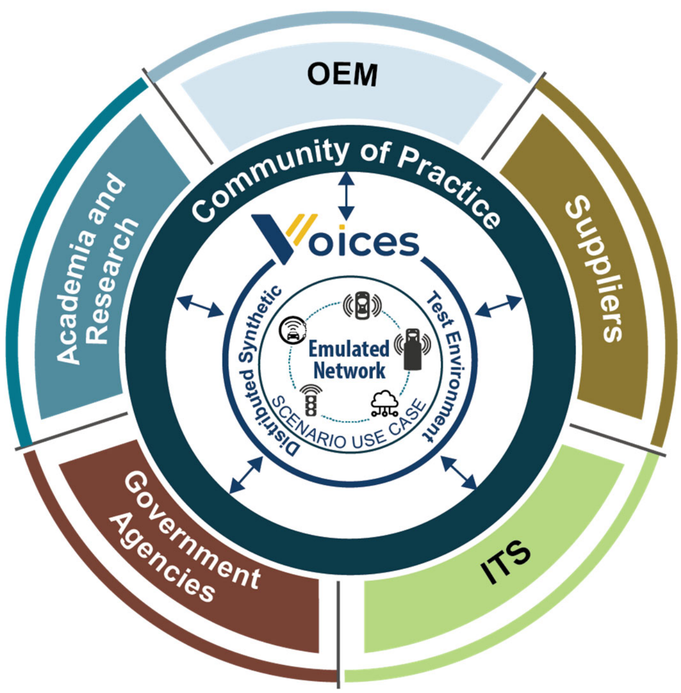
Virtual Open Innovation Collaborative Environment for Safety

Introduction

The United States Department of Transportation (USDOT) has initiated the Virtual Open Innovation Collaborative Environment for Safety (VOICES) proof of concept (PoC) project. Through the VOICES project, the USDOT intends to seed a platform designed to facilitate collaborative research, development, and testing, while protecting intellectual property (IP), among diverse stakeholders engaged in the design, build, test, and evaluation of the safety, performance, and interoperability of transportation automation and connectivity technologies that could significantly improve the safety, mobility, efficiency, and environmental impacts of transportation in the United States (U.S.). This paper discusses the current state of transportation in the U.S. and emerging transportation technologies, resulting in a need for an environment that promotes collaborative and interoperable development and testing of these technologies. The deployment of current and emerging advanced driver assistance systems (ADAS), connected vehicle-to-everything (V2X) systems, automated driving systems (ADS), and cooperative driving automation (CDA) systems could benefit from common test infrastructure, tools, and methods. The VOICES PoC will be accessible to Federal, State, and local governments; transportation infrastructure and automotive industries; manufacturers; technology developers; research institutions; and academia (see figure 1).



ITS = intelligent transportation systems, OEM = original equipment manufacturer

Source: USDOT.

Figure 1. Diagram. VOICES overview.

VOICES will enable these stakeholders to interact simultaneously in synchronized use cases and scenarios through the VOICES platform to research, develop, and assess transportation solutions in a distributed virtual environment that produces a high-fidelity representation of the transportation ecosystem. The platform will allow for sharing of infrastructure and resources to help overcome costly barriers to safe development and deployment of automation and connected technologies while providing opportunities to grow and address the skillset of the Nation's transportation workforce for the future. The initial PoC project will focus on the utility of VOICES to advance CDA-based solutions. The goal of the PoC is threefold: (1) establish a community of practice (CoP) for advancing the research, development, and testing of CDA systems; (2) establish requirements for and demonstrate a distributed synthetic test environment (DSTE) that meets the needs of the CoP (see figure 2); and (3) transfer this technology to the private sector.

This white paper explores some of the current challenges related to CDA development and deployment within the current transportation system, and subsequently describes the aspects of VOICES that are geared to address these challenges directly. This paper identifies how stakeholders are engaged as part of the VOICES project, provides technical details on the software platform and the plans for the PoC and CoP engagement strategies and organizational structure, presents plans to transfer the technology after the PoC, and identifies the high-level workforce benefits expected form this collaborative effort.

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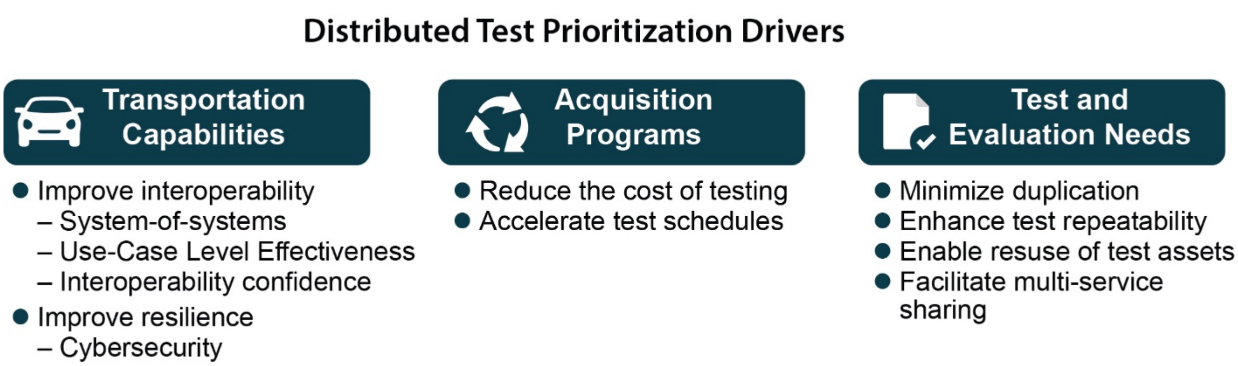
Current State of Surface Transportation

The state of the U.S. surface transportation system has experienced steady improvements over the years in terms of traffic safety and mobility. Concurrently, the yearly size of the U.S. vehicle fleet and vehicle miles traveled (VMT) increased steadily. In spite of the improvements, traffic safety and mobility problems still exact a heavy cost on U.S. society. For instance, an estimated 36,096 people died in motor vehicle traffic crashes based on data from the 2019 Fatality Analysis Reporting System, with an estimated fatality rate of 1.10 per 100 million VMT in 2019.[1] In 2017, the average commuter in the Nation's top urban areas wasted nearly seven full working days in extra traffic delays, which translated to over $1,000 in personal costs. In addition, congestion caused urban Americans to travel an extra 8.8 billion hours and purchase an extra 3.3 billion gallons of fuel for a congestion cost of $166 billion.[2] Congestion also cost the trucking industry an estimated $74.5 billion in 2018, equal to an entire year of productivity for more than 425,000 truck drivers.[3] These added costs affect national productivity, quality of life, economic efficiency, and global competitiveness. However, the recent introduction of emerging technologies, principally enabled by automation and connectivity, postures surface transportation for transformative advances that may address these challenges. In addition to advances in automated driving technology, this transformation must address challenges within the infrastructure that includes key enablers for improving the safety and security of automated vehicles (AVs).

Opportunities and Challenges of Emerging Technologies

AVs and CDA systems offer potential solutions to meet societal challenges due to their capability to increase safety by avoiding human errors, improve efficiency by better usage of existing roadways, and significantly reduce emissions in mobility applications. In addition, AVs could enable handicapped and elderly people to participate in an active social life. According to Morgan Stanley, ADS will save the U.S. economy a total of $1.3 trillion per year–fuel $158B, crashes $563B, congestion $138B, and productivity $422B.[4] To realize the potential benefits of ADS and CDA systems and mitigate inherent risks, there is a need to develop, test, and deploy such technologies in a responsible manner, and for novel tools to streamline time to market. Based on a recent study, it could take 11 billion VMT of on-road driving exposure to demonstrate that ADS perform 20 percent better than the human driver fatality rate of 1.09 fatalities per 100 million VMT.[5] It would take 500 years to accumulate such VMT based on the experience of a fleet of 100 ADS-equipped vehicles driving non-stop over a year at an average speed of 25 miles per hour. There are alternatives to this isolated, brute-force approach to on-road demonstration of ADS safety. The transportation ecosystem could benefit from collaborating and establishing widely accepted approaches to test procedures and virtual testing that demonstrate the reliability of ADS in a much shorter time. Live, virtual, and constructive (LVC) distributed testing platforms, in concert with shared scenario libraries, could reduce the financial and human resources, and time, required to solve the problems that otherwise suffer from siloed testing and issues of trust in the validity of virtual testing results, as shown in Figure 2.



Source: USDOT.

Figure 2. Diagram. Distributed synthetic test environment objectives.

Developers recognize the tremendous challenge in CDA development and view cooperation and virtual testing as a strategic advantage to enter the market, especially when extending ADS technology to CDA. The requirements of vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication make collaboration during the development and testing phases even more critical. There are minor partnerships in which automakers collaborate with a limited set of their peers and suppliers to develop and test parts of the autonomy stack (e.g., sensing, world modeling, planning, and control).[6] The testing toolchains and scenario databases used in these limited partnerships are increasingly fragmented (i.e., they lack interoperability and comparability, which makes it challenging to leverage resources across industry). Furthermore, current test systems and validation methods are impractical to completely guarantee the AV functional safety and operational capability under all possible traffic and environmental conditions due to the resources and time required. CDA and ADS developers validate technologies using a mix of proving grounds, on-road operations, and virtual environments, and there is value in enabling collaboration across the variety of toolchains used in these environments and building trust in the results. Testing in real traffic faces limitations and drawbacks, such as inability to control and reproduce safety hazards or specific operating scenarios. Closed course testing is expensive and test track facilities are limited in their ability to recreate all types of conditions. Furthermore, the current development of multiple test environments and tools only represents a fraction of the capabilities needed to fully understand the operational capabilities of various CDA use cases. An ADAS company predicted that the effort to develop validation environments for AVs is 10 to 20 times higher than the effort to develop lower-level AV functions due to the need for higher fidelity and complexity (i.e., to capture the wide range of operational scenarios and accurate sensor models). This ratio increases to 20 to 50 times more for higher-level AV functions.[7] An accelerated and more efficient validation procedure is possible through an interoperable distributed testing environment that can combine real components with simulated components in different variations (i.e., combine closed course, on-road, and simulation in the same test with multiple actors using different toolchains). In addition, there will be significant time and cost savings in creating common test scenario libraries in a standardized format for easily creating and employing Operational Design Domain (ODD)-relevant scenarios that represent the range of expected operating conditions.

Historically, the USDOT has collaborated with industry and other non-Federal transportation stakeholders in the development of marketable systems that help road users and operators avoid motor vehicle crashes and reduce traffic congestion, especially where the case for safety and mobility benefits are strong. The incentive for industry to collaborate with the USDOT has been greatest in cases having high market appeal but also uncertainty relative to product success (i.e., high investment risk).[8] One of the benefits of the VOICES POC lies in providing initial capital expenditure in funding and staff for CDA development. The PoC looks to provide a basis for continued CDA development, management, operation, and use by stakeholders. Some of the benefits of VOICES PoC participation include:

- Reducing the time to market by generating a more comprehensive understanding of the risks and benefits of CDA.
- Accelerating the identification and collection of valuable CDA use cases by pooling resources across the community.
- Testing and evaluating emerging CDA features and technology.
- Accelerating development of the simulation toolchain by improving the fidelity of simulations evaluating CDA use cases.
- Enhancing public trust in CDA technology by demonstrating improvements to safety and energy efficiency.
- Receiving access to tools and data that community members can use for the testing and evaluation of CDA features.

Feedback on USDOT AV 3.0 and AV 4.0

Stakeholders submitted about 150 comments to the Office of the Secretary of Transportation in response to the publication of *Preparing for the Future of Transportation: Automated Vehicles 3.0* (AV 3.0) in October 2018 and *Ensuring American Leadership in Automated Vehicle Technologies: Automated Vehicles 4.0* (AV 4.0) in January 2020.[9,10] Some comments encouraged the USDOT to take a leading role in the collaboration, testing, and interoperability of connected and automated vehicles.

Respondents encouraged the USDOT to maximize its potential to collaborate with AV stakeholders, whether that be private industry, the public, or other Federal agencies. The majority of these respondents indicated that collaboration should be a priority. Examples of cooperation include:

1. Establishment of national standards for the planning, design, deployment, and maintenance of transportation infrastructure and operating systems needed to support CDA deployment, including protections for data privacy.
2. Development and deployment of a more uniform set of safety messages.

For AV testing, respondents recommended that the USDOT:

1. Continue to reduce testing barriers.
2. Provide opportunities to evaluate CDA features and connectivity to different infrastructure components.
3. Help test out remote operations.
4. Ensure the testing of new technologies in scenarios representing common traffic situations where all road users may be vulnerable as technologies are deployed.
5. Bolster acceptance of virtual testing by igniting interest in the development of simulation-based prototypical safety cases.
6. Exercise its role as a convener of State highway officials to facilitate discussion and coordination to enable seamless vehicle testing across borders.

For interoperability, respondents requested that the USDOT support:

1. Technology-neutral voluntary standards to enable innovation and interoperability.
2. Clear definitions of relevant terms to ensure performance metrics are comparable across technology platforms.

VOICES

The VOICES PoC project addresses CDA development challenges and demonstrates the value of collaborative research and testing, by enabling disparate remote organizations to work together in a virtual environment where their systems comingle, interact, and communicate in a high-fidelity representation of the surface transportation ecosystem. To do this, the VOICES project will adapt the proven distributed virtual environment infrastructure of the Test and Training Enabling Architecture (TENA) developed by the U.S. Department of Defense (DOD) for protected collaboration and technology testing as an enabling component of VOICES. VOICES provides the opportunity for collaborators to add, integrate, and test various capabilities in a system of systems while protecting their IP. Moreover, VOICES affords researchers and developers configurable and protected access to engineering resources that are essential to their research and development (R&D) of traffic safety and mobility applications. The platform can validate combinations of virtual and live “in-the-loop” test methods and tools. VOICES aims to develop an approach to gathering common scenario libraries that benefit the development and evaluation of system performance, and advance the understanding of typical conditions that exist within particular ODDs (e.g., intersections with unique roundabouts or traffic control devices).

Stakeholders from private-sector companies and innovators, academia, and State and local governments are encouraged to participate in and access the VOICES platform during the two-year project period and beyond. The VOICES PoC project provides an opportunity for technical and non-technical stakeholders to shape and refine the PoC technical solution, formulate technology transfer (T2) strategies, and identify options for governance, operations, and long-term sustainment of VOICES.

VOICES leverages and extends infrastructure and capabilities put in place by the USDOT and USDOD investments over the course of the last decade to address testing the safety, performance, and interoperability of mobile, intelligent, connected systems in a system of systems environment. It is the Government's intent to transfer the operational control of VOICES to industry or academia following the project that produces the initial instance of the VOICES platform. The strategy to perform the technology transfer of VOICES will be developed in concert with industry through the CoP.

Stakeholder Engagement in VOICES

The USDOT conceived the VOICES PoC project to deal with the challenges and grasp the opportunities of emerging ADS and CDA technologies. This project also satisfies some stakeholders' comments in response to the USDOT AV 3.0 and AV 4.0. As an integral part of this project, the USDOT will engage stakeholders to refine the project and develop a platform valuable to all stakeholders.

Involvement in VOICES

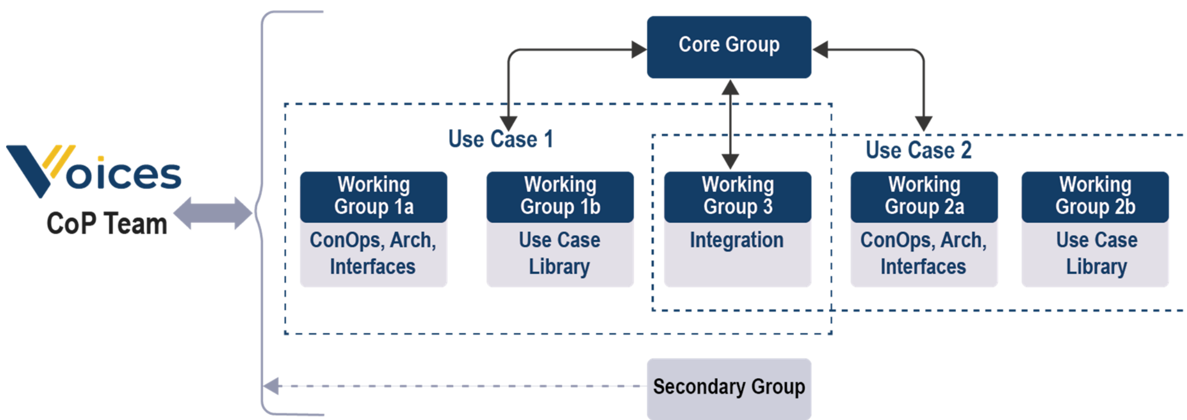
The engagement of stakeholders from the VOICES PoC project's initial execution stages and beyond is critical to helping shape the program and transition the VOICES PoC to an operational system. Thus, the program will establish a new open and voluntary VOICES CoP to ensure a common mechanism of collaboration among stakeholders who will:

1. Have direct input on the common interfaces and technology that the CDA community is creating.
2. Define use cases needed for research and testing in the CDA community.
3. Participate in cooperative distributed testing.
4. Share information and lessons learned from collaborative testing.
5. Create a coalition of the willing to carry forward VOICES in a sustainable model after the project concludes.

VOICES will foster an industry-driven CoP to establish a PoC CDA test architecture and open use case database. From a systems engineering perspective, CoP members will identify their needs and priorities, which will ultimately drive the success of participation in the PoC and T2. These inputs will effectively contribute to the VOICES technical requirements, concept of operations (ConOps), architecture, and interfaces. CoP members will also inform and contribute to the development of a CDA use case test framework and open CDA use case database. Active participation by stakeholders in the VOICES CoP will accelerate the development of voluntary industry standard(s) based on the definition, method, and format of CDA use cases, and CDA common interfaces used in VOICES. This effort will ensure that the VOICES technology and platform developed under this project can be useful for the broader cooperative and automated driving communities. Most importantly, the CoP will inform and contribute to the eventual T2 and adoption of the VOICES PoC by surface transportation stakeholders. The intended lasting impact of VOICES is to cultivate a user-driven approach, inform governance and operations, and encourage the continued use and advancement of VOICES tools and use cases to achieve improvements in traffic safety, mobility, economic benefit, and efficiency.

VOICES CoP membership will be open to a diverse group of participants from across the surface transportation industry, including but not limited to: original equipment manufacturers (OEMs) and ADS developers, infrastructure owners and operators (IOOs), infrastructure technology developers, system integrators and suppliers, simulation toolchain suppliers, cloud services suppliers, sensor suppliers, and universities and research institutes.

As shown in figure 3, the VOICES CoP will consist of one core group, multiple working groups, and one secondary group. Core group members will lead the CoP and will have the freedom and ability to interact with the various working groups in order to achieve CoP goals, and to distribute or request appropriate resources. Working groups will be comprised of relevant subject matter experts who will provide pertinent insight, and they will have the ability to work with the VOICES CoP team to discuss goals, resources, and barriers. Secondary group members will fulfill a monitoring role that involves low commitment but allows them to inject their industry knowledge and resources when available. The CoP will be organized by specific use cases, with each use case having specific working groups that are composed of core stakeholders. The project team anticipates that the ConOps, architecture, interfaces, and toolchain will look significantly different across use cases; for example, cooperative perception use cases may require higher fidelity environmental modeling than would an Eco Approach and Departure[11] use case. Segmenting CoP stakeholders by use case allows stakeholders interested in similar use cases to collaborate on the identification of these considerations. The core group of stakeholders will support the T2 process by creating an ecosystem that values and adopts the outputs of VOICES.



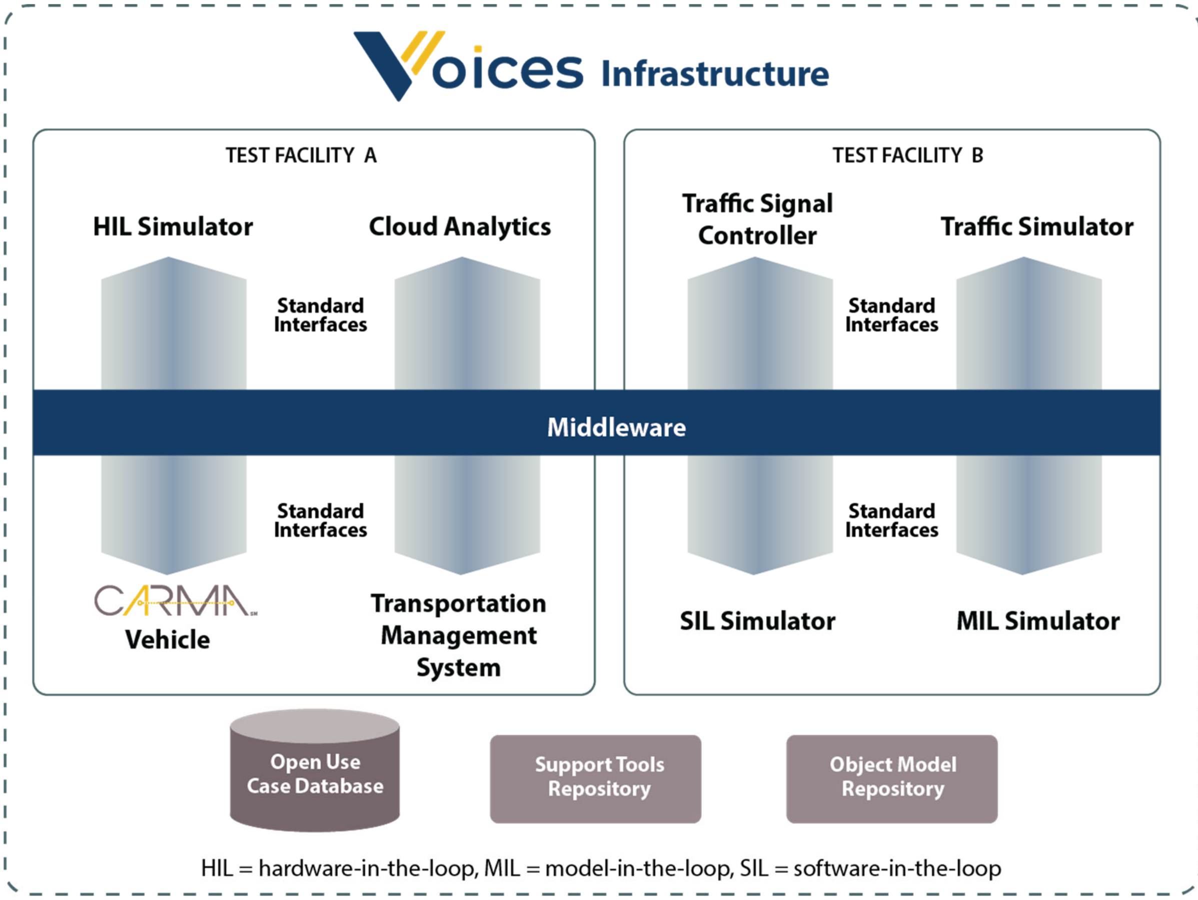
Arch = architecture; ConOps = concept of operations; CoP = community of practice.

Source: USDOT.

Figure 3. Diagram. VOICES community of practice organization.

Description of VOICES

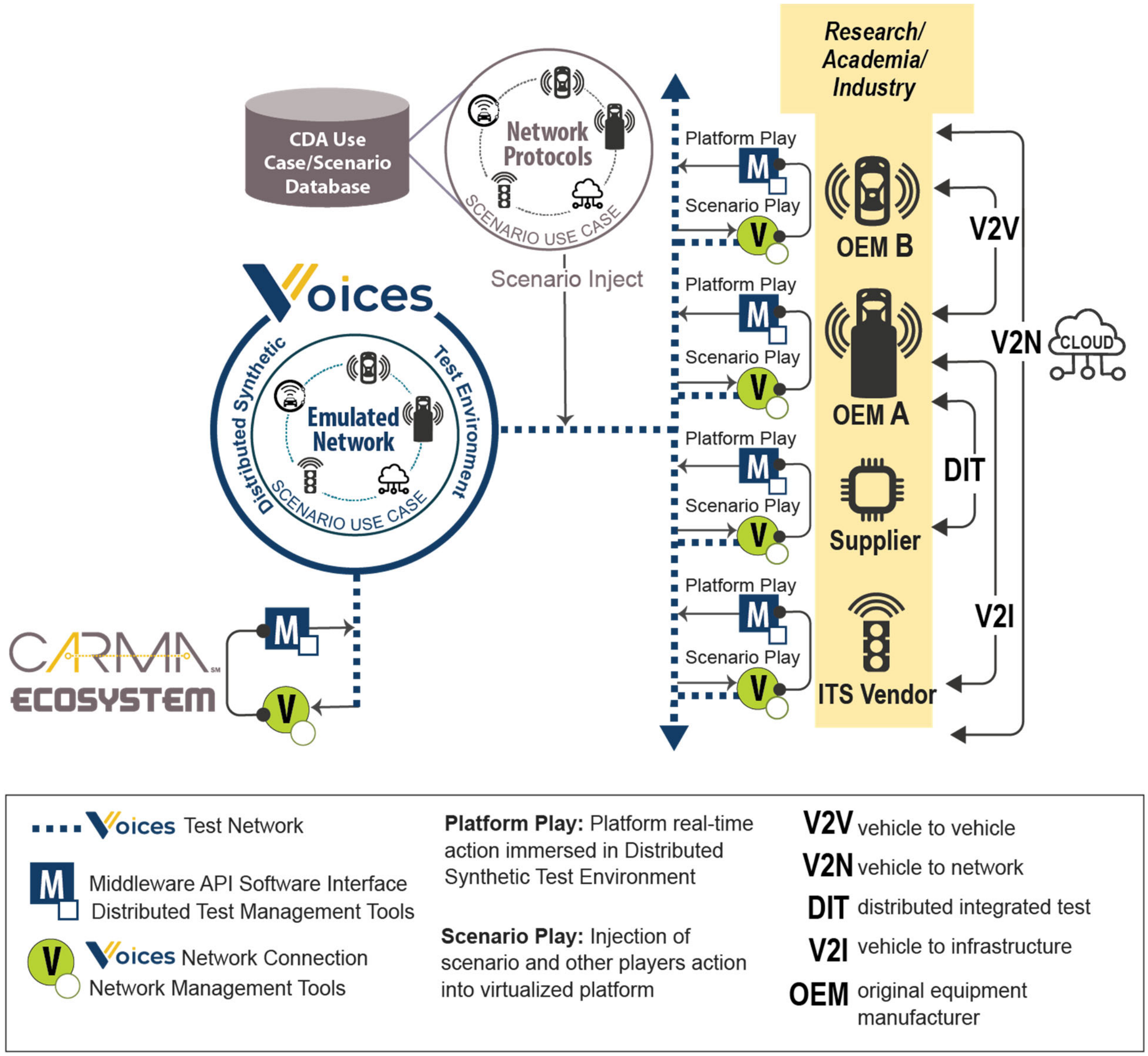
VOICES aims to provide a common architecture that greatly improves the reuse and interoperability of test assets, thus reducing development, operation, and maintenance costs of test facilities. Figure 4 shows the VOICES infrastructure. VOICES will employ a middleware that provides system developers with a unified application programming interface (API) to support the real-time exchange of software objects, messages, and data streams used by facility resource applications and tools during the execution of a test event. The middleware will use a repository that functions as a database containing standardized resource interface definition and executable versions of the utilities and tools, along with related documentation, where event planners can select existing capabilities to support a test event. VOICES object models define the common data and interfaces shared by all participating applications. A data archive will store and provide for the retrieval of all persistent information associated with a test event, such as scenario information and references to all data collected for the particular event.



Source: USDOT.

Figure 4. Diagram. VOICES distributed test infrastructure.

As previously stated, the VOICES project will leverage TENA as the middleware component of VOICES. TENA is part of a larger system that will integrate CARMA℠ tools–which are open source software products developed by the USDOT for CDA research, testing, and development–and provide a common use case database for users and stakeholders interested in the development and testing of CDA and other applications.[12] Figure 5 provides a system view of the VOICES platform, illustrating the incorporation of a DSTE connecting multiple, distributed R&D sites to each other and to the CARMA ecosystem, and a CDA use case/scenario database.



Source: USDOT.

Figure 5. Diagram. VOICES platform system view.

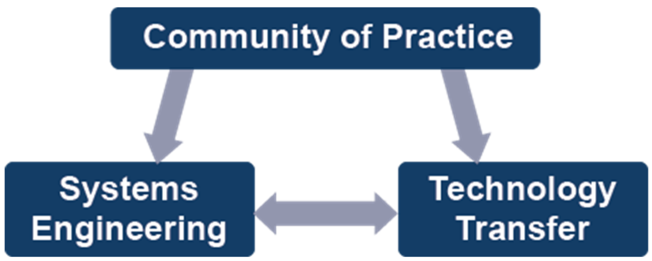
Generally, the VOICES platform facilitates distributed virtual collaboration among willing participants where established data links, between hardware and software components residing in same and separate locations, exchange data at or about real-time rates over robust, secure, and protected virtual connections. VOICES can also be augmented with high-fidelity simulation models of underlying systems, sensors, and actuators, which enables closed-loop compatibility and interoperability assessment of subsystems among participating and sharing entities' products.

The VOICES DSTE allows real-time collection and storage of data for tests in progress, and sets up tests that are composed of real and simulated entities distributed across multiple sites.

The current focus of the VOICES PoC project is on CDA technology that could provide opportunities for achieving substantial benefits in traffic safety and mobility through a more integrated consideration of the road user, motor vehicle, and infrastructure relationships. CDA can enable applications that are not achievable by individual ADS-equipped vehicles operating independently of one another and/or transportation infrastructure.[13] VOICES PoC incorporates CARMA tools and the CDA use case database in order to facilitate the faster conceptualization and rapid development of applications that implement transportation systems management and operations (TSMO) strategies.[14] This VOICES PoC tackles the challenges facing CARMA collaborators–including physical separation between developers, insufficient access to experts, inability to test interoperability between infrastructure components and a suite of disparate systems, and the cost of physical equipment and testing–to develop CDA TSMO concepts.

VOICES PoC Project

VOICES PoC is a two-year project that consists of three inter-related research tracks: CoP, systems engineering, and T2 (see figure 6).



Source: USDOT.

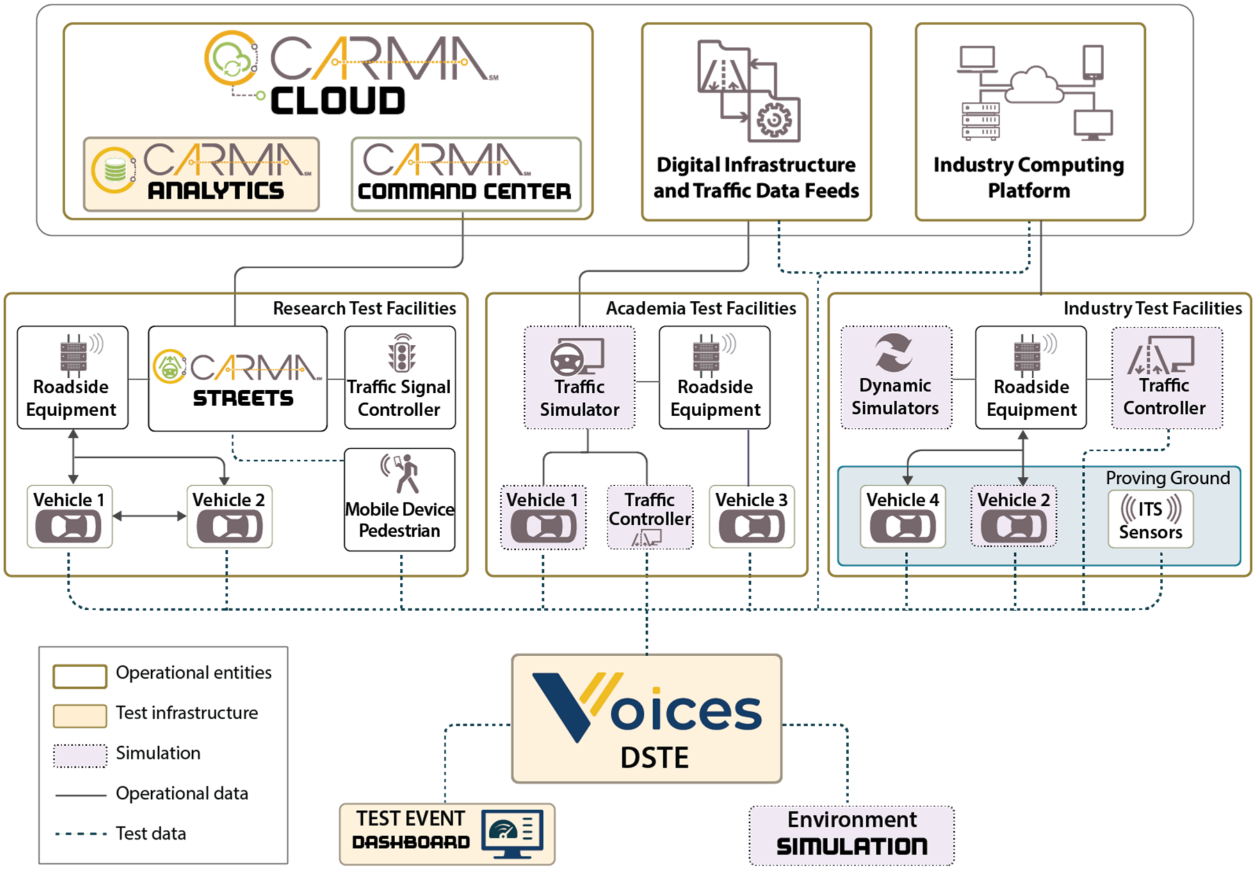
Figure 6. Diagram. VOICES program research tracks.

The CoP provides input and feedback to research activities performed under systems engineering and T2. The VOICES project team plans to form the initial CoP group in the first quarter of the year 2021.

The systems engineering track comprises two groups of activities: development and operational/support groups. Development activities include the design and build of the DSTE; the creation of a CDA test use case database and its interface to the DSTE; the modification, integration, and connection of the CARMA ecosystem[15] to the DSTE; and the formation of interfaces of participants' sites to the DSTE. Operational/support activities include interactions with the test sites, test set-ups, and conducting of the tests. VOICES PoC systems engineering will:

- Develop a distributed test environment architecture.
- Utilize a middleware and/or develop an API that interfaces a standardized CDA use case architecture to proprietary CDA simulations.
- Develop network connection interfaces between the CDA distributed testbed network and selected test sites.
- Establish the initial CDA distributed testbed network and cloud infrastructure.
- Develop PoC test plans to validate the capabilities of the CDA distributed testbed.
- Perform PoC tests of the Initial Operating Capability[16] of the CDA distributed testbed.

The DSTE provides easy access to a variety of simulation tools for CDA development. VOICES components integrate into one or more CARMA systems to enforce a standard API, such as between the automation and communication components within a vehicle. Figure 7 illustrates how products in the CARMA ecosystem integrate into VOICES.



DSTE = distributed synthetic test environment, ITS = intelligent transportation system.

Source: USDOT.

Figure 7. Diagram. VOICES platform integration with the CARMA ecosystem.

The VOICES PoC will perform demonstrations of three use cases leveraging the VOICES platform. From early discussions with potential CoP stakeholders, there are at least three use cases of interest to the community: cooperative perception, (intersection) Eco Approach and Departure, and platooning. Following discussions with the CoP, the VOICES team will specify the use cases for demonstration, define common interfaces enabling the necessary interoperability among the systems being tested as well as components within the CARMA ecosystem, execute use case demonstration, and publish use case results. Ideally, the series of demonstrations will increase in complexity, LVC testing of vehicles, vulnerable road users, and infrastructure systems.

T2 activities will begin with the launch of the VOICES program. Initial T2 activities will include conducting a T2 strategy study to identify and assess the methods and options to transfer primary ownership, management, and operational control of VOICES technology to industry without Federal oversight. This study will also identify the hardware and software components of VOICES as candidate configuration items and related technologies that are suitable for possible T2. In addition, T2 activities will identify and assess possible governance, operational, and business model approaches, as well as options for the governance, operations, long-term sustainment, and scaling of VOICES beyond the two-year project period. The VOICES team will execute the T2 for VOICES based on the selected T2 strategy and governance, operational, and business models. The team will facilitate the transfer of the VOICES system to the private sector beyond the two-year life of this project.

VOICES and Workforce Development

VOICES will provide the platform, tools, and environment for engineers and researchers to master new skills or expand their current skills, in order to research, test, develop, assess, and validate CDA applications and to ensure that the Nation's transportation resources function safely as an integrated national system.

Today's workforce faces challenges to develop and test automated transportation technologies, including the need to acquire the critical STEM skills to maintain currency with the rapid pace of advancement of key enabling and emerging technologies. As found in a recent U.S. Government Accountability Office (GAO) audit of workforce, the USDOT should take steps to ensure its workforce has the skills needed to oversee the safety of autonomous systems. New and improved workforce skills in engineering, data analysis, and cybersecurity are needed to understand and assess the impacts of highly automated transportation technologies.[17] Congress directed the Secretary of Transportation to establish a Highly Automated Systems Safety Center of Excellence in order to have a workforce capable of reviewing, assessing, and validating the safety of automated technologies.[18] VOICES will act as a critical platform to standardize methods for testing ADS/CDA systems, to include training on common tools and providing a common test environment for Government, industry, and academia to collaborate.

Universities and research organizations have created educational and collaborative programs, such as F1TENTH, to promote the learning and application of engineering and science to develop and enhance the skill levels of students and researchers in automated technologies.[19] VOICES is intended to integrate researchers and academic institutions into the VOICES platform to support university research and education. As a virtual collaborative environment, VOICES provides an opportunity for CDA professionals to:

- Develop, test, and validate automated and connected systems of systems in a realistic virtualized intelligent and connected transportation ecosystem.
- Examine, assess, and assure interoperability between systems.
- Characterize system behavior and capability, and measure system performance with integrated LVC testing.
- Make use of and learn accessible simulation tools.
- Develop and execute distributed test procedures using a common database of use cases.

The VOICES CoP involves many stakeholders of various backgrounds and skill levels across the intelligent and connected transportation ecosystem, and provides a forum for them to collaborate on their automation and CDA expertise and best practices in order to develop a common suite of skills and body of knowledge. CoPs generally expand workforce skills by engaging in a process of collective learning to share best practices and create new knowledge, in order to advance various domains of professional practice. Thus, the VOICES CoP contributes to increasing awareness and better understanding for all members across a multitude of engineering and scientific topics that are applicable to CDA development and evaluation. The VOICES project seeks the active participation of a broad base of stakeholders as members of the VOICES distributed network, including academia, research organizations, Federal government agencies, State and local DOTs, the automotive sector, IOOs, the wireless communication industry, and transportation technologists. Collaboration among these entities via the VOICES platform can enhance the professional capacity building of the workforce specific to each sector type. Involvement and integration of academic institutions with the VOICES platform supports university research and education, encouraging the development of CDA-related curricula for undergraduate, graduate, and PhD programs. VOICES will produce a degree of commonality and standardization in the methods and tools to assess and validate the interoperability and performance of automated systems. This standardization, along with the use of common tools and environments, can contribute to lowering the barriers to entry for professionals to engage in the development and testing of automated systems. Consequently, VOICES can contribute to the creation of a future workforce skilled in the various disciplines of engineering and sciences needed to research, develop, and evaluate highly automated transportation systems. Finally, the VOICES project will produce tools, user manuals, and training modules in support of its Initial Operational Capability, which would serve to educate, train, and develop the Nation's workforce.

Project Points of Contact

For more information on the VOICES PoC, or to join the VOICES CoP, please contact the USDOT at voices@dot.gov.

List of Acronyms

ADAS	advanced driver assistance systems
ADS	automated driving system
API	application programming interface
AV	automated vehicle
CDA	cooperative driving automation
ConOps	concept of operations
CoP	community of practice
DIT	distributed integrated test
DOD	Department of Defense
DOT	Department of Transportation
DSTE	distributed synthetic test environment
GAO	Government Accountability Office
HIL	hardware-in-the-loop
IOO	infrastructure owner and operator
IP	intellectual property
ITS	intelligent transportation system
LVC	live, virtual, and constructive
MIL	model-in-the-loop
ODD	Operational Design Domain
OEM	original equipment manufacturer
PoC	proof of concept
R&D	research and development
SIL	software-in-the-loop
T2	technology transfer

TENA	Test and Training Enabling Architecture
TSMO	transportation systems management and operations
U.S.	United States
USDOT	United States Department of Transportation
V2I	vehicle-to-infrastructure
V2N	vehicle-to-network
V2V	vehicle-to-vehicle
V2X	vehicle-to-everything
VMT	vehicle miles traveled
VOICES	Virtual Open Innovation Collaborative Environment for Safety

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