Impacts of Automated Vehicles (AVs) on Highway Infrastructure

Workshop Summary
Aug 29, 2019
Project Overview

**GOAL**
To develop practicable documentation and webinars to educate and inform DOT stakeholders about AV-related infrastructure needs.

**OBJECTIVES**
1) To assess and understand the demands and potential impacts of AVs on our current & future infrastructure assets.
2) To guide and assist DOTs on how to determine their “Readiness” for AV use on its highways.
Is your Country prepared to accept Autonomous Vehicles?

The ‘Autonomous Vehicles Readiness Index’ is intended to provide an understanding of various countries’ preparedness and openness in adopting autonomous vehicle technology. Autonomous vehicles (AVs) are poised to revolutionize not only transportation but the way people live and work throughout the world.

20 countries were studied based on economic size and progress in adopting Autonomous Vehicles.

The four Metrics used to calculate AVRI (Autonomous Vehicles Readiness Index).

Countries best equipped to accept Autonomous Vehicles:

- The Netherlands: Technology & Innovation (1), Infrastructure (1), Policy & Legislation (3), Consumer Acceptance (2)
- Singapore: Technology & Innovation (2), Infrastructure (2), Policy & Legislation (1), Consumer Acceptance (1)
- United States: Technology & Innovation (3), Infrastructure (2), Policy & Legislation (10), Consumer Acceptance (4)
- Sweden: Technology & Innovation (4), Infrastructure (6), Policy & Legislation (8), Consumer Acceptance (1)
- United Kingdom: Technology & Innovation (5), Infrastructure (10), Policy & Legislation (4), Consumer Acceptance (3)
- Germany: Technology & Innovation (6), Infrastructure (12), Policy & Legislation (5), Consumer Acceptance (12)
Stakeholder Workshops

- AASHTO Maintenance Mtg, Grand Rapids, MI, July 17, 1 – 4 PM
- TRB AVS Mtg, Orlando, FL, July 18, 4 – 6 PM

- FHWA Introduction
- Project Overview
- Setting the Stage
- Discussion of Impacts on Infrastructure Categories
  - Traffic Control Devices
  - TSMO and ITS
  - Multimodal infrastructure
  - Physical Infrastructure
- Readiness Actions
- Wrap Up
Workshop Purpose

- Share what we have learned from AV Industry & AASHTO Maintenance
  - Now – priorities for today
  - Future – thoughts about the near-term future (in the next 10 years)
  - Readiness – assessing infrastructure readiness

- Gather feedback in four functional areas of infrastructure
  - Traffic control devices
  - TSMO/ITS
  - Urban multimodal
  - Physical infrastructure (pavements, bridges, and culverts)

- Obtain your feedback
  - Support
  - Concerns
  - Contributions
  - Questions.
Poll Everywhere

- Highly interactive sessions
- Using Poll Everywhere Tool throughout the session
- Allows participants to engage with their phones
- Connect via cellular or wifi
- Provides real-time feedback and real-time interaction
AASHTO Committee on Maintenance -- Workshop

Current run (last updated Jul 18, 2019 10:47am)

14 Polls
117 Participants
60 Average responses
34% Average engagement

AVS Session

Current run (last updated Jul 19, 2019 11:11am)

16 Polls
50 Participants
25 Average responses
41% Average engagement
<table>
<thead>
<tr>
<th>Industry Category</th>
<th>Count</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road Industry: Agency</td>
<td>16</td>
<td>34%</td>
</tr>
<tr>
<td>Road Industry: Consultant/Contractor</td>
<td>8</td>
<td>17%</td>
</tr>
<tr>
<td>Road Industry: Supplier/Manufacturer</td>
<td>2</td>
<td>4%</td>
</tr>
<tr>
<td>Road Industry: Other</td>
<td>3</td>
<td>6%</td>
</tr>
<tr>
<td>Auto Industry: OEM</td>
<td>5</td>
<td>11%</td>
</tr>
<tr>
<td>Auto Industry: Supplier Manufacturer</td>
<td>1</td>
<td>2%</td>
</tr>
<tr>
<td>Auto Industry: Other</td>
<td>5</td>
<td>11%</td>
</tr>
<tr>
<td>None of the Above</td>
<td>7</td>
<td>15%</td>
</tr>
</tbody>
</table>
Setting the Stage
- Reality v Hype
- In-Depth AV Industry Interviews
Discussion of Infrastructure Impacts
Infrastructure Categories and Definitions

Highway Infrastructure Categories

- **Physical Infrastructure**
  - Pavements, Bridges and Culverts

- **Traffic Control Devices**
  - Pavement Markings, Traffic Signs, Traffic Signals, Temporary Traffic Control, Roadside Hardware

- **TSMO and ITS Infrastructure**
  - ITS Roadside Equipment, TSMO Strategies, TSMO Systems

- **Urban Multimodal Infrastructure**
  - Bicycle, Pedestrian, and Transit Infrastructure, Curb Space
Category 1: Traffic Control Devices (TCDs)

- Pavement Markings
- Traffic Signs
- Traffic Signals
- Temporary Traffic Control
- Roadside Hardware
Developing an Understanding

- **January 2018 – FHWA ADS Request for Information (RFI)**
  - Greater *uniformity and quality in road markings* and other TCDs would enable automation

- **October 2018 – USDOT Automated Vehicles 3.0**
  - *Quality and uniformity of road markings*, signage, and other TCDs support safe and efficient driving by both human drivers and automated vehicles.

- **December 2018 – FHWA National Dialogue Outcome**
  - Highway infrastructure *standards should be updated to respond to AV technology*

- **April 2019 – AV Industry Interview Takeaway**
  - *Uniformity and maintenance of physical Infrastructure*: Physical infrastructure should be consistent and in *good-state-of-repair*, especially with regard to road markings, signage, and potholes
Key Areas of Pavement Marking Needs

Uniformity
• Uniform applications - most common challenge
• Pavement markings are the highest priority for today’s vehicle technologies, which are building blocks for tomorrow’s more fully automated vehicles

Design / Quality
• Durable markings that remain visible in wet conditions, low-sun conditions, high-glare conditions, etc.

Maintenance
• Maintenance criteria for machine vision systems
Compliance with MUTCD ≠ Uniformity

- MUTCD is silent on certain issues (such as contrast marking patterns)
- MUTCD allows flexibility in other areas (such as use of dotted lane line extensions along entrance and exit ramps)
- US map shows state DOT policies for pavement marking width
Examples of Vehicle Industry Input

- TCD uniformity “interests” identified through various engagements with auto industry representatives, companies, and associations.
- Example shown here where Google Earth image was annotated with “interest”

Add dashed lane lines across entrance ramp and exit ramp openings in all states. Some states do this today.
Examples of Vehicle Industry Input

- Another Google Earth image annotated showing an “interest” to use contrast markings on light colored pavements.
Do you agree or disagree that IOOs should prioritize changes to pavement marking practices to support AV deployment?

Response options

<table>
<thead>
<tr>
<th>Response options</th>
<th>Count</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly Agree</td>
<td>22</td>
<td>56%</td>
</tr>
<tr>
<td>Somewhat Agree</td>
<td>10</td>
<td>26%</td>
</tr>
<tr>
<td>Neither Agree or Disagree (Neutral)</td>
<td>3</td>
<td>8%</td>
</tr>
<tr>
<td>Somewhat Disagree</td>
<td>2</td>
<td>5%</td>
</tr>
<tr>
<td>Strongly Disagree</td>
<td>2</td>
<td>5%</td>
</tr>
</tbody>
</table>

Engagement: 78%

Responses: 39
What other near-term changes to the TCD infrastructure would best support AV deployment?

<table>
<thead>
<tr>
<th>Responses</th>
<th>Upvotes</th>
<th>Downvotes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uniform work zone set ups</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>I2V communications between signals and approaching vehicles (i.e. SPaT)</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>Intelligent traffic control devices</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Ensure that network connectivity (i.e. fiber or cell coverage) is available</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>LED signage read-ability by on-board camera systems</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>Digitize WZ and sign location data</td>
<td>7</td>
<td>0</td>
</tr>
</tbody>
</table>

Engagement: 54%

Responses: 36
Category 2: TSMO and ITS

- ITS Roadside Equipment
- TSMO Strategies
- TSMO Systems

Source: USDOT

Source: FHWA
What near-term changes to TSMO/ITS infrastructure would best support AV deployment?

<table>
<thead>
<tr>
<th>Responses</th>
<th>Upvotes</th>
<th>Downvotes</th>
</tr>
</thead>
<tbody>
<tr>
<td>V2V and V2I connectivity</td>
<td>13</td>
<td>1</td>
</tr>
<tr>
<td>Connectivity</td>
<td>11</td>
<td>1</td>
</tr>
<tr>
<td>Sharing of real-time advisories with AVs using V2I comms</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>Ensure reliable work zone data is available... active. Location, etc</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>Decommission Legacy equipment to free up funding</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>AV vendors’ ability to share information with public agencies.</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Backhouse IT infrastructure to handle data exchange and data sharing between roadside units, vehicles and interagency.</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Creation of Manual of Uniform Digital TCDs</td>
<td>4</td>
<td>0</td>
</tr>
</tbody>
</table>
Category 3: Urban Multimodal Infrastructure

- Bicycle, Pedestrian, and Transit Infrastructure
- Curb Space

Source: www.pedbikeimages.org/Ann McCrane
**What near-term changes to urban multimodal infrastructure would best support AV deployment?**

<table>
<thead>
<tr>
<th>Responses</th>
<th>Upvotes</th>
<th>Downvotes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction of conflict multimodal points</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>Mode separation</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Video analytics and MEC (multiaccess edge computing) at Traffic signals to process and communicate near ped/bike misses share with buses, vehicle using DSRC / 4GLTE &amp; 5G</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>Automated collision avoidance systems on buses</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>Grade separated lanes for bikes</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Automated buses operating on dedicated lanes: a rubber-tired light rail system</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>5G</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Uniformity of curbs and crosswalks</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Enhanced pedestrian crossing sections</td>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>

**Engagement**: 42%

**Responses**: 32
Given the constraints and uncertainties regarding AV interactions with infrastructure, what existing practices for pavements, bridges, and culverts do you think should be prioritized?

<table>
<thead>
<tr>
<th>Responses</th>
<th>Upvotes</th>
<th>Downvotes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter maintenance</td>
<td>21</td>
<td>0</td>
</tr>
<tr>
<td>pavement markings</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>Additional funding</td>
<td>14</td>
<td>0</td>
</tr>
<tr>
<td>Pavement marking maintenance will need to be a priority.</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Pavement condition</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>pothole patching</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Use of real time gps data to reduce need for markings, signs, weather, etc</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>funding of infrastructure maintenance given current dependency on gas taxes</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Pot holes</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Asset management</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>pavement marking b/c without adequate marking, the functionality will not operate</td>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>
Readiness
Infrastructure AV Readiness Checklist

- **Freeways/Expressways**

  **Expanded effort in preventative maintenance**
  - Addressing potholes, edge wear, rutting

  **Revisiting Pavement Marking Uniformity**
  - 6-inch width
  - Dotted edge line extensions along ramps
  - Chevron markings in gore areas
  - Continuous markings for Work Zone tapers
  - Eliminate Botts Dots as a substitute for markings
  - Contrast markings on light colored pavements

  **Positioning Signs**
  - Minimize confusing speed limit signs along parallel routes

  **Improving TSMO Practices**
  - Greater standardization of active traffic management/dynamic management signage (like for Variable Speed Limits, Lane Controls, Work Zone Management)
Infrastructure AV Readiness Checklist

- Other Highways

  Preventative Maintenance
  - Potholes, edge wear, rutting

  Markings
  - 6-inch width on edge lines with posted speeds > 40 mph
  - Continuous markings for Work Zone tapers
  - Eliminate Botts Dots as a substitute for markings
  - Contrast markings on light colored pavements

- Improving TSMO

  - Greater standardization of active traffic management/dynamic management signage (like for Variable Speed Limits, Lane Controls, Work Zone Management)
Infrastructure AV Readiness Checklist

- **Urban / Local Roads**

**Preventative Maintenance**
- Potholes, edge wear, rutting

**Markings**
- Continuous markings for Work Zone tapers
- Eliminate Botts Dots as a substitute for markings

**TSMO**
- Equip intersections with SPaT and devices that can communicate the presence of vulnerable road users to vehicles
- Equip parking systems with V2I capabilities
- Greater standardization of active traffic management/dynamic management signage (like for Variable Speed Limits, Lane Controls, Work Zone Management)

**Multimodal**
- Adopt mode separation policies (e.g., Complete Streets)
- Anticipate growing curbside demand in site design, street design, and access management practices.
- BRT lanes retrofitted with AV technologies provide opportunities for automated transit systems testing
# How ready are IOOs to support AV deployment?

<table>
<thead>
<tr>
<th>Response options</th>
<th>Count</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Ready</td>
<td>2</td>
<td>6%</td>
</tr>
<tr>
<td>Somewhat Ready</td>
<td>5</td>
<td>16%</td>
</tr>
<tr>
<td>Neither Ready of Unready</td>
<td>3</td>
<td>10%</td>
</tr>
<tr>
<td>Somewhat Unready</td>
<td>11</td>
<td>35%</td>
</tr>
<tr>
<td>Very Unready</td>
<td>10</td>
<td>32%</td>
</tr>
</tbody>
</table>
Please indicate why you believe IOOs are ready or unready to support AV deployment.

<table>
<thead>
<tr>
<th>Responses</th>
<th>Upvotes</th>
<th>Downvotes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insufficient resources and agencies lack the organizational structure and culture for innovation.</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>More advanced IOOs tend to have a champion at the senior management level</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Not ready because of Funding and lack of standards</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Deployment can go now without mods to infrastructure. AV tech developers can and will adapt to serve their market and grow their business.</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Legacy culture</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>We don’t know what we don’t know.</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>
AASHTO MaC Response to Readiness

- How ready is your agency?
  - Very ready: 0 (0%)
  - Somewhat ready: 8 (15%)
  - Neutral: 13 (24%)
  - Unready: 10 (18%)
  - Very Unready: 23 (43%)

- Common comments
  - Lack of resources / funding
  - Needs not well defined
  - Striping inadequate
  - Lack of an understanding
AASHTO Committee on Maintenance -- Workshop

Please indicate why you feel your agency is ready or unready to address AV impacts to highway infrastructure.

Responses

- Striping
- Lack of understanding
- Autos will go airborne
- beginning to train staff.
- Technology keep changing
- Revenue increase
- Early stages of preparation.
- Pavement markings are not ready.
- current revenue source based on mostly gas tax, which will likely decline with AV adoption.
- Our current pavement conditions are driving the funding priorities toward resurfacing and capacity projects. The ability to dedicate funding to this is not there yet.
- Speed of technology changing
- No proven confidence in AV
- Slowly preparing with signs and stripping.
- Pavement condition
- Too much weather
- Striping
- Need to know where to even begin
Next Steps

- Review Literature (completed)
- Engage Stakeholders (on-going)
- Conduct AV Industry Interviews (completed)
- Develop Draft Findings (completed)
- Obtain Feedback (completed)
  - Present, vet, discuss (workshops)
    - AASHTO Maintenance Conference, Grand Rapids, MI
    - TRB Automated Vehicle Symposium, Orlando, FL
- Refine Findings (on-going)
- Develop Techbrief (future task)
- Conduct Webinars (future task, by EOY)