detail**	**WZDx element**	**Initial Recommendations**
CQ1 Need common definitions of computable quality metrics for CAV-Path data	Provide quality data with computable metrics and / or confidence measures to support multi-input decision-making	–	–
Accuracy	–	•location_verify_method •beginning_accuracy	•**List and define all enum values** •**Add computable metrics and confidence values to all data elements**
		•ending_accuracy	–
		•start_date_accuracy	–
		•end_date_accuracy	–

Currency	–	•datafeed_frequency_update •timestamp_metadata_update •update_date •creation_date	•**Add computable metrics and confidence values to all data elements**
Completeness	Provide metrics for completeness of event set (% events present in data stream)	–	•**Add completeness metrics**
CQ2 Need common metadata about CAV-Path data	–	issuing_organization contact_name contact_email	–

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