Digital Infrastructure for Autonomous Vehicles
Requirements, Deployment and Plans
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Purpose of the report

With the promise of autonomous vehicle (AV) technology and its potential use cases as demonstrated by various pilot programs, digital infrastructure has emerged as a win-win combination for cities, transportation authorities, transit agencies, suppliers and AV companies. Digital infrastructure has proven effective in improving safety, traffic management and asset maintenance. It improves transportation system resilience and allows incremental, flexible implementation, both for infrastructure readiness and vehicle automation.

The COVID-19 pandemic has made digital infrastructure a priority to safeguard people and assets as cities continue to deliver essential services. The market size for traffic intersection upgrade/V2I smart intersections in the United States is expected to grow from about $2 billion in 2020 to $18 billion in 2040. The market size of smart pavements is also expected to grow significantly in these years. As the share of connected and autonomous vehicles (CAVs) increases in the vehicle mix, changes are expected to be revolutionary. It is vital for government agencies and businesses to future-proof plans and explore strategies for deployment.

The report *Digital Infrastructure for Autonomous Vehicles - Requirements, Deployment and Plans* provides a comprehensive overview of digital infrastructure development as cities, government agencies, state DOTs, transit agencies, research institutions and private companies prepare to launch AVs. The report introduces key concepts and covers the domains of policy and standards development; infrastructure digitization; AV/CV deployment in public transit; market size; existing and planned test facilities; key suppliers; costing and funding; challenges; lessons learned and opportunities for businesses.
1.1 Introduction

• Digital refers to information technology (IT) systems that electronically collect, process, and transmit information. Digital infrastructure comprises a new interface between the vehicle, driver, traffic control and road infrastructure. It is essential to improve safety and effectiveness of automated vehicles (AVs).

• AVs collect inputs, use image and pattern recognition to compare results with preloaded maps, plot a path, and send instructions to powertrain and control systems for managing acceleration, braking and steering. These functions can be supported by enabling intelligent infrastructure.

• Digital upgrades required in prevailing road infrastructure include pavement sensors and markings, road signs, traffic control devices (TCDs), maintenance protocol, data management, communication systems and mapping. Transportation authorities can adopt a phased approach when developing infrastructure that supports AVs.

• Hybrid digital infrastructure involves adding digital components to traditional physical infrastructure with digital components. For example, roadways embedded with sensors to detect and send information.

• Dedicated digital infrastructure is inherently digital. For example, fiber optic cables, sensor networks and connected devices.

• Smart infrastructure technologies are collectively known as intelligent transportation systems (ITS).

• Cooperative Intelligent Transport Systems (C-ITS) refers to wireless communications between vehicles (V2V), vehicles and infrastructure (V2I), among infrastructure (I2I) and vehicles to other users (V2X)

• Actual deployment of AVs will be determined by the preparedness of infrastructure providers. This is quite a challenge because the roadway environment is diverse, comprising freeway, arterial, collector/distributor, local roads, intersections, traffic circles and ramps, each with different lane configurations and variable access rules.

• Digital infrastructure has been enabled by advances in robotics, artificial intelligence (AI), machine learning (ML), the Internet of Things (IoT) and wireless communications.

• Interactive cloud-based analytics and visualization platforms provide real-time insights for AV perception; infrastructure asset monitoring for predictive maintenance; and various applications for safety, infotainment, in-vehicle commerce, etc.
2.3 Federal, state and local initiatives

<table>
<thead>
<tr>
<th>Initiative</th>
<th>Description</th>
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<tbody>
<tr>
<td>FHWA CV Pooled Fund</td>
<td>Partnership of 27 core members, including Virginia DOT; tests infrastructure-oriented CV applications</td>
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<tr>
<td>FHWA V2I Benefits Tool</td>
<td>Decision support tool for V2I applications</td>
</tr>
<tr>
<td>FHWA Machine Vision</td>
<td>Onboard system to support V2I, interpret special roadside static signs and machine-readable signs</td>
</tr>
<tr>
<td>Partnership for Analytics Research in Traffic Safety (PARTS)</td>
<td>Data-sharing partnership between the government and the private sector to collaborate on safety. PARTS-2 was announced in January 2020 under the AV 4.0 initiative. It will expand to 70% of the U.S. automobile market, allowing private-sector partners to learn from each other and prevent safety issues.</td>
</tr>
<tr>
<td>First Responder Safety Technology Pilot</td>
<td>Announced in January 2020 to deploy V2X communication for emergency response vehicles and transit vehicles. It uses spectrum allocated in the 5.9 GHz band for transportation safety-related communications.</td>
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<tr>
<td>Work Zone Data Exchange</td>
<td>Project began in March 2018 to develop an efficient and reliable system for real-time data processing</td>
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<tr>
<td>Security Credential Management System</td>
<td>Provides message security solution for V2V and V2I communication</td>
</tr>
<tr>
<td>ITS JPO Connected Vehicle Reference Implementation Architecture (CVRIA)</td>
<td>List of interfaces to be considered for standardization and plan for the development, modification and/or harmonization of defined interfaces; architecture viewpoints for 88 CV safety, mobility, environmental and support applications; incorporated into the National ITS Architecture Reference for Cooperative and Intelligent Transportation (ARC-IT)</td>
</tr>
<tr>
<td>Smart Roadside Program</td>
<td>Provides AVs with information about pavement and traffic conditions from weather sensors along roads</td>
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</table>
2.3 Federal, state and local initiatives

3rd Generation Partnership Project (3GPP)

- **3GPP** is a global initiative that develops standards for cellular telecommunications technologies, such as radio access.
- **3GPP Release 14** featured cellular V2N communication and standards for V2V and V2I.
- Release 15 and Release 16 serve requirements of advanced automotives and ITS.

**3GPP V2X Pilot in Virginia – Q3 2020**

- In January 2020, Virginia DOT, Virginia Tech, Audi and Qualcomm announced plans to deploy V2X technology along U.S. highways 50 and 29, interstates 66 and 495 and state routes 7 and 650, which include signalized intersections. The initial deployment is expected to take place on select roadways in Virginia beginning in the third quarter of 2020.
- The project is in line with the USDOT announcement to establish a First Responder Safety Pilot Program.
- C-V2X solution in initial deployment is based on **3GPP Release 14 and Release 15** specifications. It uses 20 MHz from the 5.905 – 5.925 GHz ITS band, the same spectrum that the FCC has proposed allocating for C-V2X. Advanced C-V2X mode has an evolution path to 5G using **3GPP Release 16** specifications.
- Virginia Tech Transportation Institute will develop the software and systems to support primary use cases and conduct a demonstration of C-V2X technology operating in these use cases.
- On arterial roadways, the signal phase and timing (SpaT) from a traffic signal will be transmitted with a Qualcomm 9150 C-V2X chipset solution to Audi Q8 SUVs. These vehicles have the Traffic Light Information (TLI) service to provide drivers a countdown to the green light.
- Audi has provided V2X TLI in 25 cities and nearly 10,000 intersections nationwide, including over 1,700 intersections in the Washington D.C. metropolitan region. DOTs in Utah and Colorado have formed similar partnerships with Panasonic.
3.1 Upgrade of existing assets

Pavement Markings
Bright, durable and machine-readable lane markings enhance AV safety. Lane markings on a bright road surface can be enhanced by using contrast color (black, white) marking on left and right side.

Signing
A variety of symbols, shapes, and colors are used as signs. Retro-reflective signs function in limited visibility. Machine-readable signs include embedded code for vehicles and mapping devices.

Maintenance
AVs require road surface, markings, signs and signals to be maintained to a high level. Vehicle and road sensors, weather monitoring, temperature check and road history data can predict maintenance needs.

Standardization and Consistency
Digital infrastructure and systems architecture should be standardized (for requirements and certification tests) and road signs/markings should be consistent nationwide to ensure messages between vehicles and infrastructure are seamlessly exchanged and easily understood.

Data Capture, Information Sharing and Inventory
Cities need policy for data sourcing, sharing, security, storing and reporting. New cloud-based platforms are being developed as repositories of data for various service providers. Many policy interventions are needed to make real-time data sharing successful.

Communication Infrastructure
Communication technologies such as LTE-C-V2X, dual-mode DSRC/C-V2X, and 5G new radio (NR) support V2X. Use of different technologies adds complexity for designers, engineers and planners. Adoption of one technology can trim overhead and benefit volume pricing.
4.1 Digital infrastructure to adopt AV/CV in public transit

• Public transport is a key component of the Smart City concept and forms backbone of integrated mobility. Digitalisation enables an open and interoperable IT platform with many opportunities for public transport - improved service quality, lower costs, new revenue streams, improved customer experience, mobility as a service (MaaS), predictive maintenance, etc. AV technology in sensors, machine learning, on-board computing and connectivity can be deployed on trains and buses.
• Due to its unique characteristics and behavior, such as vehicle size and frequent stops/starts, transit often deals with safety challenges and priorities that are different from those for light and commercial vehicles.
• Developing and testing safety, mobility, and environmental applications for transit vehicles is expensive and time consuming. Once a system is designed, components must be developed and integrated. A field test selected, test system deployed, data gathered and analyzed, and findings documented. The use of transit bus driving simulators to test and evaluate proposed transit technologies would reduce the time and cost associated with executing a field operational test.

<table>
<thead>
<tr>
<th>USDOT priority Transit CV safety applications for near-term</th>
<th>Description</th>
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<tbody>
<tr>
<td>Pedestrian Warning for Transit Vehicles (V2I)</td>
<td>Alert driver for the presence of a pedestrian; SPaT information and pedestrian detection data is transmitted to RSU via V2I</td>
</tr>
<tr>
<td>Vehicle Turning Right in Front of a Transit Vehicle (V2V)</td>
<td>Alert driver of a vehicle making a right turn in front of the bus as the bus driver pulls away from a bus stop; DSRC messages are transmitted to the bus via V2V to predict collisions</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Other Transit CV safety applications</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus Stop Warning</td>
<td>Alert nearby vehicles or pedestrians of the presence of a transit vehicle at or near a bus stop</td>
</tr>
<tr>
<td>Left Turn Assist</td>
<td>Alert drivers performing unprotected left turns to judge the gaps in oncoming traffic</td>
</tr>
<tr>
<td>Forward Collision Warning</td>
<td>Warn drivers if they fail to brake when a vehicle in their path is stopped or traveling slower</td>
</tr>
<tr>
<td>Blind Spot Warning/Lane Change Warning</td>
<td>Warn drivers when they try to change lanes if there is a car in the blind spot of an overtaking vehicle</td>
</tr>
<tr>
<td>Angle Collisions at Intersections</td>
<td>Alert drivers at intersections that are signalized, have stop signs, serve highway and rail, or LRT</td>
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5.1 Market size

**Market size for traffic intersection upgrade/ V2I smart intersections (million $)**

<table>
<thead>
<tr>
<th></th>
<th>2020</th>
<th>2025</th>
<th>2040</th>
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</thead>
<tbody>
<tr>
<td>V2I installation market size</td>
<td>XXX</td>
<td>XXX</td>
<td>XXX</td>
</tr>
<tr>
<td>(includes hardware, planning, software, labor)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Hardware (DSRC unit, communication equipment, power, etc.)</strong></td>
<td>XXX</td>
<td>XXX</td>
<td>XXX</td>
</tr>
<tr>
<td><strong>Planning, design, system integration, implementation</strong></td>
<td>XXX</td>
<td>XXX</td>
<td>XXX</td>
</tr>
<tr>
<td>Backhaul market size</td>
<td>XXX</td>
<td>XXX</td>
<td>XXX</td>
</tr>
<tr>
<td><strong>Total V2I installation market size</strong></td>
<td>XXX</td>
<td>XXX</td>
<td>XXX</td>
</tr>
<tr>
<td><strong>O&amp;M market size</strong></td>
<td>XXX</td>
<td>XXX</td>
<td>XXX</td>
</tr>
</tbody>
</table>

*Key assumptions:*

XXX
5.4 Key players

Security/Safety
- Mentor
- Intel
- Renesas
- ARGUS Cyber Security
- DENSO
- NXP
- Wind
- Elektrobit
- APTIV
- QNX
- KPIT
- Green Hills Software
- Hitachi
- ETAS
- Infineon
- Harman
- Bosch

Mapping
- NVIDIA
- TomTom
- Applanix
- ZENRIN
- Sanborn
- Exonav
- Civil Maps
- lvl5
- Harman
- Increment P
- Mapscape
- Deepmap
- Google
- HERE
- NavInfo
- GeoDigital
- AV America
## 8.3 Opportunities (1 of 3)

### Smart road infrastructure

US faces investment backlog of $786 billion in highway and bridges and $116 billion in transit. American Society of Civil Engineers gave U.S. roads a “D-plus” grade in its 2017 Report Card - 45% of the roads are in poor condition and situation is getting worse. Road operators see opportunities in proactive maintenance and smart technologies to improve traffic control, lane closures, ice and snow mitigation, work zone safety, etc. In May 2020, SoftBank has formed a joint venture, i-Probe, with two other Japanese companies (Pacific Consultants and Oriental Consultants Global) to support road maintenance programs in the U.S. using real-time data from connected cars. SoftBank has experience of IoT and Big Data processing and its partners have knowledge of road infrastructure.

### V2X Equipment

Digital infrastructure components such as V2X have a defined purpose with measurable benefits. They are useful in all stages of vehicle automation, form foundation of Smart Cities and enhance municipal services. Garbage cans with sensors improve fuel efficiency by 46% and collection time by 18%. Smart lighting can reduce power consumption up to 60%. Traffic Signal Preemption (TSP) is installed in about 90% of the intersections in 100 metropolitan areas in the US. AASHTO estimates that V2I will be provided on 20% of signalized intersections by 2025 and 80% of signalized intersections by 2040.

### Data platforms and analytics

Cities and transportation authorities need ITS to collect, store and use data for decision making. Microsimulation creates series of images or videos to assess impact of changes (such as adoption of AVs), plan future improvements and develop investment strategies. Urban Computing Foundation is a neutral forum to collaborate on a common set of open source tools for AVs and smart infrastructure. Contributors include Carto, Mapzen, Facebook, Google, Here Technologies, IBM, Interline, Sidewalk Labs, StreetCred Labs, Uber and UC San Diego. AASHTOWare, a division of AASHTO, and Utah-based Numetric, Inc., have developed a cloud-based SaaS platform that sources data from internal and external databases to analyze vehicle crashes and roadway design for developing State DOT countermeasures. The product will be available for licensing to customers on July 1, 2020.

### Cybersecurity

As Smart Cities come into being, the digital footprint grows and connects infrastructure, municipal services and people. With each additional access point, sensitive data exposure vulnerabilities expand. Cybersecurity involves implementing firewalls; deploying cloud, data centre, server and database security and embedding security controls. USDOT has pursued a “security by design” approach to developing system architecture for vehicles, roadside components, and communications. This ensures that vehicles exchanging data as they travel, data from infrastructure at traffic signals or work zones, and all other components and participants in the ecosystem can rely on the integrity of the data received.