CONNECTED AUTONOMOUS VEHICLES

Frequently Asked Questions

2022RIC02
April 2022

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CAV FREQUENTLY ASKED QUESTIONS

General | Timing/Preparation | Policy/Standardization | Safety | Rural | Resources

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What is CAV?

What are different types of AV and CV technologies?

What are Connected Vehicle (CV) applications?

What are the 6 levels of Automation?

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CAV FREQUENTLY ASKED QUESTIONS

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CAV FREQUENTLY ASKED QUESTIONS

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Choose a question.

What is CAV?

What are different types of AV and CV technologies?

What are Connected Vehicle (CV) applications?

What are the 6 levels of Automation?

General ?	Timing/ Preparation	Policy/ Standardization	Safety	Rural	Resources

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What is CAV?

- Connected vehicles (CV) use technology to communicate with other connected vehicles, roadside infrastructure like signs and traffic signals, smartphones, and other devices, or obtain data from the cloud. This information is used to supply useful information to a driver or vehicle to allow making safer and more informed decisions, with more time to react and prevent an incident.

- Automated vehicles (AV) use information from cameras, radar, lidar, Global Positioning System (GPS), and other sources to observe the environment around them, allowing them to steer, accelerate, and brake in certain situations with little or no human input. The amount of human interaction required varies as defined by the levels of automation (next question).

- Autonomous vehicles are automated vehicles that are capable of navigating without any human input, i.e., those at the higher levels of automation as defined below.

For more information, see: MnDOT CAV-X Office - "What are Connected and Automated vehicles?"

What is CAV?

What are different types of AV and CV technologies?

What are Connected Vehicle (CV) applications?

What are the 6 levels of Automation?

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What are different types of AV and CV technologies?

- [Advanced Driver Assistance Systems (ADAS)](#) are level 1 and 2 automation technologies that each automate a specific aspect of the driving task, such as adaptive cruise control and lane keeping.

- Automated Driving Systems (ADS) are level 3 and higher technologies that can take over all aspects of the driving task under some (level 3 and 4) or all (level 5) circumstances.

What is CAV?

What are different types of AV and CV technologies?

What are Connected Vehicle (CV) applications?

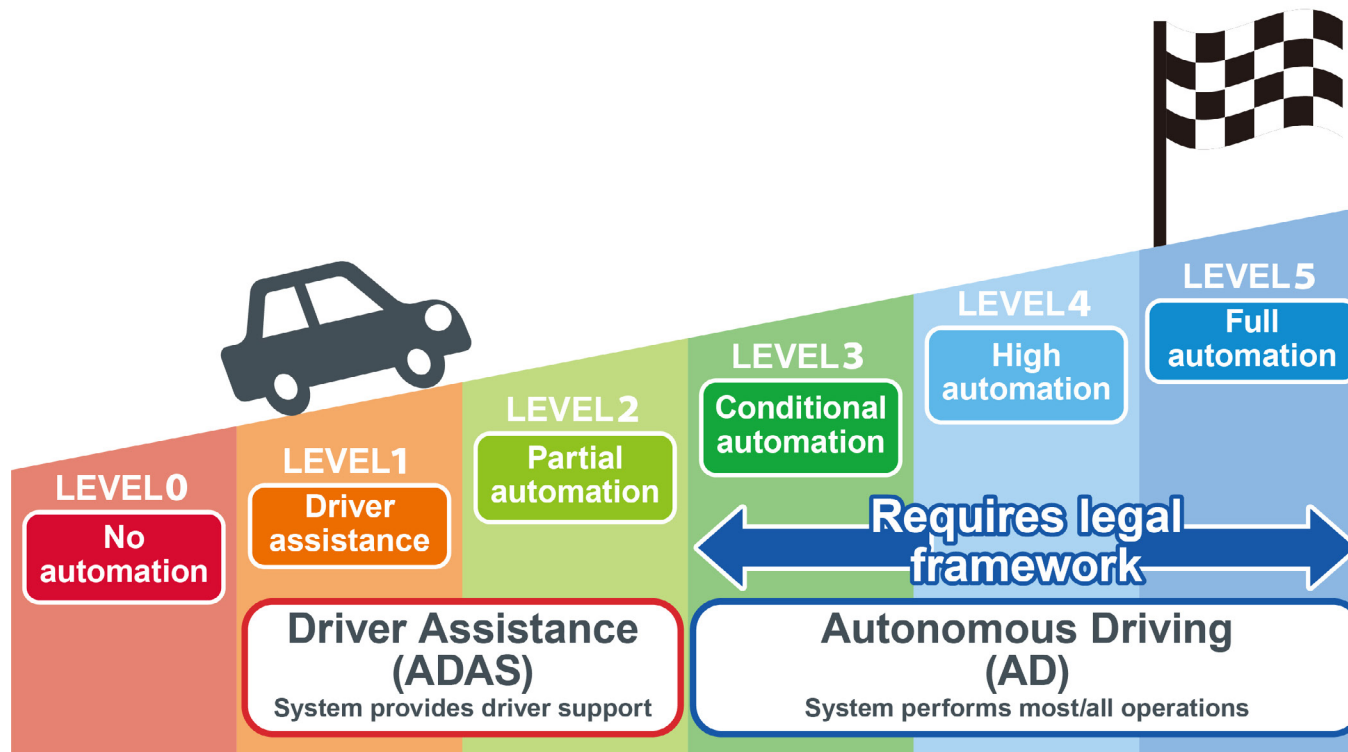What are the 6 levels of Automation?

LEVEL 0 — No automation
LEVEL 1 — Driver assistance
LEVEL 2 — Partial automation
LEVEL 3 — Conditional automation
LEVEL 4 — High automation
LEVEL 5 — Full automation

Requires legal framework

Driver Assistance (ADAS) — System provides driver support

Autonomous Driving (AD) — System performs most/all operations

Image source: www.rohm.com/blog/-/blog/id/8030373

General ?	Timing/ Preparation	Policy/ Standardization	Safety	Rural	Resources

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What are Connected Vehicle (CV) applications?

- Connected vehicle (CV) applications use real-time data shared between vehicles (and other road users) and infrastructure, in some cases along with an ADAS or ADS, to allow vehicles to avoid dangerous situations (as in red light violation warning) or operate cooperatively (as in cooperative adaptive cruise control), improving overall safety and/or mobility. Together, ADAS, ADS, and CV applications form the building blocks of a CAV ecosystem.
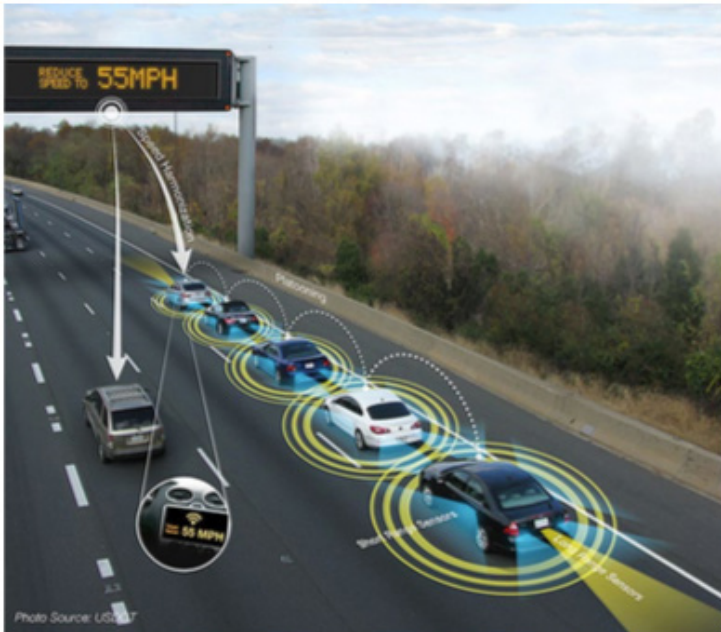
What is CAV?

What are different types of AV and CV technologies?

What are Connected Vehicle (CV) applications?

What are the 6 levels of Automation?

Image source: USDOT FHA ops.fhwa.dot.gov/publications/fhwahop17001/ch1.htm
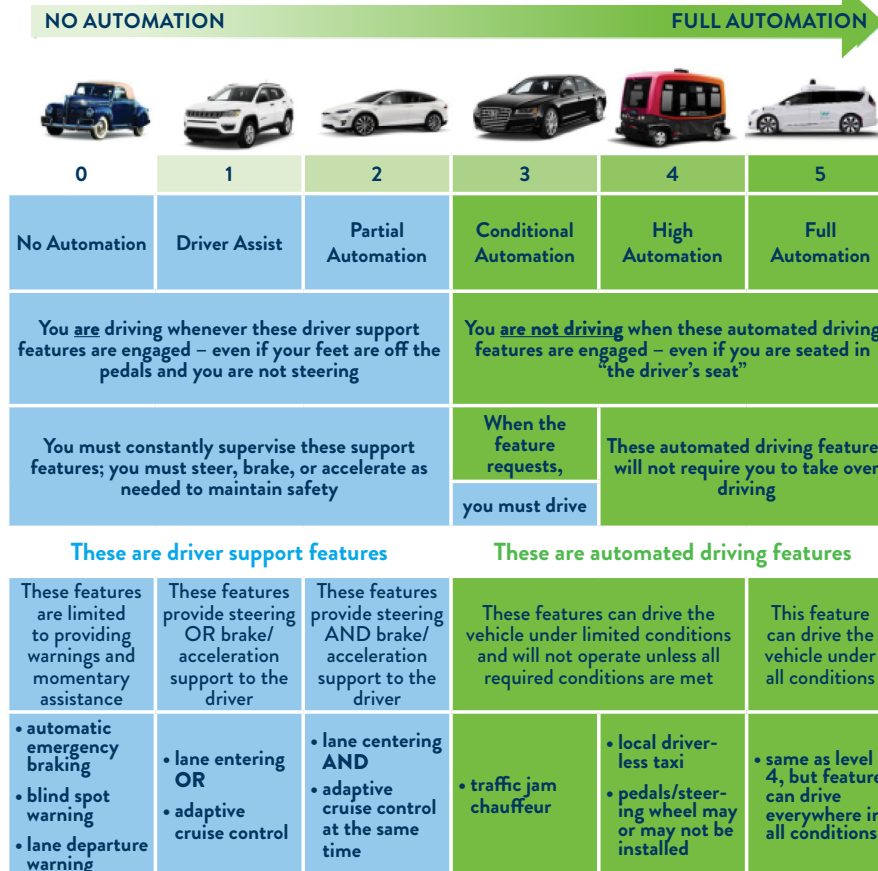
What are the 6 Levels of Automation?

- The Levels of Automation were developed by a group of automotive engineers to help us understand the different self-driving technologies.

- The Society of Automotive Engineers breaks down vehicle automation technologies into 6 levels (in addition to a level 0 with no automation). The lowest level of automation is level 1, where either steering or acceleration/braking are automated, and a human driver is required. At the highest level (level 5), all aspects of driving are fully automated, and the vehicle can reliably drive itself in all situations. In between are increasing degrees of automation with decreasing oversight required. The graphic describes each of these levels and the level of oversight required in more detail.

ZOOM OUT   ZOOM IN

SAE J3016™ LEVELS OF DRIVING AUTOMATION

NO AUTOMATION → FULL AUTOMATION

0	1	2	3	4	5
No Automation	Driver Assist	Partial Automation	Conditional Automation	High Automation	Full Automation

What does the human in the driver's seat have to do?

You **are** driving whenever these driver support features are engaged – even if your feet are off the pedals and you are not steering	You **are not driving** when these automated driving features are engaged – even if you are seated in "the driver's seat"	
You must constantly supervise these support features; you must steer, brake, or accelerate as needed to maintain safety	When the feature requests, you must drive	These automated driving features will not require you to take over driving

These are driver support features   These are automated driving features

What do these features do?

These features are limited to providing warnings and momentary assistance	These features provide steering OR brake/ acceleration support to the driver	These features provide steering AND brake/ acceleration support to the driver	These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met	This feature can drive the vehicle under all conditions

Example Features

• automatic emergency braking • blind spot warning • lane departure warning	• lane entering OR • adaptive cruise control	• lane centering AND • adaptive cruise control at the same time	• traffic jam chauffeur	• local driver- less taxi • pedals/steer- ing wheel may or may not be installed	• same as level 4, but feature can drive everywhere in all conditions

Images are from SAE and the MnDOT CAV-X website.

What is CAV?
What are different types of AV and CV technologies?
What are Connected Vehicle (CV) applications?
What are the 6 levels of Automation?

| General ? | Timing/ Preparation | Policy/ Standardization | Safety | Rural | Resources |

| Terminology | What should I know? | What's been done? | Funding | Tech Talk |

Choose a question.

- The level of automation available to consumers
- Infrastructure impacts
- Technology development

General ?	Timing/Preparation	Policy/Standardization	Safety	Rural	Resources

Terminology	What should I know?	What's been done?	Funding	Tech Talk

The level of automation available to consumers

- Level 2 - The highest level of automation available commercially today to consumers despite the media and manufacturer marketing that may tell the public otherwise. Features like Tesla's "Autopilot" and Toyota "SuperCruise" include support systems like adaptive cruise control and lane keeping.
- Level 3 - Some vehicle manufacturers are starting to produce vehicles for sale with level 3 driving systems in other countries, however these generally function in self-driving mode under very limited situations and still require a human driver.
- Level 4 - autonomous shuttles that function in specific geographic areas and weather conditions are being piloted across the country, however these systems are under active development and should not be considered proven technology.

The level of automation available to consumers

Infrastructure impacts

Technology development

NO AUTOMATION → FULL AUTOMATION

0	1	2	3	4	5
No Automation	Driver Assist	Partial Automation	Conditional Automation	High Automation	Full Automation

Image source: SAE.

General ?	Timing/ Preparation ⏱	Policy/ Standardization 📋	Safety 🛜🚗	Rural 🛣️	Resources 🌐

Terminology	What should I know?	What's been done?	Funding	Tech Talk

Infrastructure impacts

- CAV brings some impacts to infrastructure, including some new considerations along with extensions of existing needs. Connected vehicles require some information from infrastructure, most notably traffic signals, requiring updated signal controllers and communications technology to talk to vehicles. The hardware in the field also requires some level of network connectivity. For automated vehicles, quality pavement markings and traffic signs are important for vehicle navigation, bringing stricter maintenance requirements to maintain visibility and some potential changes to sign/striping technology or striping patterns.

- In the connected vehicle space, there are deployments of roadside infrastructure in some areas, largely in connection with the USDOT Connected Vehicle Pilot Deployment Program and the AASHTO Signal Phasing and Timing (SPaT) Challenge. However, there are few connected vehicles able to communicate with this infrastructure. In addition, the Federal Communications Commission (FCC) recently reallocated a portion of the radio spectrum band to other applications which impacts the number of applications that can be supported. The new federal rule also directs transportation applications using the remaining portion of the spectrum to transition to cellular vehicle-to-everything (C-V2X) technologies over an unspecified period.

The level of automation available to consumers

Infrastructure impacts

Technology development

See other sections for more information:

What kind of standards are there for CAV infrastructure? Who will provide these specifications?

Will CAVs need different pavement markings? How are pavement markings affected by CAV? What can be done and when?

Will CAVs require different signs or signals?
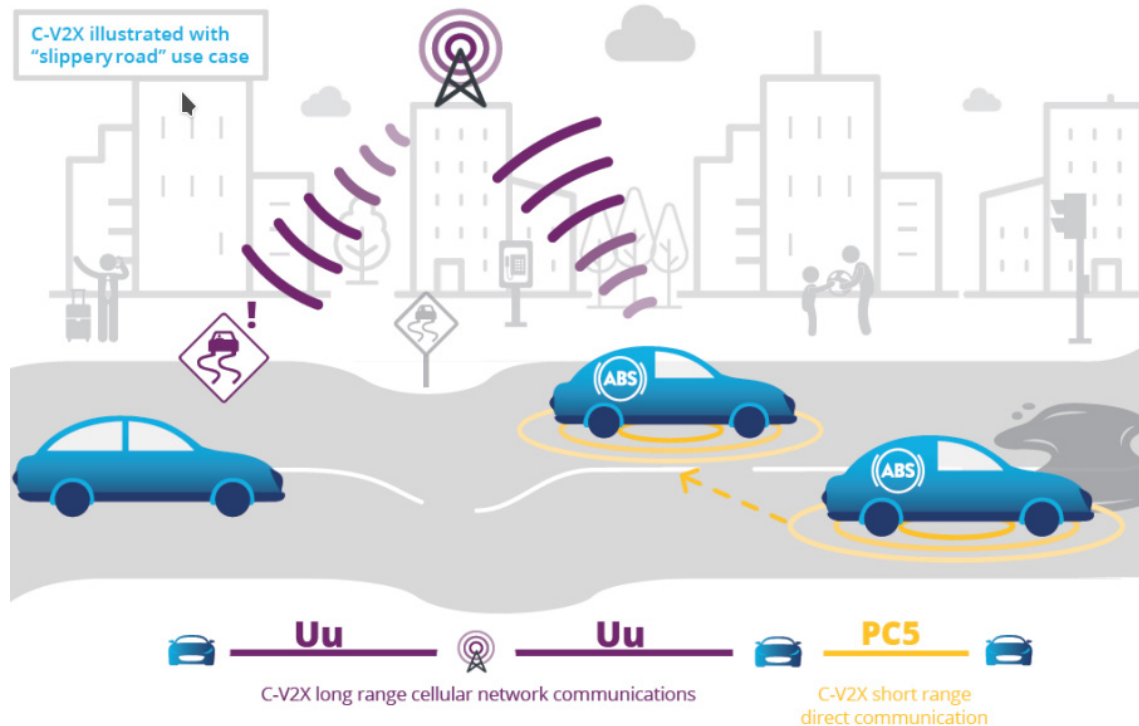
Technology development

- Development of C-V2X technology is occurring rapidly, though further development and testing will be required before this technology is reliable. C-V2X chips for integration into vehicles are being produced commercially, though these are primarily used for testing and are not yet being installed into vehicles at a large scale.

The level of automation available to consumers

Infrastructure impacts

Technology development

C-V2X illustrated with "slippery road" use case

Uu — Uu — PC5

C-V2X long range cellular network communications

C-V2X short range direct communication

Image source: 5GAA 5g-ppp.eu/wp-content/uploads/2018/09/27-Michael-Neaves.pdf

CAV FREQUENTLY ASKED QUESTIONS

Terminology | What should I know? | What's been done? | Funding | Tech Talk

Choose a question.

Minnesota research

National research

Global research

CAV FREQUENTLY ASKED QUESTIONS

| Terminology | What should I know? | What's been done? | Funding | Tech Talk |

Minnesota research

- MnDOT's CAV-X office has facilitated some testing of autonomous shuttles. CAV-X is testing and continuing to advance technology across the state, as the leading state program for this work.

- The Center for Transportation Studies at the University of Minnesota is also actively researching the technology with the new MinnCAV Ecosystem research program.

- In 2018 the Governor's Advisory Council on Connected and Automated Vehicles was established which sets the vision and goals for Minnesota's CAV program. In 2020 the Council created the statewide CAV Innovation Alliance for stakeholders to regularly convene in committees to collaborate and share technical expertise.

- In Minnesota, the Connected Corridor on Minnesota State Highway 55 west of Minneapolis has been the primary DSRC testing site. The recent FCC order requiring that such installations transition to new cellular technologies, however, means that these sites will be decommissioned.

- Minnesota has also been active in coordinating with other states and organizations to facilitate further research and develop guidance for policymakers. Minnesota is active in several transportation pooled funds involved in CAV research, including the Connected Vehicle Pooled Fund Study, Automated Vehicle Pooled Fund Study, Autonomous Maintenance Technology (AMT), Evaluating New Technologies for Roads Program Initiatives in Safety and Efficiency (ENTERPRISE), and Northwest Passage.

Minnesota research

National research

Global research

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National research

- In the United States, at least 20 states are completing some form of testing, with states such as California, Florida, and Michigan leading research.

- The National Highway Traffic Safety Administration's AV TEST Initiative is a public website that shows the active testing locations across the U.S.

- Testing of DSRC in the United States has primarily been in connection with the USDOT Connected Vehicle Pilot Deployment Program or the SPaT Challenge.

- Testing of C-V2X has increased as the technology has developed, with pilot deployments testing the technology taking place in places like China, Virginia and Michigan. C-V2X testing has not yet occurred in Minnesota.

- Organizations like AASHTO and ITS America have been active in developing policy guidance, such as AASHTO's Connected and Automated Vehicle Policy Principles and through a number of ITS America Standing Committees relating to CAV.
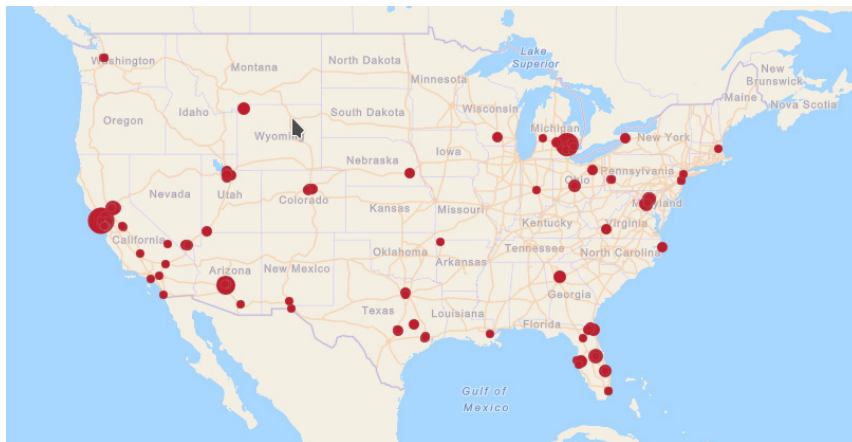
Minnesota research

National research

Global research

Image source: NHTSA https://www.nhtsa.gov/automated-vehicle-test-tracking-tool

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Global research

- Global Testing of AV systems is occurring in a number of countries, including Australia, Germany, South Korea, China, and the United States, among others.

- SAE International has led the development of a number of standards governing CAV technology to help facilitate interoperability between systems developed and deployed by different stakeholders.

Minnesota research

National research

Global research

General ?	Timing/ Preparation	Policy/ Standardization	Safety	Rural	Resources

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Will there be additional or special funding to assist agencies in preparing and/or implementing CAV?

Yes. MnDOT's CAV Challenge provides opportunities for partnership funding for testing and pilots. A list of current CAV Challenge projects can be found on the CAV Challenge web page.

The USDOT offers many grant opportunities, too. Due to the competitiveness, partnering with other agencies will be beneficial if going for a USDOT grant. With the new Federal infrastructure bill, states will see opportunities to leverage federal dollars for research and innovation for ITS and CAV.

> Will there be additional or special funding to assist agencies in preparing and/ or implementing CAV?

General ?	Timing/ Preparation	Policy/ Standardization	Safety	Rural	Resources

Terminology	What should I know?	What's been done?	Funding	Tech Talk

Choose a question.

Terms to describe CV communication

CAV communication technologies

General ?	Timing/Preparation	Policy/Standardization	Safety	Rural	Resources

Terminology	What should I know?	What's been done?	Funding	Tech Talk

What are the different terms to describe CV communication?

VEHICLE-TO-VEHICLE
VEHICLE-TO-BICYCLIST
VEHICLE-TO-PEDESTRIAN
VEHICLE-TO-HOME
VEHICLE-TO-GRID
VEHICLE-TO-INFRASTRUCTURE

Terms to describe CV communication

CAV communication technologies

Image from: http://www.dot.state.mn.us/automated/index.html

Terms to describe CV communication :

- *"Vehicle-to-vehicle" (V2V)* communication – CVs with other CVs
  » Example: vehicles communicating with each other to coordinate adaptive cruise control and drive cooperatively.

- *"Vehicle-to-infrastructure" (V2I)* communication – CVs with infrastructure
  » Example: vehicles communicating with traffic signals to optimize speed to match green lights on an arterial.

- *"Vehicle-to-pedestrian" (V2P)* communication – CVs with pedestrians
  » Example: vehicles communicating with pedestrians in a crosswalk to "see" around obstructions.

- *"Vehicle-to-bicycle" (V2B)* communication – CVs with bicycles
  » Example: vehicles communicating with bicyclists to negotiate a trail crossing.

- *"Vehicle-to-home" (V2H)* communication – CVs with home automation systems
  » Example: vehicles communicating with smart home system to adjust thermostat and turn off lights after leaving.

- *"Vehicle-to-grid" (V2G)* communication – CVs (electric vehicles) with electric grid
  » Example: electric vehicles communicating with smart grid to negotiate charging in response to overall electricity supply and demand.

- *"Vehicle-to-everything" (V2X)* communication – CVs with any other connected system or entity (includes all categories above).

General ?	Timing/ Preparation	Policy/ Standardization	Safety	Rural	Resources

Terminology	What should I know?	What's been done?	Funding	Tech Talk

What are the different types of CAV communication technologies?

- ***Dedicated Short Range Communication (DSRC)*** is one technology for V2X communication. Based on the Wi-Fi standard, development of DSRC started in 1999, with a draft standard made available in 2010. It uses communication devices located in vehicles, called on-board units (OBUs), or connected to roadside infrastructure, called roadside units (RSUs), that broadcast messages in the 5.9 GHz spectrum to other nearby units, with range limited to 1000 feet or less. Commercial OBUs and RSUs are currently available, but automakers generally are not installing OBUs into vehicles. While the National Highway Traffic Safety Administration (NHTSA) had intended to mandate that automakers do this in the recent past, in 2017 the proposal was dropped, and there has otherwise been little incentive to install OBUs into vehicles given the few infrastructure-side deployments. The Federal Communication Commission (FCC) also recently reallocated a portion of the 5.9 GHz spectrum allocated for DSRC to C-V2X, indicating pullback from the technology.

- ***Cellular Vehicle-to-Everything (C-V2X)*** is a newer, cellular-based technology for V2X communication that emerged in 2017. This allows equipped vehicles and roadside devices to communicate via traditional cell towers or directly with one another without a tower. Commercial devices are available, but the technology is still under active development. Pilot deployments are beginning to take place in China and the US. C-V2X technology is designed to work with both 4G and 5G cellular technology.

- ***5G*** refers to the next generation of cellular technology, following current 4G and previous 3G technology. This is happening separately from CV development and has broader use cases, such as personal communication and video streaming, but will provide benefits to CVs through improved network performance. 5G technology is currently being deployed by carriers and available commercially for things like home broadband and personal mobile devices, however the technology is still in development. Commercially available C-V2X devices still generally use 4G technology at this time, however some are marketed as upgradable to 5G.

Terms to describe CV communication

CAV communication technologies

General ?

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How to prepare? | Cost | Pavement Markings | Signs & Signals | Winter

Choose a secondary tab for more information.

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| **How to prepare?** | Cost | Pavement Markings | Signs & Signals | Winter |

What is the best guess on implementation timelines?

What is the best guess on implementation timelines?

- There is little agreement on when higher levels of automation will be deployed, regardless of what you may see reported by manufacturers and the media. Estimates range from deployments anywhere in the next 10 to 50 years, and even some that predict it will never happen. Despite this, however, some rough estimates can be made to help with very high-level planning, though note that these estimates are highly likely to change.

- Vehicles with Level 1 and 2 Advanced Driver Assistance Systems (ADAS) are commercially available now. These are often mislabeled in the media AVs but are not true autonomous vehicles, as they require a human driver at all times. Level 3 vehicles, where the vehicle can drive itself in certain situations but require a human operator to take over otherwise, may enter the market over the next 10 years, though it may take longer and either way will be a slow rollout. Level 4 autonomous shuttles, some of which are involved in pilot deployments for research and testing, are still under active development and will likely take 10 years or more to become reliable enough for widespread use. Level 4 and 5 vehicles will likely not be available to consumers for 20 or more years given the current pace of technological developments. These estimates also reflect when such vehicles may begin to be available and do not take fleet turnover rates into account.

- While there are examples of Level 3, 4, and 5 vehicles being tested, the technical challenges encountered during this testing indicate that these vehicles are far from ready, despite what marketing may say. Many automakers make claims that they will have automated vehicles on the road in a matter of years, but the consensus from experts casts serious doubt on these claims. The technical challenges are even leading some companies to arguably mislead consumers about the capabilities of their technology in an attempt to gain market share, so it is even more important now to distinguish hype from reality.

- Even beyond marketing claims, any timeline you see is likely an estimate based more on conjecture than any real analysis. While the technology is certainly very far along compared to 5 or 10 years ago, automated vehicles still show considerable limitations in their adaptability to real world situations. It is likely that significant leaps in artificial intelligence technology will be required before these challenges are overcome, and the timeline for that to occur is impossible to predict with much accuracy.

- For connected vehicles, the recent FCC order reallocating spectrum away from DSRC and towards C-V2X indicates that DSRC technology will likely become obsolete in the near future. C-V2X development and testing is occurring rapidly, with some consumer vehicles containing the technology available for pre-order in China, though there is still much work to be done and it is unclear when C-V2X technology will be more widely available.

General ?	**Timing/ Preparation** ⏱	Policy/ Standardization 📋	Safety 🛜🚗	Rural 🌲	Resources 🌐

How to prepare?	**Cost**	Pavement Markings	Signs & Signals	Winter

Are there estimates of how much CAV will cost agencies?

- Cost estimates are difficult, as they are highly dependent on what is implemented and on technology that is still in development. It will likely be a very significant investment, however. Implementing a particular connected vehicle application, for instance, will likely cost $50,000-$100,000 on the small end and into the millions for larger applications and deployments, with ongoing maintenance and periodic improvement costs. These kinds of deployments, however, are not something that all agencies should pursue, as decisions should be made based on staff/ agency interest and available resources.

- Many of these costs will overlap to some degree with existing infrastructure costs, and the situation will evolve over time. Some costs, like upgrading signal controllers, can be incorporated into existing procurement cycles to minimize additional cost. Changes in pavement marking practices, for instance switching to wet reflective paint, can also lead to reduced maintenance needs that affect long term costs. Many changes can also bring benefits to human drivers, through things like increased striping visibility.

- There are also things that an agency can do in the short term at no or low cost, such as joining committees to gain and share knowledge with other agencies.

- While the costs may be high, it is important to remember the potential benefits from improved safety and mobility. Compare CAV to the advent of traffic signals, the purchase and operation of which represented a significant additional cost for road authorities, but also enabled significant economic growth due to the improvements in safety and mobility. Though these benefits are not guaranteed, if they are realized they will help justify any additional costs that are incurred.

Are there estimates of how much CAV will cost agencies?

General | ? | **Timing/ Preparation** | Policy/ Standardization | Safety | Rural | Resources

How to prepare? | Cost | **Pavement Markings** | Signs & Signals | Winter

Choose a question.

Are pavement marking improvements necessary? What can be done?

When will changes need to be implemented?

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| How to prepare? | Cost | **Pavement Markings** | Signs & Signals | Winter |

Are pavement marking improvements necessary? What can be done?

- Pavement marking needs for automated vehicles is still an active area of research with a number of options being investigated. AVs may require pavement markings made using different technology or geometry/striping patterns that works better with vision sensors. Maintenance standards will likely continue to change to adapt to new technology, with required changes to be specified in federal or state updates to the MUTCD. MnDOT is piloting these new 6-inch markings on Interstate 94 and that research will be published in 2022.

- The recently proposed amendments to the Manual on Uniform Traffic Control Devices (MUTCD) include some changes intended to help standardize pavement markings, such as uniform line widths, in preparation for automated vehicles. These changes, however, are not a major departure from existing practices.

Are pavement marking improvements necessary? What can be done?

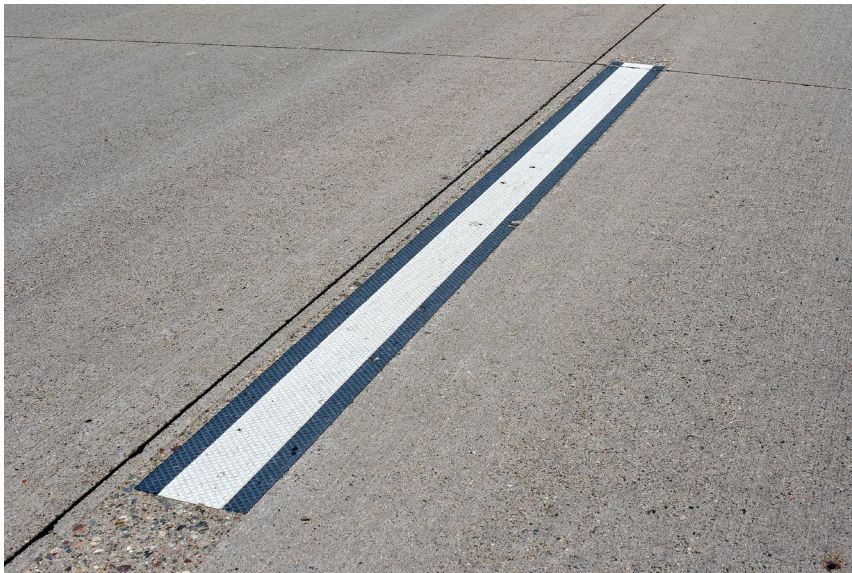When will changes need to be implemented?

Image source: MnDOT

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CAV FREQUENTLY ASKED QUESTIONS

When will changes need to be implemented?

- An updated version of the MUTCD that includes some minor changes to pavement markings to accommodate automated vehicles had been expected to be adopted by the end of 2021, however the large volume of comments received in response to the notice of proposed amendments and new administration added some uncertainty to this timeline. The recently passed infrastructure bill, however, directs FHWA to update the MUTCD within 18 months and every 3 years thereafter, including addressing vulnerable road users as recommended by many comments, in addition to automated vehicles. Should these or similar updates be enacted, some minor changes to pavement marking practices will be required, but these do not represent a significant change from current practices.

- In the short term some other small modifications to current practices may be advisable. Starting to collect and/or digitize regular pavement marking quality data on your roads now will likely help ease the transition to newer technologies and will also help with current maintenance/asset management activities. Improving the condition of current pavement markings, for instance through more frequent repainting, may also help current vehicles with driver assist systems like lane keeping operate better and help your constituents. Because of the rapidly changing technology, major changes would not be advised in the near term unless part of a pilot program or if specifically advised by MnDOT but continue to follow guidance from MnDOT and FHWA.

Are pavement marking improvements necessary? What can be done?

When will changes need to be implemented?

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| How to prepare? | Cost | Pavement Markings | **Signs & Signals** | Winter |

Will CAVs require different signs or signals?

- Current AVs interpret traffic signs and signals visually, similar to the way human drivers do, but this may change. Requirements for changes to static traffic signs are not yet well defined. It is possible that future AV-compliant signs may require features such as embedded QR codes that are readable with infrared light or other non-visible means. This is still an active area of research, however, with MnDOT testing these enhanced signs at MnROAD with partners at 3M. In the short term, agencies should make sure traffic signs are clearly visible and have good retroreflectivity.

- Improving asset management practices (for instance by employing electronic asset management systems for recording sign data) benefits agencies. These steps will help any vehicles with Advanced Driver Assistance Systems (ADAS) features on the road today, in addition to human drivers, and will help facilitate better maintenance practices.

- Connected vehicles require traffic signals to broadcast Signal Phasing and Timing (SPaT) messages and MAP (intersection geometry) messages to safely operate through intersections. These messages can be generated different ways, but in all cases require certain capabilities from the signal controller. Roadside C-V2X units that broadcast SPaT and MAP information from the signal controller are still in early development and acquiring them is therefore not a priority. Acquiring compliant controllers, however, is strongly advised. Look for controllers that meet the Advanced Transportation Controller (ATC) specification, which can integrate with both new and old signal hardware while providing network connectivity and additional computing power that will be needed to generate SPaT messages.

Will CAVs require different signs or signals?

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CAV FREQUENTLY ASKED QUESTIONS

How to prepare? Cost Pavement Markings Signs & Signals **Winter**

How will CAV be impacted by winter weather? Will CAV require different snow maintenance practices?

- AVs are still decades away from operating safely in winter weather. Snow can obscure pavement markings and traffic signs and can interfere with visual and LIDAR sensors that are used to observe the environment, causing vehicles to perform unexpectedly. This is likely to slow widespread adoption of AVs until major advancements are made. Research and testing to overcome these limitations is occurring, however, for instance as a part of MnDOT's Rochester Automated Shuttle Pilot.

- Changes in winter maintenance strategies are not likely, however the level of service required may increase. Current AV technology requires visible lane markings to work properly, generally requiring bare roads. Without further technological development, practices may need to shift to establish a new maintenance class with a high level of service that can be employed on main routes with high levels of AVs. Even such changes, however, may not be sufficient to allow widespread deployment of the technology.

- CAV may also help with winter maintenance by providing technological solutions that make maintenance activities easier or safer. For example, MnDOT is piloting systems for notifying drivers of nearby snowplows using warnings delivered through dynamic message signs and a smartphone application.

> How will CAV be impacted by winter weather? Will CAV require different snow maintenance practices?

General ? | Timing/ Preparation | **Policy/ Standardization** | Safety | Rural | Resources

Coordination | Vendors | Standards | Guidance with Vendors | Example Agreements

Choose a secondary tab for more information.

General ?	Timing/ Preparation	Policy/ Standardization	Safety	Rural	Resources

Coordination	Vendors	Standards	Guidance with Vendors	Example Agreements

Choose a question.

National level

Regional level

State level

Local level

General ?

Timing/ Preparation

Policy/ Standardization

Safety

Rural

Resources

Coordination | Vendors | Standards | Guidance with Vendors | Example Agreements

National Level

At the national level, most of the coordination is happening on specific topics and projects. Some national groups like AASHTO, USDOT, and others have also been identifying common principals and policies. For example, AASHTO has just released their Connected and Automated Vehicle Policy Principals document. The USDOT has released their Automated Vehicles Comprehensive Plan and Policy 4.0. NCHRP 20-24(98) released their CAV Research Roadmap and many pooled fund projects are active and moving forward with a variety of CAV related topics.

National level

Regional level

State level

Local level

General ?	Timing/ Preparation	Policy/ Standardization	Safety	Rural	Resources

Coordination	Vendors	Standards	Guidance with Vendors	Example Agreements

Regional level

At the regional level, the Mid America Association of State Transportation Official (MAASTO), has established a CAV Committee with members from all 10 member states. MAASTO has developed a 2030 CAV Regional Strategy and identified ten priorities which include:

- Equity, Access, and Engagement
- Coordination of Federal Grants
- Regular convening and Annual CAV Summit
- DOT Organizational Readiness
- Data Sharing
- AV Legislation
- AV Freight and Platooning
- Research
- Planning and Forecasting
- Local and Tribal Coordination

National level

Regional level

State level

Local level

General ?	Timing/ Preparation	Policy/ Standardization	Safety	Rural	Resources

Coordination	Vendors	Standards	Guidance with Vendors	Example Agreements

Regional level

At the state level, a lot of coordinating is occurring within the Governor's Advisory Council on Connected and Automated Vehicles as directed by Executive Order #19-18. The Governor's Advisory Council has created the Statewide Innovative Alliance framework to help coordinate many of the statewide transportation organizations and government departments like the Department of Employment and Economic Development (DEED), Department of Public Safety (DPS), MnDOT, local partners, and industry. Five working committees have been established and are active and are open to new members and ideas. These working committees are:

- Safety
- Labor and Workforce
- Connectivity and Data
- Infrastructure Investment
- Education and Outreach

National level

Regional level

State level

Local level

General ? | Timing/ Preparation ⏱ | **Policy/ Standardization** 📋 | Safety 📶🚗 | Rural 🛣 | Resources 🌐

Coordination | Vendors | Standards | Guidance with Vendors | Example Agreements

Local level

At the local level, the Minnesota County Engineers Association CAV Committee and City Engineers Association of Minnesota Traffic Safety Committee both meet with MnDOT's CAV-X Office multiple times a year to discuss updates in CAV and ITS technology, policy, and other CAV-related issues that benefit from coordination across agencies.

National level

Regional level

State level

Local level

General ?	Timing/ Preparation	Policy/ Standardization	Safety	Rural	Resources

Coordination	Vendors	Standards	Guidance with Vendors	Example Agreements

As vendors develop CAV, what coordination is being done to ensure standardization?

Organizations like the Society of Automotive Engineers (SAE), International Standards Organization (ISO), and the International Automotive Task Force (IATF), among others, have been active in developing AV-related standards. Additionally, the 3rd Generation Partnership Project (3GPP) has been active in defining standards around C-V2X technology, while the European Telecommunications Standards Institute (ETSI) has promoted interoperability between C-V2X devices. Despite this, automotive manufacturers do have some incentive to create a closed ecosystem that provides benefits mainly to their direct customers, which presents a challenge that may limit coordination.

As vendors develop CAV, what coordination is being done to ensure standardization?

General **?** Timing/Preparation Policy/Standardization Safety Rural Resources

Coordination | Vendors | **Standards** | Guidance with Vendors | Example Agreements

What kind of standards are there for CAV infrastructure (roads, signals, signs, markings)? Who will provide these specifications?

AV-specific standards for things like pavement markings and signs should be expected in future updates to the Manual on Uniform Traffic Control Devices (MUTCD). An update to the MUTCD containing recommendations for changes to pavement marking practices, for instance, was recently proposed, however the timeline for its adoption is unclear.

Some standards that relate to connected vehicle infrastructure, such as the Advanced Transportation Controller (ATC) standard developed jointly by the American Association of State Highway and Transportation Officials (AASHTO), the Institute of Transportation Engineers (ITE), and the National Electrical Manufacturers Association (NEMA), which defines a level of interoperability between traffic signal controllers and other systems that is essential for a connected vehicle ecosystem, have been developed.In any case, look to the usual organizations for guidance, including MnDOT, AASHTO, and the Federal Highway Administration (FHWA).

What kind of standards are there for CAV infrastructure (roads, signals, signs, markings)? Who will provide these specifications?

See Timing/Preparation section for more information:

Pavement Markings

Return to last page

| General ? | Timing/ Preparation ⏱ | **Policy/ Standardization** 📋 | Safety 📡 | Rural 🛣 | Resources 🌐 |

| Coordination | Vendors | Standards | **Guidance with Vendors** | Example Agreements |

What guidance is there for agencies when working with private vendors?

- **Create a process for vendors to contact you** without a sales pitch. MnDOT created the CAV Challenge partnership program that funnels vendor and industry inquiries by first asking them to review their program website, priorities, and by reading about MnDOT's CAV strategic plan. By encouraging industry to understand your agency priorities, they will be better informed on whether partnering with your agency will further their business goal.

- **Coordinate with MnDOT CAV-X** which has many industry connections and can help coordinate opportunities with your agency.

- **Don't duplicate projects** taking place in other parts of the state or country. There is an enormous amount of research being done collaboratively across states, but vendors are often trying to sell products that lead to duplicative efforts. Be skeptical of sales pitches.

- **Ask** for references, third party reviews, demonstrations, and feedback from MnDOT CAV-X staff.

- **Plan and expect some challenges** Variations in practices by different agencies also mean vendor systems that are advertised as turnkey are likely far from it, and vendors will often end up implementing very customized solutions for each agency. If you decide to pursue something, expect challenges and make sure it is planned for in contracts, budgets, and schedules. Use your existing vendor relationships and professional networks to find vendors you can trust.

- **Don't be afraid** to experiment and be at the forefront. You are helping develop new technology, which is never easy.

What guidance is there for agencies when working with private vendors?

Are the examples of agreements between private vendors and public agencies?

Yes. MnDOT has numerous types of agreements, including partnership agreements, memorandums of understanding and contracts that it can share if agencies are interested.

Research on how to design and operate these programs to maximize success is ongoing, with guidance expected from the Transportation Research Board in the near future. Concerns such as data privacy and cybersecurity, ownership of intellectual property, and liability are some of the challenges that should be discussed when pursuing partnerships.

Are the examples of agreements between private vendors and public agencies?

General ?
Timing/ Preparation
Policy/ Standardization
Safety
Rural
Resources

Is it safe?   Communication   Multimodal

Choose a secondary tab for more information.

| General | ? | Timing/ Preparation | ⏱ | Policy/ Standardization | 📋 | Safety | 📶🚗 | Rural | 🏞 | Resources | 🌐 |

| Is it safe? | Communication | Multimodal |

How safe is CAV?

An estimated 94% of crashes are partially attributed to human error, so theoretically by replacing the human driver with machines that are less susceptible to the types of errors made by humans, it is likely that fatalities and serious injuries could be reduced. To-date, however, there is limited research on how safe current CAV technology actually is and much more research and development will need to be done. Research regarding the integration of higher-level vehicles with lower-level vehicles has also been limited, further complicating the picture.

In addition to this, due to misrepresentation and misunderstanding, human drivers are misusing currently available automated technologies in Tesla and other lower-level automated vehicles, leading to a number of high-profile crashes in recent years. The National Highway Traffic Safety Administration only requires AV manufacturers to self-certify the safety of their vehicles, which leads to safety concerns and trust due to the lack of transparency and federal oversight. Vehicle manufacturers have only just recently been required to report crashes that occur in vehicles with lower levels of automation, so it is unclear exactly how safe they have been given the lack of transparency. Connected vehicles with human operators will likely be safer than automated vehicles until significant technological advancement occurs. Driver assist systems can be safe if their limits are adequately understood by the public. CAVs can be safe if we all educate our communities that drivers must always be attentive and ready to take over at a moment's notice.

How safe is CAV?

CAV FREQUENTLY ASKED QUESTIONS

Is it safe?   Communication   Multimodal

Choose a question.

General safety
communication

Key areas of safety
to focus on

General ?	Timing/ Preparation	Policy/ Standardization	Safety	Rural	Resources

Is it safe?	Communication	Multimodal

General safety communication

Key areas of safety to focus on

How can CAV safety be communicated to the general public?

Safety is and will continue to be the top priority in transportation. Connected and automated vehicle technology has the potential to improve safety for travelers, but the safety benefits are likely still years away and may never be fully realized. That is why Minnesota is continuing to invest in existing safety strategies and programs focused on making transportation safer today and in the future. Minnesota is focusing on ensuring safety benefits are realized for all travelers whether they are driving, riding transit, bicycling, walking, or rolling.

At the local level, the Minnesota County Engineers Association CAV Committee and City Engineers Association of Minnesota Traffic Safety Committee both meet with MnDOT's CAV-X Office multiple times a year to discuss updates in CAV and ITS technology, policy, and other CAV-related issues that benefit from coordination across agencies.

| General ? | Timing/ Preparation ⏱ | Policy/ Standardization 📋 | **Safety** 📡🚗 | Rural 🛣🌲 | Resources 🌐 |

| Is it safe? | **Communication** | Multimodal |

General safety communication

Key areas of safety to focus on

How can CAV safety be communicated to the general public?

More research and development is needed to ensure CAV is safely deployed and some key areas of safety our state is focusing on include:

- Building knowledge among people in Minnesota about what CAV is and isn't so they understand the risks and potential benefits of CAV related to safety. This includes educating on what is available now and what might be possible in the future, and understanding what people in Minnesota are excited and concerned about related to safety to inform how Minnesota plans and prepares for CAV. Common questions include:
  - » What are potential benefits and risks of using CAV technologies?
  - » What impacts do CAV technologies have on human drivers?
  - » Are new or additional driving education and training needed for new technologies?
  - » Understanding of Advanced Driver Assistance Systems (ADAS) – features that support drivers like lane keeping assist, automatic emergency breaking, adaptive cruise control
  - » Understanding of Automated Driving System (ADS) – system that performs driving and can be under limited conditions or all conditions
- Investing in infrastructure and technology to improve safety that benefits travelers today and sets us up for tomorrow
- Safely conducting research and demonstration projects in live-traffic environments to understand capabilities and limitations of CAV technologies and identify areas for improvement, such as:
  - » Winter weather functionality
  - » On- and off-road testing
  - » Interactions with other roadway users
  - » Impacts to behaviors of other roadway users

Minnesota wants to test, review, and analyze CAV technologies and to collaborate with industry partners to prioritize safety of all roadway users.

How does CAV interact with active transportation users like people who walk, bike, or roll? How is it being tested?

Similar to many of the trends in surface transportation, development of CAV technology has primarily focused on vehicles, though increasing attention has been paid towards active transportation users and their role in the future of transportation. For instance, the National Association of City Transportation Officials (NACTO) Blueprint for Autonomous Urbanism envisions a future where CAV is only a component of a people-centered transportation system, rather than requiring people to adapt to CAV technology. There are technical challenges, however, and it will take time for the details of how CAV will interact with active users to be worked out.

- Automated vehicles currently rely primarily on visual sensors (cameras) for detecting non-motorized users and other objects. Limitations in the artificial intelligence systems that interpret images and determine actions mean these systems can be easily fooled by small changes. The unexpected or unfamiliar presence or behavior of things like pedestrians, cyclists, and animals, can cause automated driving systems to act unexpectedly and lead to unsafe situations or operational failures. Major changes in AI technology to allow the highly flexible, top-down reasoning that humans demonstrate will be required for this to change.

- There are also challenges from developments associated with changes in vehicle technology that are not strictly related to connectivity or automation, such as electric vehicles with limited sound creating safety risks for the visually impaired around nearby vehicles.

- Connected vehicle technology offers some potential avenues for addressing these limitations with pedestrians and bicycles (for instance by using smartphones or other connected personal safety devices), though there are a number of limitations to this approach that still leave the potential for unsafe situations, in particular those arising from interactions with unequipped users.

How does CAV interact with active transportation users like people who walk, bike, or roll? How is it being tested?

General ?

Timing/
Preparation

Policy/
Standardization

Safety

Rural

Resources

Gravel Roads   Broadband Issues

Choose a secondary tab for more information.

General ?

Timing/ Preparation

Policy/ Standardization

Safety

Rural

Resources

Gravel Roads   Broadband Issues

How will CAV work on non-paved roads?

How will CAV work on non-paved roads?

Currently, AVs cannot navigate on gravel roads or roads without clear lane markings. High-precision digital maps and Global Navigation Satellite Systems (GNSS) technology (e.g., GPS) may provide an alternative, though developing these maps in rural areas is a challenge due to the amount of infrastructure and limitations in connectivity. That said, high-precision digital maps and GNSS alone are not enough for AVs to navigate on unpaved roads. Technological approaches for addressing these challenges are being researched, however, and it is likely the state of the industry will change over time.

General ? | Timing/ Preparation | Policy/ Standardization | Safety | **Rural** | Resources

Gravel Roads | **Broadband Issues**

How will CAV work in rural areas or areas lacking broadband?

Some degree of connectivity in rural areas, even low-bandwidth and high-latency connectivity, will likely be required. However, this is all under active research and may vary depending on the architecture of the system that is ultimately implemented and how resilient it is against loss of connectivity. AVs will likely continue to need high-accuracy digital maps for navigation, however the required update frequency of these maps has not yet been determined. CVs will be able to communicate with nearby devices using peer-to-peer technology, allowing many applications to function properly. However, the Security and Credential Management System (SCMS) requires vehicles and infrastructure to be connected to the internet for periods of time to download certificates required to ensure a secure system. Improving internet connectivity in rural areas is a general political and economic priority, however, and these challenges will likely become less significant over time. Advancements in ground- and satellite-based wireless internet will likely assist in this area.

How will CAV work in rural areas or areas lacking broadband?

General ?

Timing/ Preparation

Policy/ Standardization

Safety

Rural

Resources

Selected Resources   Other Resources

Choose a secondary tab for more information.

| General ? | Timing/ Preparation ⏱ | Policy/ Standardization 📋 | Safety 📡🚗 | Rural 🛣 | **Resources** 🌐 |

Selected Resources

Choose a selected resource.

Type	Focus	Name
State Government Agency/ Resources	State	MnDOT CAV-X
Newsletter	State, Local	University of Minnesota CTS Newsletter
Multi-State Organization	State, National	AASHTO
Professional Organization	National, with regional and state chapters	ITS America
Federal Government Agency	National	USDOT*
Professional Organization	International	AUVSI
Industry/ Academic Organization	National, International	PAVE

*Includes additional resources and links to committees, newsletters, etc.

General ?	Timing/ Preparation ⏱	Policy/ Standardization 📋	Safety 🚗📶	Rural 🛣🌲	Resources 🌐

Selected Resources | Other Resources

Minnesota Department of Transportation Connected and Automated Vehicles (MnDOT CAV-X)*

Type: State Government Agency/ Resources
Focus: State

- » Guiding Principles
- » Governor's Advisory Council
- » Innovation Alliance
- » Destination CAV Newsletter
- » State Aid CAV
- » State Aid E-Scene

MnDOT's Connected and Automated Vehicle (CAV-X) Office is tasked with facilitating engagement, policy, testing, and partnerships that advance connected and automated vehicle technology in the state of Minnesota. The CAV-X Office website is a clearinghouse of information on CAV, including background information, policy and planning resources, and information on CAV-related projects. This is a great first stop for understanding what is happening in Minnesota and how your agency can start preparing for a CAV future.

Local agencies may also be interested in visiting the State Aid for Local Transportation CAV web page for information targeted towards local agencies. MnDOT's State Aid office also produces the monthly E-Scene digital magazine that contains highlights of information that is relevant to county and city engineers. Two recent editions included articles describing what Minnesota and MnDOT are doing to prepare for CAV. This is a great resource for staying up to date with recent developments that local road operators should be aware of, both inside and outside the CAV realm.

Agencies interested in staying more active are invited to attend the quarterly Governor's CAV Advisory Council virtual meetings (see website for latest meeting links), or join the Minnesota CAV Innovation Alliance (by contacting Tara Olds).

For more resources, the MnDOT Library provides access to magazines, manuals, technical reports, reference materials, and other transportation-related publications. Their librarians also provide personalized services for things like literature searches. You can also sign up for periodic email alerts on a number of topics that will send updates with a curated list of news headlines, including a weekly Connected and Automated Vehicle alert that is a great way to stay up to date on the latest CAV news.

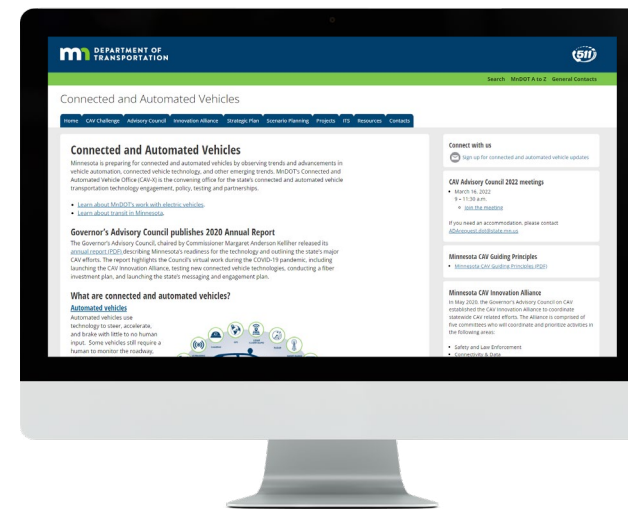| MnDOT CAV-X |
|---|
| University of Minnesota CTS |
| AASHTO |
| ITS America |
| USDOT* |
| AUVSI |
| PAVE |

*Includes additional resources and links to committees, newsletters, etc.

| General ? | Timing/ Preparation ⏱ | Policy/ Standardization 📋 | Safety 📡🚗 | Rural 🛣 | Resources 🌐 |

Selected Resources | Other Resources

University of Minnesota Center for Transportation Studies (CTS)

Type: Newsletter

Focus: State

The University of Minnesota's Center for Transportation Studies publishes the monthly Catalyst newsletter that highlights the latest transportation research happening at the U of M. The newsletter covers research that affects various areas of transportation, including CAV, transit and urban mobility, vulnerable road users, and others. This research can often lead to pilot projects in the short term and changes in practices in the long term, so following the latest developments can help give a sense of what the future holds. Subscribe to the free newsletter to stay up to date on the latest work being conducted at UMN.
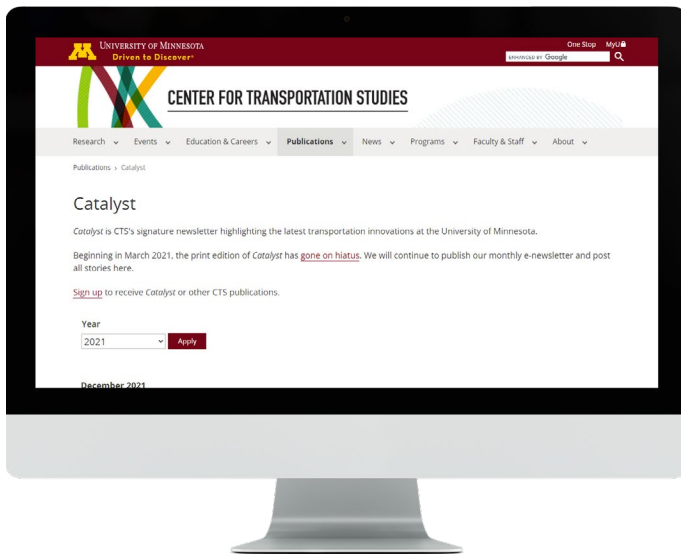
MnDOT CAV-X

University of Minnesota CTS

AASHTO

ITS America

USDOT*

AUVSI

PAVE

*Includes additional resources and links to committees, newsletters, etc.

CAV FREQUENTLY ASKED QUESTIONS
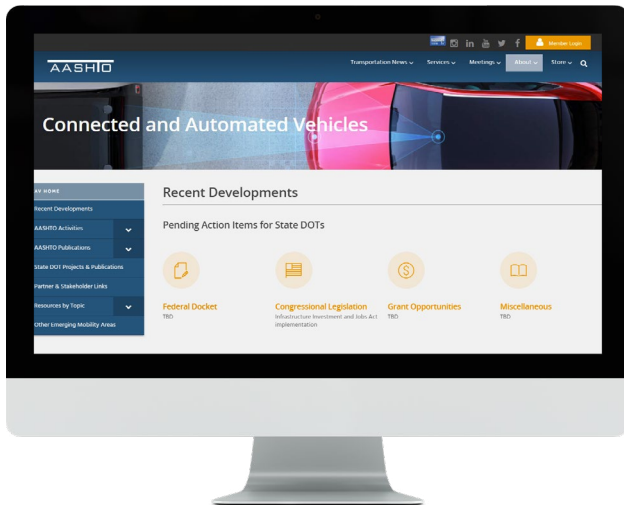
Selected Resources | Other Resources

American Association of State Highway and Transportation Officials (AASHTO)

Type: Multi-State Organization
Focus: State, National

The American Association of State Highway and Transportation Officials (AASHTO) is an organization representing state Departments of Transportation that publishes standards, specifications, test protocols, and guidelines used in the design and operation of transportation facilities around the United States. Well known to practitioners for their publication A Policy on Geometric Design of Highways and Streets, they also are involved in the development of standards that are relevant for a CAV ecosystem, such as the Advanced Transportation Controller standard, developed jointly with the Institute of Transportation Engineers (ITE) and the National Electrical Manufacturers Association (NEMA). They also maintain a portal of CAV-related activities and resources and have a number of committees and task forces focused on the planning and deployment of CAV technology. They are also involved in the Cooperative Automated Transportation (CAT) Coalition, which provides a number of CAV-related resources.

Selected Resources sidebar

- MnDOT CAV-X
- University of Minnesota CTS
- AASHTO
- ITS America
- USDOT*
- AUVSI
- PAVE

*Includes additional resources and links to committees, newsletters, etc.

Selected Resources | Other Resources

International Transportation Society of America (ITS America)

Type: Professional Organization

Focus: National, with regional and state chapters

The Intelligent Transportation Society of America (ITS America) is a professional organization that advocates for the development and deployment of Intelligent Transportation Systems (ITS) in the United States. They produce the twice-monthly newsletter Momentum, available to members, that covers recent policy, technical, and programming updates in the industry. They also provide a free newsletter in collaboration with SmartBrief that highlights recent news stories relevant to the industry. Members of ITS America include state and city departments of transportation, regional and local transportation and planning agencies, private companies providing ITS products and services, auto manufacturers and suppliers, research organizations, academic institutions, and industry associations.

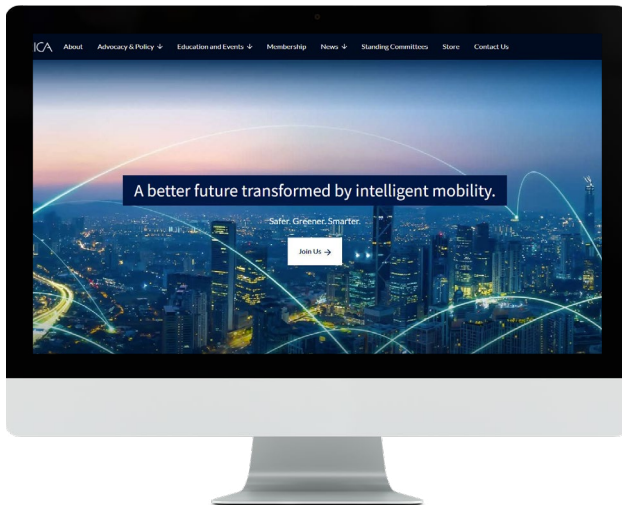MnDOT CAV-X

University of Minnesota CTS

AASHTO

ITS America

USDOT*

AUVSI

PAVE

*Includes additional resources and links to committees, newsletters, etc.

A better future transformed by intelligent mobility.
Safer. Greener. Smarter.
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General ? Timing/ Preparation ⏱ Policy/ Standardization 📋 Safety 🚗 Rural 🛣 Resources 🌐

Selected Resources | Other Resources
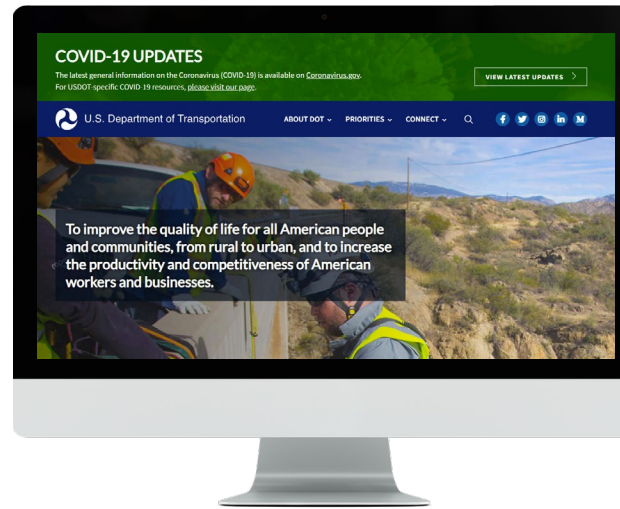
United States Department of Transportation (USDOT)

Type: Federal Government Agency
Focus: National

- ITS Joint Program Office
- FHWA
- FMCSA
- NHTSA

The USDOT is an excellent source of information concerning all aspects of transportation, including CAV. In the area of CAV and ITS, the Intelligent Transportation Systems (ITS) Joint Programs Office (JPO) leads research, development, and implementation of ITS to improve safety and mobility for people and goods, facilitating collaboration on multimodal ITS research involving various federal agencies. Their website provides resources from research in areas such as automation, cybersecurity, data access and exchanges, and emerging technologies, as well as repositories for open-source software projects and datasets relating to ITS applications. The office also manages the Connected Vehicle Pilot Deployment Program, one of the major current initiatives advancing connected vehicle technology. The USDOT ITS JPO is a good resource for learning about recent developments in federal research relating to CAV.

In addition to the ITS JPO, useful information on CAV and other topics can be learned from the Federal Highway Administration (FHWA), the Federal Motor Carrier Safety Administration (FMCSA), and the National Highway Traffic Safety Administration (NHTSA).

COVID-19 UPDATES
The latest general information on the Coronavirus (COVID-19) is available on Coronavirus.gov.
For USDOT-specific COVID-19 resources, please visit our page.

VIEW LATEST UPDATES

U.S. Department of Transportation — ABOUT DOT | PRIORITIES | CONNECT

To improve the quality of life for all American people and communities, from rural to urban, and to increase the productivity and competitiveness of American workers and businesses.

MnDOT CAV-X
University of Minnesota CTS
AASHTO
ITS America
USDOT*
AUVSI
PAVE

*Includes additional resources and links to committees, newsletters, etc.

General [?]	Timing/Preparation	Policy/Standardization	Safety	Rural	Resources

Selected Resources   Other Resources

Association of Unmanned Vehicle Systems International (AUVSI)*

Type: Professional Organization
Focus: International

The Association for Unmanned Vehicle Systems International (AUVSI) is a professional organization advocating for the advancement of unmanned systems and robotics, composed of corporations and professionals involved in industry, government, and academia. Their weekly and daily eBrief newsletter, available to members, highlights developments in automation and robotics from a business, policy, and technology perspective, with a selection of articles available to non-members. They also maintain an up-to-date map of Level 4 commercial motor vehicle operations and testing regulations in the United States.

MnDOT CAV-X

University of Minnesota CTS

AASHTO

ITS America

USDOT*

AUVSI

PAVE

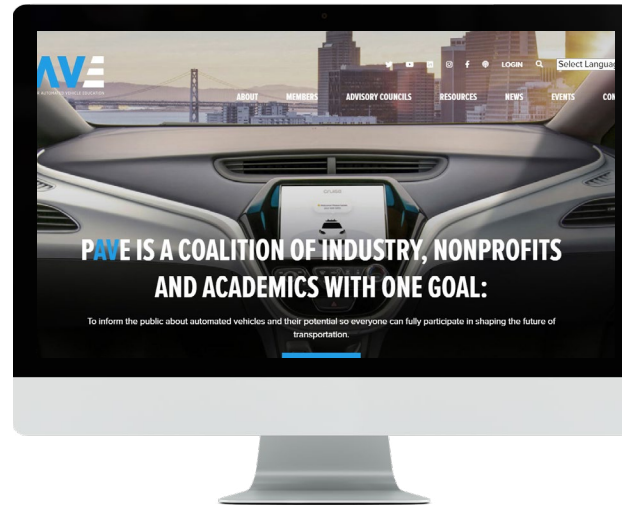*Includes additional resources and links to committees, newsletters, etc.

Partners of Automated Vehicle Education (PAVE)

Type: Industry/ Academic Organization

Focus: National, International

PAVE is a coalition of industry partners, nonprofit organizations, and academics focused on educating the public and policymakers on automated vehicles. Their public sector advisory council includes representatives from several state Departments of Transportation, including MnDOT, along with a handful of municipalities and other public sector agencies. Their resources page provides a variety of useful materials for learning about automated vehicles and their impacts, including in areas such as assisted driving features, freight, policy, and social impacts, among others. In particular, their frequent webinars are a good way to stay up to date on the recent developments in the automated vehicle space.

PAVE IS A COALITION OF INDUSTRY, NONPROFITS AND ACADEMICS WITH ONE GOAL:

To inform the public about automated vehicles and their potential so everyone can fully participate in shaping the future of transportation.

MnDOT CAV-X

University of Minnesota CTS

AASHTO

ITS America

USDOT*

AUVSI

PAVE

*Includes additional resources and links to committees, newsletters, etc.

General ? Timing/Preparation Policy/Standardization Safety Rural **Resources**

Selected Resources | **Other Resources**

Other Resources/Organizations

Name	Type	Scope/Focus
Institute of Transportation Engineers (ITE)	Professional Organization	National
Transportation Research Board (TRB)	National Academy	National
National Cooperative Highway Research Program (NCHRP)	National Academy	National
American Association of Motor Vehicle Administrators (AAMVA)	Nonprofit Organization	National
Insurance Institute for Highway Safety (IIHS)	Nonprofit Organization	National
American Automobile Association (AAA)	Nonprofit Organization	National
J.D. Power	Consumer Research Company	National
National Operations Center of Excellence (NOCoE)	Professional Organization Partnership	National
Transportation Pooled Funds*	Pooled Funds	National, Regional
Alliance for Automotive Innovation	Industry Organization	National
Cooperative Automated Transportation Coalition	Professional Organization Partnership	National
American Public Works Association (APWA)	Professional Organization	National, state chapters
National Association of City Transportation Officials (NACTO)	Multi-City Organization, Resource	National, city-focused
National Association of Counties (NACO)	Multi-County Organization	National, county-focused
SAE International	Professional Organization	National, international
American Society of Civil Engineers (ASCE)	Professional Organization	National, state chapters

CAV FREQUENTLY ASKED QUESTIONS

Definitions

Connected vehicles (CV) use technology to communicate with other connected vehicles, roadside infrastructure like signs and traffic signals, smartphones, and other devices, or obtain data from the cloud. This information is used to supply useful information to a driver or vehicle to allow making safer and more informed decisions, with more time to react and prevent an incident.

Automated vehicles (AV) use information from cameras, radar, lidar, Global Positioning System (GPS), and other sources to observe the environment around them, allowing them to steer, accelerate, and brake in certain situations with little or no human input. The amount of human interaction required varies as defined by the levels of automation (next question).

Autonomous vehicles are automated vehicles that are capable of navigating without any human input, i.e., those at the higher levels of automation as defined below.

Advanced Driver Assistance Systems are level 1 and 2 automation technologies that each automate a specific aspect of the driving task, such as adaptive cruise control and lane keeping.

Automated Driving Systems are level 3 and higher technologies that can take over all aspects of the driving task under some (level 3 and 4) or all (level 5) circumstances.

Connected vehicle (CV) applications use real-time data shared between vehicles (and other road users) and infrastructure, in some cases along with an ADAS or ADS, to allow vehicles to avoid dangerous situations (as in red light violation warning) or operate cooperatively (as in cooperative adaptive cruise control), improving overall safety and/or mobility. Together, ADAS, ADS, and CV applications form the building blocks of a CAV ecosystem.

"Vehicle-to-vehicle" (V2V) communication – CVs with other CVs. Example: vehicles communicating with each other to coordinate adaptive cruise control and drive cooperatively.

"Vehicle-to-infrastructure" (V2I) communication – CVs with infrastructure. Example: vehicles communicating with traffic signals to optimize speed to match green lights on an arterial.

"Vehicle-to-pedestrian" (V2P) communication – CVs with pedestrians. Example: vehicles communicating with pedestrians in a crosswalk to "see" around obstructions.

"Vehicle-to-bicycle" (V2B) communication – CVs with bicycles. Example: vehicles communicating with bicyclists to negotiate a trail crossing.

"Vehicle-to-home" (V2H) communication – CVs with home automation systems. Example: vehicles communicating with smart home system to adjust thermostat and turn off lights after leaving.

"Vehicle-to-grid" (V2G) communication – CVs (electric vehicles) with electric grid. Example: electric vehicles communicating with smart grid to negotiate charging in response to overall electricity supply and demand.

"Vehicle-to-everything" (V2X) communication – CVs with any other connected system or entity (includes all categories above).

Dedicated Short Range Communication (DSRC) is one technology for V2X communication. Based on the Wi-Fi standard, development of DSRC started in 1999, with a draft standard made available in 2010. It uses communication devices located in vehicles, called on-board units (OBUs), or connected to roadside infrastructure, called roadside units (RSUs), that broadcast messages in the 5.9 GHz spectrum to other nearby units, with range limited to 1000 feet or less. Commercial OBUs and RSUs are currently available, but automakers generally are not installing OBUs into vehicles. While the National Highway Traffic Safety Administration (NHTSA) had intended to mandate that automakers do this in the recent past, in 2017 the proposal was dropped, and there has otherwise been little incentive to install OBUs into vehicles given the few infrastructure-side deployments. The Federal Communication Commission (FCC) also recently reallocated a portion of the 5.9 GHz spectrum allocated for DSRC to C-V2X, indicating pullback from the technology.

Cellular Vehicle-to-Everything (C-V2X) is a newer, cellular-based technology for V2X communication that emerged in 2017. This allows equipped vehicles and roadside devices to communicate via traditional cell towers or directly with one another without a tower. Commercial devices are available, but the technology is still under active development. Pilot deployments are beginning to take place in China and the US. C-V2X technology is designed to work with both 4G and 5G cellular technology.

5G refers to the next generation of cellular technology, following current 4G and previous 3G technology. This is happening separately from CV development and has broader use cases, such as personal communication and video streaming, but will provide benefits to CVs through improved network performance. 5G technology is currently being deployed by carriers and available commercially for things like home broadband and personal mobile devices, however the technology is still in development. Commercially available C-V2X devices still generally use 4G technology at this time, however some are marketed as upgradable to 5G.

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