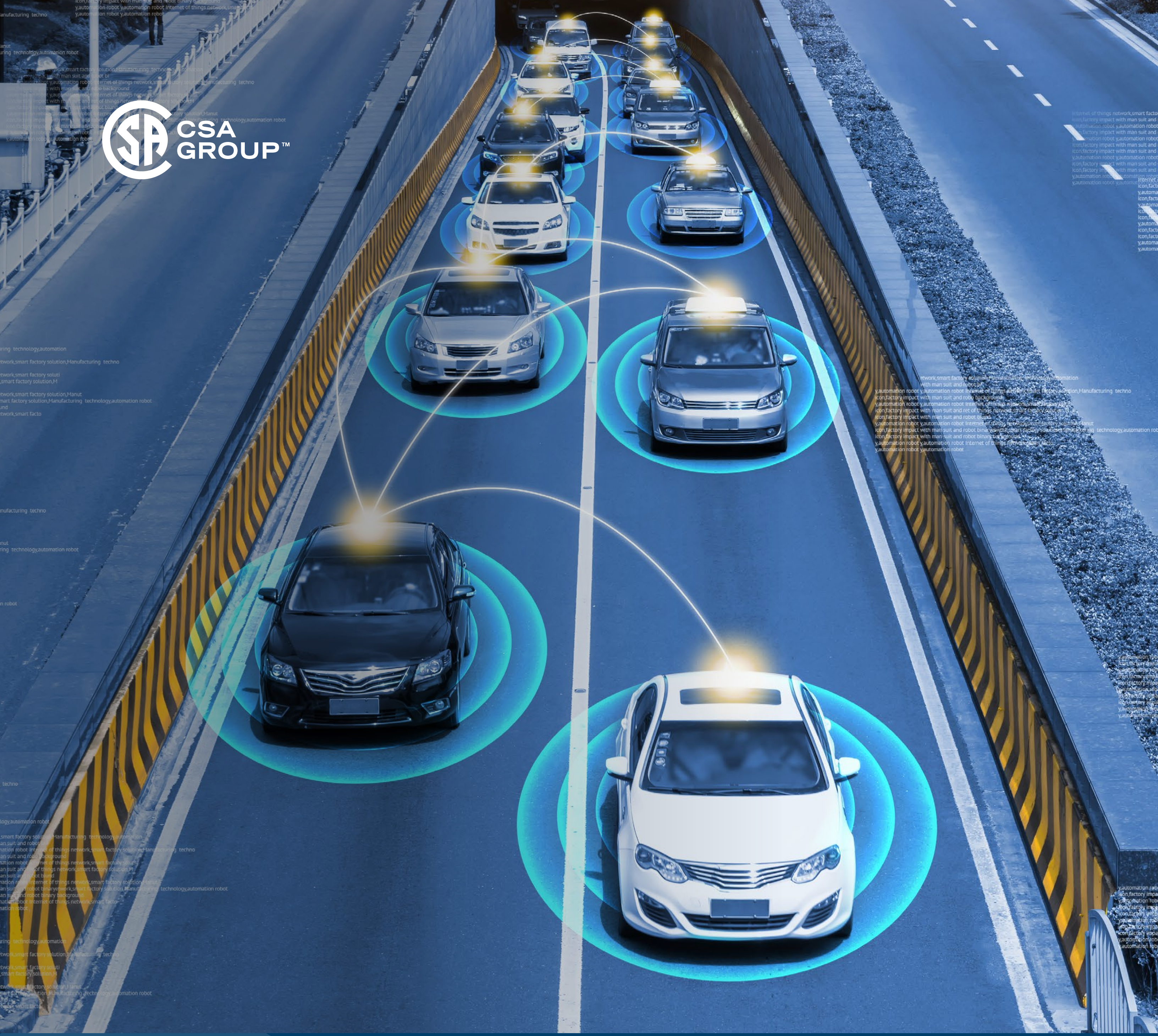

STANDARDS RESEARCH

Connected and Automated Vehicle Technologies – Insights for Codes and Standards in Canada

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Executive Summary

Transportation will rapidly change and evolve with the advancement of connectivity and automation technology. Connected and automated vehicles (CAVs) will fundamentally change the way people and goods are transported from one place to another. Ensuring the safety of their operation and maintaining a safe transportation network will be paramount for the seamless integration of CAVs on public roads. To support this advancement of technology, it is important to develop an understanding of their impacts on their surrounding environments, as well as an understanding of the existing landscape of relevant codes and standards, which provide guidance for the safety and security of technology and products for use by the public. In this regard, codes and standards will play a critical role in the safe, secure, and seamless integration of CAVs onto roads and for public use. Identifying gaps in the existing landscape provides insight on where future work needs to be focused and on the challenges that are being faced by the industry.

The advancement of technology and the impacts of CAVs on the transportation network are international challenges. It is important for there to be consistency and harmonization on how the challenges are addressed around the world. To date, there have been efforts carried out by public agencies and road authorities in Canada, the United States, Australia, Europe, and Asia outlining plans for preparing for connectivity and automation, as well as testing various technologies and strategies. Key standard development organizations (SDOs) have already begun updating and/or developing standards related to various aspects of CAVs. This report reviews these activities to provide an overview of the current landscape of codes and standards for CAV technology, identifying critical needs and potential gaps that should be considered and addressed.

Primary and secondary research was used in this study to develop an understanding of the existing work and standards landscape, as well as to identify the gaps that require attention. Key stakeholder interviews were conducted with representatives from public sector agencies, academia, private organizations, and members on standards committees to gather their input and perspectives on the needs and perceived gaps within codes and standards. These results were reconciled with industry research and a literature review to complete a comprehensive analysis of the codes and standards landscape.

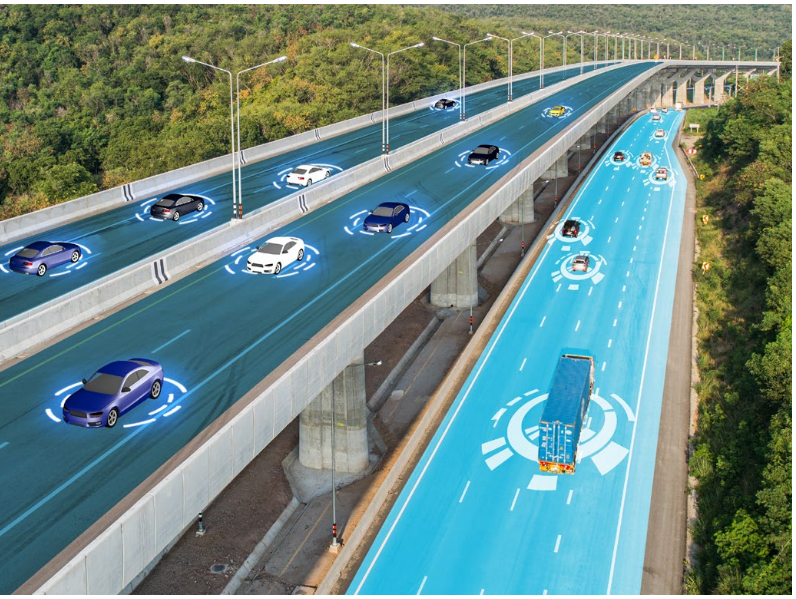
The existing standards for CAVs are categorized into five main groups:

- **Digital Infrastructure –** relating to how equipment stores and exchanges of data support intelligent transportation services;
- **Physical Infrastructure –** relating to the physical roadway infrastructure upon which the transportation system operates;
- **Usage, Human-Machine, and Accessibility –** relating to the standards focused on use cases, accessibility needs, and human-machine interfaces for CAVs;
- **Cybersecurity, Data Training, and Privacy –** relating to the administrative, physical, and technical actions associated with the security, integrity, and privacy of data and networks, as well as algorithm training;
- **Vehicle Aspects –** relating specifically to vehicles and onboard equipment supporting automation, connectivity, and safety.

CAVs and the application of these technologies continue to evolve and, in some cases, continue to do so in the absence of standards. This study identifies areas of focus to address critical needs and fill many of the gaps and questions around CAV development, deployment, and safety. The critical needs and potential gaps identified can be grouped into eight themes:

- **Harmonization and Interoperability –** need for consistency of standards across regions and countries, as well as the ability for technology to effectively interact and cooperate with each other;
- **Uncertainty with Enabling Communication Technologies –** uncertainty with the communication technology and spectrum allocation that is endorsed and supported by government agencies and widely used by manufacturers;
- **Compliance Verification –** gaps in standards and processes to verify that technology meets safety, security, and interoperability requirements;
- **Physical Infrastructure –** gaps in standards for physical infrastructure to accommodate CAV technologies;
- **Operational Design Domain –** gaps in standards and regulations regarding where, and under what conditions, CAVs are currently able to safely and efficiently operate;
- **High Definition Mapping and Localization –** gaps related to the development and availability of high definition (HD) mapping and localization technology to support the operation of CAVs;
- **Cybersecurity and Protection of Privacy –** critical needs for standards and security frameworks related to cybersecurity and privacy protection, specific to the CAV industry;
- **Technology Maturity –** gaps that are reflective of the fact that AV-enabling technologies have issues in some scenarios and all circumstances (e.g., operations in non-optimal conditions).

These eight theme areas identify opportunities where participation in standards development activities and/or coordination on related efforts would help ensure that standards, guidelines, and frameworks are established to help support safe operation and widespread adoption of CAV technologies.



"The adoption and development of CAVs will bring significant changes and will inevitably impact how people and goods are transported from one place to another, facilitating safer and more efficient and sustainable transportation."

1 Introduction

Connected and automated vehicles (CAVs) utilize the unification of two sets of technology – connectivity and automation. These vehicles have the capability to be connected to a network or to exchange information with each other, as well as with connecting to surrounding road infrastructure and traffic network operators. They also have the capability to automate driving tasks with varying levels of automation.

For more than a decade, CAVs have been identified as one of the key anticipated major disruptors in transportation. The adoption and development of CAVs will bring significant changes and will inevitably impact how people and goods are transported from one place to another, facilitating safer and more efficient and sustainable transportation. The technologies have advanced in recent years, and there are vehicles already on the road today with sophisticated technologies and capabilities for connected vehicle (CV) systems and enhanced driver assistance, such as adaptive cruise control and assisted lane keeping. It is uncertain what the full impacts of CAVs will be, how the volume of CAVs on the road will increase, or how quickly CAV technologies will continue to advance and be adopted. However, the continued incremental adoption of CAV technologies is inevitable, and it is clear that a consistent set of regulations, codes, and standards are key to facilitating safe adoption and minimizing disruptions in the short and long term.

This research report is intended to review the existing standards landscape as it relates to relevant infrastructure, communications, data management and privacy, cybersecurity, and vehicle technology. A comprehensive literature review, consultation with experts, and interviews with key industry stakeholders provided the seed information to develop insights for CAVs that identify a framework for a roadmap that addresses the needs for codes and standards in Canada, and that maximizes standards harmonization domestically and internationally.

2 Study Methodology

The insights provided in this report were developed based on information and data gathered and consolidated from both primary and secondary research. The primary research was conducted through interviews with key industry agencies and organizations in the public and private sectors, including representation from:

- Public transportation agencies
- Academic and research institutions
- Industry
- Standards development organizations and committee members

The interviews gathered insight on the current activities of the industry with regards to CAVs and necessary preparations, as well as the role that standards and codes play in these activities. This also allowed industry stakeholders to raise concerns and identify gaps that they believe are creating barriers to the further progress of their CAV-related activities.

Insight provided from the interviews has been augmented and reconciled with information gathered through concurrent desktop research efforts. This included a jurisdictional scan and literature review, as well as a review of findings from the CAV Stakeholder Engagement Workshop conducted by the CSA Group in November of 2018 [1]. This research formed the basis for the background information on CAV technology, considerations for preparations, and relevant codes and standards. The interview results were used as the basis of the gap analysis, gathering industry input on what is still needed to better facilitate its work and CAV preparation efforts.

3 Results and Discussion

3.1 What Are CAV Technologies?

CAV technologies are at the forefront of an automotive revolution and are fundamental to the next generation of intelligent transportation systems (ITS) [2]. Connectivity and automation are two main categories of technology that are related and complementary, but they are not codependent and can be defined separately.

3.1.1 What Are Connected Vehicles?

Connected vehicles (CVs) are able to gather information from and communicate with other vehicles and their surroundings (e.g., infrastructure, pedestrians/cyclists), thereby enhancing safety and mobility. CVs can provide useful information to surrounding vehicles to help make safer and more informed decisions with greater advanced timing and without the inherent sightline limitations of vehicle-mounted sensors [3].

Outside of North America, the term cooperative intelligence transportation systems (C-ITS) is commonly used for applications and operations of CVs, which leverages a combination of the following [4]:

- **Vehicle-to-Vehicle Communications (V2V) –** often for safety-related applications, such as collision avoidance and vehicle platooning.
- **Vehicle-to-Infrastructure Communications (V2I/I2V) –** for safety and mobility applications, including vehicle-to-traffic signal interactions to support improved vehicle junction transit, replication of roadside signage in vehicle for driver warning, and speed limit adherence.
- **Vehicle-to-Network Communications (V2N) –** supports broadcast and wide area applications, such as over-the-air (OTA) updates and real-time routing information.
- **Infrastructure-to-Infrastructure Communications (I2I) –** supports the aggregation of local sensors or vehicle-based messages that either extend communications from the vehicle to the roadside infrastructure or communications from roadside infrastructure to vehicles.
- **Vehicle-to-Everything Communications (V2X) –** a superset all of the above, supporting communications to any local devices or remote/central systems for any application.

3.1.2 What Are Automated Vehicles?

Automated vehicles (AVs) are equipped with onboard equipment (e.g., cameras, LiDAR, radar) to sense the surrounding environment without necessarily communicating with other vehicles or the surrounding infrastructure [5].

An AV combines data and intelligence from its equipment to automate various aspects of the dynamic driving task to the level of capability of its operational design domain and fallback elements. These elements determine the level of automation the vehicle is capable of operating within to navigate through the road network [6].

SAE International has categorized vehicles into six levels of automation, ranging from Level 0 with no automation to fully autonomous at Level 5 (see adaptation of levels in Figure 1) [7]. The term highly automated vehicle (HAV) is used to describe a Level 3, 4, or 5 driving automation system.

"CAVs have the potential to improve safety, optimize the performance of the transportation networks, increase vehicle utilization, and allow commuters to use their commute time for other activities."

3.1.3 What Are Connected and Automated Vehicles?

Combining connectivity and automation results in the development of connected and automated vehicles (CAVs) that augment information collected from surrounding infrastructure and vehicles with the information and data collected by its onboard sensors to make decisions and traverse a transportation network. CAVs have the potential to improve safety, optimize the performance of the transportation networks, increase vehicle utilization, and allow commuters to use their commute time for other activities. Conversely, there are also viewpoints that CAVs may lead to longer commutes and less efficient trips, on average [8].

As CV and AV technologies are complementary, and it is most likely that combined CAVs will be much more prominent in the market in the future compared to vehicles with separate CV and AV offerings, this report primarily uses the combined CAV reference. CAV technologies are most likely going to be found universally in Level 4 and Level 5 vehicles, while Level 3 vehicles may range from no connectivity to V2X connectivity.

3.2 Preparing for CAVs Around the World

Preparing for CAVs has become a popular topic for many transportation agencies, both in North America and around the world, and agencies have initiated planning activities to prepare for CAVs entering the transportation network. Through these plans, national, regional, and local transportation authorities are identifying the needs of CAVs with regards to infrastructure, operations, institutional, policy, and legislative considerations.

3.2.1 Canada

Transport Canada has led or supported the development of reports to help provide guidance relating to CAVs, and has supported projects for the safe testing of AVs. The publications include:

- *Canadian Jurisdictional Guidelines for Safe Testing and Deployment of Highly Automated Vehicles*, developed by the Canadian Council of Motor Transport Administrators (CCMTA), provides a series of considerations and recommendations to support Canadian jurisdictions and lower levels of government in developing CAV testing programs to prepare for the deployment of emerging transportation technologies. The document discusses the roles and responsibilities of federal, provincial/territorial, and municipal governments in testing CAV techologies as well as guidelines for governments and manufacturers to follow [9].
- *Testing Highly Automated Vehicles (HAV) in Canada – Guidance for Trial Organizations* clarifies, for trial organizations, the role of federal and provincial/territorial levels of government involved in facilitating trials, while also establishing Canada as a destination for trials of HAVs. The trial guidelines establish a set of voluntary minimum safety practices and expectations that trial organizations are expected to follow for the temporary trials of AVs and AV systems [10].

Figure 1: *SAE International Levels of Automation (SAE J3016) [7]*

LEVEL 0 **NO AUTOMATION**	LEVEL 1 **DRIVER ASSISTANCE SYSTEMS**	LEVEL 2 **PARTIAL AUTOMATION**	LEVEL 3 **CONDITIONAL AUTOMATION**	LEVEL 4 **HIGH AUTOMATION**	LEVEL 5 **FULL AUTOMATION**
A human driver is required for all aspects of the dynamic driving task. Vehicles may have assistive technology providing warnings to the driver but cannot sustain vehicle control.	A human driver performs most of the driving operation, with the automated system assisting with minor operations of the dynamic driving task. For example, with lane keeping assistance the driver controls the speed, while the automated system self corrects steering toward the centre of the lane. *Level 1 automation is available in many vehicles available on the market.*	An automated driving system can be in control of the dynamic driving task including steering, acceleration, and braking. However, the driver must remain engaged in the driving task and monitor the environment at all times. *Level 2 automation available in a number of vehicles for purchase in Canada.*	An automated driving system is in full control of the dynamic driving task including steering, acceleration, and braking. The vehicle is able to scan its environment, react accordingly, recognize its limitations and request intervention by a human driver. The human driver does not need to consistently monitor the driving environment, but should be prepared to intervene if needed. *Level 3 (or above) automation is not currently available in vehicles for purchase in Canada.*	An automated driving system is able to perform the whole dynamic driving task including steering, acceleration and braking within a defined environment, even if a human driver does not respond to a request to intervene. The vehicle can come to a safe stop if it operates beyond the boundaries of its safe operating conditions. The human driver does not need to monitor the driving environment or be available to intervene with the driving task.	An automated driving system performs the entire dynamic driving task independently and regardless of conditions without the need for a human driver to be present. The vehicle is truly a self-driving entity and can decide to abort a trip and come to a full stop.

- *Canada's Safety Framework for Automated and Connected Vehicles* provides stakeholders with a stable policy direction for safely deploying CAV on public roads in Canada. It provides an overview of Canada's current legislative, regulatory, and standards programs [11].
- *Safety Assessment for Automated Driving Systems in Canada* was developed by Transport Canada as a tool to support vehicle manufacturer safety reviews of SAE Levels 3 to 5 vehicles before being deployed on Canadian roads [12].
- *National Cybersecurity Strategy* was developed by Public Safety Canada to outline the global cybersecurity environment and provide information on ongoing and future efforts to protect Canada's systems and critical network infrastructure and to respond to new challenges and opportunities associated with cybersecurity [13].

The projects include:

Led by the University of Alberta Centre for Smart Transportation and the University of British Columbia, the ACTIVE-AURORA project was launched in 2014 and focuses on testing a variety of applications relating to CV technologies. The project consists of four test beds and two laboratory test environments, with ACTIVE representing the Edmonton component (University of Alberta) and AURORA representing the Vancouver component (University of British Columbia) [14].

Since 2017, Transport Canada has also been collaborating with industry to undertake testing and evaluation of cooperative truck platooning systems (CTPS) and V2V communication systems at their testing facility in Blainville, Quebec. The goal of this research is to identify the fuel-consumption savings and improvement of road safety that could be introduced from platooning [15].

Transport Canada created the Program to Advance Connectivity and Automation in the Transportation System (ACATS)[1] to help Canadian jurisdictions prepare for the technical, regulatory, and policy issues emerging as CAV technologies are introduced in Canada. To date, ACATS has committed approximately $3 million in funding, including funding for the following reports and documents [16]:

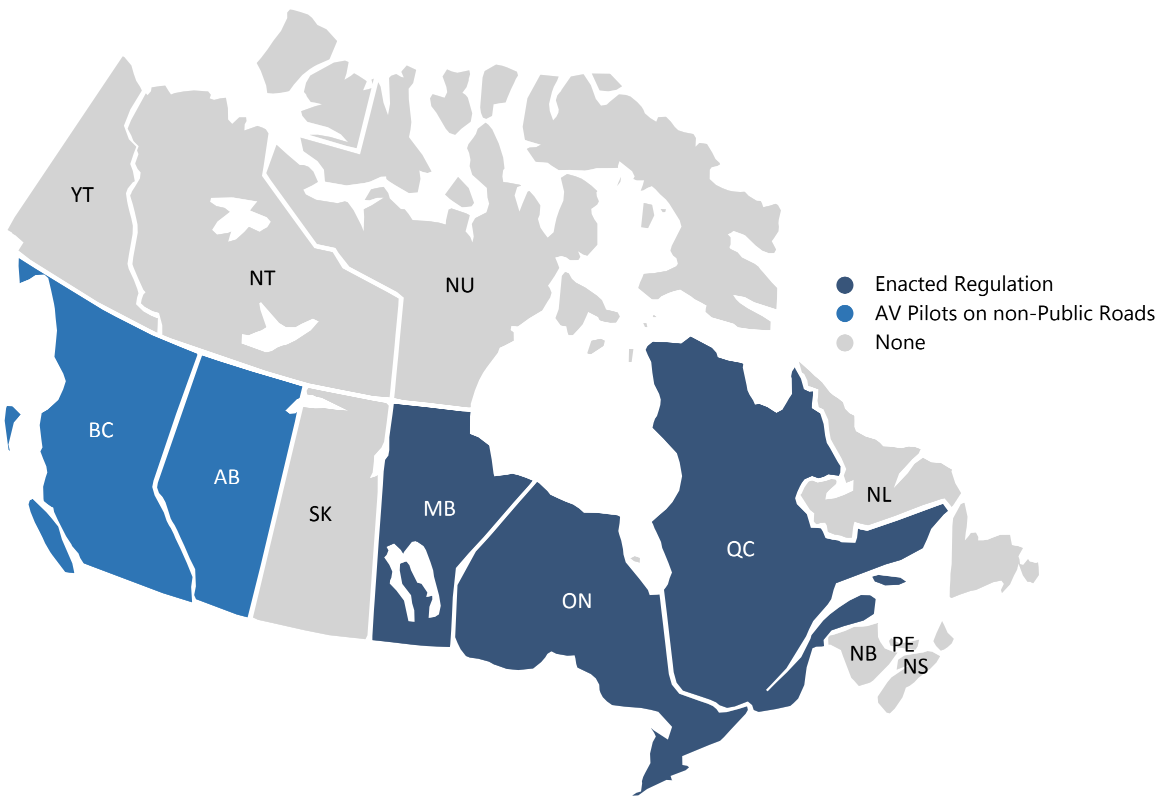
- *CAV Readiness Plan for the GTHA and Kitchener/Waterloo Corridor* – led by a steering committee that includes the Ministry of Transportation Ontario (MTO), Metrolinx, the Region of Peel, and the City of Toronto, the plan provides public agencies with readiness guidelines related to infrastructure, institutional, operations, and public policy considerations. The committee also developed a list of CAV programs, as well as a governance structure for regional collaboration and the development of a CAV Liaison Committee.
- *Codes and Standards Roadmap for CAVs* – led by CSA Group, guidelines and a standardization roadmap are being developed for the safe deployment of CAV technologies in Canada.
- *Impacts of CAVs for Pedestrians with Sight Loss* – led by Canadian National Institute for the Blind (CNIB), the study focuses on assessing how pedestrian with sight loss may be affected by CAVs [17].
- *CAV Testing Strategy and Capacity Building* – led by City of Vancouver, the intent of the project is to prepare an urban CAV testing strategy for future trials and use, focusing on civic fleets and infrastructure.
- *ITS Architecture for Canada Version 3 Update* – led by Intelligent Transportation System Society of Canada (ITS Canada), the project is intended to update the Canadian ITS Architecture to include CAVs and realign it with the US ITS Architecture (ARC-IT), including enhancements and the Connected Vehicle Reference Implementation Architecture (CVRIA) [18].
- *City of Calgary Autonomous Shuttles* – led by City of Calgary, the project consists of a pilot test for an electric autonomous shuttle travelling at a low speed and capable of carrying 10 to 12 passengers between the Calgary Zoo and the Spark Science Centre. The intent of the project is to understand how an automated shuttle operates in Calgary, increase public awareness of the technology, gather feedback, and help inform and train highly qualified public sector officials in the area of CAVs [19].
- *National Smart Vehicle Demonstration and Integration Trial: Phase I* – led by Canadian Urban Transit Research and Innovation Consortium (CUTRIC), the project is intended to explore the integration of automated connected, low-speed, electrified shuttles (e-LSA) into various Canadian communities and jurisdictions as first-mile/last-mile transit applications [20].

In 2019, Transport Canada also awarded a contract to advance the development of a Canadian Security Credential Management System (SCMS) for connected vehicles. The SCMS will ensure the security and trust of CV communications. The purpose of the initiative is to identify Canadian stakeholder requirements for the SCMS and determine a recommended operational model for its deployment in Canada. A project has also been initiated with the University of Alberta, in Edmonton, to integrate SCMS into the ACTIVE CV test bed to assist in testing and preparing for the security and privacy of connected vehicles [21, 22].

As illustrated in Figure 2, to date, Ontario, Quebec, and Manitoba have made updates to provincial regulations to enable AV testing on public roads. Other provinces have also engaged in AV pilots, but these demonstrations have been restricted to private property sites [23]. It should also be noted that in the absence of specific regulations, CAVs are still allowed in other provinces as long as they meet Canadian Motor Vehicle Safety Standards (CMVSS). However, they may not be able to be operated

[1] https://www.tc.gc.ca/en/programs-policies/programs/program-advance-connectivity-automation-transporation-system.html

Figure 2: *AV-Related Activities in Canada (as of March 2020)*



in automated modes and are limited to either manual operation or the use of driver assistive technology (e.g., adaptive cruise control, lane keep assist).

Ontario has been a progressive province, updating its Highway Traffic Act and enacting Ontario Regulation 306/15: Pilot Project – Automated Vehicles in January 2016 to regulate the testing of automated vehicles on public roads. Further regulation updates in January 2019 have allowed for originally manufactured Level 3 AVs to be operated by the general public, with more advanced driverless AV testing being conducted as part of pilot projects under specific safety conditions, as well as truck platooning on defined corridors [24]. With permissive regulation in place, and provincial support through the Autonomous Vehicle Innovation Network (AVIN), there is an array of CAV pilots and research and development (R&D) initiatives in Ontario, involving partnerships between private industry, academics, and public agencies [25].

Quebec has also made strides in AV testing but has not formally enacted regulations or limited restrictions on vehicle operations, like Ontario. In 2018, the Quebec government amended the Highway Safety Code and introduced the definition of an AV. While this has created an opportunity to implement pilot projects to test AVs, it does not permit higher-level AVs on public roads if they are not part of an approved pilot project authorized by the Minister of Transport [26].

Manitoba is the third province to address AV testing through legislation. In March 2020, the Manitoba government enacted Bill 23, the Vehicle Technology Testing Act (Various Acts Amended), amending the province's Highway Traffic Act to enable the testing of CAVs on Manitoba's public roads [27]. The bill also amended the Insurance Act and the Manitoba Public Insurance (MPI) Corporation Act, covering registration and insurance requirements for vehicle testing organizations. The development of the corresponding regulations and a permitting system to implement the changes and authorize testing is now underway with stakeholder consultations [28, 29].

3.2.2 United States

As part of policy initiatives, the US Department of Transportation (USDOT) has published a number of reports and guidance documents, including:

- *Automated Driving Systems: A Vision for Safety 2.0,* which calls for industry, state and local governments, safety and mobility advocates, and the public to lay the path for the deployment of automated vehicles and technologies [30].
- *Preparing for the Future of Transportation: Automated Vehicles 3.0,* which builds on the above and expands the scope to cover all surface on-road transportation systems; it was developed through the input from a diverse set of stakeholder engagements [31].
- *Ensuring American Leadership in Automated Vehicle Technologies: Automated Vehicles 4.0,* which unifies collaborative efforts in automated vehicles for stakeholders and outlines past and present federal government efforts to address areas of concerns related to AV technologies [32].

Involvement in CAVs dates back nearly two decades when the USDOT engaged in research relating to V2V crash avoidance systems with automotive original equipment manufacturers (OEMs), and then formally in 2006 with the establishment of the Crash Avoidance Metrics Partnership (CAMP) to help OEMs develop and prototype V2V safety applications. The CAMP partnership includes Ford, General Motors, Honda, Hyundai-Kia, Volkswagen, Mercedes-Benz, and Toyota.

Since then, US government agencies, at all levels, have continued to sponsor pilot projects across the country to promote the evolution of the technologies and explore the impacts of connectivity and automation technology on road infrastructure. An early example includes the Michigan Department of Transportation (MDOT) and the University of Michigan Transportation Research Institute partnership for the testing of connected vehicles in Ann Arbor. This initiative began in 2012 and has evolved into the public-private partnership that is Mcity, a 13-hectare mock city and proving ground built to test CAVs on the University of Michigan's campus [33]. Another example is the USDOT Connected Vehicle Pilot Deployment Program, which supports the advancement of CV technologies through cooperative agreements for pilot deployments in New York City, Wyoming, and Tampa [34].

Other CAV pilots and demonstration projects are being completed under the umbrella of Smart City programs, such as Smart Columbus, which includes a CV environment and self-driving automated shuttles [35].

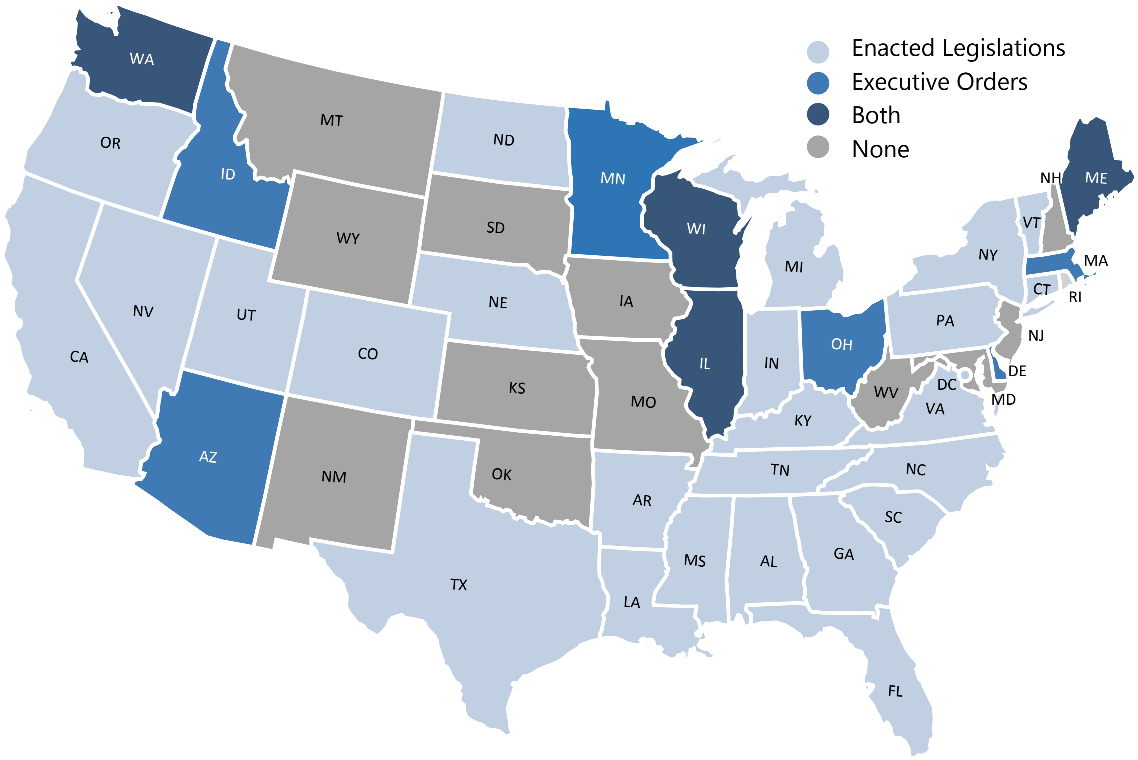
In addition to some of the public-private initiatives, industry players such as Uber, Lyft, Waymo (Google), Tesla, and other automotive OEMs and start-up aritifical intelligence (AI) companies are actively developing and testing CAVs on public roads and private campuses and tracks [36].

Automated Driving System (ADS) Demonstration Grants Program

The ADS Demonstration Grants Program is a stream of dedicated funding from the USDOT focusing on AV research and development. The funds are used for planning, research, and demonstration grants for automated driving systems and other driving automation systems and technologies. A total of USD $60 million is dedicated to demonstration grants that are designed to test the safe integration of ADS into on-road transportation systems [194].

Beginning in 2011 with the State of Nevada, legislation and policy frameworks have been developed and implemented across the majority of the United States to authorize and regulate AV operations (Figure 3) [37]. It should be noted that most of the states bordering Canada, particularly those with high-volume crossings, have active CAV policies.

Figure 3: *States with AV-related Legislation and Executive Orders (as of March 2020)*



The USDOT's Cooperative Automation Research Program is focused on measuring the efficiency and safety benefits of augmenting CAV technology capabilities to facilitate vehicle platooning, particularly as it relates to freight vehicles. Studies to date have investigated human factors, interactions with other vehicles, and how the loading weights of differently sized platoons affect bridges and infrastructures. SAE International, Toyota, Ford, and GM have established the Autonomous Vehicle Safety Consortium (AVSC). The membership has expanded to include Uber, Lyft, Honda, Volkswagen, and Daimler. The AVSC leverages the expertise of its membership and engages government and industry groups to establish a set of guiding safety principles with respect to AVs to help inform standards development [38]. The AVSC conducts a series of workshops and stakeholder engagement to gather the perspectives of various key players in the industry. The first, and currently the main, activity output from the AVSC will be a roadmap of priorities for manufacturers, developers, and integrators of CAV technology, with a focus on data sharing, vehicle interaction with other road users, and safety testing [39].

3.2.3 Europe

Many European countries have established legislation or policy frameworks governing AV operations, with the Netherlands, Germany, and the United Kingdom (UK) being key examples.

The European Road Transport Research Advisory Council (ERTRAC) has established a technical working group with a focus on CAVs. The working group developed a *Connected and Automated Driving Roadmap* that identifies challenges and strategies to address on topics related to user awareness, human factors, socio-economic assessments, safety validation, new mobility services, big data, physical and digital infrastructure, in-vehicle technology, and technology deployment [40].

The British Standards Institution (BSI), Transport Systems Catapult, and the Centre for Connected and Autonomous Vehicles jointly developed the *Connected and Autonomous Vehicles: A UK Standards Strategy* report that focuses on mapping the international standards landscape for CAVs, understanding the key challenges and opportunities facing UK organizations working on CAVs, and identifying areas where standardization may be needed to support the deployment of CAVs in the UK [41].

3.2.4 Australia

The National Transport Commission (NTC), an independent body that develops regulation for Australia's roads and other transport systems, has been tasked with establishing a national law for AVs, to help guide manufacturers and operators looking to introduce the technology to Australia. In October 2019, the NTC published an *Automated Vehicle Program Approach* document which outlines the current AV reform program, including purpose, work completed to date, further planned reforms, and interaction with other agencies [42]. Other NTC guidelines developed by the NTC include *National Enforcement Guidelines for Automated Vehicles* and *Guidelines for Trials of Automated Vehicles in Australia* [43].

The state of New South Wales recently developed a five-year *Connected and Automated Vehicles Plan* that provides clear goals and actions to fulfill the NSW Future Transport vision. It puts actions in place regarding laws and safety, infrastructure and planning, transport services, data and customer readiness. The strategies are developed to embrace the technology as well as address potential challenges, such as cybersecurity and ensuring safe interactions between AVs and other vehicles using the road [44].

Austroads, an organization of road transport and traffic agencies in Australia and New Zealand, led the development of the *Infrastructure Changes to Support Automated Vehicles on Rural and Metropolitan Highways and Freeways* study that investigated road asset standards and their relevance to CAV operations. Findings showed that the reasons for limited development of asset standards are due to the lack of clear guidance and cost considerations. The study provides some initial guidance on thresholds for line marking width and reflectivity and sign maintenance, to the benefit of both human drivers and CAVs [45].

3.2.5 Asia

Many countries in Asia have initiated plans to prepare for CAV technology on their roads, focusing primarily on vehicle testing programs. In 2018, the Chinese government approved AV tests on public roads, regulating the process of pilot testing [46]. Shanghai also created a 100-square-kilometre National Intelligent Connected Vehicle Pilot Zone for closed-course testing of autonomous vehicles [47].

Singapore opened the Centre of Excellence for Testing and Research of Autonomous Vehicles in 2017, including elements of an urban environment to allow for realistic testing. Data gathered from this facility has assisted with the development of the Government's Technical Reference 68, which is a set of national standards developed to promote the safe deployment of fully driverless vehicles in Singapore [48]. The Singapore Land Transport Authority is also leading CAV testing and planning for deployment through the Singapore Automated Vehicle Initiative (SAVI) [49]. In 2017, the Singapore Ministry of Transport introduced a series of Autonomous Vehicle Rules for pilot testing trials. An amendment to the Road Traffic Act now recognizes that motor vehicles may no longer require human drivers [50].

In South Korea, a 5G technology equipped experimental city (K-City) was developed to test AVs, with a focus on testing and commercializing Level 3 AVs [48]. The South Korean Ministry of Land, Infrastructure and Transport also plans to create detailed maps for AVs through its C-ITS project for enhancing the safety of AVs [51].

3.2.6 Summary

Countries across North America, Europe, Australia, and Asia are actively preparing for CAVs. Activities range from the development of guidance documents and frameworks, to legislation and regulations, as well as encouragement of R&D and advancement of the industry to ensure safe testing and operation of CAVs

"Coordinated efforts relating to CAV codes and standards moving forward will play a large role in the safe development and operation of CAV technologies."

across both the private and public sectors. With respect to Canada, great strides have been made in the past five to six years in taking a position on CAVs and leveraging the early work accomplished in the United States and other countries to mitigate potential risks.

Although there have been efforts to date in Canada and internationally, there is considerable work remaining. Coordinated efforts relating to CAV codes and standards moving forward will play a large role in the safe development and operation of CAV technologies. Harmonization of international codes and standards, especially within regions with shared borders such as in North America, will play a critical role in working towards the consistent development of the technology, improving opportunities for interoperability, and simplifying requirements across the automotive and technology sectors.

4 Standards Landscape for CAV Technologies

4.1 Overview

In general, standards are intended to support the safety, compatibility, and interoperability of products across the industries, regardless of the supplier, with consistent interactions and processes. Standards provide guidance for communications and data transmission, as well as minimum requirements for safety, security, and privacy.

From a technical perspective, the CAV ecosystem includes inter-related industries. The automotive industry, including OEMs, small and medium-sized enterprises (SMEs), and aftermarket providers, relates to vehicle and on-board equipment; the ITS industry relates to information and communication for advanced applications and operations; the telecommunications industry relates to supporting the exchange of data and information; and the physical infrastructure industry relates to roadway and bridge design, lane markings, signage, and land use.

CAV technologies are rapidly evolving and relevant standards are being, or have been, developed by a wide range of international, global, and national SDOs. Examples of the main SDOs leading the development of CAV-related standards include the following:

- International Organization for Standardization (ISO)
- International Electrical and Electronics Engineers (IEEE)
- European Committee for Standardization (CEN)
- European Telecommunication Standards Institute (ETSI)
- SAE International
- National Transportation Communications for ITS Protocol (NTCIP)
- National Electrical Manufacturers Association (NEMA)

- ASTM International
- International Electrotechnical Commission (IEC)
- Institute of Transportation Engineers (ITE)
- American Association of State Highway and Transportation Officials (AASHTO)

NOTE: See Appendix A – Relevant Standards for further descriptions of each SDO.

Many of these SDOs have active technical committees and working groups that are relevant to CAVs, either directly or indirectly, and help oversee the development and evolution of relevant standards and protocols. For example, ISO has three technical committees (TCs) relating to the standardization of road vehicles and their equipment (TC22), the standardization of ITS (TC204), and the standardization of geographic information (TC211). TC204 itself has 12 active working groups with their own focus areas. A summary of relevant SDO committees and groups is provided in Table 1, and further details are provided in Appendix B – Relevant Technical Committees and Working Groups. Examples of key committees and working groups include:

- ISO Technical Committee 204 Intelligent Transport Systems and Technical Committee 22 Road Vehicles
- CEN Technical Committee 301 Road Vehicles and Technical Committee 278 Intelligent Transport Systems
- SAE International Technical Committees on Communications (V2X) and Technology (DSRC, C-V2X) and On-Road Automated Driving (ORAD)

Technical committees and working groups include international member participation. There is active coordination with other groups and activities, as well as partnerships and co-participation in development efforts. Using TC 204 as an example, there are currently 29 participating countries and 30 observing countries, as well as active liaisons with other SDOs and organizations (e.g., IEEE, SAE) [52]. Section 4.2 provides an overview of many of the harmonization efforts that are ongoing in the industry.

Relevant standards relating to CAVs were reviewed and categorized into the following five groups:

- **Digital Infrastructure –** standards focused on how equipment stores and exchanges data to support intelligent transportation services.
- **Physical Infrastructure –** standards relating to the physical roadway infrastructure upon which the transportation system operates.
- **Usage, Human-Machine, and Accessibility –** standards focused on use cases, accessibility needs, and human-machine interfaces for CAVs.
- **Cybersecurity, Privacy, and Data Training –** standards that define the administrative, physical, and technical actions related to the security, integrity and privacy of data and networks, as well as algorithm training.
- **Vehicle Aspects –** standards specifically relating to vehicles, including those relating to automation, connectivity, and safety.

Summaries of the key findings, by category, are included in Sections 4.3 to 4.7, and individual standards and protocols that were assessed as relevant are summarized in Appendix A – Relevant Standards.

4.2 Harmonization Efforts

Harmonization of codes and standards is critical to ensure the consistent development and implementation of CAV and related technologies. Harmonization supports common technical understanding and designs, as well as interoperability of systems across borders.

In 2009, the United States and the European Commission (EC) signed an Implementing Arrangement to ensure the interoperability of cooperative systems worldwide and reduce the development and adoption of redundant standards [53]. Through this agreement, the Standards Harmonization Working Group (HWG) provides a basis for EU-US harmonization efforts along the following five tracks:

- High-level assessment (completed in 2011)
- Agreement on governmental harmonization principles (final draft)

Table 1: *Summary of Key Technical Committees and Active Working Groups*

Technical Committee	Working Group/ Subcommittee	Area/Scope
ISO TC 204 INTELLIGENT TRANSPORT SYSTEMS	WG 1	Architecture
	WG 3	ITS database technology
	WG 5	Fee and toll collection
	WG 7	General fleet management and commercial/freight
	WG 8	Public transport/ emergency
	WG 9	Integrated transport information, management and control
	WG 10	Traveller information systems
	WG 14	Vehicle/roadway warning and control systems
	WG 16	Communications
	WG 17	Nomadic devices in ITS Systems
	WG 18	Cooperative systems
	WG 19	Mobility integration
ISO TC 222 ROAD VEHICLES	SC 31	Data communication
	SC 32	Electrical and electronic components and general system aspects
	SC 33	Vehicle dynamics and chassis components
	SC 34	Propulsion, powertrain, and powertrain fluids
	SC 35	Lighting and visibility
	SC 36	Safety and impact testing
	SC 37	Electrically propelled vehicles
	SC 38	Motorcycles and mopeds
	SC 39	Ergonomics
	SC 40	Specific aspects for light and heavy commercial vehicles, busses, and trailers
	SC 41	Specific aspects for gaseous fuels
CEN TC 301 ROAD VEHICLES	WG 6	M/421 vehicle OBD, repair and maintenance information
	WG 7	Supplementary grip devices
	WG 11	Safety of roller brake testers
	WG 14	Electricity fuel labelling
	WG 15	Safety of machines for mounting and demounting vehicles tires
	WG 16	Performance assessment of the portable mission measuring systems (PEMS)
CEN TC 278 ROAD VEHICLES	WG 1	Electronic fee collection and access control (EFC)
	WG 3	Public transport (PT)
	WG 4	Traffic and traveller information (TTI)
	WG 5	Traffic control (TC)
	WG 7	ITS spatial data
	WG 8	Road traffic data (RTD)
	WG 13	Architecture and terminology
	WG 14	After theft systems for the recovery of stolen vehicles
	WG 15	eSafety
	WG 16	Cooperative ITS
	WG 17	Urban ITS

- Gap/overlap analysis for standard needs (planning underway)
- Facilitation of harmonization of specific standards (ongoing)
- Planning future cooperation (ongoing)

US Harmonization Efforts

The USDOT has established the Joint Declaration of Intent on Research Cooperation in Cooperative Systems with the European Union (EU) and has a joint pledge with the European Commission Information Society and Media Directorate to work together to identify the research areas that would benefit from a harmonized approach and be addressed by coordinated or joint research [56].

A majority of HWG activities take place through flexible organizational constructs called harmonization task groups (HTGs) that provide focused analysis leading to the harmonization and/or joint development of specific standards, protocols, and policies [54]. An example of work completed to date includes the harmonization of vehicle safety messages, specifically the US Basic Safety Message (BSM) and the EU Cooperative Awareness Message (CAM).

Dating back to 2012, the USDOT's ITS Joint Program Office (ITS JPO), under the management of the ITS Architecture and Standards Programs, led the development of a focused Connected Vehicle Reference Information Architecture (CVRIA) to provide a framework to support pilot programs and initiatives and to help identify gaps and needs for CV-related standards. The CVRIA evolved with the industry, culminating with version 2 in 2017, which was subsequently incorporated into the more comprehensive Architecture Reference for Cooperative and Intelligent Transportation (ARC IT) [55].

As mentioned previously, ITS Canada recently initiated an update of the ITS Architecture for Canada, which will realign with the US ARC-IT and include the incorporation of the CVRIA [18]. The next update for the US ARC-IT, planned for 2020, is expected to greatly expand its mapping to international standards, which will automatically be adopted for the Canadian version.

Also led by the ITS JPO, and in parallel to the architecture efforts, the ITS Standards and Architecture Harmonization program has teamed up with SDOs and public agencies to accelerate the development of open, non-proprietary communications interface standards to support ITS application development and deployment. To date, nearly 100 standards have been developed under the program. Through the program, the USDOT also participates in international standards harmonization activities in an effort to ensure that standards provide connectivity among vehicles and between vehicles and infrastructure [56].

The Canada-US Regulatory Cooperation Council (RCC) developed a Connected Vehicles Work-Plan. Transport Canada and the USDOT are working on a coordinated and collaborative development effort for V2V and V2I communications technology and applications for vehicles, including architecture and standards to support interoperable deployment. This includes joint planning and priority development, as well as collaborative research projects and the exchange/sharing of information to support analysis, architecture, and standards development [57].

Additionally, the RCC Motor Vehicles Working Group is exploring existing and new motor vehicle safety standards work plans. It is a joint venture between the Motor Vehicle Safety group of Transport Canada and the US National Highway Traffic Safety Administration (NHTSA) designed to facilitate the alignment of motor vehicle safety standards [58].

The United Nations has also established a Working Party on Automated/Autonomous and Connected Vehicles (WP.29 GRVA). This Working Party is part of the World Forum for Harmonization of Vehicle Regulations. Its

"The primary technology options for CAV connectivity and V2X communications include dedicated short-range communications (DSRC) and cellular communications."

priorities include activities related to research and policy on safety and security of vehicle automation and connectivity, advanced driver assistance systems, and dynamic driving tasks (e.g., steering and braking) [59].

4.3 Digital Infrastructure

4.3.1 Technologies

The primary technology options for CAV connectivity and V2X communications include dedicated short-range communications (DSRC) and cellular communications.

DSRC is a short-to-medium range wireless technology designed specifically for vehicle-related uses and is industry-proven through a wide range of applications, including tolling and transit signal priority.

Cellular connections, commonly referred to as cellular vehicle-to-everything (C-V2X) may be designed to use cellular communication technologies, including:

- 4G LTE (Fourth-Generation Wireless Long-Term Evolution) is the current standard for wireless broadband communication, with wide network coverage in Canada. Two complementary communication modes exist [60].
- PC5 Interface – Direct (side link) communication for V2V, V2I, and V2P operating in ITS bands independent of a cellular network. This is information (e.g., location, speed) communicated within a short range (<1 km).
- Uu Interface – Network (Up/Downlink) communication for V2N operating on traditional mobile bands. This is information (e.g., accident detection) communicated over a long range (>1 km).
- 5G (Fifth-Generation Wireless) is the next generation of wireless broadband communication, with promises of lower latency and increased bandwidth and reliability over 4G LTE.

3GPP

The 3rd Generation Partnership Project (3GPP) unites telecommunications standard development organizations, providing them with a stable environment to produce reports and specifications. The original scope of 3GPP (in 1998) was to produce technical specifications and technical reports for a 3G Mobile System based on an evolved Global System for Mobile (GSM) cellular networks and has been amended to include both 4G LTE and 5G. The specifications developed as part of 3GPP also allow for non-radio access to the core network and the capability for interworking with non-3GPP networks [195].

It should be highlighted that C-V2X uses cellular *technologies in the 5.9GHz band*, as opposed to *networks in traditional cellular bands*, and does not require towers. Therefore, it is viewed as a direct competitor to DSRC. The 5G Automotive Association (5GAA) has over 130-member companies from the automotive and information and communications technology (ICT) industries, and actively advocates that connectivity be achieved through 5G-based C-V2X technology [61].

It should also be noted that DSRC and C-V2X are not interoperable technologies and there are doubts whether they could ever work together effectively, as translation technology would worsen latency and diminish quality of transmission.

Due in part to its proven and demonstrable performance, the NHTSA in 2014 initiated the rulemaking process for a mandate requiring that all vehicles sold in 2021 be equipped with DSRC-based V2V/V2X technology, or similar technology that met minimum performance requirements. The federal administration has not acted on the proposal [62].

Announcements in November 2019 from the FCC on proposed changes to spectrum allocation added to the uncertainty by referencing C-V2X, as opposed to referencing DSRC as it had in 2016. The FCC sought comments on the proposal in early 2020.

4.3.2 Spectrum Allocation

In 1999, the Federal Communications Commission (FCC) allocated 75 MHz of the 5.9GHz radiofrequency band to DSRC for use with ITS [63] and all seven channels are being actively utilized for DSRC-based deployments. The FCC sponsored interference testing associated with the allocated spectrum, and there is also private sector research testing C-V2X technology using the band [64].

The FCC has recently announced its intentions to reallocate the lower 45MHz of the 5.9GHz band for unlicensed uses, such as Wi-Fi [65]. This has led to anxieties from transportation stakeholders over concerns that decreasing the spectrum intended for critical safety-related applications, particularly when noise/interference at the edges is considered, could compromise the bandwidth availability and quality [64]. Innovation, Science, and Economic Development Canada (ISED) has historically followed the US FCC in terms of harmonizing its spectrum allocations, which it did in 2004 when it allocated similar 5.9GHz spectrum for use by DSRC for ITS [66]. If and when the United States reallocates the 5.9GHz band, or commits to either DSRC or C-V2X, it is not known whether Canada will react similarly, or how quickly [67].

4.3.3 Communications

As with most technical industries, the communications and operations of CAVs make use of international network and communications standards (e.g., the IEEE 802 family, the Internet Protocol suite), and where necessary develop standards as necessary for specific CAV applications.

ISO TC 204 has been active in the development of a Communications Access for Land Mobiles (CALM) family of standards, which specify a common architecture and network protocols and communications interface definitions for wireless communications using different media technologies (e.g., DSRC, C-V2X). The CALM standards are explicitly designed to support media-independent handover (MIH), addressing CAV needs associated with moving vehicles [52].

The IEEE 1609 Family of Standards for Wireless Access in Vehicular Environments (WAVE) collectively enable secure DSRC-based V2X wireless communications, and support interoperable and homogeneous communications interfaces between different automotive and device manufacturers [68].

SAE have a pair of standards, J2945 and J3161, which specify performance requirements for use cases, such as adaptive cruise control, for both DSRC and C-V2X, respectively [69, 70].

The OmniAir certification programs are multi-protocol testing programs that ensure certified devices and systems are interoperable and perform in accordance to established requirements. OmniAir provides certification for tolling devices and CVs, accreditation to members as OmniAir authorized test labs, and qualifies the test equipment used by test labs for device certification.

In particular, the OmniAir certification program for CVs and related devices (e.g,. OBUs/RSUs) allows for the measurement of compliance with specifications and ensures interoperability among other products and services that meet OmniAir specifications [71]. The Government of Quebec and Propulsion Quebec (the cluster for electric and smart transportation) in collaboration with Transport Canada successfully hosted a five-day OmniAir PlugFest in Blainville, QC, in May 2019.

OmniAir – CAV Technology Certification

The OmniAir Consortium was founded in 2004 and is a leading industry association promoting interoperability and certification for CAVs, ITS, and transportation payment systems. The consortium members include public agencies, private companies, research institutions, and independent test labs. In addition to advocacy for national certification programs, OmniAir provides its members with opportunities to collaborate and advance the deployment of standards-based interoperable transportation technology for improved safety and efficiency [196].

4.3.4 Data Management and Messaging

Specifications for data formats and content relating to CAVs generally connect to specific use cases, and as such there are a number of standards relevant to CAV applications and operations. SAE is the main SDO active with data and message standards, such as J2735, which relates to messages using DSRC/WAVE and J3016, which relates to automated driving systems [7, 72].

Data and messaging standards, such as those specified by SAE, may specify mandatory and optional elements. Supporting standards may provide guidance based on needs and requirements (e.g., particular to a use case) and define what messages and data elements should be included, which may include reclassifying optional elements as mandatory. This is the case with ISO/TS 19091, which focuses on V2I applications at signalized intersections, and specifies requirements for signal phase and timing (SPaT), MAP, signal status message (SSM), and signal request message (SRM) data elements [73].

The Roadside Unit (RSU) Working Group of the NTCIP is currently developing NTCIP 1218 V01, which will specify protocol and data definitions to allow central interfaces (e.g., from a Traffic Management Centre) with RSUs, for a variety of purposes, from configuration to data collection. RSUs may be configured to collect BSM data from CAVs, integrate with traffic signal controllers, transmit information to CAVs (e.g., alerts, SPaT, Map), as well as perform other functions [74].

The USDOT has also made progress in defining design requirements and user needs of RSUs through the RSU Specification 4.1. ITE is an SDO that has been designated by the USDOT to develop ITS standards. USDOT is currently working on converting the RSU Specification 4.1 into an industry-based consensus RSU standard that is supportive of interoperability for infrastructure owners and operators, and ensures the ability to connect to technology developed by OEMs and other RSU message users [75, 76].

NEMA recently commissioned the development of NEMA TS 10 – Connected Vehicle Infrastructure-Roadside Equipment, which is a technical specification that harmonizes and accelerates the deployment of CV roadside infrastructure technology. There are various types of roadside devices that are covered under NEMA TS 10, including traffic signals, crosswalk signs, flashing safety beacons, ramp meters, and other electronic traffic control equipment. A key component of a CV ecosystem is the ability for vehicles and infrastructure to effectively communicate with each other regardless of device type or its underlying technology. With NEMA TS 10, DSRC and C-V2X can operate together in the same spectrum through either a dual-mode or dual-active roadside CV device [77].

4.3.5 Relevant Standards and Other Documents

Table 2 provides a summary of relevant digital infrastructure standards, relating to protocols and data messaging to support the V2X communications.

Table 2: *Summary of Relevant Digital Infrastructure Standards*

Standard	Title / Description
ASTM F3200	Standard Terminology for Driverless Automatic Guided Industrial Vehicles
ETSI 302 895	Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Local Dynamic Map (LDM)
IEEE 802.11	Local Area Network (LAN) and Metropolitan Area Network (MAN) Standards
IEEE 1609	Wireless Access in Vehicular Environments (WAVE)
ISO 14296	Intelligent transport systems – Extension of map database specifications for applications of cooperative ITS
ISO 14825	Intelligent transport systems – Geographic Data Files (GDF) – GDF5.0
ISO 22951	Data dictionary and message sets for pre-emption and prioritization signal systems for emergency and public transport vehicles (PRESTO)
ISO/TS 17424	Intelligent transport systems – Cooperative ITS – State of the art of Local Dynamic Maps concepts
ISO/TS 19091	Intelligent transport systems – Cooperative ITS – Using V2I and I2V communications for applications related to signalized intersections
ISO/TS 19321	Intelligent transport systems – Cooperative ITS – Dictionary of in-vehicle information (IVI) data structures
NEMA TS 10	Connected Vehicle Infrastructure-Roadside Equipment
NTCIP 1211 V02	Object Definitions for Signal Control and Prioritization (SCP)
NTCIP 1218 V01	Object Definitions for Roadside Units (RSUs)
SAE J2945	DSRC Systems Engineering Process Guidance
SAE J3161	C-V2X Deployment Profiles
SAE J3186	Application Protocol and Requirements for Maneuver Sharing and Coordinating Service
SAE J2735	Dedicated Short-Range Communications (DSRC) Message Set Dictionary
SAE J2944	Operational Definitions of Driving Performance Measures and Statistics
TCP/IP	Transmission Control Protocol/Internet Protocol
UDP	User Datagram Protocol
Wi-Fi Alliance	Wi-Fi Certification for Wireless Devices that Implement IEEE 802.11 Specifications and Protocols

4.4 Physical Infrastructure

Standards as they relate to physical roadway infrastructure have been in place for decades, but for the most part are based on the needs and requirements of conventional vehicles with a driver responsible for all driving tasks.

To automate the driving tasks, it is critical for CAVs to sense and understand their surroundings. Increases in levels of automation and expansion of CAV operating domains are likely to require national consistency and changes to roadway infrastructure, such as to make lane markings easy to detect (e.g., widen, increase contrast) and signs easier to understand (e.g., ensure consistency, add digital elements) [45]. As sensor and advanced analytics technologies continue to evolve, and as the CAV industry is advancing, infrastructure standard requirements may be higher in the short term than in the long term.

The US Federal Highway Administration (FHWA) and the Transportation Association of Canada (TAC) are responsible for maintaining the Manual on Uniform Traffic Control Devices in their respective countries: the MUTCD in the United States and the MUTCDC in Canada [78, 79]. These documents offer guidance on traffic control device types, use, and placement for a variety of road authorities and are widely adopted by jurisdictions across each of the nations. In general, the guidance presented in the MUTCDC and MUTCD is very similar in nature, although there are a number of noted differences. For instance, the MUTCD has a larger inventory of warning and regulatory signs for designers and provides a much more extensive guidance on signage for toll roads and managed lanes, in comparison to the MUTCDC. There are also differences in the warning and pedestrian crossing signage guidance used at roundabouts, as well as a few pedestrian signals used in the US that are included in the MUTCD but that are not commonly used in Canada (e.g., hybrid beacons). The MUTCD also contains more details on signage and pavement markings for rail crossings, which is limited in the MUTCDC as this information is contained in the Transport Canada Grade Crossing Guidelines. To date, the MUTCD and MUTCDC have focused on the needs of manually driven vehicles, and have not been updated to specifically address needs associated with CAVs.

The US National Committee on Uniform Traffic Control Devices (NCUTCD) assists in the development of standards, guides, and warrants for traffic control devices and practices used to regulate, warn, and guide traffic on streets and highways and provides recommendations to the FHWA and other appropriate agencies [80]. The NCUTCD is consulting with industry and investigating CAV-related needs and potential required changes to the MUTCD. The NCUTCD is actively considering opportunities and strategies for pavement marking and signage uniformity, as well as engaging with the auto industry (e.g., vehicle manufacturers) and highway industry (e.g., AASHTO, FHWA) to understand their expectations on roadway infrastructure. There are also considerations of CAV impacts on geometric design that are being discussed at various consultations and committee meetings. These discussions have indicated that the potential impacts of CAVs on geometric design are still unknown at this time. The geometric design guidance will not change in the near future, with an enhanced focus on improving line painting and signage used by current CAV technologies. The NCUTCD presented a summary of its efforts and latest findings at TAC's Spring Technical Meetings in 2019, as TAC is also beginning to investigate what changes may be required for the MUTCDC to accommodate CAVs.

SAE International's On-Road Automated Driving (ORAD) committee is investigating infrastructure needs related to automated driving as part of a task force. The scope and purpose of this task force is to develop infrastructure information to support AV technologies, while also maintaining human driver needs during the transitional phases. There is a diverse group of participants that are providing input to this work, including infrastructure organizations, automotive industry players, and academia. Current activities of this task force include working with the Behaviors and Maneuvers Task Force, as well as drafting a survey to gather information from stakeholders regarding infrastructure needs, such as road surface requirements and lane markings [81].

In the United States, the Transportation Research Board (TRB) undertook a National Cooperative Highway Research Program (NCHRP) project to develop a consensus-based Connected Roadway Classification System (CRCS) Development project for AASHTO (NCHRP 20-24(112)). The project consisted of developing a framework for use by state and local transportation agencies, as well as metropolitan planning organizations that are implementing CAV compatible infrastructure. Feedback from transportation asset owners, OEMs and private sector stakeholders was solicited to develop a CRCS to assess the infrastructure and to incorporate new knowledge that emerges on how infrastructure can support CAV operations. The research team identified three approaches to classify roadway infrastructure improvements to support CAVs. The first approach was to increase a vehicle's ability to connect to the infrastructure and other vehicles (i.e., talk to the road). The second approach was to support the safety and operation of AVs (i.e., see the road). The third approach was to change roadway infrastructure to create an operational design domain (ODD) that supports improved vehicle safety, automation, and operation (i.e., simplify the road) [82].

The EU has commissioned a new project, INFRAMIX, with the objective of preparing road infrastructure with specific adaptations to support both conventional vehicles and new innovations in connected and automated transportation [40]. A component of this project includes classifying and harmonizing the capabilities of road infrastructure to support and guide CAVs, which would otherwise be limited by the range and capability provided by on-board sensors. A classification scheme, similar to the SAEJ3016 levels of automation, has been developed following the work from INFRAMIX [40, 83].

The levels of classification, known as Infrastructure Support Levels for Automated Driving (ISAD), can be assigned to parts of a transportation network to give CAV operators a sense of the readiness and support provided to CAVs on specific segments of the road [83]. An adaptation of the ISAD levels are shown in Figure 4.

Figure 4: *Infrastructure Support Levels for Automated Driving (ISAD) [83]*

Digital Infrastructure			Conventional Infrastructure	
LEVEL A **COOPERATIVE DRIVING**	**LEVEL B** **COOPERATIVE PERCEPTION**	**LEVEL C** **DYNAMIC DIGITAL INFORMATION**	**LEVEL D** **STATIC DIGITAL INFORMATION/ MAP SUPPORT**	**LEVEL E** **COVENTIONAL INFRASTRUCTURE/ NO AV SUPPORT**
Based on the real-time information on vehicles movements, the infrastructure is able to guide AVs (groups of vehicles or single vehicles) in order to optimize the overall traffic flow.	Infrastructure is capable of perceiving microscopic traffic situations and providing this data to AVs in real-time.	All dynamic and static infrastructure information is available in digital form and can be provided to AVs.	Digital map data is available with static road signs. Map data could be complemented by physical reference points (landmarks signs). Traffic lights, short term road works and VMS need to be recognized by AVs.	Conventional infrastructure without digital information. AVs need to recognise road geometry and road signs.
Digital map with static road signs	*Digital map with static road signs*	*Digital map with static road signs*	*Digital map with static road signs*	*Digital map with static road signs*
VMS, warnings, incidents, weather	*VMS, warnings, incidents, weather*	*VMS, warnings, incidents, weather*	*VMS, warnings, incidents, weather*	*VMS, warnings, incidents, weather*
Microscopic traffic Situation	*Microscopic traffic Situation*	*Microscopic traffic Situation*	*Microscopic traffic Situation*	*Microscopic traffic Situation*
Guidance: speed, gap, lane advice	*Guidance: speed, gap, lane advice*	*Guidance: speed, gap, lane advice*	*Guidance: speed, gap, lane advice*	*Guidance: speed, gap, lane advice*

4.4.1 Relevant Standards and Other Documents

Table 3 provides a summary of manuals, policies, and guidance documents that provide standards and direction on requirements for the design of roadways and related physical infrastructure.

Table 3: *Summary of Relevant Physical Infrastructure Manuals, Policies, and Guidance Documents*

Document
AASHTO Policy on Geometric Design of Highways and Streets
AASHTO Roadside Design Guide
FHWA Manual on Uniform Traffic Control Devices (MUTCD)
NCHRP 20-24(112) Connected Roadway Classification System Development (prepared for AASHTO)
TAC Geometric Design Guide for Canadian Roads
TAC Manual on Uniform Traffic Control Devices for Canada (MUTCDC)

4.5 Usage, Human-Machine, and Accessibility

4.5.1 Usage

Integrating CAVs with the road environment and urban fabric depends on guidelines focused on advising and expanding planning initiatives to exploit the benefits of the technology, while minimizing the negative impacts. Strategies and readiness guidelines have been developed by public transportation agencies around the world to identify the steps and areas of focus needed to smoothly integrate CAVs onto public roads. For example, the CAV Readiness Plan for the Greater Toronto and Hamilton Area (GTHA) and Kitchener/Waterloo Corridor provides public agencies with a set of guidelines and programs to start preparations for CAVs and for identifying areas of focus to address CAV challenges and benefits in transportation planning initiatives, congestion management strategies, and policy development.

4.5.2 Human-Machine

The interaction between the vehicle operator and the automated driving system, also known as the human-machine interface, is another important area of focus. Standards have been developed, such as SAE J3016, that clearly identify the role of the human operator/occupant and the automated driving system, at various levels of automation. Identifying and understanding the distinct roles of the driver and the automated driving system of a vehicle is critical to maintain the safe operation of vehicles on the road.

4.5.3 Accessibility

It is also important that accessibility across the transportation network and across vehicles be developed and maintained with the advancement of CAVs and other technologies. CAV technology can introduce mobility opportunities to those who otherwise may not be able to drive independently due to age or disability. When used for purposes of transporting individuals with mobility assistive devices (e.g., wheelchairs), CAVs will need to be designed in accordance to existing standards surrounding such motor vehicles. Another important accessibility consideration for CAVs is their ability to effectively interact with all users, as well as all persons in the road environment, including those using mobility devices or who have hearing and visual impairments. Transport Canada's ACATS program has dedicated funding to studying accessibility needs of road users, including vulnerable road users with various accessibility challenges, such as sight loss, hearing loss, and mobility needs. CNIB, in partnership with Western Michigan University and the University of Toronto, was awarded ACATS funding for a project to develop an understanding of how pedestrians with vision impairment may be impacted by CAVs on roadways and how to ensure a safe interaction. This project consisted of a global best practice literature review on mobility and transportation for individuals with sight loss, a stakeholder survey, and stakeholder outreach and engagement. Key recommendations from CNIB and this research project emphasize the importance for accessibility considerations to be made in early phases of design, and system development and standards should reflect these requirements [17].

"CAV technology can introduce mobility opportunities to those who otherwise may not be able to drive independently due to age or disability."

The Alliance of Automobile Manufacturers in the United States organized a three-part workshop in 2019 on the subject of AVs and increased accessibility. The intent was to explore the accessible passenger and vehicle transportation needs for individuals with disabilities and for older adults. The workshops also explored the legal and policy landscape as it relates to accessibility needs. A series of recommendations were developed as outcomes of the workshops, ranging from identifying needs for collaboration between members of the transportation ecosystem, needs for inclusive AV design considerations, legal frameworks, and specific equipment and technology requirements, such as human-machine interface for cognitive and sensory disabilities, as well as wheelchair tiedown and occupant restraint systems [84].

There have been studies investigating the need for AVs to communicate their presence and intent to pedestrians and others in the road environment, such as use of lights to signal to pedestrians and other vulnerable road users that they have been detected and the vehicle is aware of their presence [85]. This illustrates the need for consideration of accessibility for all, as a consequence of relying solely on lights would lead to accessibility issues with those with vision impairment.

4.5.4 Relevant Standards and Other Documents

Table 4 provides a summary of relevant standards, which primarily focus on the testing and operations of in-vehicle human-machine interfaces. As demonstrated, there are limited standards relating to accessibility for, and interaction with, pedestrians and other road users.

Table 4: *Summary of Relevant Usage, Human-Machine, and Accessibility Standards*

Standard	Title / Description
ASTM F3244	Standard Test Method for Navigation: Defined Area
ASTM F3265	Standard Test Method for Grid-Video Obstacle Measurement
SAE J1725	Structural Modification for Personally Licensed Vehicles to Meet the Transportation Needs of Persons with Disabilities
SAE J2395	ITS In-Vehicle Message Priority
SAE J3016	Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles
SAE J3077	Definitions and Data Sources for the Driver Vehicle Interface (DVI)
SAE J3114	Human Factors Definitions for Automated Driving and Related Research Topics
SAE J3171	Identifying Automated Driving Systems – Dedicated Vehicles (ADS-DVs) Passenger Issues for Persons with Disabilities

4.6 Cybersecurity, Privacy, and Data Training

4.6.1 Cybersecurity and Privacy

Many security and privacy standards, policies, and procedures are relevant to CAV applications to prevent malicious acts and to protect privacy.

Both the USDOT and ETSI have programs to develop security credential management systems (SCMS) to ensure secure V2X communications in the United States and the European Union, respectively [86]. In the United States, CAMP has developed a Proof of Concept SCMS, and in 2017 a SCMS Operational Environment (production-ready) became available and has been used by connected vehicle pilot sites [87]. In Europe, the European Commission (EC) has implemented a pilot to test operations of a European C-ITS security credential management system.

Both the US and EU systems are designed as purpose-built public key infrastructure (PKI) solutions, where safety and mobility messages are authenticated and validated, without personal or equipment-identifying information [87]. SCMS is not a standard; however, the supportive backend technology is currently being standardized under IEEE 1609.2.1. There are still differences in its designs and implementations – the United States uses a group of electors, while Europe uses a single trust list manager to add/remove certificate authorities. However, both SCMS solutions are designed in compliance with the secure message formats specified in IEEE 1609.2 Standard for WAVE [68].

Transport Canada has recently initiated the development of a nationally coordinated SCMS in Canada. The process includes a review and analysis of both the US and European systems, with consideration for security, privacy, sovereignty, interoperability affordability, and accessibility [22, 21].

In 2000, the Government of Canada passed legislation known as the Personal Information Protection and Electronic Documents Act (PIPEDA). This serves as the federal privacy law for private sector organizations and establishes the base rules for the handling of personal information, which is applicable to automotive and technology companies developing technology that increasingly handles personal data [88].

In 2019, the Office of the Privacy Commissioner of Canada sponsored a project by the Ontario Technology University to develop a Privacy Code of Practice for CAVs. The project aims to build consensus amongst stakeholders regarding the development of a code that provides enhanced security for Canadians with respect to CAVs, while also providing clear rules for CAV organizations with respect to the collection, use, and disclosure of personal information. The research team outlined specific types of data that could be generated by CAVs and categorized this data with respect to its sensitivity and level of security required for protection. Understanding the sensitivity associated with data provides insight into the necessary privacy safeguards required when the data are collected and used. Although this code does not have any legal effect, it aims to provide advisory guidance as opposed to endorsing legal compliance with PIPEDA and Canadian privacy law [89, 90].

In 2014, the Auto Alliance, Global Automakers, and 14 independent automakers created a partnership to form the Automotive Information Sharing and Analysis Center (AUTO-ISAC). The membership now consists of light- and heavy-duty vehicle OEMs, suppliers, technology companies, and members of the commercial vehicle sector. AUTO-ISAC serves as an industry-led community focused on sharing and analyzing intelligence about emerging cybersecurity risks to vehicles. It has recently broadened its focus to consider a more comprehensive view of the CV ecosystem [91].

4.6.2 Data Training

Although not necessarily directly applicable for standard specifications, datasets developed for the purposes of training the algorithms of vehicle automation systems are important to further enhance the capabilities of the technology to adapt to its surroundings and under specific use cases. The University of Waterloo and the University of Toronto are working together to develop an open-source dataset to train and test vehicle perception algorithms in inclement weather conditions, which has recently been released. This Canadian Adverse Driving Conditions Dataset (CADC) is designed to allow software developers to test the performance of their advanced automation algorithms under conditions where perception and processing abilities may be compromised due to snowy weather and low visibility [92].

4.6.3 Relevant Standards and Other Documents

Table 5 provides a summary of relevant standards, focusing on techniques and guidance relating to cybersecurity and the protection of personally identifiable information. It should be noted that data privacy in Canada is governed under both PIPEDA and Canadian privacy law.

Table 5: *Summary of Relevant Cybersecurity, Privacy, and Data Training Standards, Policies, and Procedures*

Standard	Title / Description
ISO/IEC 20889	Privacy Enhancing Data De-Identification Terminology and Classification of Techniques
ISO/IEC 27001	Information technology — Security Techniques — Information Security Management Systems — Requirements
ISO/IEC 29100	Information Technology — Security Techniques — Privacy Framework
ISO/IEC 29101	Information Technology — Security Techniques — Privacy Architecture Framework
ISO/IEC 29134	Information Technology — Security Techniques — Guidelines for Privacy Impact Assessment (PIA)
ISO/TR 12859	Intelligent Transport Systems — System Architecture — Privacy Aspects in ITS Standards and Systems
NIST Cybersecurity Framework	Provides a voluntary set of guidelines for managing and reducing cybersecurity risk
NIST Advanced Encryption Standard (AES)	Specifies a cryptographic algorithm, approved by the Federal Information Standards (FIPS), that can be used to protect electronic data
SAE J3061	Cybersecurity Guidebook for Cyber-Physical Vehicle Systems
SAE J3063	Active Safety Systems Terms & Definitions
Secure Sockets Layer (SSL)	Standard security technology for establishing an encrypted link between a server and a client
Security Credential Management System (SCMS)	Public Key Infrastructure (PKI) — based approach that employs encryption and certificate management to facilitate secured communication

4.7 Vehicle Aspects

Motor vehicle safety standards play a key role in vehicle design and technology. In Canada and the United States, Transport Canada and the NHTSA, respectively, are responsible for developing and enforcing these standards. There are also initiatives in place to further ensure alignment and harmonization between the Canadian and US standards. Vehicle manufacturers follow a self-certification approach to ensure that their vehicles meet the relevant motor vehicle safety standards.

In North America, the federal governments are responsible for specifying and enforcing regulations and standards relating to motor vehicles and safety-related components (e.g., child seats) through the Canada Motor Vehicle Safety Standards (CMVSS) in Canada and the Federal Motor Vehicle Safety Standards (FMVSS) in the United States, which provide comprehensive requirements for vehicle design, construction, and performance. These standards relate to motor vehicles, including all OEM equipment and parts. While some aftermarket parts are not covered by these national vehicle safety standards, they may be covered by industry standards (e.g., a wheel standard issued by SAE International) or be regulated separately based on safety needs [93]. It should also be noted that vehicles designed strictly for off-road use, such as farm tractors, construction equipment, and utility-terrain vehicles (UTVs) are not regulated under national vehicle safety standards.

Compliance to both sets of standards is administered by self-certification, whereby OEMs in North America self-certify that vehicles for sale meet the vehicle safety standards relevant to that country. There is significant overlap and alignment between the CMVSS and the FMVSS. Therefore, OEMs manufacture vehicles in compliance with both in order to enable sale in both Canada and the United States and import between the countries. Conversely, the international United Nations regulatory and standards requirements differ significantly, and it is difficult to import foreign vehicles not originally manufactured to meet North American specifications [94].

Current regulations and standards in North America do not necessarily align with emerging AVs (e.g., lack of a steering wheel and a rear-view mirror) and for AV shuttles that have operated in Canada, many of the vehicles have been imported through an exemption as they were used for pilots/tests. In 2018, the NHTSA published a notice of proposed rulemaking seeking comment on identifying regulatory barriers in the existing FMVSS to the testing, compliance certification, and compliance verification of motor vehicles with automated driving systems in an effort towards removing such barriers [95].

At this time, there are a limited number of published standards for CAVs and associated onboard technologies (e.g., on-board unit, or OBU). However, there are many ongoing initiatives and technical committees focusing on related aspects. Since 2017, there has been a CEN/ISO committee working on standards regarding road adaptation for advanced driver assistance systems (ADAS) and AVs. There are also published ISO standards and standards projects in development for a number of ADAS features that have relevance for full automation, such as lane keeping (ISO 11270) and adaptive cruise control (ISO 15622) [41].

4.7.1 Relevant Standards and Other Documents

Table 6 provides a summary of relevant vehicle aspect standards, which relate primarily to the safety and performance of technologies and systems that support assisted and automated driving.

Table 6: *Summary of Relevant Vehicle Aspect Standards*

Standard	Title / Description
IATF 16949	Automotive Quality Management Systems (QMS)
ISO 2575	Road vehicles – Symbols for controls, indicators and tell-tales
ISO 11067	Intelligent transport systems — Curve speed warning systems (CSWS) — Performance requirements and test procedures
ISO 11270	Intelligent transport systems — Lane keeping assistance systems (LKAS) — Performance requirements and test procedures
ISO 15622	Intelligent transport systems – Adaptive cruise control systems – Performance requirements and test procedures
ISO 15623	Intelligent transport systems — Forward vehicle collision warning systems — Performance requirements and test procedures
ISO 19237	Intelligent transport systems – Pedestrian detection and collision mitigation systems (PDCMS) – Performance requirements and test procedures
ISO 19638	Intelligent transport systems — Road boundary departure prevention systems (RBDPS) — Performance requirements and test procedures
ISO 20035	Intelligent transport systems — Cooperative adaptive cruise control systems (CACC) — Performance requirements and test procedures
ISO 21717	Intelligent transport systems — Partially Automated In-Lane Driving Systems (PADS) — Performance requirements and test procedures
ISO 22839	Intelligent transport systems – Forward vehicle collision mitigation systems – Operation, performance, and verification requirements
ISO 26262	Road vehicles — Functional safety
ISO/DIS 20901	Intelligent transport systems — Emergency electronic brake light systems (EEBL) — Performance requirements and test procedures
ISO/PAS 21448	Road Vehicles – Safety of the intended functionality
SAE J1698_201703	Event Data Recorder (EDR)
SAE J3088_201711	Active Safety System Sensors
SAE J3018_201909	Safety-Relevant Guidance for On-Road Testing of SAE Level 3, 4, and 5 Prototype Automated Driving System (ADS) — Operated Vehicles
SAE J3048_201602	Driver-Vehicle Interface Considerations for Lane Keeping Assistance Systems
SAE J3087_201710	Automatic Emergency Braking (AEB) System Performance Testing
SAE J3092	Dynamic Test Procedures for Verification & Validation of Automated Driving Systems (ADS)

5 Critical Needs and Potential Gaps in Codes and Standards

5.1 Identification of Themes

To supplement research into ongoing initiatives, 14 industry stakeholders were interviewed for additional insights. The stakeholder group consisted of representatives of public transportation agencies, academic and research institutions, industry representatives (OEMs, technology companies), as well as SDOs. Their input, as well as the findings from the literature review, helped identify the critical needs and potential gaps summarized in this section.

CAV technologies, and the application of these technologies, continue to evolve. Additionally, CAV technologies, as well as applications and operations, extend across multiple industries, including vehicle manufacturing and parts, communications, and transportation. These complex factors are challenging, and although it is evident that there is currently coordination and cooperation across standards programs and initiatives, there is no single entity overseeing all aspects and ensuring a common direction.

Even though stakeholders raised concerns with over-regulating the technologies in the CAV industry, there were concerns with gaps and delays between the development and release of technologies due to the slow adoption of, or a lack of, policies and regulations from government.

> "Codes, standards and/or regulations will have higher credibility if they are developed, published, or endorsed by the federal or provincial government."
>
> —Interview participant

Interviewed stakeholders highlighted safety as an essential benefit for CAV applications and use cases. They raised concerns for ensuring functional safety in design of production-level automated systems and their holistic safety testing of CAV capabilities in wider systems contexts.

A common concern, particularly from transportation agencies, relates to the short- to medium-term transition period as the prevalence of CAVs increase, as well as how these automated CAVs and traditional vehicles will interact in a safe manner.

Based on input from interviewed stakeholders, identified critical needs and potential gaps can be grouped into eight themes:

- **Harmonization and Interoperability –** need for consistency of standards across regions and countries, as well as the ability for technology to effectively interact and cooperate with each other.
- **Uncertainty with Enabling Communication Technologies –** uncertainty with the communication technology and spectrum allocation that is endorsed and supported by government agencies and widely used by manufacturers.
- **Compliance Verification –** gaps in standards and processes to verify that technology meets safety, security, and interoperability requirements.
- **Physical Infrastructure –** gaps in standards for physical infrastructure to accommodate CAV technologies.
- **Operational Design Domain –** gaps in standards and regulations regarding where, and under what conditions, CAVs are currently able to safely and efficiently operate.
- **High Definition Mapping and Localization –** gaps related to the development and availability of high definition (HD) mapping and localization technology to support the operation of CAVs.
- **Cybersecurity and Protection of Privacy –** critical needs for standards and security frameworks related to cybersecurity and privacy protection, specific to the CAV industry.
- **Technology Maturity –** gaps that are reflective of the fact that AV-enabling technologies have issues in some scenarios and all circumstances (e.g., operations in non-optimal conditions).

"Communication technology also has a large application in facilitating public safety and emergency response. It can be used to notify emergency services of incidents and/or provide them with the ability to request priority on a transportation network and respond to emergencies."

Each of the above themes is explored in relation to stakeholder input from interviews, as well as the standards research conducted.

5.2 Harmonization and Interoperability

There is a gap in consistency associated with the international spectrum allocation of communication bands for dedicated V2X ITS applications. As these are not harmonized globally, manufacturers and providers need region-specific products, making it more difficult to ensure interoperability.

> "There are parallel efforts in the US and Europe, and cooperation, but continued effort is required to ensure harmonization."
>
> "The lack of clear regulations, standards, and guidance allows private industry a lot of freedom for how they develop and implement technology."
>
> **—Interview participant**

Interoperability is an important consideration, as it can directly affect the quality and effectiveness of CAV applications and operations, which is essential from the perspective of ensuring safety.

Communication technology also has a large application in facilitating public safety and emergency response. It can be used to notify emergency services of incidents and/or provide them with the ability to request priority on a transportation network and respond to emergencies. Identifying the technology to achieve this level of communication and interoperability is a key priority of public agencies and a natural direction for the anticipated progress of the technology.

Similarly, and on a more general level, identifying standard sets for information and data, such as those relating to road and weather conditions, can leverage the benefits of CAV technology and contribute to smooth transportation operations.

5.3 Uncertainty with Enabling Communication Technologies

It was highlighted by many of the interviewed stakeholders that much of the CAV industry, including private sector companies and public transportation agencies, are waiting for a clear decision to be made on whether the preferred communications technology for V2X will be DSRC or C-V2X. It can be perceived that the lack of clear direction may be limiting investment, as companies seek to invest in the correct technology, and the open and large-scale deployment of CAV technologies.

> "Lots of emphasis on wireless technology itself, with little attention to wireless backhaul – most expensive and an important component for deployment."
>
> **—Interview participant**

Most CAV-related standards activities have focused on short-range V2V and V2I applications, with less consideration for longer-range wide-area applications. There are gaps in performance standards specific to backhaul support for V2X applications. This may be related to the fact that most demonstrations and tests have occurred in areas where agencies have established high-speed networks for the backhaul of data (e.g., fiber). However, the importance of these applications will increase as greater numbers of CAVs operate in more rural areas.

Interviewed stakeholders also raised concerns that efforts have focused on communications technologies specific to CAVs, but there is a lack of standards or guidance on how to build services on other available communication technologies.

A stakeholder also highlighted in ISED's RSS-252 called "Intelligent Transportation Systems – Dedicated Short Range Communications (DSRC) – On-Board Unit (OBU) RSS-252 – ITS – DSRC – OBU can support V2V applications as it establishes certification requirements for licence-exempt DSRC for OBU devices in Canada. However, there is no corresponding exemption relating to RSUs, limiting V2I applications. A developmental licence is required for those seeking to test V2I applications using RSUs; however, this process has been simplified over the years [96].

5.4 Compliance Verification

Many interviewed stakeholders raised the verification of compliance and certification, with respect to devices and infrastructure, as a major gap relating to CAV technology standards. Self-certification is the established backbone of the North American automotive market, but as noted in Section 4.7, current vehicle safety standards do not address CAV technologies specifically and, in some cases, are barriers to ADS.

> "There needs to be build and design standards around testing in the interest of public safety – CAVs should have a government licence and certification procedure for CAV technology to be used on public streets (similar to a driver's licence for people)."
>
> **—Interview participant**

Verifying CAV technologies through the entire supply chain is seen as critical in order to ensure that these technologies not only meet requirements for interoperability but also meet minimum desired security guidelines and contain enough safeguards in the supply chain. There are similar needs and considerations related to installation and maintenance services.

> "OEMs are developing CAV technologies in isolation and to operate independently. This is a concern for lower-tier governments developing their own road/ safety standards."
>
> **—Interview participant**

Stakeholders have questions regarding expectations for various authorities and regulators (road, infrastructure, electrical) with respect to application implementations and technology installations. For installations, it was noted there could be different types of certification and testing needs, such as for a device itself (e.g., certified RSUs) and the actual installation (e.g., certified installers and certified system acceptance). To ensure the successful operation of a connected transportation system and the necessary technology and interoperability of equipment needed to facilitate a CAV operation, a consistent certification procedure needs to be in place. Developing this certification procedure may require the identification of who is responsible for ensuring that their equipment meets a set of certification requirements. For example, vehicle manufacturers and technology developers may need to become responsible for self-certification (similarly to vehicle safety certification) of their products, ensuring interoperability among their own devices and other manufacturers' devices. It is still a question of whether companies can meet this obligation themselves or if an alternative, third-party certifier needs to be identified [97].

5.5 Physical Infrastructure

Gaps in standards for physical infrastructure to accommodate CAV technologies was raised by many interviewed stakeholders. One stakeholder highlighted challenges experienced with an AV shuttle pilot, including the need to grind down speed bumps, and adjust sensors to weather.

> "There is a lot of waiting for development of codes and standards in industry. Infrastructure needs to be prioritized and upgraded."
>
> "We are at a point where the mobility industry needs much more interaction with the infrastructure side of the topic."
>
> **—Interview participant**

A recent Austroads study identified the following attributes that may require analysis to determine a roadway's CAV readiness [45]:

- **Line markings –** width, contrast, and consistency are important, with consistency having a strong performance impact for vehicle manufacturers.
- **Static signs –** the standards for static signs (speed zone, advisory speed, etc.) need to be consistently adopted, avoiding variations.
- **Electronic signs –** consideration needs to be given to sign specifications to ensure that all road users (including CAVs) can read them, including electronic sign refresh rates, pixel illumination, and alternative ways on how information can be provided to CAVs.
- **Roadworks –** there is a need for consistency in the treatment of road construction sites. Currently there are significantly different approaches between projects and across different jurisdictions.
- **Road continuity –** there is a need for vehicles to identify changes to the continuity or use of different road types. This requirement is in addition to a geofenced location, for example, that restricts access and requires the vehicle to identify a change in the road and act accordingly.

> "Ensure the environment is as conducive as possible for development of technologies – reduce the number of variables on the roads (markings, signage, maintenance, construction) to help OEMs."
>
> **—Interview participant**

There are views in the CAV industry that CAVs should be adapted to existing transportation networks, and not the reverse. This perspective considers shared streets, lane restrictions, construction zones, varied weather conditions, and other attributes as the "real world," and one in which CAVs will have to evolve. However, it is also recognized that there is a benefit to the development of physical infrastructure guidance that can inform infrastructure owners and operators (IOOs) when making investments in updating or upgrading their infrastructure to facilitate CAV operations.

Consistency with infrastructure standards is important as different approaches to CAV deployments may make it very difficult for the technology to be implemented; it will not be technically or economically viable for the automotive manufacturing industry to customize software and sensor system designs to be able to adapt their operations based on different jurisdictions. There needs to be consistency on how the technology is regulated to reduce the barriers to its deployment. It is important to bring the interested groups and organizations together to seek agreement at some level on how to develop codes, standards, and guidelines (e.g., the MUTCDC) that are sufficiently harmonized [98].

5.6 Operational Design Domain

CAV technologies and implementations are generally designed for specific operational design domains (ODDs), which may constrain operations to limited environmental attributes, including roadway types (e.g., freeways) and weather conditions (e.g., clear pavement). Although SAE J3016 describes ODDs as limitations with respect to levels of automation (see Figure 1) and to the road environment, temporary conditions, traffic characteristics, and environmental conditions [99], it does not include specific metrics for these limitations, and is not likely to be expanded to do so. As such, it would be beneficial to develop a set of standards or metrics that could be used as a benchmark for testing in various ODDs.

Operational Design Domain (ODD)

"...operating conditions under which a given driving automation system or feature thereof is specifically designed to function, including, but not limited to, environmental, geographical, and time-of-day restrictions, and/or the requisite presence or absence of certain traffic or roadway characteristics."

—SAE J3016

Interviewed stakeholders identified gaps in where and under what conditions CAVs are currently able to safely and efficiently operate. In particular, it was highlighted that Canada's four distinctive seasons can be a challenge, especially the winter temperature and road conditions. There has not necessarily been enough focus on developing and testing standards for these environments.

"There are large gaps in ensuring technologies perform in all conditions – a lot of testing is in the Southern States in the US with fairly consistent good weather conditions."

—Interview participant

A road certification/risk rating framework may be required based on CAV requirements and road attributes to guide the evaluation of roadways for their suitability for specific vehicles and use cases. This framework would identify requirements that include clear road markings, appropriate and consistent signage on the network, communication, and connectivity to support cooperative driving and to identify which vehicles can operate on which roadways. The World Road Association studied challenges and opportunities, with respect to CAVs, for road operators and concluded that priority should be given to resolving infrastructure issues and needs for harmonization on expressways. The greatest volume of traffic occurs on expressways and this is where higher levels of automated driving will most likely appear first [4].

The human-machine interface and human factors of vehicle designs are critical areas to ensure safe operation of the vehicles. Standards focusing on adapting vehicle automation for different user needs and groups, including vehicle designs that are intuitive and safe for the operator and other road users, are critical areas of consideration [40].

5.7 High Definition Mapping and Localization

A critical need for safe automated driving is understanding the surrounding environment, and accurately knowing where the vehicle itself is with respect to identified obstacles. Generally, locating the vehicle relies on Positioning, Navigation and Timing (PNT) technologies, enabled by Global Navigation Satellite Systems (GNSS) such as the Global Positioning System (GPS). With respect to its surroundings and obstacles, high definition (HD) maps, which are accurate to the centimetre, can provide three-dimensional representations of the environment and may be updated continuously with dynamic information (e.g., identification of obstacles, collisions, weather, construction, emergency vehicles, or lane closures) [100].

High-accuracy GNSS technology is rapidly evolving and is further enhanced by other enabling technologies, such as real-time kinematic (RTK) corrections, to meet the many localization needs of AVs. GNSS has a number of vulnerabilities, such as spoofing, intentional and unintentional interference, and cyberattacks, and there are gaps in relevant security standards.

Gaps associated with HD maps identified by stakeholders relate to their availability and incompatibility, which relates to the cost and effort involved in the development of the maps. Mapping companies, as well as most AV companies, are actively developing HD maps. However, these efforts are not compatible, for the most part, as the needs for each company may differ and there is no industry standard.

An example of current work in the area is being led by the University of Waterloo. As part of the AVIN Regional Technology Development Site in Waterloo, it is pursuing the development of OpenHDMaps, an open standard for HD mapping and localization. On an international scale, Working Group 3 of ISO TC204 has been studying the integration of local dynamic maps to support dynamic data and changes to static maps.

5.8 Cybersecurity and Protection of Privacy

In comparison to other areas of interest described above, there has been limited activity with respect to cybersecurity and protection standards in the CAV industry.

> "Cybersecurity is at an infancy stage, but an important focus area for all players."
>
> **—Interview participant**

The design and development of SCMS, to manage credentials and ensure secure V2X communications, has been the most relevant efforts to date. The planned designs address concerns to minimize the use of personal or identifiable information, while authenticating trusted devices and users. Stakeholders identified a number of questions and gaps relating to the SCMS, including:

- **Misbehaviour detection and management –** identifying what constitutes misbehaviour and their potential impacts on the network; a standard can be developed to define how each misbehaviour is classified based on severity and threat level, what steps should be taken to resolve them (e.g., which misbehaviours result in certificate revocation and removal from the network) and who is responsible to manage this.
- **Privacy and cybersecurity –** identifying how data privacy is maintained and who claims ownership of data generated by CAVs; this also includes harmonizing privacy standards across countries and SCMS. A number of standards, guidelines, or best practices will need to be developed, and they will need to discuss how to handle data generated by CAVs, how to effectively anonymize the dataset, and how to define privacy statements and consumer informed consent for CAVs.

> "Cybersecurity inside the car needs to also be standardized, especially around the idea of installing a new part and establishing trust between communicating parts."
>
> **—Interview participant**

Interviewed stakeholders also raised concerns with respect to how over-the-air (OTA) updates will be deployed and how they will be authenticated. Vehicle manufacturers are developing OTA updates to improve convenience and maintain vehicle performance by pushing software updates directly to the vehicle, as opposed to requiring visits to service centres for manual updates. Pushing updates to vehicles, however, requires considerations to ensure the updates are secured and not compromised. As well, there is a need for the development of standards similar to the recommendations identified in ITU-T X.1373, which focus on the secure software update capability for intelligent transportation system communication devices and preventing threats to those software updates, such as OTA updates [101].

There are also needs for measures to protect the security of cyber-physical systems on the transportation network, such as vehicle systems receiving updates or connected traffic signal controllers. In an increasingly connected environment, critical infrastructure will become susceptible to being compromised through the network, requiring that the necessary cybersecurity measures be considered.

> "There is public concern with the likelihood of a vehicle being hacked more so than its ability to drive itself – we need standards in place to protect vehicles from this security risk."
>
> **—Interview participant**

System security is a concern across all industries, and there are many relevant standard activities in the area. A number of stakeholders raised concerns about the risks of hacking in a connected environment, which highlights its importance from a public safety perspective and the critical need for continued advancement in system security standards.

5.9 Technology Maturity

Stakeholders identified a number of gaps that can, to some extent, be classified as indicative of AV-enabling technologies not being ready for any and all circumstances. These gaps include, but are not limited to, issues or difficulty relating to identifying vehicles in non-optimal conditions (e.g., inclement weather, low visibility), as well as those that have non-optimal reflectivity or those that may be considered unique or less common (e.g., motorcycles). Similarly, it was also identified that AVs may be able to detect construction areas, but may have difficulty detecting whether there is active construction activity at the time.

Connectivity solutions, where information is provided through V2X, may address some of the known gap areas, but are likely not feasible for widespread and comprehensive adoption, particularly in the short term. It is more likely that many of these gaps will be addressed through the continued evolution and improvement of sensing and AI technologies, and it is expected that the detection capability will improve significantly. Additionally, as testing and demonstration of AVs continue and expand, the amount of data and experience will further improve machine learning to understand more unique situations and decrease the occurrence of what are now considered to be uncertain scenarios.

6 Analysis and Recommendations

CAV technologies are anticipated to provide significant benefits relating to safety and efficiency, but there remains many unknowns regarding how CAVs will safely integrate into the current transportation network, as the adoption and the prevalence of CAVs increase.

This report has highlighted that there are many different standards development activities and efforts being led by several SDOs, which together address the needs of a majority of common and safety-critical use cases for CAVs. However, gaps were identified through engagement of industry stakeholders, and were grouped into eight trend areas: harmonization and interoperability; uncertainty with communications; verification; infrastructure; operational design domain; high-definition maps and PNT; cybersecurity, protection of privacy, and technology maturity. While standards, protocols, and guidelines may not address all the challenges in this report, standards are important tools that can be combined with regulations, policies, and programs to support change and foster continued evolution of supporting technologies.

The findings in this report highlight that there are several similar US and international standards, and although there is purposeful coordination between their developments, it can raise concerns with respect to harmonization and potential confusion with respect to which standard is appropriate (where and under which conditions). For these reasons, a CAV code that compiles applicable standards and adds context pertaining to the testing and piloting, manufacturing, installation, deployment, and operation of CAV technologies, is needed. Applications for use in Canada could be valuable to manufacturers, infrastructure owner operators, and others across the industry.

A common CAV code, or at least significantly similar CAV codes, developed in coordination with the US could help address concerns with **harmonization and interoperability** within the North American market.

As an industry that is continuing to rapidly evolve with standards being developed and updated in lock step, it will be important that revisions of a CAV code be on a frequent cycle. In the interim, it will be equally important to monitor the progress and evolution of relevant standards from both North American and international SDOs.

The current North American automotive market, where vehicle safety standards significantly overlap and align, currently supports the manufacturing of common vehicles between the countries, which has benefits for all parties involved. The current **uncertainty with communications** in the US, with respect to spectrum allocation and preferred V2X communication technology, poses risks to this model as the US is expected to address these uncertainty gaps, and the decisions made may not align with those of Canada. To minimize such a risk, and similar to what has been done in the past, it would be best for Canada to closely monitor the US as it makes decisions, and to adapt and realign as changes and clarifications are made. Given the context of the North American market and the fact that Mexico shares a border with the U.S, similar changes on Canada's part would be beneficial.

There are established agencies and programs that are recognized as the trusted authority for testing and certification of CAV technologies (e.g., OBU, RSU, DSRC-V2X), and it is expected that certification services will continue to expand technologies as standards are specified and required in the US. Canada could address the **compliance verification gap** through the common CAV code and by officially recognizing and requiring certification where applicable.

Readiness of the **physical infrastructure** is another common gap area between Canada and the US and, as responsible maintainers of the MUTCDC, a first step for the Transportation Association of Canada could be to actively coordinate with the NCUTCD in the US and/or TAC could lead its own gap analysis study to identify what updates may be required to better support CAVs.

OEMs are continually solving issues that relate to the needs of the intended ODDs of their products. To help address other gaps relating to the **operational design domain,** industry leaders in Canada could potentially work with SDOs that are focused on road infrastructure, such as ITE and AASHTO, to pursue a road certification or risk matrix to evaluate the readiness of roads and highways, with respect to SAE levels of automation and ODD.

A possible area of further standards development to address considerations for **compliance verification** of the **operational design domain** for CAVs, in coordination with other countries or SDOs, may be to consider the development of performance standards for CAVs with respect to where and when they may be allowed to operate in a fully autonomous mode.

In parallel to the efforts above relating to the **physical infrastructure** and the **operational design domain,** research should continue to be conducted with respect to developing policies and practices related to interactions with humans, including supporting vulnerable road users (VRUs) and interfaces between drivers/passengers and CAVs across all levels of automation.

Gaps with respect to **high-definition maps and localization** is an area where Canadian stakeholders are active, and they should continue to help lead the development of open standards for use by the industry globally. It should be noted, however, that in the interim, OEMs and others in the industry will continue to develop their products and will not limit the marketability of their products to ODDs that rely on map data from third parties. Industry stakeholders have indicated that AVs will likely continue to use their own sensing technologies (e.g., 3D LiDAR, video and infrared detection) as the primary sources upon which decisions and actions are made, as opposed to HD maps and other connected technologies supporting PNT. This is not to discount the value of secure and reliable HD maps and PNT and the importance of open standards for interoperability, but is meant to highlight that current gaps may also be addressed through the advancement of other technologies.

Although there are active efforts relating to developing standards, guidelines, and frameworks related to **cybersecurity and protection of privacy,** it is a consensus priority area and highlights the importance of continuing to support these ongoing efforts. In Canada, this includes the current effort to advance a Canadian security credential management system (SCMS), which will incorporate privacy by design and help ensure that CAV communications are secure and trustworthy. The US has a parallel effort of its own that is being monitored, and with consideration for ensuring harmonization across the border, there are considerable benefits for Canada to align with the US design and, to the degree possible, ensure coordination and interoperability.

The final gap trend area, **technology maturity,** is to some degree self addressed through a feedback loop of development, demonstrable learning, identification of persisting issues, and further development to improve and re-engineer. In these cases, it is too early to understand whether standards are necessary to address technology gaps and, if so, what standards would be appropriate. In the interim, it is important to develop an environment that is encouraging and welcoming of R&D and innovation, which may include a combination of funding efforts, minimizing restrictions and barriers, and attracting talent and industry. Canada has been successful in building such an ecosystem and there is significant CAV industry presence and innovative R&D activities. Continuing to foster this environment will help address **technology maturity** gaps locally and globally. There are also opportunities to coordinate with some of the US programs, such as the Connected Vehicles Pooled Fund Study.

In conclusion, active coordination and alignment with the US with respect to CAV standards, guidelines, and frameworks will ensure local harmonization and interoperability, which is critical in light of our shared border and automotive industries. Such coordination will also likely accelerate the activities and will allow Canada to be prepared to help ensure safe operation and widespread adoption of CAVs.

7 Conclusion

This research report is an initial step in the process of developing an understanding of the existing standards landscape as it relates to CAVs and relevant infrastructure, communications, data management and privacy, cybersecurity, and vehicle technology. A comprehensive literature review, expert consultation, and interviews with key industry stakeholders was compiled to identify existing standards and gap areas that should be addressed. The report provides seed information that can identify a framework and process for addressing the needs for the development of a codes and standards roadmap in Canada and for maximizing standards harmonization domestically and internationally.

The findings of this report revealed evidence of a significant amount of R&D, policy development, and standards development efforts on CAVs in Canada, the United States, and internationally. International SDOs have formed working groups to address many of the emerging trends in transportation technology and focus on reviewing and updating existing standards, identifying gaps, and developing new standards, where necessary. These efforts need to continue in

"Key areas where Canada can contribute and/or take a leading role include standards harmonization efforts and the development of a CAV code and frameworks for cybersecurity and protection of privacy, as well as research, development, and testing of CAV technologies."

order to further develop the technology and leverage its benefits to transportation. A focus on international cooperation and standards harmonization will allow for the interoperability of the technology, promotion of consistent safety regulation, and diminished trade barriers.

Canada is well-positioned to play an important role in the relevant efforts moving forward. Key areas where Canada can contribute and/or take a leading role include standards harmonization efforts and the development of a CAV code and frameworks for cybersecurity and protection of privacy, as well as research, development, and testing of CAV technologies. Active cooperation and alignment of efforts with US counterparts will ensure interoperability and shared knowledge and is critical considering the shared border that supports the automotive industry.

Transportation is a rapidly evolving industry, and although many efforts have been initiated to begin preparing for connected and automated technology, there is still a lot of work that needs to be done. It is important that the necessary codes and standards are in place to guide the industry, promote safety, and foster the innovation and growth of CAV technology.

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Appendix A – Relevant Standards

As introduced in Section 4, key leading global and national Standards Development Organizations (SDOs) include the following:

- **International Organization for Standardization (ISO) –** ISO is an independent, non-governmental international organization with a membership of 164 national standards bodies, and through its members, it brings together experts to share knowledge and develop voluntary, consensus-based, market-relevant international standards that support innovation and provide solutions to global challenges [102].
- **International Electrical and Electronics Engineers (IEEE) –** IEEE is the world's largest technical professional organization dedicated to advancing technology for the benefit of humanity. IEEE and its members inspire a global community to innovate for a better tomorrow through its more than 423,000 members in over 160 countries, and its highly cited publications, conferences, technology standards, and professional and educational activities [103].
- **European Committee for Standardization (CEN) –** CEN is an association that brings together the national standardization bodies of 34 European countries and supports standardization activities in relation to a wide range of fields and sectors, including air and space, chemicals, construction, consumer products, defence and security, energy, the environment, food and feed, health and safety, healthcare, ICT, machinery, materials, pressure equipment, services, smart living, transport, and packaging [104].
- **European Telecommunications Standards Institute (ETSI) –** ETSI is a European Standards Organization (ESO) dealing with telecommunications, broadcasting, and other electronic communications networks and services. ETSI supports European regulations and legislation through the creation of harmonized European standards. It was originally founded to serve European needs, but now the standards are used around the world [105].
- **SAE International –** SAE International is a global association of more than 128,000 engineers and related technical experts in the aerospace, automotive, and commercial-vehicle industries, with an online database of over 37,000 standards relating to quality, performance, safety, and product life cycles [106].
- **National Transportation Communications for ITS Protocol (NTCIP) –** NTCIP is a family of standards that provides both the rules for communicating (called protocols) and the vocabulary (called objects) necessary to allow electronic traffic control equipment from different manufacturers to operate with each other as a system. NTCIP is a joint product of the National Electrical Manufacturers Association (NEMA) teamed with the Institute of Transportation Engineers (ITE) and the American Association of State Highway and Transportation Officials (AASHTO) [107].
- **National Electrical Manufacturers Association (NEMA) –** NEMA is a global association that represents nearly 325 electrical equipment and medical imaging manufacturers that make safe and reliable products and systems for major markets, including building systems and infrastructure, lighting systems, utility products and systems, transportation systems, and medical imaging [108].
- **ASTM International –** ASTM International is a global association recognized for the development and delivery of voluntary consensus standards. Over 12,000 ASTM standards are used around the world to improve product quality, enhance health and safety, strengthen market access and trade, and build consumer confidence. ASTM's members create the test methods, specifications, classifications, guides, and practices that support industries and governments worldwide in a variety of industries, including metals, construction, petroleum, consumer products, and many more [109].

- **International Electrotechnical Commission (IEC) –** IEC is a leading organization for the preparation and publication of international standards for all electrical, electronic, and related technologies. The IEC provides a platform to companies, industries, and governments for meeting, discussing, and developing the international standards they require [110].
- **Transportation Association of Canada (TAC) –** TAC is a not-for-profit, national technical association that focuses on road and highway infrastructure and urban transportation, with approximately 500 members from all levels of governments, private sector companies, academic institutions, and other associations. While TAC itself does not set standards, it is a principle source of guidelines for planning, design, construction, management, operation, and maintenance of road, highway, and urban transportation infrastructure systems and services [111].
- **Institute of Transportation Engineers (ITE) –** ITE is an international membership association of transportation professionals who work to improve mobility and safety for all transportation system users and who help build smart and livable communities. Through its products and services, ITE promotes professional development and career advancement for its members, supports and encourages education, identifies necessary research, develops technical resources that include standards and recommended practices, develops public awareness programs, and serves as a conduit for the exchange of professional information [112].
- **American Association of State Highway and Transportation Officials (AASHTO) –** AASHTO is a nonprofit, nonpartisan association representing highway and transportation departments in the 50 states, the District of Columbia, and Puerto Rico. It represents transportation modes that included air, highways, public transportation, active transportation, rail, and water. Its primary goal is to foster the development, operation, and maintenance of an integrated national transportation system [113].

The existing standards relevant to CAV technologies are extensive and are categorized into five main groups:

- Digital Infrastructure
- Physical Infrastructure
- Usage, Human-Machine, and Accessibility
- Cybersecurity, Privacy, and Data Training
- Vehicle Aspects

Although some of the listed standards have relevance across categories, they are organized based on their purpose. Information regarding relevant systems architecture and guidelines are also described in more detail in this appendix.

A.1 Digital Infrastructure

The standards discussed in this section focus on addressing reliable and independent transition of information between vehicles, surrounding infrastructure and technology, as well as the equipment that stores and exchanges data to support intelligent transportation services.

A.1.1 ASTM F3200 Standard Terminology for Driverless Automatic Guided Industrial Vehicles

This terminology document covers terms associated with driverless ground industrial vehicles. Providing a common and consistent lexicon, the purpose of this terminology is to facilitate communication for those involved in the research, design, deployment, and use of driverless ground vehicles, including but not limited to, manufacturing, distribution, and security. The terminology covers terms used in performance test methods of automatic guided vehicles (AGVs), autonomous mobile robots, and all other driverless ground vehicles. In addition, given the increase in intelligent vehicle systems with onboard equipment, robotics industry terms that are used in associated test methods and descriptions are included [114].

A.1.2 ETSI 302 895 Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Local Dynamic Map (LDM)

ETSI 302 895 defines the functional behaviour associated with a local dynamic map (LDM) for use in ITS station units. It specifies functions and interfaces that are supported by the LDM. These functions and interfaces provide secure access while managing stored data objects for safety-related and vehicle- to-vehicle (V2V)-related applications [115].

A.1.3 IEEE 802.11 Local Area Network (LAN) and Metropolitan Area Network (MAN) Standards

The IEEE 802.11 family of standards recommend practices for local, metropolitan, and other area networks. The scope of this standard is to define a medium access control (MAC) and several physical layer (PHY) specifications for wireless connectivity to support intelligent transportation system (ITS) communications, including vehicle-to-vehicle and vehicle-to-infrastructure systems. IEEE 802.11 provides regulatory bodies a way of standardizing access to frequency bands for local area communication. Dedicated short range communication (DSRC) and Wi-Fi are based on IEEE 802.11 protocol [116].

IEEE 802.11p is an amendment to the IEEE 802.11 standard, adding capability for wireless access in vehicular environments (WAVE). The enhancements it defines are required to support ITS applications. This includes V2X communication between vehicles and between vehicles and roadside infrastructure in the 5.9 GHz band licensed for ITS [117].

A.1.4 IEEE 1609 Wireless Access in Vehicular Environments (WAVE)

The IEEE 1609 family of standards covers methods for securing wireless access in vehicular environments (WAVE) management of messages and application of messages, as well as describes the administrative functions that support core security functions. IEEE 1609 is a higher-layer standard based on IEEE 802.11p that defines an architecture and a complementary standardized set of services and interfaces that collectively enable secure V2V and V2I wireless communications, and that support interoperable communications interfaces between different automotive and device manufacturers [118].

A.1.5 ISO 14296 Intelligent Transport Systems — Extension of Map Database Specifications for Applications of Cooperative ITS

ISO 14296:2016 is developed by ISO/TC 204 and provides map-related functional requirements, data model and elements for applications of cooperative ITS requiring information derived from map databases [119].

A.1.6 ISO 14825 Intelligent Transport Systems — Geographic Data Files (GDF) — GDF5.0

ISO 14825:2011 specifies conceptual and logical data models and physical encoding formats for geographic databases for ITS applications and services focusing on road and road-related information. This includes the specification of potential content of the databases, how the content should be represented, and how relevant information about the database can be specified. Typical ITS applications and services that are targeted by this standard include in-vehicle or portable navigation systems, traffic management centres, and services linked with road management systems and public transport systems [120].

A.1.7 ISO 22951 Data Dictionary and Message Sets for Preemption and Prioritization Signal Systems for Emergency and Public Transport Vehicles (PRESTO)

ISO 22951:2009 relates to systems that use priority signal control functions to help emergency vehicles operate. Public transport vehicles, such as buses, are also targeted to receive priority signal control service. This type of system is composed of a traffic management centre, in-vehicle units, roadside communication units, and roadside units. The scope of the standard includes message sets and data dictionaries related to communications between roadside communication units and each in-vehicle unit, and other roadside units, as well as between in-vehicle units and roadside units. ISO 22951 is published by the ISO/TC 204 intelligent transport systems Technical Committee [121]. ISO 22951 is similar to NTCIP 1211 V02.

A.1.8 ISO/TS 17424 Intelligent Transport Systems — Cooperative ITS — State of the Art of Local Dynamic Maps Concepts

ISO/TS 17424:2015 surveys the status of local dynamic map (LDM) regarding architecture, implementation, and standardization efforts. It summarizes the high-level architecture of the most important implementations and compares it with the CEN/ETSI/ISO ITS-Station architecture [122].

A.1.9 ISO/TS 19091 Intelligent Transport Systems — Cooperative ITS — Using V2I and I2V Communications for Applications Related to Signalized Intersections

ISO/TS 19091:2019 defines the message set, data structures, and data elements for V2I applications at intersections to improve safety, mobility, and environmental efficiency. A systems engineering process is employed to trace use cases to requirements and requirements to messages and data concepts. The focus of this standard is to identify details of the signal phase and timing (SPaT), MAP, signal status message (SSM), and signal request messages (SRM) supporting the use cases defined. ISO/TS 19091 is published by the ISO/TC 204 intelligent transport systems Technical Committee [73].

A.1.10 ISO/TS 19321 Intelligent Transport Systems — Cooperative ITS — Dictionary of In-Vehicle Information (IVI) Data Structures

ISO/TS 19321:2015 specifies the in-vehicle information (IVI) data structures that are required by different ITS services (for example, refer to ISO/TS 17425 and ISO/TS 17426) for exchanging information between ITS stations. A general, extensible data structure is specified. This is split into structures called containers to accommodate present-day information. Transmitted information includes IVI such as contextual speed, road works warnings, vehicle restrictions, lane restrictions, road hazard warnings, location-based services, and re-routing [123].

A.1.11 NEMA TS 10 Connected Vehicle Infrastructure-Roadside Equipment

NEMA TS 10 was commissioned by the NEMA Transportation Management Systems Section and serves as a harmonized technical specification for roadside connected vehicle devices. The various types of roadside devices covered include traffic signals, crosswalk signs, school zone safety beacons, ramp meters, and other electronic traffic control equipment. With NEMA TS 10, DSRC and C-V2X can work together in the same spectrum through a dual-mode or dual-active roadside connected vehicle device [77].

A.1.12 NTCIP 1211 V02 Object Definitions for Signal Control and Prioritization (SCP)

The signal control and prioritization (SCP) of the NTCIP has led the development of NTCIP 1211 V02, and it defines the management information base for SCP Systems. It defines individual parameters that represent the configuration, status, and control information that is unique to an SCP and defines a set of objects for use in controlling traffic signal systems in priority applications. NTCIP 1211 v02 is an NTCIP Device Data Dictionary Standard, which formally expresses management information in terms of objects (data elements, data frames, and messages) for use within NTCIP systems [124]. NTCIP 1211 V02 is similar to ISO 22951.

A.1.13 NTCIP 1218 V01 Object Definitions for Roadside Units (RSUs)

The RSU Working Group of the NTCIP is currently developing NTCIP 1218 V01, which is in the functional requirements phase. The purpose of this standard will be to specify protocol and data definitions to allow a traffic management centre (TMC) monitor operational status of the RSU, including the status of applications and processes, as well as configure the RSU to interface with other components in a connected vehicle environment, including connected vehicles, traffic signal controllers, SCMS, and other connected devices (e.g., smart phones).

The focus of the draft NTCIP 1218 V01 is the interface between the RSU and TMC, although other interfaces with the RSU may be defined depending on user needs. The objectives include having the TMC configure an RSU to collect basic safety message (BSM) information, send/receive data to/from the signal controller, transmit alert and traveller information to vehicles, transmit SPaT or MAP data to connected vehicles, coordinate signal prioritization between connect vehicles and controllers, collect traffic performance measure data, monitor and log RSU operational data, and manage and operate the interface with the SCMS [74].

A.1.14 SAE J2945 DSRC Systems Engineering Process Guidance

This standard serves as a guide for the SAE J2945/x family of standards. The scope for the DSRC system environment is to provide information exchange between a host vehicle and another DSRC-enabled device, such as onboard V2V communications, roadside device, or traffic management centre [69]. Two relevant standards include SAE J2945/1, which describes system requirements for onboard V2V safety communications systems [125], as well as SAE J2945/2, describing the DSRC interface requirements for V2V safety awareness applications [126].

A.1.15 SAE J3161 C-V2X Deployment Profiles

SAE J3161 is currently under development and uses the existing SAE 2945 as a basis. It is intended to describe a reference system architecture based on C-V2X technology. It also describes cross-cutting features unique to C-V2X that can be used by applications and future application standards. The audience for this document includes the developers of applications and application specifications, and those interested in C-V2X system architecture [70].

A.1.16 SAE J3186 Application Protocol and Requirements for Maneuver Sharing and Coordinating Service

SAE J3186 is currently being developed and is intended to provide requirements to support applications for the maneuver sharing and coordinating service (MSCS) beyond broadcasting basic safety messages. This can improve road safety and traffic efficiency by sharing and coordinating vehicle manoeuvres via V2X communications. The document will define message sets for MSCS, resulting in identifying new message types, data frames, and data elements for SAE J2735 [127].

A.1.17 SAE J2735_2016 Dedicated Short-Range Communications (DSRC) Message Set Dictionary

This SAE standard specifies a message set, its data frames and data elements, specifically for use by applications intended to utilize the 5.9 GHz dedicated short-range communications (DSRC) for wireless access in vehicular environments (WAVE) communications systems. The scope of this standard is focused on DSRC/WAVE; however, the message set, its data frames, and data elements have been designed to be of use for applications that may be deployed in conjunction with other wireless communications technologies. This standard specifies the definitive message structure and provides background information to allow for the interpretation of message definitions from the point of view of an application developer implementing the messages [72].

A.1.18 SAE J2944_2015 Operational Definitions of Driving Performance Measures and Statistics

This recommended practice provides definitions and guidance for performance measures and statistics concerned with driving on roadways. As a result of this guidance, measurements and statistics are calculated and reported in a consistent manner in SAE and ISO standards, journal papers, technical reports, and presentations so that the procedures and results can be more readily compared. Only measures and statistics pertaining to driver/vehicle responses that affect the lateral and longitudinal positioning of a road vehicle are reported [128].

A.1.19 Transmission Control Protocol/Internet Protocol (TCP/IP)

The TCP/IP enables smartphones, computers, and other devices to communicate with one another and transmit/receive data, even if they are built by different manufacturers and are using different software. TCP allows for a reliable delivery stream through an IP network and TCP/IP forms the basis of present-day Internet usage [129].

A.1.20 User Datagram Protocol (UDP)

The UDP is a connectionless protocol that is designed to stream data, similar to the data transmission of the TCP protocol. UDP is a simple protocol that is unreliable and is primarily used when transfer speed is more important than the data [130].

A.1.21 Wi-Fi

Wi-Fi is a trademark of the Wi-Fi Alliance and is the most common local area network standard using radio frequency for communication. Wi-Fi Alliance certifies wireless devices that implement IEEE 802.11 specifications and protocols [131].

A.2 Physical Infrastructure

The standards covered in this section relate to physical roadway infrastructures (lane markings, signage, etc.) that have been used for many years but are primarily based on the needs and requirements of conventional vehicle operations.

A.2.1 AASHTO Policy on Geometric Design of Highways and Streets

The Policy on Geometric Design of Highways and Streets (referred to as the Green Book) is developed by the American Association of State Highway and Transportation Officials (AASHTO). It is the industry guide for engineers and designers on present-day highway and street design research and practices [132].

A.2.2 AASHTO Roadside Design Guide

The AASHTO Roadside Design Guide synthesizes current information and operating practices related to roadside safety, focusing on safety designs and treatments to minimize injuries beyond driving lanes and the road's shoulder [133].

A.2.3 FHWA Manual on Uniform Traffic Control Devices (MUTCD)

Published by the Federal Highways Administration (FHWA), the MUTCD defines standards used by road operators across the US to install and maintain traffic control devices on public streets, highways, bikeways, as well as private roads available for public travel [78].

A.2.4 NCHRP 20-24(112) Connected Roadway Classification System Development

Prepared for the AASHTO Committee on Agency Development, and funded/published by the National Cooperative Highway Research Program (NCHRP), the framework can be used to classify three approaches to enhancing the roadway's infrastructure readiness: increasing connectivity (allowing vehicles to "talk to roadways"), enhancing roadway elements such as signing and pavement markings (allowing vehicles to "see the roadway"), and controlling the operational design domain (ODD) within which vehicles will operate ("simplifying the roadway") [82].

A.2.5 TAC Geometric Design Guide for Canadian Roads

The TAC Geometric Design Guide for Canadian Roads is a reference document for roadway design practitioners (planners, designers). It provides guidance on developing design solutions that meet the needs of road users, including guidelines for freeways, arterials, collectors, and local roads in urban and rural locations, as well as integrated bicycle and pedestrian design solutions [134].

A.2.6 TAC Manual on Uniform Traffic Control Devices for Canada (MUTCDC)

The Manual of Uniform Traffic Control Devices for Canada (MUTCDC) is a document developed by the Transportation Association of Canada. The MUTCDC is an important document for Canadian traffic engineering practitioners. It offers guidance on traffic control device types, use, and placement for a variety of road authorities and jurisdictions across the nation [135].

A.3 Usage, Human-Machine, and Accessibility

These standards define the use of connectivity and automation to support transportation operations and management, as well as define the role of the user and the machine while meeting the criteria of accessibility for a variety of user needs.

A.3.1 ASTM F3244 — 17 Standard Test Method for Navigation: Defined Area

The purpose of this test method is to evaluate an autonomous-unmanned ground vehicle's (A-UGV) capability of traversing through a defined space. This test method defines a set of generic 2D area shapes representative of user applications for different A-UGV types and is intended for use by manufacturers, installers, and users [136].

A.3.2 ASTM F3265 — 17 Standard Test Method for Grid-Video Obstacle Measurement

ASTM F3265 is a test method that measures an autonomous-unmanned ground vehicle's (A-UGV) kinetic energy reduction when objects appear in its path and within the stop-detect range of the vehicle's safety sensors. The test method measures the performance of the A-UGV only and does not measure the effect on the stability of loads. The test method is intended for use by A-UGV manufacturers, installers, and users [137].

A.3.3 SAE J1725 Structural Modification for Personally Licensed Vehicles to Meet the Transportation Needs of Persons with Disabilities

SAE J1725 is a standard that is currently in the process of being updated. It applies to the structural integrity, performance, driveability, and serviceability of personally licensed vehicles. The intent is to ensure that these vehicles meet the needs of persons with disabilities. The recommendations in this standard may be applicable to other vehicles (e.g., paratransit) but they are only directed to personal vehicles [138].

A.3.4 SAE J2395_200202 ITS In-Vehicle Message Priority

SAE J2395 applies to original equipment manufacturers (OEMs) and aftermarket ITS message-generating systems for passenger vehicles and heavy trucks. It describes the method for prioritizing ITS in-vehicle messages and/or displayed information based on a defined set of criteria. Each set of criteria has a fixed number of levels that are used to rank a given message or information item to determine its prioritization value, which is used to determine the priority in which overlapping, in-vehicle messages are presented to the driver [139].

A.3.5 SAE J3016_2018 Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles

This SAE document is a recommended practice describing motor vehicle driving automation systems that perform part or all of the dynamic driving task (DDT). It provides a taxonomy with definitions for six levels of driving automation, ranging from no driving automation (level 0) to full driving automation (level 5), in the context of vehicles and their operation on roadways. These definitions, and additional supporting terms and definitions, can be used to describe the full range of driving automation features equipped on vehicles in a consistent manner. This document was developed under the SAR On-Road Automated Driving (ORAD) Committee [7].

A.3.6 SAE J3077_201512 Definitions and Data Sources for the Driver Vehicle Interface (DVI)

SAE J3077 provides a summary of the activities to-date of the Research Foundations Task Force of the SAE's Driver Vehicle Interface (DVI) Committee. It establishes working definitions of key DVI concepts, as well as an extensive list of data sources relevant to DVI design and the larger topic of driver distraction.

This document is intended to aid researchers and facilitate DVI design and usability by establishing working definitions of key concepts, while providing references to existing research in this area. New automotive technologies, such as crash avoidance systems, connected vehicles, and vehicle automation, offer many opportunities for improving mobility and driving safety. However, if the driver-vehicle interface is not designed in a manner consistent with driver limitations and capabilities, these potential advantages may not be realized and these technologies can even lead to unintended negative outcomes [140].

A.3.7 SAE J3114_201612 Human Factors Definitions for Automated Driving and Related Research Topics

SAE J3114 provides terms and definitions that are important for the user's interaction with SAE J3016 level 2 to level 4 driving automation system features [141].

A.3.8 SAE J3171_201911 Identifying Automated Driving Systems — Dedicated Vehicles (ADS-DVs) Passenger Issues for Persons with Disabilities

SAE J3171 focuses on persons with certain visual, cognitive, or physical impairments and how level 4 and 5 automated driving systems-dedicated vehicles (ADS-DVs) will eventually enable persons who are otherwise unable to obtain a driver's licence to travel on their own. SAE J3171 is limited to fleet operated on-demand shared mobility scenarios, as this is considered to be the first way people will be able to interact with ADS-DVs. It does not address fixed-route transit services or private vehicle ownership, and does not include the design of chair lifts, ramps, or securements for wheeled mobility devices [142].

A.4 Cybersecurity, Privacy, and Data Training

These standards define the administrative, physical, and technical actions to ensure integrity and privacy of data and information, and they also define data formats, data management practices, and content relevant to CAV applications and operations.

A.4.1 ISO/IEC 20889 — Privacy Enhancing Data De-identification Terminology and Classification of Techniques

ISO/IEC 20889 provides a description of techniques for privacy-enhancing data de-identification to be used to describe and design de-identification measures in accordance with the privacy principles in ISO/IEC 29100. In particular, the document specifies terminology, classification of de-identification techniques according to their characteristics, and their applicability for reducing the risk of re-identification.

ISO/IEC 20889 is applicable to all types and sizes of organizations, including public and private companies, government entities, and not-for-profit organizations, that control or process personal identifiable information and implement data de-identification processes for privacy enhancing purposes [143].

A.4.2 ISO/IEC 27001 Information Technology — Security Techniques — Information Security Management Systems — Requirements

ISO/IEC 27001:2013 specifies requirements for establishing, implementing, and maintaining an information security management system within the context of an organization. It includes requirements for the assessment and treatment of information security risks tailored to the needs of the organization. The requirements set out in the standard are generic and are intended to be applicable to all organizations, regardless of type, size, or nature [144].

A.4.3 ISO/IEC 29100 — Information Technology — Security Techniques — Privacy Framework

ISO/IEC 29100 provides the definition of a privacy framework which:

1. Specifies common privacy terminology
2. Describes privacy safeguarding considerations
3. Defines actors and their roles in processing of personal identifiable information (PII)
4. Provides references to known privacy principles for information technology

This standard is applicable to people and organizations involved in specifying, procuring, developing, testing, and maintaining information and communication technology systems or services where privacy controls are required to process PII. ISO/IEC 29100 is developed under the ISO/IEC JTC 1/SC 27 Information Security, Cybersecurity, and Privacy Protection Task Force [145].

A.4.4 ISO/IEC 29101 — Information Technology — Security Techniques — Privacy Architecture Framework

ISO/IEC 29101 focuses on defining a privacy architecture framework that specifies concerns for information and communication technology (ICT) that process personally identifiable information. The standard also lists components for the implementation of such systems and provides architectural views contextualizing these components. It is published under the ISO/IEC JTC 1/SC 27 Information Security, Cybersecurity, and Privacy Protection Technical Committee [146].

A.4.5 ISO/IEC 29134 — Information Technology — Security Techniques — Guidelines for Privacy Impact Assessment (PIA)

ISO/IEC 29134 focuses on guidelines for a process on privacy impact assessments (PIA), as well as a structure and content for a PIA report. This standard is relevant for designing or implementing projects, including the operation of data processing systems and services that process personally identifiable information. It is published under the ISO/IEC JTC 1/SC 27 Information Security, Cybersecurity, and Privacy Protection Technical Committee [147].

A.4.6 ISO/TR 12859 Intelligent Transport Systems — System Architecture — Privacy Aspects in ITS Standards and Systems

ISO/TR 12859 provides general guidelines for developers of ITS standards and systems regarding data privacy aspects and legislative requirements for the development and revision of ITS standards and systems [148].

A.4.7 NIST Cybersecurity Framework

The Cybersecurity Framework focuses on using business drivers to guide cybersecurity activities and consider risks as part of the risk management process. The Framework consists of the core, the profile, and the implementation tiers. The core is a set of cybersecurity activities, outcomes, and references that are common across critical infrastructure sectors. The profiles help align cybersecurity activities with requirements, risk tolerances, and resources. The implementation tiers provide a mechanism to view and understand the approach to manage cybersecurity risk. The Framework allows for the application of principles and best practices to risk management, improving the security and resilience of the critical infrastructure [149].

A.4.8 NIST Advanced Encryption Standard (AES)

The Advanced Encryption Standard (AES) was established by NIST in 2001. It specifies a cryptographic algorithm used to protect electronic data. The overall goal was to create a Federal Information Processing Standard (FISP) specifying an encryption algorithm that can protect sensitive government information [150]. The AES algorithm can encrypt data and convert it to an unintelligible form (ciphertext). Alternatively, it can also decrypt data, converting it back into its original form (plaintext) [151].

A.4.9 SAE J3061 Cybersecurity Guidebook for Cyber-Physical Vehicle Systems

This Guidebook provides guidance on vehicle-based cybersecurity practices that have been implemented or have been reported in industry, government, and conference papers. This recommended practice establishes high-level guiding principles for cybersecurity, including a complete lifecycle process framework to incorporate cybersecurity into cyber-physical vehicle systems, information on existing tools and methods for designing, verifying and validating cyber-physical vehicle systems, as well as a foundation for further standards development activities in vehicle cybersecurity [152].

A.4.10 SAE J3063 Active Safety Systems Terms & Definitions

This report provides a list of terms, definitions, abbreviations, and acronyms to enable the use of common terminology in engineering reports, diagnostic tools, and publications related to active safety systems. The definitions are descriptions of functionality rather than technical specifications. Included are warning and momentary intervention systems, which do not automate any part of the dynamic driving task on an ongoing sustained basis [153].

A.4.11 Secure Sockets Layer (SSL)

SSL is a standard security technology for establishing an encrypted link between a server and a client. It provides a secure channel between two machines or devices operating over the Internet or an internal network, allowing for sensitive information to be transmitted securely [154]. More specifically, SSL is a security protocol that describes how algorithms should be used and determines the variables of encryption for both the link and the transmitted data [155].

A.4.12 Security Credential Management System (SCMS)

SCMS is a proof-of-concept (POC) message security solution for V2V and V2I communication. It is a public key infrastructure (PKI)-based approach that employs encryption and certificate management to facilitate secured communication. Unlike traditional PKIs, SCMS provides a framework for paving user permission to participate in an application without revealing their identity [156].

A.5 Vehicle Aspects

This section describes standards related to vehicles and onboard equipment technologies, including those related to automation and connectivity. Despite there being limited published standards for automated vehicles, there are a number of ongoing initiatives focusing on related aspects of advanced driver assistance systems.

A.5.1 IATF 16949 Automotive Quality Management Systems (QMS)

IATF 16949:2016 was jointly developed by the International Automotive Task Force (IATF) members and submitted to the International Organization for Standardization (ISO) for approval and publication [157]. It is a common and independent automotive quality system standard that is fully aligned with the structure and requirements of ISO 9001:2015 – Quality Management System Requirements [158, 159].

IATF 16949 focuses on the development of a quality management system that provides for continual improvement, defect prevention, and reduction of variation and waste in the supply chain [157, 159].

A.5.2 ISO 2575 Road Vehicles — Symbols for Controls, Indicators and Tell-Tales

ISO 2575:2010 specifies the symbols (i.e., conventional signs) to be used on controls, indicators, and tell-tales applying to vehicles and buses. The standard also indicates the colours of optical signals to inform the driver of either correct operation or malfunctioning of a given vehicle device [160].

A.5.3 ISO 11067 Intelligent Transport Systems — Curve Speed Warning Systems (CSWS) — Performance Requirements and Test Procedures

ISO 11067:2015 applies to vehicles with at least four wheels and contains information regarding basic control strategies, minimum functionality requirements, basic driver interface elements, minimum requirements for diagnostics and reaction to failure, and performance test procedures for curve speed warning systems (CSWS). This technology warns the driver about the danger caused by maintaining excessive speed while travelling along upcoming curved roads so that the driver may reduce the vehicle speed. The system does not control the vehicle to meet the desired speed. The safe operation of the vehicle remains the responsibility of the driver [161].

A.5.4 ISO 11270 Intelligent Transport Systems — Lane Keeping Assistance Systems (LKAS) — Performance Requirements and Test Procedures

ISO 11270:2014 is applicable to passenger cars, commercial vehicles, and buses and contains information regarding basic control strategies, minimum functionality requirements, basic driver interface elements, minimum requirements for diagnostics and reaction to failure, and performance test procedures for LKAS. This technology provides support for safe lane keeping operations by drivers and does not perform automatic driving or prevent possible lane departures. LKAS is intended to operate on highways and equivalent roads and consists of recognizing the location of the vehicle inside its lane and influencing lateral vehicle movement. The support at roadway sections having temporary or irregular lane markings (such as roadwork zones) is not within the scope of ISO 11270 [162].

A.5.5 ISO 15622 Intelligent Transport Systems — Adaptive Cruise Control Systems — Performance Requirements and Test Procedures

ISO 15622:2018 contains information regarding the basic control strategies, minimum functionality requirements, basic driver interface elements, minimum requirements for diagnostics and reaction to failure, and performance test procedures for adaptive cruise control (ACC) systems.

These systems are realized as either full speed range adaptive cruise control (FSRA) systems or limited speed range adaptive cruise control (LSRA) systems. ACC is fundamentally intended to provide longitudinal control of vehicles while travelling on highways under free-flowing conditions and congested traffic conditions for FSRA-type systems. ISO 15622 replaced the ISO 22179:2009 standard [163].

A.5.6 ISO 15623 Intelligent Transport Systems — Forward Vehicle Collision Warning Systems — Performance Requirements and Test Procedures

ISO 15623:2013 covers operations on roads with curve radii over 125 m, and applies to motor vehicles including cars, trucks, buses, and motorcycles. It specifies performance requirements and test procedures for systems capable of warning the driver of a potential rear-end collision with vehicles ahead while it is operating at ordinary speed. The system operates in a specified speed range, on a specified road curvature range, and on certain types of vehicles. The safe operation of the vehicle remains the responsibility of the driver [164].

A.5.7 ISO 19237 Intelligent Transport Systems — Pedestrian Detection and Collision Mitigation Systems (PDCMS) — Performance Requirements and Test Procedures

ISO 19237:2017 consists of a concept of operation and system requirements on test procedures for pedestrian detection and collision mitigation systems (PDCMS). The standard specifies the behaviours that are required for PDCMS and the system test criteria necessary to verify that the implementation of the system meets the specified requirements. The PDCMS is designed to reduce the severity of pedestrian collisions that cannot be avoided and may help reduce the likelihood of a fatality or the severity of the injury. PDCMS requires information regarding distance to pedestrians, the motion of the pedestrians, the motion of the subject vehicle (SV), and driver commands and actions [165].

A.5.8 ISO 19638 Intelligent Transport Systems — Road Boundary Departure Prevention Systems (RBDPS) — Performance Requirements and Test Procedures

ISO 19638:2018 is intended for light duty passenger vehicles and heavy vehicles and contains information regarding the basic control strategies, minimum functionality requirements, basic driver interface elements, minimum requirements for diagnostics and reaction to failure, and performance test procedures for road boundary departure prevention systems (RBDPS). This system is a driving safety support system that acts to prevent road departures in order to reduce damage and accidents arising from road boundary departures.

RBDPS is intended to operate on roads (well-developed and standardized freeways or highways) having solid lane markers. Roadwork zones or roads without visible road boundary markers are not within the scope of this document. RBDPS is not designed to operate continuously, but to operate automatically only when possible road boundary departures are detected or predicted. The driver's decision and operation takes priority at all times [166].

A.5.9 ISO 20035 Intelligent Transport Systems — Cooperative Adaptive Cruise Control Systems (CACC) — Performance Requirements and Test Procedures

ISO 20035:2019 is applicable to motor vehicles, including light vehicles and heavy vehicles, and it addresses two types of CACC systems – wireless communication with preceding vehicles (V2V) and infrastructure (V2I). Both types of CACC systems require active sensing, such as radar, LIDAR, or camera systems. A combined V2V and I2V CACC system is not addressed in this standard. The document addresses the classification of the types of CACC, the definition of the performance requirements for each CACC type, and the minimum set of wireless data requirements and test procedures. Coordinated strategies to control groups of vehicles, such as platooning, in which vehicle controllers base their control actions on how they affect other vehicles and to determine short following clearance gaps, are not within the scope of this document [167].

A.5.10 ISO 21717 Intelligent Transport Systems — Partially Automated In-Lane Driving Systems (PADS) — Performance Requirements and Test Procedures

The ISO 21717:2018 document is applicable to passenger cars, commercial vehicles, and buses. It is not applicable to automated driving systems of level 3 or higher (as defined in SAE J3016:2016). It contains information regarding the basic control strategies, minimum functionality requirements, basic driver interface elements, minimum requirements for diagnostics and reaction to failure, and performance test procedures for partially automated in-lane driving systems (PADS). PADS is fundamentally intended to provide partially automated driving by longitudinal and lateral control of equipped vehicles while travelling on highways [168].

A.5.11 ISO 22839 Intelligent Transport Systems — Forward Vehicle Collision Mitigation Systems — Operation, Performance, and Verification Requirements

ISO 22839:2013 defines the concept of operation, system requirements, minimum functionality, and test methods for a forward vehicle collision mitigation system (FVCMS). The standard specifies the behaviour required for FVCMS and the system test criteria necessary for verifying if implementation of the technology meets the requirements of the standard [169].

A.5.12 ISO 26262 Road Vehicles — Functional Safety

ISO 26262 is applied to safety-related systems that include one or more electrical or electronic systems that are installed in passenger cars with a maximum gross vehicle mass up to 3,500 kg. It addresses possible hazards caused by malfunctioning behaviour of electrical or electronic safety-related systems, including the interaction of these systems [170].

A.5.13 ISO/DIS 20901 Intelligent Transport Systems — Emergency Electronic Brake Light Systems (EEBL) — Performance Requirements and Test Procedures

ISO/DIS 20901 is currently under preparation for final publication. Its scope applies to light duty and heavy vehicles, and contains information regarding the basic alert strategies, minimum functionality requirements, basic driver interface elements, minimum requirements for diagnostics and reaction to failure, and performance test procedures for emergency electronic brake light systems (EEBL). The system alerts a driver against the danger caused by emergency braking the forward transmitting vehicle on the upcoming road so that the driver may reduce the speed. The system does not include the means to control the vehicle to meet the desired speed [171].

A.5.14 ISO/PAS 21448 Road Vehicles — Safety of the Intended Functionality

ISO/PAS 21448:2019 provides guidance on design, verification, and validation measures needed to achieve the safety of the intended functionality. It is intended to be applied to functionality where situational awareness is critical to safety, and where that situational awareness is derived from complex sensors and processing algorithms; especially emergency intervention systems and advanced driver assistance systems (ADAS) with levels 1 and 2 as per SAE J3016. This edition of the document can be considered for higher levels of automation, but additional measures might be necessary [172].

A.5.15 SAE J1698_201703 Event Data Recorder (EDR)

SAE J1698 consists of a series of standards that describe common definitions and operational elements of event data recorders. The series includes the following documents [173]:

- **SAE J1698-1 Output Data Definition:** Identifies common data output formats and definitions for data elements that may be useful for analysis of vehicle accidents and similar events that meet specific trigger criteria.
- **SAE J1698-2 Retrieval Tool Protocol:** Utilizes existing industry standards to identify common physical interfaces and define protocols needed to retrieve records stored by event data recorders.
- **SAE J1698-3 Compliance Assessment:** Defines procedures that may be used to validate that the event data recorder output conforms with reporting requirements specified by applicable motor vehicle safety standards and other applicable vehicle accident testing.

A.5.16 SAE J3088_201711 Active Safety System Sensors

SAE J3088 is a standard developed by the Active Safety Systems Committee, Active Safety Systems Sensors Task Force. Its primary focus is on identifying the functionality and performance expected from active safety sensors, as well as establishing a basic understanding of how sensors work [174].

A.5.17 SAE J3018_201909 Safety-Relevant Guidance for On-Road Testing of SAE Level 3, 4, and 5 Prototype Automated Driving System (ADS) — Operated Vehicles

SAE J3018 provides guidance on safety for on-road testing of vehicles being operated by SAE J3016 levels 3 to 5 prototype of the automated driving system (ADS), while under the supervision of system fallback test drivers. This standard does not provide guidance for evaluating the performance of vehicles equipped with ADS post-production [175].

A.5.18 SAE J3048_201602 Driver-Vehicle Interface Considerations for Lane Keeping Assistance Systems

SAE J3048 provides guidance for the implementation of driver-vehicle interfaces for lane keeping assistance systems (LKAS), as defined by ISO 1127. This standard addresses driver-vehicle interface parameters for passenger cars and trucks. It does not address system or operational requirements for LKAS [176].

A.5.19 SAE J3087_201710 Automatic Emergency Braking (AEB) System Performance Testing

SAE J3087 describes a recommended practice for automatic emergency breaking (AEB) system performance testing. It identifies and describes equipment, facilities, methods, and procedures needed to evaluate the ability of the AEB system in a vehicle to detect another vehicle in its immediate path and to respond accordingly. It also identifies target test scenarios and measurement methods and explains performance data of interest [177].

A.5.20 SAE J3092 (Work in Progress) Dynamic Test Procedures for Verification & Validation of Automated Driving Systems (ADS)

SAE J3092 is a standard that is currently under development focusing on providing dynamic test procedure information and guidelines for verification and validation of automated driving systems (ADS) for all types of motor vehicles. It provides a generic template for the verification and validation of ADS, as well as a few specific key examples. The verification and validation apply to the functionality and dependability of on-road ADS for correctness and completeness. The functionality is defined by its functional specification of behaviour, while the dependability is defined by its safety, reliability, availability, maintainability, and integrity. Different means for verifying and validating will be adopted as ADS evolve. SAE J3092 is intended to harness best practices and information from industry [178].

A.6 Systems Architecture and Guidelines

This section describes frameworks for planning and designing applications, as well as guidelines and methodologies for integration and testing.

A.6.1 Architecture Reference for Cooperative and Intelligent Transportation (ARC-IT)

The Architecture Reference for Cooperative and Intelligent Transportation (ARC-IT) provides a common framework for planning, defining, and integrating intelligent transportation systems. It provides a common basis for planners and engineers to design and implement systems using a common language as a basis for delivering ITS, but does not mandate any implementation. It consists of four views:

1. **Enterprise View** – relationships between organizations
2. **Functional View** – logical interactions between functions
3. **Physical View** – connection between physical objects
4. **Communications View** – layered protocols facilitating data exchange between physical objects

ARC-IT serves as the national ITS reference architecture for the United States [179].

A.6.2 ASTM F3218 — 19 Standard Practice for Documenting Environmental Conditions for Utilization with A-UGV Test Methods

ASTM F3218 is a standard practice that provides brief introduction to a list of environmental conditions that can affect performance of autonomous – unmanned ground vehicle (A-UGV) performance, including lighting, external sensor emission, temperature, humidity, electrical interference, air quality, ground surface, and boundaries. This practice then breaks down each condition into subcategories so that the user can document the various aspects associated with the category prior to A-UGV tests (e.g., as defined in ASTM F3244) [180].

A.6.3 ITS Architecture for Canada

The ITS architecture for Canada is a common framework for planning, defining, and integrating intelligent transportation systems. The architecture describes interactions between physical components of the transportation systems (travellers, vehicles, roadside devices, and control centres). It also describes the information and communications system requirements, including how data should be shared and used, and the standards required to facilitate information sharing.

It was developed to support ITS implementations in urban, interurban, and rural environments across the country. The architecture is currently being updated to version 3 to realign it with the current US ARC-IT and include applications related to connected and automated vehicles [18].

A.6.4 NIST 6910-4D/RCS 2.0 A Reference Model Architecture for Unmanned Vehicle Systems

NIST 6910-4D/RCS 2.0 provides a reference model for unmanned military vehicles on how their software components should be identified and organized, and how they should interact, such that missions can be analyzed, decomposed, distributed, planned, and executed intelligently, effectively, efficiently, and in coordination. The reference model provides well-defined and highly coordinated sensory processing, knowledge management, cost and benefit analysis, and behaviour generation functions, as well as the associated interfaces that are based on proven scientific principles and are consistent with military hierarchical command structures. The architecture forms a standard framework to facilitate component and interface standards development, including command and control, sensors, communication, mapping, operating environments, safety, security, software engineering, user interface, data interchange, and graphics [181].

Appendix B – Relevant Technical Committees and Working Groups

Standard development organizations consist of various technical committees, advisory groups, and working groups that conduct the work and research for standard development. This section focuses on the relevant committees of the International Organization for Standardization (ISO), European Committee for Standardization (CEN), SAE International, and the National Transportation Communications for Intelligent Transportation System Protocol (NTCIP).

B.1 International Organization for Standardization (ISO)

ISO has three relevant technical committees related to the standardization of road vehicles and their equipment (TC 22), standardization of intelligent transport systems (TC 204), and standardization of geographic information (TC 211).

B.1.1 ISO Technical Committee 204 Intelligent Transport Systems

ISO/TC 204 was created in 1992 and is responsible for the overall system aspects and infrastructure aspects of intelligent transport systems (ITS), as well as the coordination of the overall ISO work program, including the schedule for standards development, while considering the work of existing international standardization bodies.

TC 204 is responsible for 274 published ISO standards, with 80 ISO standards under development. The scope of TC 204 includes the standardization of information, communication, and control systems in surface transportation. This includes multimodal transportation, traveller information, traffic management, public transport, commercial transport, as well as emergency and commercial services. TC 204 currently has 12 working groups covering a wide variety of focus areas, which are identified in Table 7 [52].

Table 7: *Active ISO TC 204 Working Groups*

Working Group	Convenor
WG 1: Architecture	USA
WG 3: ITS database technology	Japan
WG 5: Fee and toll collection	Sweden
WG 7: General fleet management and commercial/freight	Canada
WG 8: Public transport/ emergency	USA
WG 9: Integrated transport information, management, and control	Australia
WG 10: Traveller information systems	UK
WG 14: Vehicle/roadway warning and control systems	Japan
WG 16: Communications	USA
WG 17: Nomadic devices in ITS Systems	Korea
WG 18: Cooperative systems	Germany
WG 19: Mobility integration	Norway

B.1.2 ISO Technical Committee 22 Road Vehicles

ISO/TC 22 was created in 1947 and is directly responsible for 17 published ISO standards, with one ISO standard under development. The scope of TC 22 is to address questions related to the standardization concerning compatibility, interchangeability, and safety, with particular reference to terminology and test procedures (including the characteristics of instrumentation) for evaluating the performance of vehicles and their equipment. TC 22 currently has 11 subcommittees covering a wide variety of focus areas, as identified in Table 8 [182].

B.1.3 ISO Technical Committee 211 Geographic Information/Geomatics

ISO/TC 211 was created in 1994 and is directly responsible for 75 published ISO standards, with 24 ISO standards under development. The scope of TC 211 is standardization in the field of digital geographic information. It aims to establish a structured set of standards for information concerning objects directly or indirectly associated with a location relative to the Earth. The standards developed under TC 211 may specify methods, tools, and services for data management (including definition and description), acquiring, processing, analyzing, accessing, presenting, and transferring such data in digital/electronic form between different users, systems, and locations. The work links to appropriate standards for information technology and data where possible, and provides a framework for the development of sector-specific applications using geographic data [183].

Table 8: *Active Subcommittees of ISO/TC 22*

Subcommittee	Scope
SC 31	Data communication
SC 32	Electrical and electronic components and general system aspects
SC 33	Vehicle dynamics and chassis components
SC 34	Propulsion, powertrain, and powertrain fluids
SC 35	Lighting and visibility
SC 36	Safety and impact testing
SC 37	Electrically propelled vehicles
SC 38	Motorcycles and mopeds
SC 39	Ergonomics
SC 40	Specific aspects for light and heavy commercial vehicles, busses, and trailers
SC 41	Specific aspects for gaseous fuels

B.2 European Committee for Standardization (CEN)

Similar to ISO, CEN has its own set of technical committees focusing on developing European standards relating to vehicles (TC 301) and ITS (TC 278). There is also active coordination with the corresponding ISO working groups.

B.2.1 CEN Technical Committee 301 Road Vehicles

CEN/TC 301 is responsible for the preparation of European road vehicle standards addressing European mandates. Due to the global nature of the automotive industry, the international level of standards development (e.g., ISO/TC 22 Road Vehicles) takes priority.

CEN/TC 301 has a total of six working groups covering a variety of areas, which are identified in Table 9 [184].

Table 9: *Active Working Groups of CEN/TC 301*

Working Group	Scope
WG 6	M/421 Vehicle OBD, repair and maintenance information
WG 7	Supplementary grip devices
WG 11	Safety of roller brake testers
WG 14	Electricity fuel labelling
WG 15	Safety of machines for mounting and demounting vehicles tires
WG 16	Performance assessment of the portable emission measuring systems (PEMS)

B.2.2 CEN Technical Committee 278 Intelligent Transport Systems

CEN/TC 278 is responsible for the development of European standardization in the field of telematics as applied to road traffic and transportation. It supports communication between vehicles and road infrastructure, communication between vehicles, traffic and parking management, user fee collection, public transport management, and user information.

CEN/TC 278 has a total of 11 working groups covering a variety of areas, as identified in Table 10 [185].

B.3 SAE International

Standards from SAE International are used to advance mobility engineering globally. The SAE Technical Standards Development Program is the organization's primary focus for the mobility industries it serves. The SAE Motor Vehicle Council and its Truck and Bus Council have a wide variety of relevant technical committees for connected and automated mobility [186].

Table 10: *Active Working Groups of CEN/TC 278*

Working Group	Scope
WG 1	Electronic fee collection and access control (EFC)
WG 3	Public transport (PT)
WG 4	Traffic and traveller information (TTI)
WG 5	Traffic control (TC)
WG 7	ITS spatial data
WG 8	Road traffic data (RTD)
WG 13	Architecture and terminology
WG 14	After theft systems for the recovery of stolen vehicles
WG 15	eSafety
WG 16	Cooperative ITS
WG 17	Urban ITS

B.3.1 V2X Communications Steering Committee

The V2X Communications Steering Committee consists of technical committees covering a variety of V2X communication applications. This includes the V2X Core Technical Committee, work on topics that promotes solutions common to multiple applications and technologies [187]. The V2X Vehicular Application Technical Committee defines V2X application and communication focusing on vehicle and mobile device applications to address safety, mobility, and other transportation needs [188]. Other technical committees cover topics related to infrastructure applications, traffic signal applications, tolling applications, and security [186].

B.3.2 DSRC Technical Committee

The DSRC Technical Committee is part of the Connected Vehicles Steering Committee of the Motor Vehicle Council Vehicle Engineering Systems Group. This committee is responsible for developing and maintaining SAE message set standards, recommended practices, and information reports for use with short-to-medium-range wireless communication protocols specifically designed for road vehicle use [189].

B.3.3 C-V2X Technical Committee

The C-V2X Technical Committee is part of the Connected Vehicles Steering Committee of the Motor Vehicle Council Vehicle Engineering Systems Group. This committee is responsible for adapting, developing, and maintaining SAE standards, recommended practices, and information reports regarding cellular radio access technologies, such as evolving 4G LTE and 5G cellular technologies that require interoperability and performance standards for road vehicles and other road users. The committee coordinates task force efforts on development and delivery of SAE documents and liaises with the other organizations involved with vehicular-oriented cellular standards and deployments [190].

B.3.4 Automated and Connected Commercial Vehicles Committee

The Automated and Connected Commercial Vehicles Committee is part of the Truck-Bus Council. It has the responsibility to initiate, develop, review, and approve technical reports related to automated/autonomous/connected commercial vehicle systems. The committee explores varying needs and opportunities related to standards development for automated commercial vehicles with the objective of integrating aspects of safety, communications, human factors, sensors, performance, and powertrain elements [191].

B.3.5 On-Road Automated Driving (ORAD) Committee

The On-Road Automated Driving (ORAD) Committee is part of the Motor Vehicle Council Driver Assistance Systems Steering Committee. ORAD is responsible for developing and maintaining technical reports (e.g., standards, recommended practices, and information reports) related to motor vehicle driving automation system features across the full range of levels of driving automation. The focus is primarily on automated driving systems (ADS) levels 3 to 5, as defined by SAE J3016. The ORAD committee does not focus on specific subsystems (e.g., communications, active safety, or other driver assistance technologies) but rather contributes to other committees and task forces in these distinct areas of expertise [192].

B.4 National Transportation Communications for Intelligent Transportation System Protocol (NTCIP)

NTCIP is a family of standards that provides both the protocols (rules for communicating) and objects (vocabulary) needed for traffic control equipment, from different manufacturers, to operate with each other as a single system [193]. NTCIP has a number of working groups responsible for developing standards. The Roadside Unit (RSU) Working Group is identified as developing standards most relevant to CAVs.

B.4.1 Roadside Unit (RSU) Working Group

The NTCIP Roadside Unit (RSU) Working Group is responsible for developing, maintaining, and monitoring technical issues of NTCIP standards regarding roadside units. This a new working group that has no previous publications. It is currently working on developing the NTCIP 1218 V01 standard on object definitions for RSUs, and specifying protocols and data definitions [74].

B.4.2 Signal Control and Prioritization (SCP) Working Group

The Signal Control and Prioritization (SCP) Working Group (SCP WG) is responsible for development and maintenance of those NTCIP standards that are specifically related to signal control and prioritization transportation sensor systems, specifically NTCIP 1211 (a data dictionary standard).

CSA Group Research

In order to encourage the use of consensus-based standards solutions to promote safety and encourage innovation, CSA Group supports and conducts research in areas that address new or emerging industries, as well as topics and issues that impact a broad base of current and potential stakeholders. The output of our research programs will support the development of future standards solutions, provide interim guidance to industries on the development and adoption of new technologies, and help to demonstrate our on-going commitment to building a better, safer, more sustainable world.

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