

**NDOT Research Report**

**Report No. 592-18-803**



**AUTONOMOUS VEHICLE FEASIBILITY STUDY**



**October 2019**

**Nevada Department of Transportation**

**1263 South Stewart Street**

**Carson City, NV 89712**



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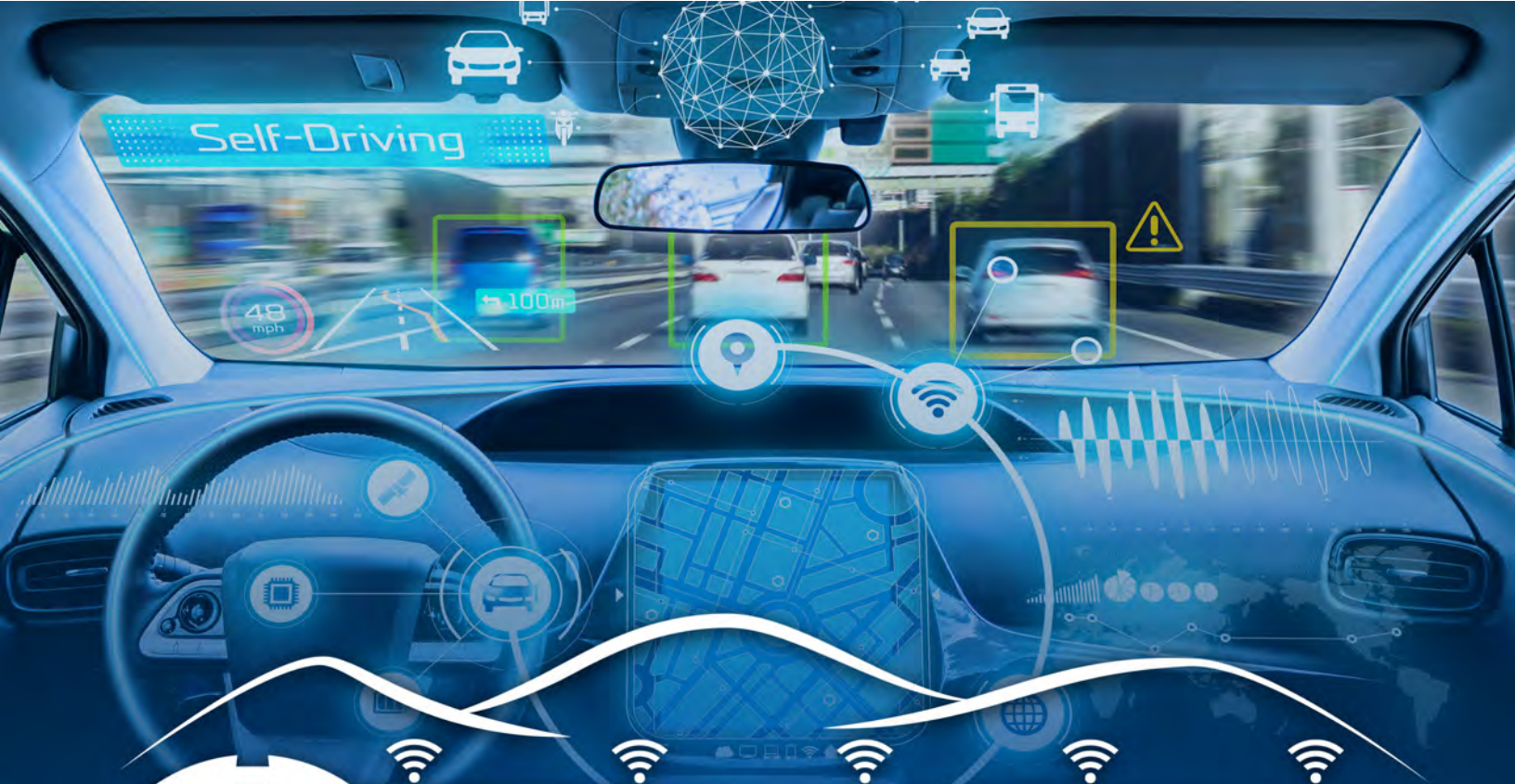
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16. Abstract Massive employment growth at the Tahoe Reno Industrial Center (TRIC), with housing stock primarily in the Reno/Sparks area – and a constrained transportation corridor (I-80) connecting the two – is leading to significant congestion with the potential to slow desired economic development in the region. In addition to other strategies under consideration by the Nevada Department of Transportation (NDOT), such as shared mobility systems or widening of I-80 to accommodate existing and future commuter traffic, the objective of this study was to determine the potential ridership and design standard requirements of a dedicated AV facility (potentially a single lane or one lane in each direction with consideration of one-lane bridges as a cost savings measure) that would reduce construction costs by inhibiting heavy-duty truck or bus usage. The AV-only roadway is anticipated to incorporate technology from both AV and connected vehicle (CV) roadside technology to support optimized use, vehicle platooning and lane management functions.  The following AV Feasibility Study Framework was developed by the research team to allow NDOT to apply the same decision-making framework not only to this study, but also to any future AV roadway studies: (1) Identify Potential AV Developer Partners; (2) Review AV Developer Product Roadmap; (3) Identify Mutually Beneficial Use Cases; (4) Determine Physical and Intelligent Transportation System Infrastructure Needs; (5) Identify Suitable Nevada Corridor; and (6) Estimate Benefits of Use Cases. Extensive outreach to potential users revealed a strong preference to test AVs on roads shared with non-AVs – a more practical and immediate application of technology. NDOT will continue to promote advanced transportation technology solutions, and armed with the findings documented in this final report, has a better understanding of how to do so.			
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# **AUTONOMOUS VEHICLE FEASIBILITY STUDY**

## **FINAL REPORT**

*PREPARED FOR:*

***NEVADA DEPARTMENT OF TRANSPORTATION***

*PREPARED BY:*

***CAMBRIDGE SYSTEMATICS, INC.***

*WITH:*

***CA GROUP, INC.***

*OCTOBER 2019*

CAMBRIDGE SYSTEMATICS



Think  Forward

# Table of Contents

- 1.0 Introduction.....1**
  - 1.1 Project Objective ..... 1
  - 1.2 Summary of Regulation Requirements .....2
  - 1.3 Research Approach.....3
  - 1.4 Organization of this Document.....5
- 2.0 I-80 Corridor Overview .....7**
- 3.0 Autonomous Vehicle Feasibility Study Framework.....13**
- 4.0 Application of Framework to this Study.....15**
  - 4.1 Identify Potential AV Developer Partners.....15
    - User Advisory Group .....15
    - March 12 and 18 UAG Meetings.....15
    - Connected and Autonomous Vehicle Industry Interviews.....18
  - 4.2 Review AV Developer Product Roadmap .....21
    - Aptiv .....21
    - EdgeConneX.....22
    - Keolis.....23
    - Boring Company.....23
    - HNTB.....24
    - Qualcomm .....24
  - 4.3 Identify Mutually Beneficial Use Cases .....25
  - 4.4 Determine Physical and ITS Infrastructure Needs.....26
    - Autonomous Vehicle Roadway Design.....28
    - Additional ITS Infrastructure Elements to Consider .....31
    - Feedback from the CAV Industry .....32
  - 4.5 Identify Suitable Nevada Corridor .....33
    - Proposed Alignment.....33
    - Proposed Autonomous Vehicle Roadway Design .....34
  - 4.6 Estimate Benefits of Use Cases.....37
    - Study Corridor .....37
    - Base and Alternative Scenarios.....37
    - Demand.....37
    - Simulation Literature Review .....38
    - AV-Specific Simulation Characteristics.....38

**5.0 Recommendations for Future Work .....43**

**Appendix A. Background on Connected and Autonomous Vehicle Technology .....45**

    A.1 Background on Autonomous Vehicles .....45

    A.2 Background on Connected Vehicles and Smart Infrastructure .....50

**Appendix B. User Advisory Group Recruitment Flyer .....57**

**Appendix C. User Advisory Group Interviews .....59**

    March 12, 2019 Meeting in Reno .....59

    March 18, 2019 Webinar .....62

    Aptiv .....67

    EdgeConneX .....72

    Keolis .....74

    HNTB .....78

    Qualcomm .....80

**Appendix D. Acronyms and Abbreviations .....83**

## List of Tables

Table 1. Autonomous Vehicle Feasibility Study Research Focus Areas.....	4
Table 2. Companies Involved in the Connected and Autonomous Vehicle Industry Interviews.....	20
Table 3. Aptiv High-Priority Use Cases.....	22
Table 4. Roadway Design Criteria—Traditional versus Autonomous Vehicle-Only .....	28
Table 5. I-80 Corridor Peak Hour Demand .....	38
Table 6. CAV Simulation Model Inputs .....	40
Table 7. Proposed CAV Simulation Parameters.....	40
Table 8. Examples of ITS Technology Applications in CV.....	54

## List of Figures

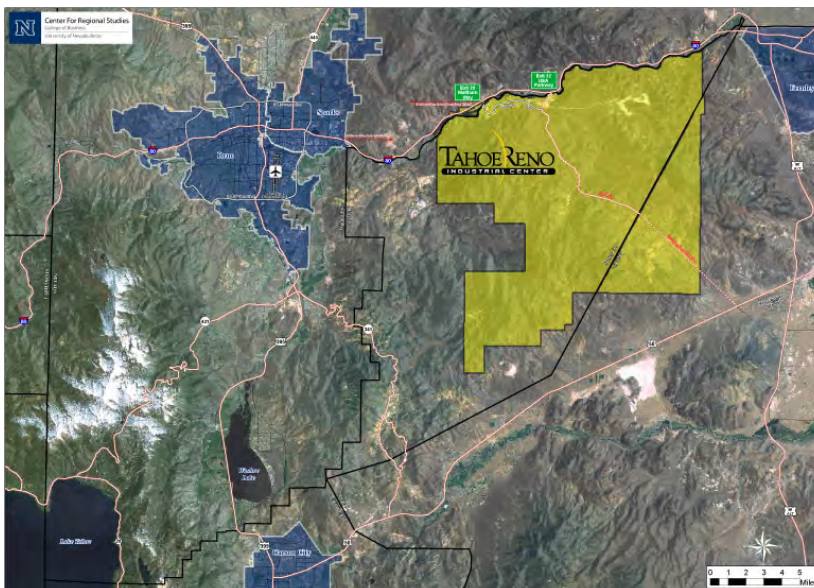
Figure 1. Nevada DMV Autonomous Vehicle Self-Certification Safety Requirements .....	3
Figure 2. Tahoe Reno Industrial Center Commute Origin .....	9
Figure 3. Tahoe Reno Industrial Center Commute Mode .....	10
Figure 4. Tahoe Reno Industrial Center Commute Time .....	10
Figure 5. I-80 Traffic Conditions from 2016 to 2040 .....	11
Figure 6. Autonomous Vehicle Feasibility Study Framework .....	13
Figure 7. Key User Advisory Group Feedback Collected .....	18
Figure 8. Connected Autonomous Vehicle Industry High-Priority Use Cases.....	26
Figure 9. Operational Design Domain Taxonomy.....	27
Figure 10. Proposed Autonomous Vehicle Roadway Alignment .....	34
Figure 11. Comparison of a Traditional Roadway Design versus Autonomous Vehicle-Only Roadway Design .....	35



## 1.0 INTRODUCTION

Massive employment growth at the Tahoe Reno Industrial Center (TRIC), with housing stock primarily in the Reno/Sparks area—and a constrained transportation corridor (I-80) connecting the two—is leading to significant congestion with the potential to slow desired economic development in the region.

Current peak-hour traffic to and from the Reno/Sparks area and TRIC is causing congestion in Washoe County that backs up from USA Parkway eastbound for more than a mile, and from the Pyramid Way area westbound for several miles. With the continued expansion and development at TRIC, this congestion is anticipated to grow and lessen further the Level of Service for facility users. Eventually, growth at TRIC may be impacted by the substandard operations of I-80. At the same time, widening I-80 through these areas presents many geometric challenges anticipated to dramatically increase the cost of any potential solutions.



The Nevada Department of Transportation (NDOT) has recognized this worsening issue and has initiated a study to explore the feasibility of an autonomous vehicle (AV) only facility and its' potential to improve the travel in this region at a lower cost than highway expansion because of the terrain challenges. An additional goal of this effort was to investigate partnerships with the autonomous vehicle industry in exploring this feasibility and subsequent development of a plan towards developing this facility, if it is found to be feasible..

### 1.1 Project Objective

With NDOT's vision to be a leader and partner in delivering effective transportation solutions for a safe and connected Nevada, NDOT recognizes that autonomous vehicles will be part of future transportation, the question was posed as to how NDOT might partner with the autonomous vehicle industry in such a way as to be mutually beneficial to both the forward progress of the autonomous vehicle industry as well as the improved operation of the State highway system. With this in mind, a specific problem area (I-80) presented itself as an opportunity to help achieve this goal.

In addition to other strategies being examined in other planning studies, such as shared mobility systems or widening of I-80 to accommodate existing and future commuter traffic, this feasibility study explored design standards for a first of its' kind autonomous vehicle-only roadway between Reno/Sparks and TRIC and examined public private partnerships as a potential avenue, if an autonomous vehicles-only facility was found to be feasible.

The objective of this study was to determine the potential ridership and design standard requirements of a dedicated AV facility (potentially a single lane or one lane in each direction with consideration of one-lane bridges as a cost-saving measure) that would reduce construction costs by inhibiting heavy-duty truck or bus usage. The AV-only roadway is anticipated to incorporate technology innovations from both AV and CV roadside technology to support optimized use, vehicle platooning and lane management functions.

## 1.2 Summary of Regulation Requirements

Nevada has dedicated efforts to be on the leading edge of transportation, officially becoming the first U.S. State to adopt laws allowing operation of AVs, such as Assembly Bill 69 (AB69), which was passed in 2017. AB69 authorizes AVs and driver-assistive platooning technology to be tested or operated on a highway within Nevada if certain requirements related to safety are met. AB69 also prohibits local governments from imposing a tax, fee or other requirement on autonomous vehicles or autonomous driving systems. The Nevada Department of Motor Vehicles has updated its autonomous vehicle website to align with AB69 amendments from the 2017 Legislative Session.<sup>1</sup> The website outlines the processes and application paperwork needed to submit self-certification for autonomous testing, as well as for public use operations. Minimal platooning requirements will be added to the DMV website.



The first of two self-certification processes is the Self-Certification for Autonomous Testing (Application OBL 326). This self-certification process is available for all levels of autonomy. Once manufacturers and developers who are interested in testing their vehicles in Nevada submit their completed “Autonomous Vehicle Testing Registry Application” packet and the DMV has verified that all requirements are met, they will issue a certificate of compliance for testing, along with sets of red license plates for each vehicle listed in the packet. Recertification is required if there are changes in the autonomous technology. The DMV also requires any incidents exceeding \$750 in damage or traffic violation to be reported within 10 days.

The second of two self-certification processes is the Self-Certification for Operations (Public Use, Application OBL 326A). This application must be completed in conjunction with Application OBL 326. A separate “Autonomous Vehicle Certification Registry” packet must be submitted to the DMV for each make, model, year and technology. Just like Application OBL 326, Application OBL 326A is available for all levels of autonomy and requires recertification if the autonomous technology changes. Figure 1 shows the sections of the OBL 326 and 326A applications pertaining to safety requirements.

To date, two AV pilots have utilized Nevada’s new self-certification process. In 2017, the City of Las Vegas and Regional Transportation Commission of Southern Nevada (RTC/SNV) partnered with Navya,



<sup>1</sup> Accessed at: <https://dmv.nv.com/autonomous.htm>.

(Footnote continued on next page...)

Keolis and AAA to provide free rides for a year in a 12-passenger driverless shuttle along the City's newly designated Innovation District. The shuttle operated for 1,515 hours, with 32,827 riders.<sup>2</sup> Also in 2017, the University of Nevada, Reno has partnered with Proterra, a manufacturer of electric buses, to test the effectiveness of using both LIDAR and infrared sensors to detect vehicles and pedestrians from in-service transit vehicles.<sup>3</sup>

## Figure 1. Nevada DMV Autonomous Vehicle Self-Certification Safety Requirements

### SECTION (2)

Each **AUTONOMOUS** testing vehicle listed on page 4, which **requires a human operator** to be present inside the vehicle and seated in a position to take immediate control; must be,

\_\_\_\_\_ Equipped with a means to engage and disengage the automated driving system which is easily accessible to the human operator of the autonomous testing vehicle.

\_\_\_\_\_ Equipped with an indicator located inside the autonomous testing vehicle which indicates when the automated driving system is operating the autonomous testing vehicle.

\_\_\_\_\_ Equipped with a means to alert the human operator to take manual control of the autonomous testing vehicle if a failure of the system occurs which renders the automated driving system unable to perform the dynamic driving task relevant to its intended operation design domain.

### SECTION (3)

Each **FULLY AUTONOMOUS** testing vehicle listed on page 4, which **does not require a human operator** to be present inside the testing vehicle; must be,

\_\_\_\_\_ Capable of achieving a minimal risk condition if a failure of the automated driving system occurs which renders the autonomous testing vehicle unable to perform the dynamic driving task relevant to its intended operational design domain. The autonomous testing vehicle can achieve a reasonably safe state which may include, without limitation, bringing the autonomous testing vehicle to a complete stop.

\_\_\_\_\_ I understand if the technology is not able to achieve the minimal risk condition then a human operator must be present in the autonomous testing vehicle and ready to take control in the event of a failure of the automated driving system.

Source: <https://dmvnev.com/pdfforms/obl326.pdf> and <https://dmvnev.com/pdfforms/obl326a.pdf>.

## 1.3 Research Approach

Leveraging the timeliness of Nevada's newly passed regulations authorizing testing and public operations of autonomous vehicles, this Autonomous Vehicle Feasibility Study was led by a research team consisting of Cambridge Systematics Inc., with support from CA Group. This study did not serve to determine the feasibility of the driverless technology itself, but rather to evaluate the requirements that would not only enable an AV-only roadway to attract enough demand to address a specific traffic issue experienced in the I-80 corridor, but also examine funding mechanisms for an autonomous vehicles only facility along I-80, if it is found to be feasible. The research therefore centered on two key areas:

- Determine through assessment, sketch planning and simulation, potential ridership levels, lane and bridge options/configurations, technology infrastructure, and potential benefits and costs to develop a

<sup>2</sup> Accessed at: <http://www.aaahoponlasvegas.com/>.

<sup>3</sup> Accessed at: <https://www.proterra.com/press-release/emphasizing-safe-intelligent-transportation-proterra-begins-first-autonomous-bus-program-in-the-united-states/>.

first of its kind AV-only roadway between Reno/Sparks and TRIC. The purpose of this was to provide a direct set of quantitative results regarding feasibility.

- Examine and begin the initial steps in the development of a Public Private Partnership formation to provide the necessary funding mechanisms for constructing the facility, which could potentially include leasing the facility to various vendors or allowing a proposer to fund the facility with repayment from user fees from the vehicles. The purpose of this was to provide a qualitative assessment of the feasibility of the business/funding case.

In order to assess the two key areas above, the research team targeted the following research focus areas as part of their literature review.

**Table 1. Autonomous Vehicle Feasibility Study Research Focus Areas**

Research Area	Purpose
<b>Regulation requirements</b>	While Nevada passed AB69, it is crucial to understand any regulation requirements or additional benefits NDOT may impose on an official AV-only roadway.
<b>Private-sector partners</b>	The User Advisory Group is a great starting point to engage potential private-sector partners who may have inputs regarding design requirements.
<b>Funding options</b>	The research team looked into business models of shared-cost strategies for facility implementation, operations and maintenance (e.g., leasing the facility, vehicle user fees, etc.). Operations and maintenance costs were considered as well.
<b>Autonomous vehicle (AV) technologies</b>	Facility design standards are dependent on the types of AV tests conducted on the facility (e.g., passenger vehicles, buses, shuttles, shared mobility, parcel delivery, etc.). Cold weather climate tests may warrant wider shoulder widths for vehicle skidding or snow removal equipment.
<b>Connected vehicle (CV) and intelligent transportation system (ITS) technologies</b>	AVs will need to communicate with the roadside system in order to authorize facility usage, regulate lane control for a one lane facility, conduct incident management, etc. CV technology also can be used to optimize vehicle platooning on the facility.
<b>Facility design standards</b>	Design standards/requirements were informed by the various potential operational scenarios finalized by the users of the facility.
<b>Ridership</b>	Traffic data such as volume and speeds were used to assess the current and future conditions along the I-80 corridor. Outputs from the region’s travel demand model, as well as research into likely penetration rates of AVs provided insight into potential users of the new facility.
<b>Rideshare applications</b>	Rideshare or transit applications of AV technologies have the ability to further increase person throughput on an AV-only roadway.

This Final Report is the end product of this research effort that summarizes the research approach, information learned from the community, results of this research study, and recommendations for future work.

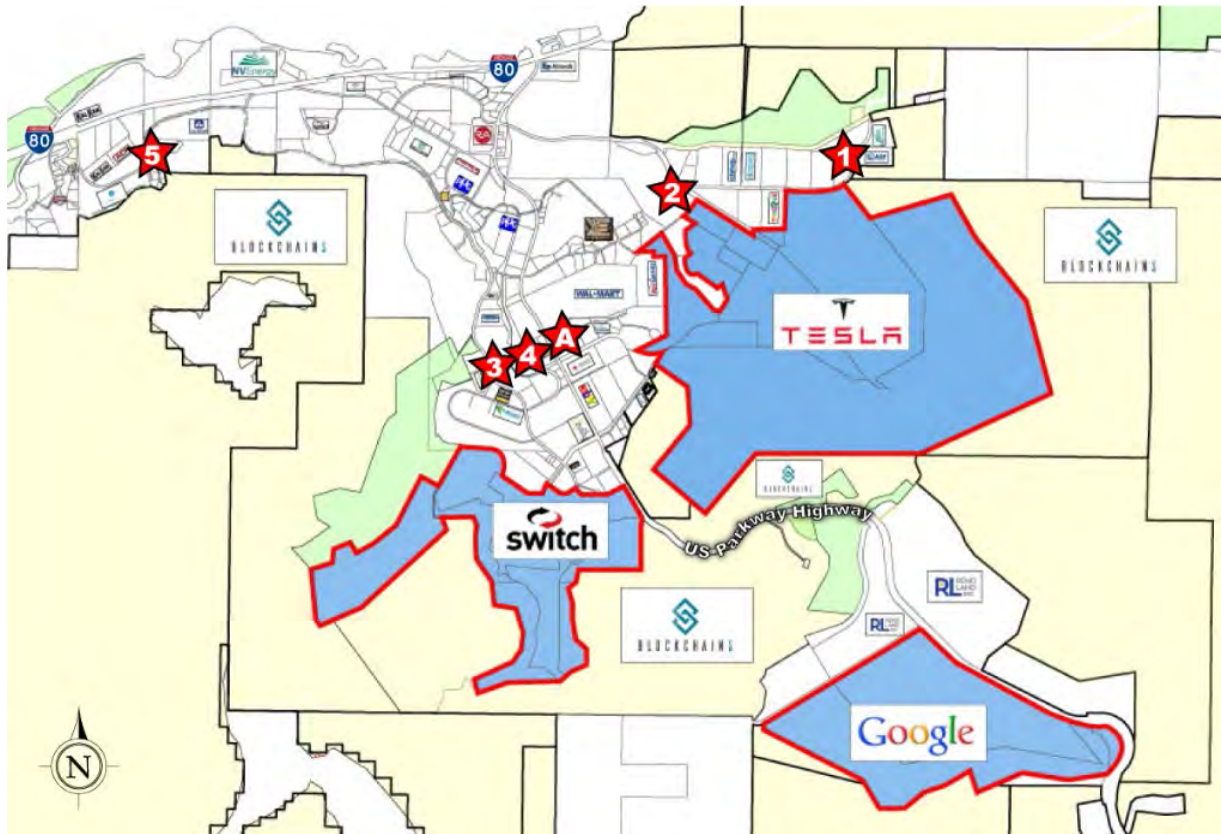
## 1.4 *Organization of this Document*

The remainder of this Final Report is organized as follows:

- **Section 2. I-80 Corridor Overview** provides a high-level summary of the recent developments in the I-80 corridor which is anticipated to lead to major congestion issues in the near future.
- **Section 3. Autonomous Vehicle Feasibility Study Framework** introduces the framework developed by the research team for this feasibility study.
- **Section 4. Application of Framework to this Study** details the work conducted and information collected by the research team for each step of the Autonomous Vehicle Feasibility Study Framework.
- **Section 5. Recommendations for Future Work** provides input on ways that NDOT can further enhance their connected and autonomous vehicle program.
- **Appendix A. Background on Connected and Autonomous Vehicle Technology** provides a summary of the technologies for readers who want a deeper understanding of the vehicles that would be using the AV-only roadway.
- **Appendix B. User Advisory Group Recruitment Flyer** shows the project flyer created to encourage participation in the User Advisory Group.
- **Appendix C. User Advisory Group Interviews** includes detailed discussion notes from each of the group meetings and one-on-one interviews.
- **Appendix D. Acronyms and Abbreviations** lists the definitions for all acronyms and abbreviations included in the Final Report.

## 2.0 I-80 CORRIDOR OVERVIEW

According to the Economic Development Authority of Western Nevada (EDAWN), TRIC covers 107,000 acres of land and currently is home to over 130 companies, including the Tesla Gigafactory. Currently, Tesla employs over 3,000 workers, Panasonic approximately 1,200, and Walmart and Zulily approximately 500 each. More than 30,000 vehicles travel I-80 between Reno-Sparks and USA Parkway every single day. Commuters travel approximately 10 to 50 miles each way to reach TRIC.



While a 12-mile USA Parkway extension was recently completed (now it is 18-miles long, with a 4-lane roadway between I-80 and U.S. 50), EDAWN anticipates TRIC employment increasing from 12,000 to 25,000 employees in the next 10 years, which will further exacerbate the congestion issue along the I-80 corridor, with approximately 80 percent of TRIC employees commuting from the Reno/Sparks area.<sup>4</sup>

<sup>4</sup> Economic Development Authority of Western Nevada, EDAWN Update presentation, February 12, 2019.

NDOT has several ongoing studies to evaluate alternatives for addressing congestion through the I-80 Truckee River Canyon, including: I-80 Corridor Study, Northern Nevada Traffic Study (both led by research team member CA Group), Inter-County and Regional Transit Plan, and I-80/I-580 System to System Interchange Study. A TRIC employee survey was conducted in 2018, as part of the Inter-County and Regional Transit Plan project. The survey resulted in responses from 1,148 TRIC employees and was available for input from October 24 to November 30, 2018.

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*“Traffic conditions are worsening each year on I-80.”*

*“Your job growth projections at the Tri-Center seem low. Rumor has it that Blockchains alone will hire around 20,000 employees in the next 10 years.”*

*—Comments from the March 2019 User Advisory Group Meeting*

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Figure 2 generally shows where trips to TRIC originate and was created based on the results of the 2018 TRIC employee survey. The survey results show that practically every zip code in the immediate area originates trips to TRIC.

The 2018 survey responses show 80.3 percent of TRIC employees traveling from the west along I-80. Figure 3 shows the mode split specific to those who currently work at TRIC. Based on the survey, 34.3 percent of respondents currently use travel modes other than driving alone. Figure 4 shows that the majority of TRIC employees typically travel less than 45 minutes to work.<sup>5</sup>



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<sup>5</sup> Nevada Department of Transportation, Inter-County and Regional Transit Plan, 2018 TRIC Employee Survey.

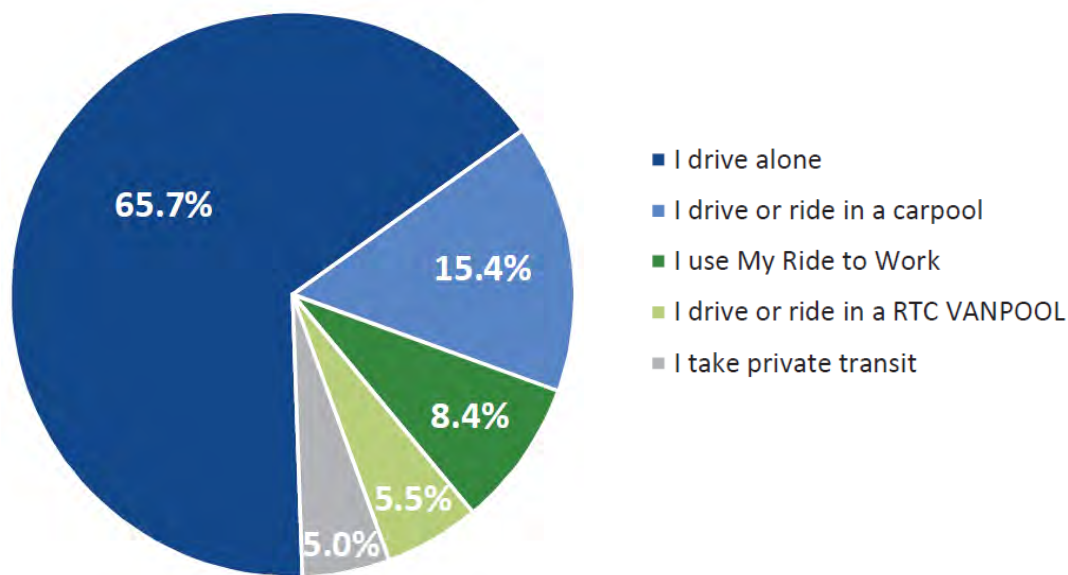
Figure 2. Tahoe Reno Industrial Center Commute Origin



Source: Nevada Department of Transportation, Inter-County and Regional Transit Plan, 2018 TRIC Employee Survey.



**Figure 3. Tahoe Reno Industrial Center Commute Mode**



Source: Nevada Department of Transportation, Inter-County and Regional Transit Plan, 2018 TRIC Employee Survey.

**Figure 4. Tahoe Reno Industrial Center Commute Time**

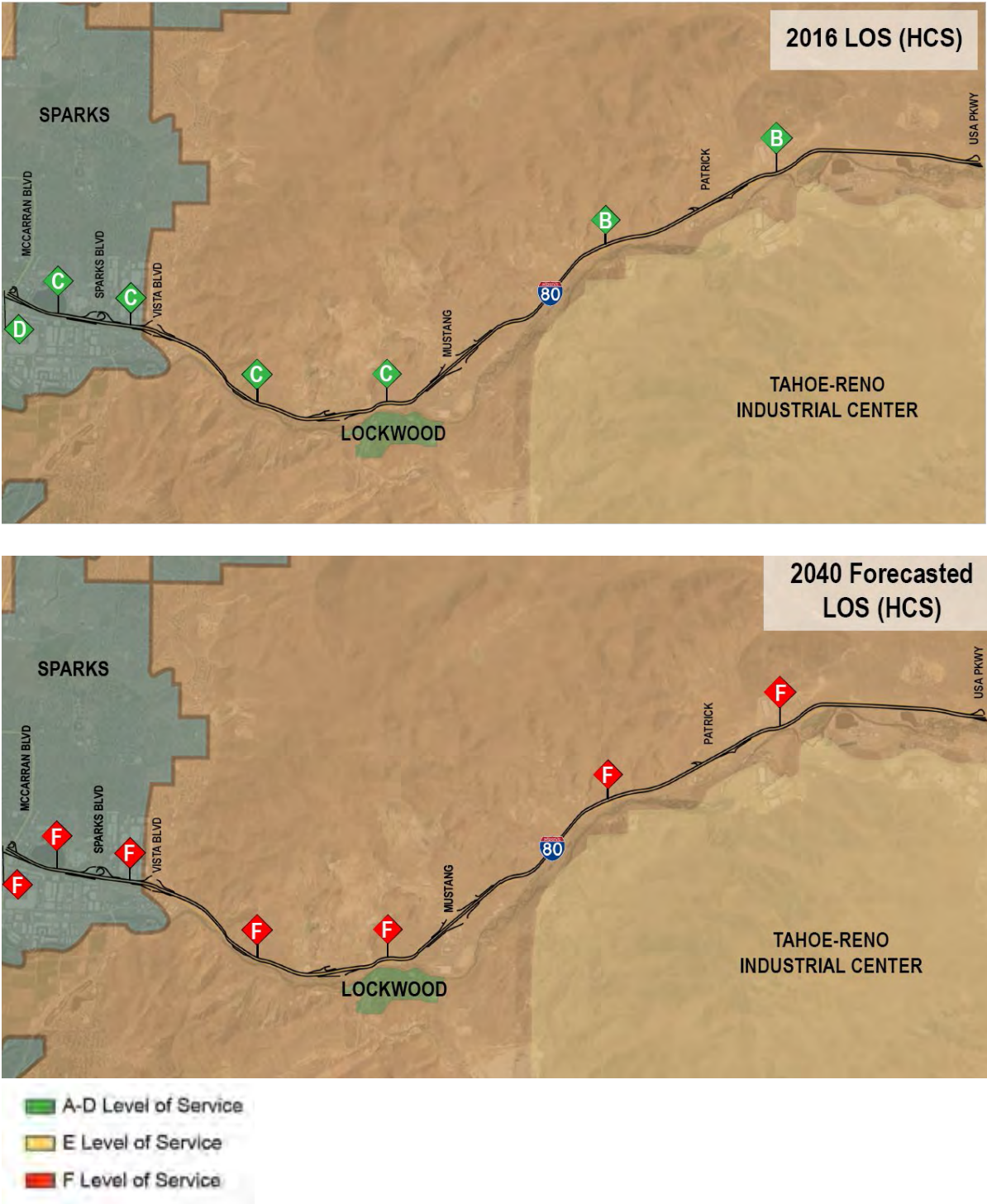


Source: Nevada Department of Transportation, Inter-County and Regional Transit Plan, 2018 TRIC Employee Survey.

The I-80 Corridor Study determined through an employer survey that the majority of materials needed for manufacturing and a significant share of the products produced are trucked along I-80 to destinations east and west—primarily Northern California. The stretch of I-80 from Sparks to Storey County is situated between mountains and the Truckee River. Expanding the I-80 will be both extremely costly and constrained. It is critical to determine whether the I-80 can handle future levels of trucks hauling materials and finished products and passenger cars carrying employees.

2016 traffic volumes and 2040 traffic forecasts along the I-80 corridor are used in Figure 5 to show the anticipated level of service degradation commuters can expect as more businesses are attracted to TRIC. While 2016 traffic conditions appear to be moderately congested, by the time the traffic study was completed, traffic volumes already grew by another 7,000 vehicles per day.

Figure 5. I-80 Traffic Conditions from 2016 to 2040

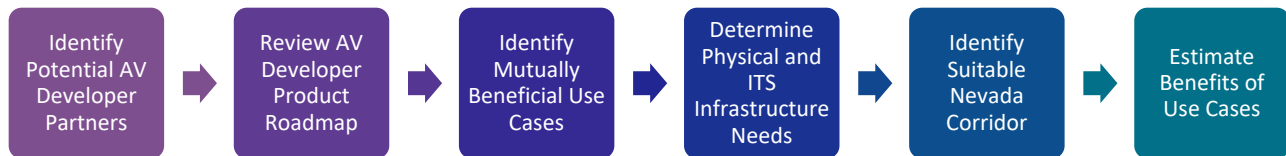


Source: CA Group.

## 3.0 AUTONOMOUS VEHICLE FEASIBILITY STUDY FRAMEWORK

An AV Feasibility Study Framework was developed by the research team that allows NDOT to apply the same decision-making framework not only to this study, but also to any future AV roadway studies. The objective of this framework is to enable NDOT to leverage partnerships with the AV industry to test innovative AV use cases that address existing and future transportation issues. While NDOT would like to focus on the TRIC corridor in northwestern Nevada for this particular research study, AV-only roadways are likely to become more prevalent in the future as AV technology matures. This framework serves to help NDOT identify additional candidate corridors as potential AV-only roadways.

**Figure 6. Autonomous Vehicle Feasibility Study Framework**



The goal of each step outlined in Figure 6 is as follows:

1. **Identify Potential AV Developer Partners**—Identify AV developers with an interest in testing innovative AV use cases in Nevada. As it is envisioned that a Public Private Partnership may provide the necessary funding mechanism for constructing the facility, the first step involves gauging the interest of AV developers to enter into a partnership.
2. **Review AV Developer Product Roadmap**—Determine short- and long-term use cases on each AV developer’s product roadmap. In order to meet their company’s goals, each AV developer maintains a prioritized list of use cases that guides the technological direction of their AV developments. Since constructing a new facility can take years (considered long term in the AV development industry), it is beneficial to understand both their short- and long-term objectives.
3. **Identify Mutually Beneficial Use Cases**—Identify use cases (short- and/or long-term) that are a high priority to both NDOT and AV partners. AV developers are more likely to enter into a partnership with NDOT if NDOT can provide the legislative clearance to either modify traffic regulations on existing facilities (e.g., add an AV-only lane), or provide right-of-way access to construct a brand new facility dedicated to AVs, which could enable AV developers to test high-priority use cases that require special roadway conditions.
4. **Determine Physical and ITS Infrastructure Needs**—Identify operational environment required for high-priority use cases. The first step to determining the feasibility of proposed roadway changes would be to determine physical (e.g., roadway type or geometry) and ITS infrastructure (e.g., vehicular communication technology, traffic management zones) needs for each high-priority use case of interest to both parties.

5. **Identify Suitable Nevada Corridor**—Identify best physical location for AV test facility. Depending on the high-priority use cases of interest, the facility may need to be located in urban or rural conditions, with specific speed limits or traffic conditions. This is an opportunity for NDOT to determine where the AV facility may be located to simultaneously address existing or future transportation issues.
6. **Estimate Benefits of Use Cases**—Build simulation to model anticipated benefits of AV facility. To ensure that both NDOT and AV developers benefit from this partnership, simulating traffic conditions of the proposed AV facility helps to estimate anticipated travel benefits.

## 4.0 APPLICATION OF FRAMEWORK TO THIS STUDY

This section details the work conducted and information collected by the research team for each step of the Autonomous Vehicle Feasibility Study Framework introduced in Section 3.0.

### 4.1 Identify Potential AV Developer Partners

#### User Advisory Group

In order to better understand the user needs of the I-80 corridor users, the research team first assembled a User Advisory Group (UAG) comprised of local stakeholders and Reno/Sparks residential communities. The purpose of the User Advisory Group was to provide a broad range of input and concerns regarding implementation of an AV-only roadway in the study area (e.g., technical, organizational, and/or institutional). The UAG was consulted on the development of operational scenarios and assisted in evaluating real-world user needs for the facility.

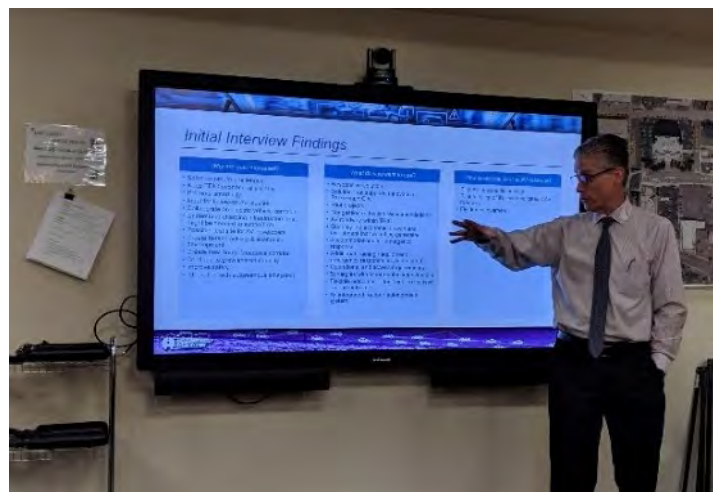
NDOT assisted with inviting the participation of stakeholders (refer to flyer shown in Appendix B) interested in potential partnerships for facility implementation, companies interested in conducting tests on the facility, and commuter groups who would be open to being involved in pilot connected and autonomous vehicle (CAV) tests on the facility. Also, the research team targeted to involve organizations that may see the facility as an opportunity to test new concepts for their businesses. For example, the new facility may provide an optimal test site for autonomous parcel delivery for UPS, which has a distribution facility located at Vista and I-80 right before the Canyon.

By joining the UAG, members were expected to gain a better understanding of how the AV roadway would affect businesses in the area, advance their business' technology goals, attract employees with high-tech perks such as taking an AV shuttle to work, and have a voice in the transportation changes coming to Nevada.

#### March 12 and 18 UAG Meetings

In March 2019 two meetings were held with the User Advisory Group—one in Reno and a follow-up webinar—to introduce the research to the participants and gather feedback from them regarding the user needs for an AV-only roadway.

These meetings were well attended by representatives from a good mix of public agencies and private industry, including:



- March 12, 2019 Meeting in Reno—Blockchains, Department of Motor Vehicles, FedEx, Federal Highway Administration—Nevada Division, Nevada Department of Transportation, Nevada Center for Applied Research—University of Nevada, Reno, Nevada Highway Patrol, Nevada Institute for Autonomous Systems, Nevada State Office of Energy, NV Energy, Reno Land, Inc., Story County, and Tesla.
- March 18, 2019 Webinar—Department of Motor Vehicles, Governor’s Office of Economic Development (GOED), Keolis, Lyon County, Nevada Department of Transportation, NV Energy, Reno Land, Inc, Regional Transportation Commission of Washoe County, and Tesla.

Three sets of questions, listed below, were used to collect input from the UAG attendees.

1. How would you use and benefit from the AV roadway?
  - a. How would an AV roadway benefit your agency, business, or employees?
  - b. How would an AV roadway support your business/organization goals (e.g., reduce commute time, attract talent, support innovation, etc.)?
  - c. How would your organization utilize an AV roadway along this study area?
    - i. Personal AV commuting?
    - ii. Employee AV shuttle bus?
    - iii. AV parcel delivery truck?
    - iv. Other uses?
2. What might be the level of use of the AV Roadway?
  - a. The year is 2025 and AV’s are now commonplace on Nevada roads. In this new environment, please make a “*guesstimate*” on what level of usage might your base of employees be expected to use the AV roadway (either in a personal AV or an employee shuttle bus AV)?
    - i. Small (<10 percent of employees).
    - ii. Medium (between 10 percent and 30 percent of employees).
    - iii. Large (over 30 percent of employees).
3. How would an AV roadway be implemented?
  - a. How could your organization assist in the development of an AV roadway (e.g., infrastructure, policy, ridership, technology, etc.)?
  - b. Who else would be an important partner or stakeholder to include?
  - c. Are there any policy constraints to consider?

Some key takeaways from the meetings are listed below and in Figure 7. The complete summary is included in Appendix C.

- Anticipates that an estimated 50–80 percent of TRIC employees would use this new AV-only roadway.
- Recommends that this roadway can be used in the short-term for non-AV commuter buses until AV technology matures. Mini-bus AVs may have more benefits (e.g., increased person throughput) compared to personal AVs. However, this solution would require the need to consider road damage from AV buses.
- Due to the highly directional congestion flows (eastbound in the AM; westbound in the PM), the UAG recommends lane management functions (e.g., reversible lanes).
- Hesitation to design an AV-only roadway for a single purpose (i.e., passenger AVs) if the roadway construction and maintenance becomes a significant investment.
- Suggests considering converting existing roadways in lieu of building a new AV roadway. There are some companies that have technology that can be implemented into existing roadways. That could help bridge the technology.

**Figure 7. Key User Advisory Group Feedback Collected**

<i>Why are you interested?</i>	<i>What do you want to see?</i>	<i>How would you use the AV roadway?</i>
<ul style="list-style-type: none"> <li>• Solve commute challenges.</li> <li>• Keep TRIC economically viable</li> <li>• Promote smart city.</li> <li>• Input for follow-on AV studies</li> <li>• Collaborate on electric vehicle corridors.</li> <li>• Understand charging infrastructure that might be needed to support AV.</li> <li>• Possible test site for AV developers.</li> <li>• Create hi-tech activity and economic development.</li> <li>• Create new South Meadows corridor.</li> <li>• Continue to grow shared mobility.</li> <li>• Improve safety.</li> <li>• Integration with autonomous air system.</li> <li>• Opportunities for workforce development (e.g., help define technology and maintenance requirements).</li> </ul>	<ul style="list-style-type: none"> <li>• Responsive solution.</li> <li>• Solution that supports Innovation Park/Smart City.</li> <li>• Pilot projects.</li> <li>• Congestion reduction recommendations.</li> <li>• AV roadway within TRIC.</li> <li>• Quantify the economic growth and investment that would be generated.</li> <li>• Accommodations for emergency response.</li> <li>• Additional training/equipment emergency response providers need.</li> <li>• Operational and access requirements.</li> <li>• Synergies with other related infrastructure.</li> <li>• Flexible outcomes—don't get too focused on one outcome.</li> <li>• An integrated road-air autonomous system.</li> <li>• Leveraging existing communications investments by Switch.</li> <li>• AV roadway design that accommodates emergency vehicles, snow plows, etc.</li> </ul>	<ul style="list-style-type: none"> <li>• Pilot AV bus/shuttle service.</li> <li>• Pilot test first of it's kind dedicated CAV roadway.</li> <li>• Test drone travel (parcel and passenger).</li> <li>• Test decreased stopping site distance requirements.</li> <li>• Tesla vehicle commuting.</li> <li>• Parcel deliveries.</li> <li>• Effectiveness of camera-based sensors and LiDAR in inclement weather conditions.</li> <li>• Test limited access enforcement technology if roadway is limited to certain Society of Automotive Engineers (SAE) levels of automation.</li> </ul>

### Connected and Autonomous Vehicle Industry Interviews

Based on feedback heard from the UAG, the research team developed the following in-depth interview guide for AV developers. The purpose of the one-on-one interviews with leaders in the CAV industry was to satisfy Step 1 of the AV Feasibility Study Framework—Identify Potential AV Developer Partners. Additional questions were added to gauge the maturity of each company's AV technology and collect information to be incorporated into the simulation model to be developed.



- If NDOT were to build a separate CAV only roadway, which use cases would you be most interested in testing on this facility?
- What is the accuracy of AV lane keeping algorithms (for potential lane width reduction and shoulder removal/reduction)?
- Do your AVs support vehicle-to-vehicle and vehicle-to-infrastructure communications? If so, within what distance would the V2V communication effectively operate?
- If you AV's do not currently support vehicle-to-vehicle and vehicle-to-infrastructure communications, would you be interesting the future in exploring with the State of Nevada the testing of this technology on a Nevada dedicated CAV roadway/testbed?
- If your AVs support V2I communications, would there be any cases in which the AV would still rely on roadway signage to make decisions, assuming information from traditional roadway signs would now be replaced by "messages" from the roadside equipment installed on CAV roadway?
- Does the driving behavior logic and its parameters change under different regimes (e.g., free flow speed, car following, approaching, etc.)? How are these regimes defined and how do parameters change within each regime?
- What are the typical and maximum acceleration/deceleration rates in AV mode?
- Have you tested your vehicles in a "platooning" mode with vehicle-to-vehicle communication? If so, in a platooning mode, how close can the vehicles be safely spaces in both dry and wet conditions?
- Are manual controls allowed? If so, what are the thresholds/criteria that manual takeover is required and/or allowed?
- Does the AV driving logic encourage cooperative behavior at on-ramps?

One-on-one interviews were conducted with the following six CAV technology providers, or those familiar with the industry, to identify and discuss feasible use cases for a dedicated AV roadway. Summary of interview discussions are included in Section 4.2. The complete set of interview notes is included in Appendix C.

- **Abe Ghabra**, Managing Director of the Las Vegas Customer Technology Center at Aptiv.
- **Pack Janes**, Business Development and Strategy at EdgeConneX and **Miguel Payan**, Mobility Advisory at EdgeConneX.
- **Chris Barker**, Mobility Vice President at Keolis.

- **Steve Davis**, Project Leader and Jane Labanowski, Government Relations and Permitting at Boring Company.
- **Robert James**, Vice President of Technology and Innovation at HNTB.
- **Jim Misener**, Senior Director of Product Management at Qualcomm.

**Table 2. Companies Involved in the Connected and Autonomous Vehicle Industry Interviews**

Company	Company Description	CAV Focus
Aptiv	Aptiv PLC, formerly Delphi Automotive PLC, is a global technology company that retrofits vehicles with autonomous vehicle technology by integrating whole systems through Smart Vehicle Architecture focusing on four key areas: software, sensing and compute platforms, data and power distribution, and connected and mobility services.	Retrofitting vehicles with AV technology.
EdgeConneX	As the pioneer in defining and building the Edge, EdgeConneX has built and delivered a full spectrum of data center solutions, from Hyperscale facilities to Edge Data Centers®, Edge Small Cells and Edge PoPs® at the most critical locations—as close as possible to the end user’s point of access, from local metro services to global Cloud, Content, and Network providers.	Data center developer and manager to support edge processing capabilities.
Keolis	Keolis is a leading provider of passenger transportation services and operations, serving 2.5 billion passengers worldwide via train, bus and taxi each year through public contracts.	Low-speed transit operations.
Boring Company	The Boring Company aims to revolutionize the way that American travel through the construction of underground tunnels for high-speed autonomous vehicles that can eventually be converted to support Hyperloop technology.	Underground Loop tunnels for CAVs.
HNTB	HNTB is an infrastructure solutions consulting company, providing thought leadership in the application of technologies to Smart Cities, Connected Vehicles, Automated Vehicles, Electric Vehicles and advanced Communications Technologies.	Dedicated lanes, shuttles/ circulators.
Qualcomm	Qualcomm is a pioneer in the design of the global Cellular Vehicle-to-Everything (C-V2X) ecosystem. Qualcomm executes C-V2X deployment strategies across all global regions and works with roadside and automotive stakeholders and enabling software/ hardware stack suppliers and internal teams to accomplish broad C-V2X deployment.	Developing and executing C-V2X deployment strategy.

## 4.2 Review AV Developer Product Roadmap

### Aptiv

Aptiv vehicles currently are operating in Las Vegas, Boston, Pittsburg, Singapore, and Shanghai, with no operations in northern Nevada to date. Aptiv AVs currently consist of a fleet of retrofitted BMW 5 series vehicles which have driven over one-million AV miles without incident. Currently, all Aptiv AVs are equipped with DSRC modules and are capable of vehicle-to-everything (V2X) communications (e.g, communications with traffic lights). Aptiv uses V2I communications as a redundant information source to cameras. This is particularly useful for situations where the camera does not interpret situations with 100 percent confidence. For example, in sunny Las Vegas, cameras may have a difficult time detecting the difference between green, yellow and red traffic light colors.

Aptiv uses their cars to map the roadways using perception systems and sensors to get a high-definition view of road signage and lane markings. Aptiv augments the maps with the rules of the road. The rules break when there is roadway construction, which caused them to begin using artificial intelligence. Now their AV system uses a combination of rules-based planning and machine learning to navigate the roads. In the near future, Aptiv plans on transitioning to a new AV platform.

Aptiv anticipates that there will not be a high penetration rates of AVs on public roads until the 2050s or 2060s, so CAV-only roadway use cases are not their main focus right now. In addition, a dedicated Point A to Point B roadway or lane would be less useful to Aptiv since it is more limiting in the number of test cases they can use the facility for. Right now, their high-priority use cases (listed in Table 3), all involve interfacing with non-CAVs. Topping the list is testing how AVs communicate their intentions to other roadway users, such as other drivers, pedestrians, or bicyclists. (External Human Machine Interface). Aptiv *is* particularly interested in the development of a closed course test track to test their use cases. Ideally, the test track would include county-approved traffic lights. In Las Vegas, Aptiv has a test track that includes traffic circles, winding roads, freeways, on-/offramps, and all other situations the AV would encounter on public roads. Las Vegas also has over 100 intersections that are DSRC equipped, which Aptiv uses as part of their testing. Today, Aptiv conducts their testing through simulation first before moving forward with real-world testing. Any time the driver does not feel like the vehicle can handle a situation safely, they will disengage the AV system and manually control the vehicle. Then Aptiv will simulate the same situation to see what the AV would have done had the system not been disengaged. If there is a serious hardware failure in the compute platform, one or more sensors will issue audible commands for the driver to take over. Once their unbranded vehicles pass all tests, then they will add their Aptiv logo on it. Aptiv anticipates that once drivers are no longer required, there will be a NASA-like mission control center that will constantly monitor the status of the entire AV fleet.

**Table 3. Aptiv High-Priority Use Cases**

Use Case	Description
External Human Machine Interface	How AVs communicate their intentions to other roadway users. Testing AV road interactions with other road users, including pedestrians, drivers, and bicyclists.
Airport Pick Up/Drop Off	Testing AV-specific airport pick up/drop off (e.g., dedicated pickup spot, less busy roadway, constrained pickup time).
Curb Pick Up/Drop Off	Pilot AV-specific dedicated curbside pick up/drop off using AV-hailing kiosk, allowing AVs to use bus stops outside of bus arrival times.
Construction Materials	Training AVs to recognize construction marking materials and then infer the intent (lane diversion, keep-out areas, or yield instructions).
Post-takeover Resimulation	Use of simulation to determine what would have happened after a human safety driver takes over from the AV if the safety driver had not taken over.
Emergency Vehicles: Detection, Behavior, Access	Training AVs to distinguish emergency vehicles from other traffic in various situations and respond in the preferred, programmed maneuver(s).
Quantification of Risk Level in Operational Design Domain Elements	Help cities/DOTs determine which operational design elements (e.g., signage, obstacles, etc.) should be avoided in future infrastructure planning to in order to support AVs.
Simulation Capabilities	Development of innovative methods to enhance simulation engine capabilities for safety testing and validation.
Validation of Simulation Engines	Research involving the design and conduct of tests on a closed course to evaluate how well autonomous vehicle simulation engines model the behavior of these vehicles in the real world.
Subsystem Safety Requirements	Develop methods and models to decompose an overall system safety goal into subsystem safety requirements for some sample AV architectures.

## EdgeConneX

EdgeConneX is a private data center developer and manager. They build warehouse data centers which they lease to other companies for content hosting. They have built 36 data centers over the past 8–10 years, mostly focused on edge processing. Currently EdgeConneX is working on a connectivity proof of concept, where the data CAVs transmit to roadside units (RSU) can be wirelessly transferred to a remote data center.

Edge computing is necessary in a CAV environment because it helps reduce the cost involved with transferring CAV data to the warehouse. With edge computing, data will be processed at the edge before it is sent somewhere else for storage. The step where the AV uploads the data to the edge computing node for it to be organized and synthesized takes a lot of work. Today, getting data off of the vehicle is a challenge in terms of volume and latency, as well as determining what data/information needs to be retained in the cloud and what data is considered distracting. In addition, RSUs on the market today are not smart enough to handle computing within the RSU themselves. It is necessary to have a server near the RSU (minimum distance to be determined based on latency, bandwidth, cost) that will serve as the 5G edge computing box. While edge computing is not dependent upon 5G deployment, the infrastructure

may help to move the data to the cloud. These boxes will mostly likely be agnostic to the various vehicular communications options (DSRC, 5G, etc.).

EdgeConneX believes that the first AV-only roadway may be another 10 years out in the future and that operators of such a roadway may find long-haul trucking an easier use case than passenger AVs. For an AV-only roadway facility, EdgeConneX is particularly interested in testing use cases that use edge computing for cost-effective data transmission (flow and volume) from the vehicle to the cloud, as well as how well systems from different AV manufacturers/developers communicate with each other. Currently, AV manufacturers such as Tesla and GM have each been developing their own virtual driving system. To date, there have been little to no testing done to determine whether standardization of the virtual driving system is necessary. Regulators have not set any standards for how that may happen because they do not want to squash innovation, but at the same time, AV developers are looking for direction from regulators.

## Keolis

Keolis is one of the largest operators of metro service in the world. Keolis services include day-to-day maintenance of shuttles used in their operations, planning for ideal routes, infrastructure planning, DSRC signal planning, and wireless communications. They work with a number of shuttle manufacturers to outfit their fleets. They have spent the last two years launching autonomous shuttle service and on-demand microtransit options (i.e., 15–20 passenger vans that are ADA accessible) in new areas such as Orange County, California and has upwards of 35,000 riders. Keolis services can be utilized as last-mile connector services. While Keolis microtransit vehicles currently are not autonomous, Keolis has plans to automate the vehicles in the future, potentially partnering with Navya, a manufacturer of Keolis' autonomous shuttles. Keolis already is operating Proterra buses in Orange County and will be operating their buses in Reno in 2019. Proterra is one of several companies looking to convert their buses into autonomous vehicles, which may support 45 miles per hour (mph) and higher speeds.

In terms of high-priority use cases, Keolis' focus is on low-speed environments (25 mph or less) for transit operations particularly in intercity environments. While high speed use cases are not a high priority for Keolis right now, they are interested in introducing fixed route or on-demand transit options in the Reno/Sparks-TRIC area. By understanding ridership demands for regular non-AV transit service, Keolis can use that information to determine which transit service makes the most sense (e.g., Express buses). Express buses may eventually evolve into autonomous buses. As one of the largest operators of metro service all over the world, Keolis believes that autonomous trains are the ideal mechanism for transporting large volumes of people quickly. While that may be ideal for part of a TRIC employee's commute, realistically, 3–4 modes of transit would be needed for an end-to-end solution (e.g., last-mile challenges).

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*“We spend a lot of time making sure we do not go too far too fast.”*

– Chris Barker,  
Keolis Mobility Vice President

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## Boring Company

The Boring Company recently completed a 1.15-mile Loop tunnel in Hawthorne in Los Angeles County and currently are working on a few other projects in Las Vegas, Chicago, and Washington, DC. The Hawthorne tunnel cost around \$10 million to construct, which included the tunnel, lighting, connectivity, safety systems, and ventilation system. However, the Boring Company anticipates that in another year,

the costs will drop to \$2–3 million per lane mile. Cost savings for Loop tunnels are achieved by keeping the same design standards for every tunnel—12 feet in diameter for each tunnel, which includes one lane. Lanes can be designed to be reversible, or if multiple lanes are desired, then multiple tunnels need to be built.

The tunnel currently supports two types of vehicles: 1) compatible transit vehicles (e.g., 16-seater Tesla Model S's); or 2) compatible electric vehicles (e.g., Tesla models). All compatible vehicles require some sort of autopilot. Loop tunnels can be used as an underground highway or transit option. In the near future, the Boring Company anticipates increasing the speed limit of Loop tunnels to 125 mph.

V2X communications currently is supported in Loop tunnels. All of the vehicles that use the tunnel talk to each other and every other vehicle in the tunnel. The Boring Company believes that connectivity in the tunnel is actually better than out of the tunnel since tunnels serve as a waveguide. The 1.15-mile tunnel in Hawthorne experiences perfect connectivity using one off-the-shelf LTE system that places one antenna at one side of the tunnel, 50 feet outside of the entrance.

The Boring Company is extremely interested building a Loop tunnel beneath I-80 out to the Tesla Gigafactory, but would need NDOT's support. The Boring Company is willing to fund the environmental impact assessment in order to speed up the approval process and is interested in a much faster timeline (i.e., one year). Every tunnel is designed to be converted into a Hyperloop, once the Hyperloop concept receives regulatory approval. This can be achieved by reversing the ventilation system into a vacuum system.

## HNTB

HNTB is a consulting firm with experience in dedicated lanes and shuttles/circulators. HNTB was interviewed not for their potential as a AV developer partner, but rather their experience in designing AV-only roadways. HNTB currently is involved in a bus project for the Port Authority of New York and New Jersey (PANYNJ) through the Lincoln Tunnel that will involve dedicated bus lanes for approximately 3,600 connected buses at any given time. Autonomous features will be incorporated over time. Other HNTB projects involving automated systems include replacing people movers with automated systems in several airports; automated rail on the Dumbarton Bridge in the Bay Area, California; and retrofitting bus rapid transit vehicles to stay in lanes automatically. The key takeaways from the interview with HNTB are summarized in Section 4.4—Determine Physical and ITS Infrastructure Needs.

## Qualcomm

Qualcomm is a leader in automotive and transportation standards, as well as development and execution of strategies to establish cellular V2X ecosystems and foster global deployment. This ecosystem shift includes adaptation of ITS standards and application protocols, compliance and certification, trade association strategy and industry/Government acceptance.

In the industry right now, AV sensors are so cost prohibitive that it only makes sense to install them on trucks and high-value vehicles. This is an important factor for NDOT to consider if their goal is to increase demand on the AV-only roadway the near future. In addition, Qualcomm anticipates that it will take another 4–5 years for the AV industry to release a Level 4 AV.

The two high-priority use cases that Qualcomm is interested in using an AV-only roadway for is: 1) 5G New Radio (NR) C-V2X Sidelink Deployment; and 2) Mobile Edge Computing (MEC)/Multi-access Edge Computing Deployment. Sidelink is a 5G-based direct V2X communication that requires a 5G compatible chipset installed in the vehicle. At the end of this year/early 2020, 3GPP, the global standards organization for 5G, will complete the next phase of the global 5G NR standard, Rel-16, to include the first specification for 5G NR C-V2X. 5G NR C-V2X has several fundamental enhancements at the radio level that are unique to the technology. Rel-16 will be the first 5G standard to include sidelink. Sidelink is anticipated to provide lower latency and higher reliability for CAVs, in addition to achieving a communication range much higher than the current 300–400 meter limitation. Since it will only be effective in an environment of 100 percent connected vehicles, an AV-only roadway where all vehicles support vehicular communications, would be an idea test bed.

Network operators (T-Mobile, AT&T, etc.) say that latency issues are caused by the round trip needed to send CAV data to the cloud. To remedy this, more of the intelligence needs to be located at the edge which is the purpose of the second high-priority use case—Mobile Edge Computing/Multi-access Edge Computing Deployment (same use case proposed by EdgeConneX). Even an edge computing box placed 30–50 miles away from the RSUs would help to reduce latency dramatically. For the Reno/Sparks-TRIC corridor, one MEC located at TRIC should be enough to cover 20 miles of RSUs. While companies such as Qualcomm or EdgeConneX would set up the infrastructure needed, the business model would require agencies such as NDOT to pay for every transaction in order to use operator spectrum.

### 4.3 Identify Mutually Beneficial Use Cases

Use cases or test cases are specific situations in which a product or service could potentially be used. Some examples of potential use cases for a dedicated AV roadway include:

- **Cost effectiveness of an AV-only facility**—To date, no dedicated AV lanes or roadways exist in the U.S. This would be a good opportunity to evaluate the cost of constructing such a roadway, taking into consideration all of the ITS elements needed to support both connected and autonomous vehicles, as well as cost savings that can be achieved by removing any traditional roadway elements or design standards that become obsolete with exclusive access by AVs.
- **Emergency vehicles: detection, behavior, access**—Avs do not have very much experience interacting with emergency vehicles, whether it is detecting the presence of an emergency vehicle or understanding the necessary driving behavior in each unique emergency situation. Currently, Avs must be disengaged and the driver will take over when an emergency vehicle crosses paths with an AV. In these situations where safety is most critical, having a dedicated facility to test these types of interactions may be beneficial.
- **Validation of simulation engines**—Many AV developers test AV driving behavior for various real-world use cases through virtual simulation engines. Only after the AV driving behavior is thoroughly vetted through the use of virtual simulation engines, will the vehicles be driven on public roads. A dedicated AV facility may be useful to validate how often the simulated AV actions match reality.
- **Platooning of trucks or passenger vehicles**—Platooning is a use case that is anticipated to have significant benefits in terms of fuel usage and labor costs for industries that would no longer need to hire drivers. Various platooning operations such as joining a platoon, changing lead drivers, or

disengaging from a platoon, may benefit from having access to a dedicated AV roadway to safely conduct tests on.

- **Automated facility access**—By creating AV-only lanes or entire facilities, this introduces a need to install an access authorization mechanism that can detect whether the vehicle entering the facility meets the AV requirements. Most likely this will involve vehicular communications, and perhaps a physical barrier. Automated access would need to be tested to ensure compliance across all AV manufactures.
- **Reduced headways**—One of the stated benefits of AVs is the ability to increase vehicular throughput by reducing the headways between each AV. Without a dedicated AV facility, this use case is very difficult to test in a mixed-use environment, where AVs are forced to behave more conservatively to account for unpredictable human driving behaviors.
- **Effectiveness of e-signage**—Traditional physical roadway signs will become obsolete in a fully autonomous environment. However, the design standards for e-signage have yet to be determined. The effectiveness of various e-signage designs can be tested on dedicated AV facilities.

Figure 8 summarizes the high-priority use cases identified through the one-on-one CAV industry interviews. The initial screening criteria for determining the feasibility of a dedicated AV-only roadway, as noted in the scope of work for this project, was to “validate real-world user needs.” Extensive outreach to potential users revealed a strong preference to test autonomous vehicles on roads shared with non-autonomous vehicles—a more practical and immediate application of technology. NDOT will continue to promote advanced transportation technology solutions, and armed with findings from this research, has a better understanding of how to do so.

**Figure 8. Connected Autonomous Vehicle Industry High-Priority Use Cases**

Aptiv	EdgeConneX	Keolis	Boring	Qualcomm
<ul style="list-style-type: none"> <li>• Closed course test track.</li> <li>• Interactions with emergency responders.</li> <li>• External human machine interface.</li> </ul>	<ul style="list-style-type: none"> <li>• Edge processing and CAV data transmission to the cloud.</li> <li>• Virtual driving system interoperability</li> </ul>	<ul style="list-style-type: none"> <li>• On-demand, low speed autonomous transit service.</li> <li>• Autonomous trains.</li> </ul>	<ul style="list-style-type: none"> <li>• Loop tunnel.</li> </ul>	<ul style="list-style-type: none"> <li>• 5G NR C-V2X Sidelink deployment.</li> <li>• Mobile Edge Computing (MEC) deployment.</li> </ul>

#### 4.4 Determine Physical and ITS Infrastructure Needs

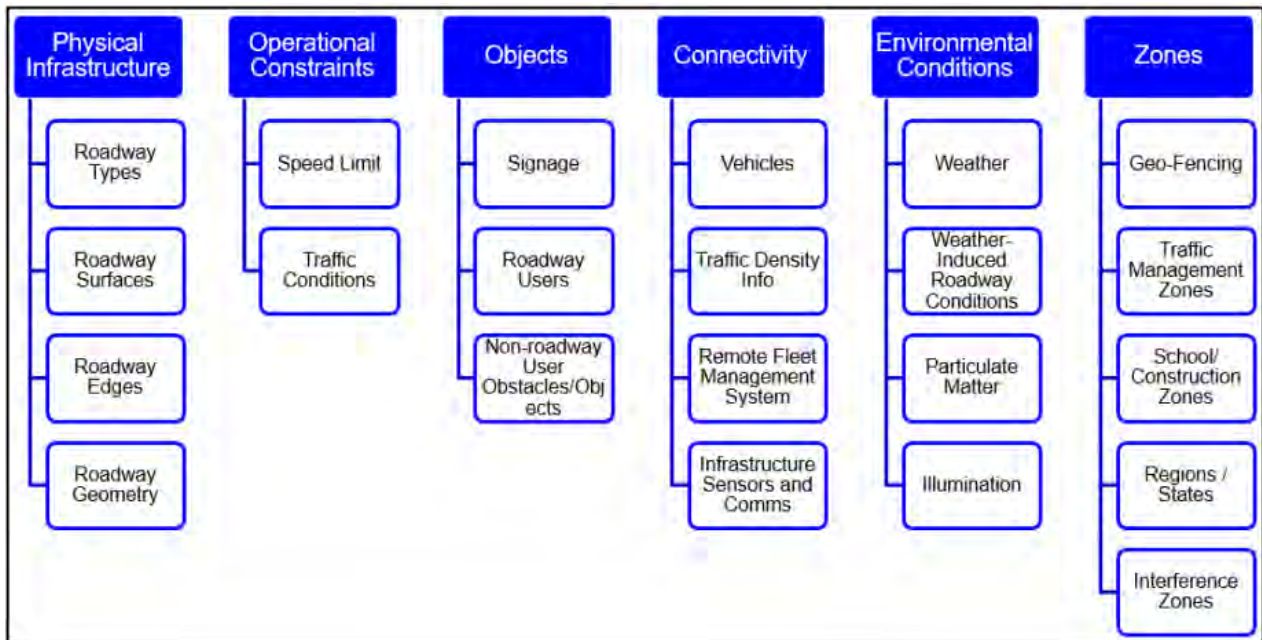
While the Autonomous Vehicle Feasibility Study came to a successful and early conclusion based on feedback from the CAV industry, the research team has documented in the following sections the research that was conducted in parallel, for the benefit of future research studies.



The first step to determining the feasibility of proposed roadway changes would be to determine physical (e.g., roadway type or geometry) and ITS infrastructure (e.g., vehicular communication technology, traffic management zones) needs for each high-priority use case of interest to both parties.

National Highway Traffic Safety Administration's (NHTSA) *A Framework for Automated Driving System Testable Cases and Scenarios* report, as part of the preliminary test framework for automated driving systems (ADS), summarizes the attributes that define the operational design domain (ODD).<sup>6</sup> The ODD describes the specific operating domains in which the ADS is designed to function. The ODD taxonomy defined for this report (refer to Figure 9) is a useful starting point for determining physical and ITS infrastructure needs because it outlines the various conditions in which Avs should be able to function, with respect to roadway types, speed range, lighting conditions, weather conditions, and other operational constraints.

**Figure 9. Operational Design Domain Taxonomy**



Source: National Highway Traffic Safety Administration, *A Framework for Automated Driving System Testable Cases and Scenarios*, DOT HS 812 623, September 2018.

If CAV developers were interested in testing Avs among conditions where loss of signal is frequent, the roadway types that they would want to target may include rural and/or urban canyons. Testing AV adherence to various roadway alignments may require targeting mountainous terrain with different roadway curvatures and grade levels. If CAV developers wanted to test the effectiveness of V2V or V2I communications, they may want an environment that is equipped with both DSRC and 5G vehicular communications technology for comparison purposes.

<sup>6</sup> National Highway Traffic Safety Administration, *A Framework for Automated Driving System Testable Cases and Scenarios*, DOT HS 812 623, September 2018.

## Autonomous Vehicle Roadway Design

With NDOT’s goal in mind to design a low-cost AV-only facility, CA Group compiled a list of roadway design criteria and realistic design adjustments accommodatable by an AV-only roadway.

**Table 4. Roadway Design Criteria—Traditional versus Autonomous Vehicle-Only**

Design Element	Minimum Criteria	CAV Criteria	Comment
Design Vehicle	Passenger car	Passenger car	The assumed vehicle for Autonomous Vehicles (AV) is a Level 4 or Level 5 passenger car. No assumptions are made for trucks.
Design Speed	American Association of State Highway and Transportation Officials (AASHTO)	65–70 mph	An AV-only roadway can support at the minimum, the same design speed as I-80, which is 65 mph through the narrows due to constraints and 70 mph along the rest of the segments.
Posted Speed	AASHTO	65–70 mph	Could change based on GPS and Vehicle operational design domain (ODD) and separate lane assignment.
Sight Distance	AASHTO	<ul style="list-style-type: none"> <li>• Reduce or eliminate reaction distance.</li> <li>• Adopt braking distance only (deceleration rate of 11.2 ft/sec)</li> </ul>	<ol style="list-style-type: none"> <li>1. <b>Stopping sight distance.</b> Could be reduced with aid of radar/LIDAR. Driver eye height would not apply. The two phases of stopping could be reduced (i.e., AASHTO allow 1.5 seconds for perception time and 1.0 second for reaction time).</li> <li>2. <b>Decision sight distance.</b> Intersection sight distance could be reduced with automated vehicle simulation.</li> <li>3. <b>Intersection sight distance.</b> AASHTO for inclusion of pedestrian interaction.</li> <li>4. <b>Passing sight distance.</b> Could be reduced with aid of GPS and Vehicle ODD (operational design domain) and automated vehicle simulation.</li> <li>5. <b>Object and Event Detection and Response (OEDR).</b> Capabilities are expected to be able to detect and respond to other vehicles (in and out of its travel path), pedestrians, bicyclist, and animals, and objects that could affect safe operation of the vehicle.</li> </ol>

Design Element	Minimum Criteria	CAV Criteria	Comment
Pavement Depth	11-inch concrete paving; 2 inch asphaltic cement; 12-inch base	0-inch concrete paving; 8-inch asphaltic cement; 16-inch base	By prohibiting access to heavy-duty vehicles, cost savings can be achieved by eliminating the need for a concrete paving layer and instead increasing the depth of both the asphaltic cement and base layers. Depending on final projected traffic volumes on the AV roadway, these thicknesses could be reduced.
Lane Width	12-foot	10-foot	10-foot lane would accommodate physical vehicle width. Could be reduced with aid of GPS and Vehicle ODD and separate lane assignment.
Shoulders Width	4-foot inside; 8-foot outside	2-foot both sides	2-foot min shoulder protects the integrity of the roadway structural section. Consider larger shoulders for number of lanes and emergency access.
Clear Zone Width	2006 Roadside Design Guide	None	Definition of clear zone would be revised based on FOV (Field of View). Physical design constraints would be based on front and side sensor coverage.
Side Slopes	2006 Roadside Design Guide 6:1 BS/FS or flatter	2:1 BS/FS	Based on geotechnical engineering. Slopes would not be a function of safety with elimination of human error and run off the road issues.
Minimum Radius	AASHTO	AASHTO	No change, based on super elevation rate (side friction factor) Turning templates would not change based on current vehicle type and turning characteristics.
Super Elevation	AASHTO	AASHTO	No change, based on side friction factor and current vehicle characteristics.
Vertical Alignment	AASHTO	AASHTO	Crest could potentially change with aid of radar/LIDAR Sag could potentially change with aid of radar/LIDAR (eliminates headlight sight distance).
Grades	AASHTO	AASHTO	No change, based on current vehicle power to weight ratio. Note. Steep ramps or undercrossing may be erroneously interpreted as an obstacle, while the second vehicle is not covered by the FOV sensor.
Gap Acceptance Length	AASHTO	AASHTO	Could potentially change with aid of GPS, Vehicle ODD, and automated vehicle simulation (change in headway distance).

Design Element	Minimum Criteria	CAV Criteria	Comment
Acceleration length	AASHTO	AASHTO	No change, based on current vehicle power to weight ratio
Acceleration Lanes: 1. Taper-type Lane Merge 2. Parallel-type Lane Merge	AASHTO	AASHTO	1. Could potentially change with aid of GPS and Vehicle ODD (operational design domain). 2. Same as above.
Deceleration Lanes 1. Deceleration Length 2. Auxiliary Lane Length	AASHTO	AASHTO	1. No change, based on driver comfort. 2. Could potentially change with aid of GPS and Vehicle ODD (operational design domain).
Divergence Angle from Mainline to Ramp	AASHTO	AASHTO	No change, based on driver comfort.
Horizontal Clearance	AASHTO	AASHTO	No change to railroad pier protection or parallel railroad.
Vertical Clearance	Based on vehicle height	AASHTO	Deviation from AASHTO based on vehicle type and lane dedication.
Taper Rate	AASHTO	AASHTO	No change, based on driver comfort
Roundabouts	AASHTO	AASHTO	Potential change with aid of GPS and Vehicle ODD (operational design domain).
Miscellaneous			1. Striping could be eliminated. 2. Signing could be eliminated. 3. Median islands could be eliminated. 4. Rumble strips could be eliminated. 5. Edge protection (i.e., Barrier rail) could be eliminated unless deemed necessary for inclement conditions. 6. Lighting and IT could be eliminated.
Temporary Traffic Control			Would need to meet the standards of design criteria.

Source: CA Group.

The following design elements would not deviate from AASHTO standards:

- Minimum radius.
- Super elevation.
- Vertical alignment (Sag K-Values may be adjusted).
- Gap acceptance length.
- Acceleration length.\*
- Acceleration lanes (taper-type lane merge, parallel-type lane merge).\*
- Deceleration lanes (deceleration length, auxiliary lane length).\*
- Divergence angle from mainline to ramp.
- Horizontal clearance.
- Taper rate.

\* These items may be adjusted for a pilot facility if no trucks are allowed.

## Additional ITS Infrastructure Elements to Consider

### *ITS/Electrical*

It is likely that connected vehicle and autonomous vehicle technology will go hand-in-hand in the development of AV-only roadways (for more background on CV and AV technology, refer to Appendix A). If this is the case, consideration for data access and data storage facilities will be required in the roadways of the future. These ITS components will require access to a power source, most likely solar or electrical.

### *Maintenance*

While some maintenance costs are anticipated to decrease due to the reduction of human errors (which would potentially translate into a reduction of vehicular crashes), other maintenance costs will increase in order to accommodate AV-specific needs. For example, the anticipated extended duration of AV and operator driven vehicles would decrease maintenance costs, but in areas where snow builds up on roads, AV-only roadway lane widths would need to be wide enough to accommodate snowplows, potentially increasing the cost of initial roadway construction from minimum AV-only roadway standards. In addition, since lane markings are particularly critical for AVs to function, more frequent restriping or roadway cleaning may be required to maintain visible lane markings.

### *Roadway Access*

The benefits anticipated for an AV-only roadway can be achieved only if non-AVs and Level 1–3 AVs do not access the facility. An enforcement mechanism would need to be installed at entry points to ensure compliance.



## Feedback from the CAV Industry

To validate the research team's design adjustments, companies in the CAV industry were interviewed. A summary of information collected with regards to roadway design elements and vehicle characteristics are summarized below.

### *Aptiv*

- Lane widths can be reduced. Aptiv Avs can localize down to one centimeter because the vehicles map out the roads they use in their routes in advance. Aptiv Avs are able to operate on non-premapped roads, just not with 100 percent confidence. However, Aptiv recommends retaining wider lane widths to account for unexpected objects or other unexpected items on the road (e.g., debris).
- Reaction time can be decreased because Avs can respond in microseconds, as opposed to several seconds required by human drivers. However, Aptiv recommends retaining extra following distance/headway requirements to account for unexpected objects or other unexpected items on the road (e.g., debris).
- Aptiv always recommends having redundant sources of information (e.g., use V2V/V2I to detect traffic light status when it is too sunny to rely on cameras).
- Lane markings are essential to AV functionality and cannot be eliminated.
- Current AV acceleration/deceleration rates are limited by the kinematic nature of existing vehicles. This may change with the advent of vehicles designed explicitly for autonomous driving.
- The design speed can be increased if the roadway is limited to Avs.

### *EdgeConnex*

- In order to support Avs, roadways will need to be equipped with RSUs and a server nearby that serves as the 5G edge computing box. The RSUs and edge computing box may be connected using fiber cable. RSUs will receive data directly from the vehicles and then send that data to the edge computing box to organize and synthesize the data that needs to be uploaded to the cloud/data warehouse.
- Edge computing boxes are agnostic to the various types of vehicular communications (e.g., DSRC, cellular).

### *Keolis*

- The accuracy of AV lane keeping algorithms depends on a number of factors, including environmental conditions (e.g., snow, rain), speed, etc.
- Navya AV shuttles currently do not recognize hand gestures, or obstructions in the roadway (e.g., potholes, debris, obstacles, etc.).

## HNTB

- Ultra wideband technology may be necessary in environments where GPS accuracy is not sufficient (e.g., mountainous areas, urban canyons, underground, and indoor).
- There is potential to use loose grade materials and lighter weight structures in-between the tire tracks to save cost. For some of the bus rapid transit corridor projects that HNTB is working on, the design requires only paving under the tire tracks.
- With 5G, effective communication distance may drop from 300 meters (DSRC) to approximately 100–150 meters. This would result in the need for more RSUs, spaced closer together.
- An AV-only roadway would have to account for non-cooperating objectives and vehicles to some extent. An AV-only roadway design may want to include entry points that are followed immediately by exit points, which can help non-cooperating vehicles exit the facility. Highway patrol may be notified via V2I communications.

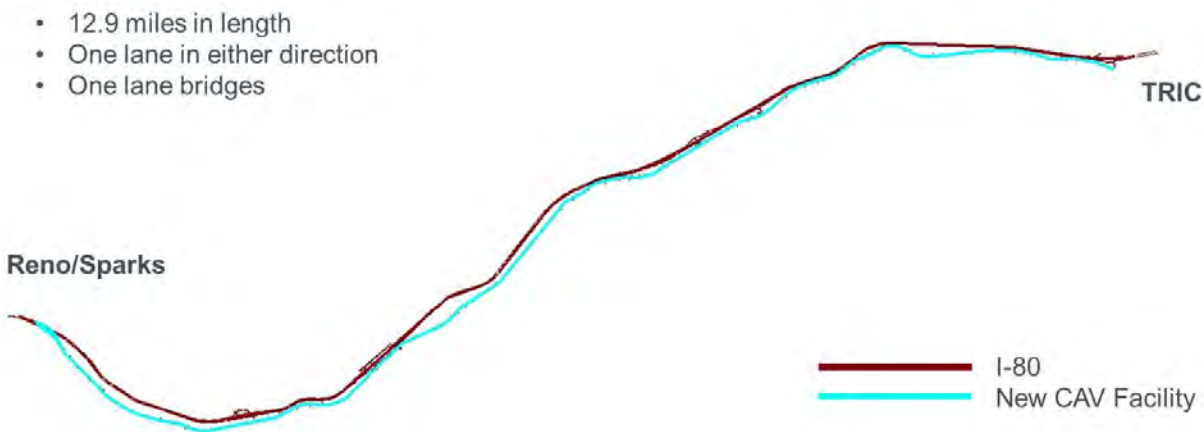
## 4.5 Identify Suitable Nevada Corridor

The next step after identifying the crucial physical and ITS infrastructure needed for use cases to be tested is to identify a suitable corridor in Nevada for the AV roadway. Depending on the use cases selected, the best option may be to convert an existing roadway, add one or more lanes to an existing roadway, or build a new facility. For the focus of this particular study, the research team is exploring the last option—specifically, building a new AV-only roadway facility between Reno/Sparks and TRIC.

### Proposed Alignment

CA Group created an alignment shapefile to be used as the foundation of the VISSIM model that would be created to estimate benefits of the AV-only roadway (the last step of AV Feasibility Study Framework). The blue line in Figure 10 represents the physical alignment of the proposed AV-only roadway in relation to the I-80 corridor (red line). The proposed alignment is 12.9 miles in length, would consist of one lane in either direction, and one-lane bridges. The proposed alignment would maximize the use of existing roads and unpaved access roads to help minimize environmental impacts and project costs. The primary constraints for this corridor include the UPRR and Truckee River.

## Figure 10. Proposed Autonomous Vehicle Roadway Alignment



Source: CA Group.

## Proposed Autonomous Vehicle Roadway Design

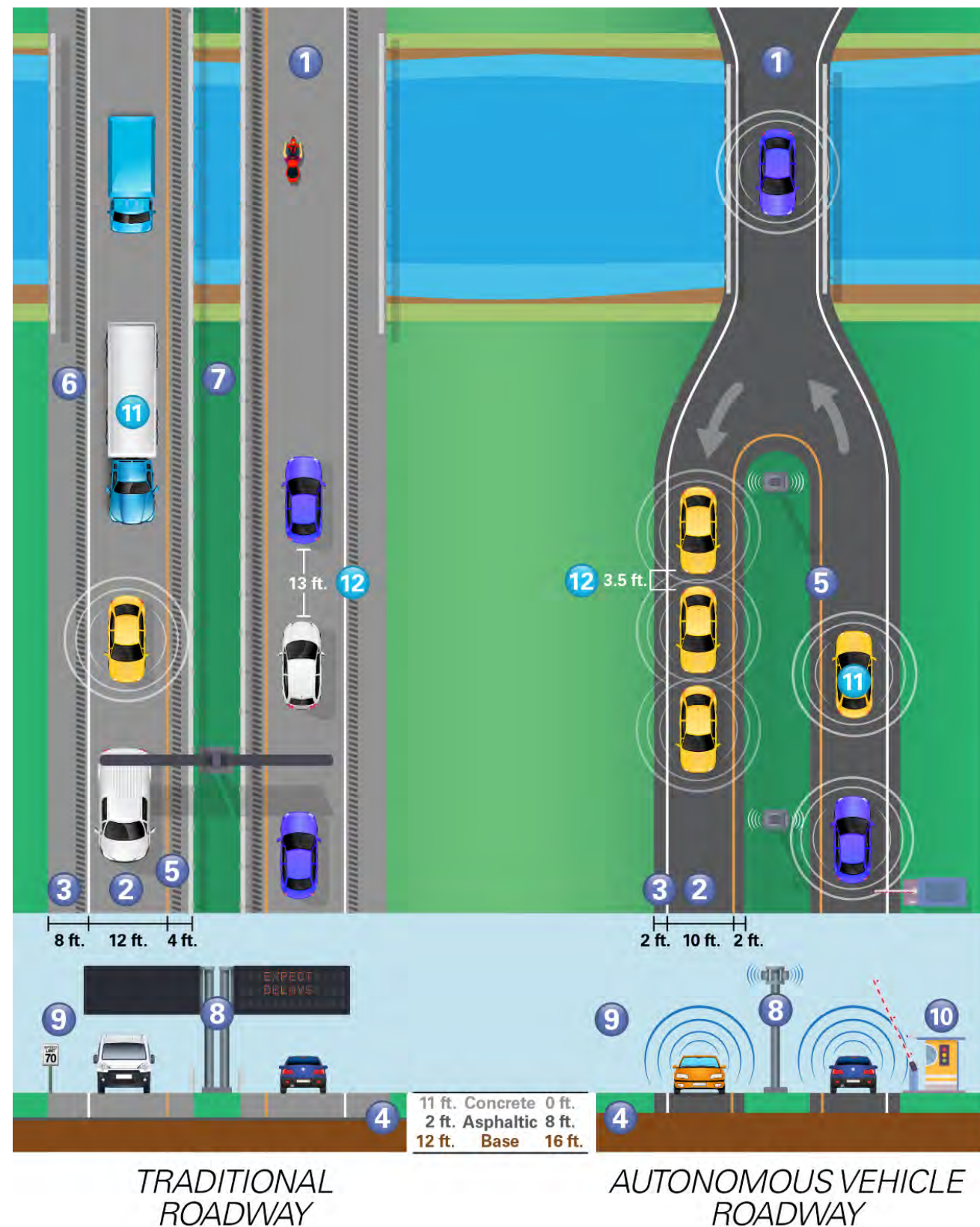
Figure 11 takes into account the research and feedback collected from Steps 1 through 5 of the AV Feasibility Study Framework to construct a visualization of a potential AV-only roadway design. A side-by-side comparison with a traditional roadway design is provided to clearly indicate design adjustments made for an AV-only roadway.

For other corridors or desirable use cases such as the ones listed below, aspects of this proposed roadway design may change.

- Rideshare.
- Company buses.
- Vanpools.
- Parcel delivery.
- Inclement weather testing.
- Emergency vehicles.
- Maintenance vehicles.



Figure 11. Comparison of a Traditional Roadway Design versus Autonomous Vehicle-Only Roadway Design



ROADWAY PHYSICAL CHARACTERISTICS

- 1 Number of Lanes** would remain the same between a traditional roadway design and an autonomous vehicle (AV)-only roadway design, but cost savings can be achieved in an AV-only roadway design by implementing one-lane bridges over canyons. Since congestion along this corridor is typically one-directional, the chances of bottlenecks at the one-lane bridges would be low. AVs would use vehicle-to-vehicle communications to ensure safe travel through the one-lane bridges.
- 2 Lane Widths** of an AV-only roadway could be reduced by as much as 2 feet (from 12 feet to 10 feet), based on AVs use of GPS to adhere to lane markings.
- 3 Shoulder Widths** of an AV-only roadway could be reduced by 2 feet (from 4 feet to 2 feet) on the inside shoulder and 6 feet (from 8 feet to 2 feet) on the outside shoulder. A 2-foot minimum shoulder protects the integrity of the roadway structural section but could be widened if emergency vehicle access is desired.
- 4 Pavement Depth** of an AV-only roadway that prohibits access by heavy duty vehicles can achieve cost savings by eliminating the need for a concrete paving layer (from 11 feet to 0 feet) and instead increasing the depth of both the asphaltic cement (from 2 feet to 8 feet) and base (from 12 feet to 16 feet).
- 5 Lane Striping** needs of an AV-only roadway are especially critical, since current AV technology relies on the visibility of these markings to function correctly.
- 6 Rumble Strips** may be eliminated from an AV-only roadway design due to the anticipated reduction of lane following deviation.
- 7 Edge Protection** such as barrier/guard rails can also be eliminated from an AV-only roadway design for the same reason as rumble strips, unless deemed necessary as a safeguard in inclement weather conditions.
- 8 Roadway Signage** such as changeable message signs or regulatory signs used on traditional roadways can be replaced with roadside units for vehicle-to-infrastructure communication.
- 9 Speed Limits** of an AV-only roadway can at a minimum, support the same design speed of a traditional roadway, if not higher.
- 10 Roadway Access** to an AV-only roadway may require an additional verification step to ensure that vehicles entering the roadway are either a Level 4 or Level 5 AV, in order to maximize the safety and mobility benefits of the vehicles on the roadway.

VEHICLE CHARACTERISTICS

- 11 Vehicle Types** permitted on an AV-only roadway would be restricted to Level 4 and Level 5 passenger vehicle AVs. For a typically congested commute corridor, restricting heavy duty vehicle access would help to reduce the overall construction costs of an AV-only roadway. Traditional roadways can also support AVs, but the AVs may not achieve the level of mobility and safety benefits possible on an AV-only roadway.
- 12 Distance between Vehicles** can be greatly reduced in a fully AV environment based on the ability to significantly decrease human reaction times required of non-AVs. In addition, vehicles with vehicle-to-vehicle (V2V) communications helps to maintain the spacing between AVs, and vehicle-to-infrastructure (V2I) communications allows transportation agencies to dynamically change minimum spacing limits based on conditions such as inclement weather.
  - (a) Headway/Following Distance between Vehicles** on an AV-only roadway can be reduced from 2 seconds to 0.6 seconds, or 13 feet to 3.5 feet.
  - (b) Desired Distance between Stopped Vehicles** on an AV-only roadway can be reduced by as much as 35-65% (from 5 feet to 1.6-3.2 feet).
  - (c) Stopping Sight Distance** can be reduced or even eliminated on AVs traveling on an AV-only roadway (from 1.5 seconds for perception time and 1.0 seconds for reaction time). Instead, AVs could adopt a minimum braking distance with a deceleration rate of 11.2 feet/second.

## 4.6 Estimate Benefits of Use Cases

The development of the AV Feasibility Study simulation model will begin with the base work completed as part of the Northern Nevada Traffic Study, including NDOT accepted 2040 volumes along the I-80 corridor. In addition, CS gathered applicable data from the Highway Capacity Software (HCS) level analysis for the corridor and a VISSIM microsimulation for the USA Parkway interchange that CA Group conducted previously. VISSIM is considered the simulation platform most suitable for CAV simulation.

### Study Corridor

This study proposes to simulate a CAV dedicated, two-lane facility parallel to I-80 between USA Pkwy and Sparks Boulevard. It is preferred that this facility follows the existing I-80 alignment as close as possible. Since I-80 westbound is closer to natural barriers such as steep rock cuts, CA Group recommended to construct the new facility along I-80 eastbound. This alignment will still require navigation around the Truckee River and existing buildings, however, reasonable vertical grades and easier construction can be accomplished on the east side of I-80.

TRIC currently accesses I-80 through USA Pkwy and U.S.-50. It is recommended to have two starting access points at the eastern terminus of the road, one from/to I-80 between USA Pkwy and U.S.-50, and the other from/to USA Pkwy. At the western terminus, it is recommended to merge the facility to I-80 east of Sparks Blvd, and widen I-80 at least one lane each direction between Sparks Blvd and U.S.-395.

Since I-80 itself will not be modeled in this study, it is assumed regardless of how and where CAV lanes merge to I-80, I-80 will have enough future capacity and there will not be any queue from I-80 merge point to the CAV facility.

### Base and Alternative Scenarios

The base scenario would include developing a limited access facility, exclusively for Level 4 or 5 CAVs, under a future year 2040 growth condition. It is assumed that non-connected vehicles will not enter the facility and the road is operated obstacle free at all times.

Since projecting future CAV market penetration rates depends on many factors, some still very much unknown, this study proposes to simulate the AV-only roadway under three levels of CAV demands: optimistic, most probable and pessimistic. The most probable demand accounts for the base scenario. Alternative scenarios will explore variations of AV characteristics such as market penetration rates, speed, or spacing capacity.

### Demand

Current peak hour demands on the I-80 corridor is available through 2016 traffic counts. Between USA Pkwy and Sparks Blvd, the highest hourly volumes are 1,045 vehicles in the westbound direction in the AM peak hour and 1,212 vehicles in the eastbound direction in the PM peak hour. Projected 2040 peak hour volumes are estimated at 1,836 vehicles for westbound in the AM peak hour and 2,444 vehicles for eastbound in the PM peak hour. This implies a compound annual growth rate (CAGR) of 2.4 percent between 2016 and 2040 for the AM peak period, and 1.4 percent for AM peak.

**Table 5. I-80 Corridor Peak Hour Demand**

Location	2016		2040		Compound Annual Growth Rate (CAGR)	
	AM	PM	AM	PM	AM	PM
Eastbound (west of Waltham Wy)	933	1,212	1,803	2,444	2.8%	3.0%
Westbound (east of USA Pkwy)	1,045	775	1,836	1,086	2.4%	1.4%

Source: CA Group—Reno Sparks Freeway Traffic Study (July 2018).

## Simulation Literature Review

Based on a literature review conducted, a ballpark estimate for a 2040 CAV market penetration rate is 40 percent. The range of the predicted market penetration rate however, covers a wide span from 10 percent to 87 percent for the year 2040. Uncertainty about regulation, taxation, improvements in cybersecurity, and public's perception of CAV safety benefits are some factors that make prediction of future market penetration rate difficult and can lead to the wide variation in these projections.

For the optimistic scenario, due to the proximity of the AV-only roadway to Tesla's Gigafactory, the research team anticipates a higher than national average market penetration rate. For the pessimistic scenario, the research team assumed a 30 percent CAV market penetration rate, while for the optimistic scenario the research team assumed a 55 percent CAV penetration rate. Some studies suggest that dedicated lanes are not successful for CAV penetration rate less than 35 percent.

## AV-Specific Simulation Characteristics

There are three different approaches for simulating CAVs. In all of them, the commonality involves adjusting the simulated driving behaviors to reflect the game changing CAV technologies. However, published field studies of the effects of CAV technology on driving is still limited. Most field tests are designed for highly controlled environments and do not include complicated situations such as weaving, cut-in vehicles, and platooning in mixed traffic. While CAV manufacturers also did testing on public roads with general traffic flows, many do not share specific information about the vehicle performance, and safety and comfort-related thresholds.

The most straight forward simulation approach, uses the existing simulation tools and only changes the driving behavior parameters according to the existing literature and field studies available. Complicated behaviors such as merging and weaving are usually simulated based on the modeler's judgment, since detailed algorithms for such models are not generally available.

In a more realistic approach to simulation, the V2X communications are specifically modeled. In this approach, the simulation tool interacts with an external script which controls the vehicles' interactions with each other and/or with the infrastructure. This approach is required for CAV applications such as speed harmonization, signal preemption and green light optimized speed advisory.

An ultimate CAV simulation would include the customization of driving behavior algorithms and adjustment of internal parameters to create dedicated CAV driving behavioral models, rather than

changing parameters for existing driving behavior models. By using new or customized algorithms, more complicated tasks such as lane changing, merging, and weaving do not need to be specifically calibrated and can be more in line with the underlying logic used within the CAV vehicles themselves. However, decades of experience and data were used to develop and calibrate the default driving behavior algorithms that exist in models available today. Changing them with existing limited data entails some risk. Besides, changing at this level requires advanced scripting and software coding to mimic or estimate the logic and behavior of future CAV vehicles; this knowledge is not widely known outside of individual CAV manufacturers, and details are often considered proprietary in nature.

In this study, the research team proposes to combine these approaches. The research team proposes changing the default driving behavior parameters according to previous studies, and use scripting to model platooning of vehicles.

Automation allows for reducing or effectively eliminating the reaction times that implicitly or explicitly exists in some parameters of existing human driving behavior models. Please note that in this limited access facility, we assume there will not be any situation that demands the drivers take control over from the AV systems. With CAV, driving behavior variations should dramatically decrease. However, people are still different when choosing levels of comfort, safety, or risk. Different CAV makers consider this difference and design their systems for their target market. In absence of strict universal rules or regulations for different CAV settings such as headway, safe distance, acceleration/deceleration range, and other parameters, it is recommended to keep some variation in parameters that affect driving behavior or vehicle performance. Moreover, since CAV will most likely provide drivers with some choices over driving settings (such as different settings for headways), in this study, drivers will be divided into three groups based on their level of cooperation/aggressiveness. This distribution specifically helps to model merge and diverge behavior more realistically.

Since all vehicles will be connected, it is assumed that vehicles will form platoon when they have a chance. However, because constant search for a leader may reduce runtime significantly, platooning opportunity is only given at the entrance points. These are the rules relevant to platooning:

- Maximum platoon size is five vehicles.
- No communication failures will be modeled (with extra scripting it is possible to have the failure probability as a distance function, but this overly complicates the simulation).
- Vehicles in a platoon have the same desired headway and speed.
- When a vehicle leaves platoon, the following vehicle speeds up to close the gap.
- Desired headways will be a distribution with average of 0.6 seconds if vehicle is following in a platoon and 0.9 second otherwise (compared to 1.4 seconds for manually driven cars).

Other driving behavior and vehicle performance parameters that are affected by AV technology include:

- Smaller stand still distance (minimum distance to an obstacle when vehicle is stopped).
- For geometric design of horizontal and vertical curves, perception/reaction time is removed.

Table 6 summarizes the types of inputs needed to set up a CAV simulation model, while Table 7 lists the proposed adjustments to default simulation parameters to reflect CAV driving characteristics.

**Table 6. CAV Simulation Model Inputs**

Input Type	Inputs Needed
Network	<ul style="list-style-type: none"> <li>Imagery.</li> <li>Alignment.</li> <li>Alternative routes for general purpose lane vehicles.</li> </ul>
Demand	<ul style="list-style-type: none"> <li>Travel Demand Model (O/D matrix per hour for autonomous vehicles and general purpose vehicles).</li> <li>Vehicles/hour—for autonomous vehicles and general purpose vehicles (2016 and 2040).</li> <li>Vehicle composition.</li> </ul>
Traffic Behavior	<ul style="list-style-type: none"> <li>Assumptions for autonomous vehicle operating characteristics (heading, speed limits, occupancy, etc.).</li> </ul>

**Table 7. Proposed CAV Simulation Parameters**

Parameter	Description	Default	CAV Application
Look ahead distance	Number of vehicles that vehicle can see forward.	2	10 (if connected, not just Automated)
CC0 Standstill Distance	Desired distance between stopped vehicles, or vehicle and obstacle.	5 ft	1.6 to 3.2 ft
CC1 Headway time	Headway in second (a distribution).	2, 0.7 s (mean and SD)	0.6, 0.1 s (flatter distribution, or discrete values)
CC2 Following variation	Distance in addition to the allowed safety distance that is permissible before the vehicle moves closer to the proceeding vehicle.	13 ft	0 to 3.5 ft
CC3 Threshold for entering following mode	Seconds before reaching safety distance the driver starts to decelerate.	-8 s	-5 to 0 (unchanged in some studies)
CC4 Negative following threshold	Maximum allowable speed difference when following vehicle is slower than the preceding vehicle.	-0.35	-0.1 to 0
CC5 Positive following threshold	Maximum allowable speed difference when following vehicle is faster than the preceding vehicle.	0.35	0 to 0.1
CC6 Speed dependency of oscillation	Influence of distance on speed oscillation while in following state.	11.4	0

Parameter	Description	Default	CAV Application
CC7 Oscillation acceleration	Influence of vehicle acceleration during car following oscillation.	0.82 ft/s <sup>2</sup>	0.82 ft/s <sup>2</sup> (some studies suggest 1.3 ft/s <sup>2</sup> but not PTV)
CC8 Standstill acceleration	Desired acceleration when starting from standstill.	11.48 ft/s <sup>2</sup>	11.48 to 13.12 ft/s <sup>2</sup>
CC9 Acceleration with 50 mph	Desired acceleration at 50 mph.	4.92 ft/s <sup>2</sup>	4.92 to 6.56 ft/ s <sup>2</sup>
Use implicit stochastics	Using distribution versus fixed values for some parameters (safety distance, desired acceleration/deceleration, uncertainty for braking deceleration).	Checked	PTV suggest to uncheck it for AV, I believe better to leave it to deal with discrepancy between car manufacturers.
Advanced merging	Vehicles act more cooperative at merging area.	Uncheck	Checked/unchecked depending on the aggressiveness of the user group.

## 5.0 RECOMMENDATIONS FOR FUTURE WORK

While this research effort determined that the stakeholder community may not be ready for near-term deployment of a specific AV roadway system in the Reno-TRIC corridor, the results presented in this report do provide a foundation that NDOT can use to outline a program to prepare for AV and CV developments over the next five years. Four key recommendations for focusing this future work are presented as follows, and are provided in the recommended order in which they should be conducted – within the period of 2020 to 2025.

- 1) **Leverage Nevada’s National Leadership in AV Regulations and Testing to Promote CV Industry Testing.** AV technology, by itself, while providing safety and comfort benefits to the public, would not provide the transportation system level benefits that would be achievable if CV – both in terms of V2V and V2I connectivity – were added/integrated. As Nevada has been an attractor state to OEM’s who are experimenting and operating AV’s on public roadways, the State is encouraged to immediately begin a bold initiative focused on promoting and funding new partnerships with OEM’s to test CAV capabilities. In particular, locations such as on I-15 through Las Vegas, and on I-80 between Reno and the TRIC, present very congested areas where future significant market penetration of CAV technology could significantly reduce incidents and increase vehicle throughput (e.g. through closer automated vehicle spacing using V2V apps) during daily peak freeway conditions. As an example of initiating this type of effort, a partnership between NDOT and Tesla to augment Tesla AV’s with CV technology, and to test them on I-80 between Reno and the TRIC, could be expected to benefit both public sector and private sector needs – thereby demonstrating public sector safety and throughput benefits while also highlighting both new capabilities for Tesla AV’s, as well as demonstrating a future benefit to Tesla employees who commute daily to their Gigafactory 1 facility on I-80.
- 2) **Simulation and Impacts Assessment of AV roadways.** Building on the foundational work completed in this research study to define the characteristics a future AV Roadway, NDOT could, in the 2020-2021 timeframe, conduct a broad research effort that encompasses simulation/modeling of AV roadways, simulation/modeling of CAV vehicles (mixed with traditional vehicles) in varying levels of market penetration on existing roadways. Additionally, this study could develop and implement the new tools and methods necessary to estimate the impacts, benefits and costs – which can be applied to the simulation/modeling results. The following are considered gaps in the types of tools available to planners today in their ability to address CV technologies. To understand the impacts, benefits and costs of different CV-related investments, new tools and analytical techniques need to be developed with effort required in both the public and commercial sectors. These needs are driven by:
  - Many tools are not equipped to address vehicle and infrastructure changes that may accompany CAV deployment, such as mixed vehicle populations and dedicated CAV lanes.
  - Driver behavior will be dynamic, with control of the vehicle shifting under different conditions, and on different roadways. Optimization tools currently in use are not well suited to address this.
  - Current decision support tools, which help evaluate and select operational strategies, are not set up to take advantage of CAV applications and data.

- Guidance regarding use of these tools for CAV applications and evaluations is not established; comparing different studies and tool results right now has a disappointing “apples and oranges” character to it.

From a national perspective, the type of research, tools development and simulation capability is needed, and has surprisingly not been sponsored by the USDOT ITS Joint Program Office or AASHTO. As such, this represents a CAV research area which provides the ability for Nevada to take a national leadership role.

- 3) Develop Guidance for Advancing Existing ITS Strategies and Investments into CAV Technologies.** From a public agency operations perspective, CAV technology can be thought of as advanced and mobile component of ITS. NDOT and the numerous transportation agencies in the state that implement and maintain ITS equipment could benefit from a shared understanding and vision for the transition to a greater CAV focus. This can be developed as a formal guidance document that provides a framework for integrating CAV developments into ITS planning and preliminary systems engineering activities. Development of this guidance should be a joint effort led by NDOT, and involve regional transportation agencies, counties, municipalities, and transit agencies. It is recommended that this effort begin about 2022, when the direction that CV technology is taking (i.e. DSRC 5.9 GHz versus Cellular/emerging 5G communications) should be solidified.
- 4) Planning for Implementing Future AV roadways in the TRIC Region.** Based on the completion of the above steps, by 2023 to 2024, NDOT may want to consider implementing a formal planning and preliminary design effort for an AV roadway in the Reno-to-TRIC corridor, with options encompassing a separate facility or dedicated AV lanes on I-80. The future need for this planning effort was established in this research study from the following stakeholder needs:
  - Stakeholders that participated in the User Advisory Group for this research study anticipated that an estimated 50-80 percent of TRIC employees would use this new AV-only roadway.
  - Stakeholders recommended that this roadway can be used in the short-term for non-AV commuter buses until AV technology matures.
  - Due to the highly directional congestion flows (eastbound in the AM; westbound in the PM), the stakeholders recommended lane management functions (e.g., reversible lanes).
  - Hesitation to design an AV-only roadway for a single purpose (i.e., passenger Avs) if the roadway construction and maintenance becomes a significant investment.
  - Some stakeholders suggested considering converting existing roadways in lieu of building a new AV roadway.




# APPENDIX A. BACKGROUND ON CONNECTED AND AUTONOMOUS VEHICLE TECHNOLOGY

## A.1 Background on Autonomous Vehicles

Over the next several decades, AV will transform mobility in Nevada and throughout the world. The emergence of potentially safer, more reliable vehicles, designed to perform safety-critical driving functions and monitor roadway conditions, will fundamentally change the way travelers utilize transportation systems across all modes. AV technologies, in coordination with CV technologies, will have potentially transformative impacts on personal and freight travels, business models, land use, and quality of life. While there are many benefits expected, ushering in AV also will present challenges, especially during the transition period (potentially decades long), where AV, CV, and more traditional vehicles without advanced technologies will share Nevada’s roads. Transportation agencies need to address vehicles with varying capabilities from partly automated vehicles, such as those on the roadways today that provide functions (e.g., automated braking and lane-assist), to highly automated vehicles (HAV) that do not require a driver.

A diverse set of AV capabilities currently can be seen in pilot deployments or showcases across different types of vehicles from military to agricultural vehicles.<sup>7,8</sup> One of the first successful pilots was seen in commercial vehicle environments, where freight companies have successfully tested HAV capabilities.<sup>9,10</sup> Vehicle tests in the commercial vehicle environment have allowed agencies and automakers to begin testing in controlled urban

**Automation Technologies**



**Connected Vehicles (CV)** combine advanced technologies (such as advanced vehicle sensors, wireless communications, global positioning system (GPS), smart infrastructure, and others) to identify hazards and delays on the roadway; and to provide drivers with warnings and real-time traveler information. CV technology can be used in vehicles with or without automated functions, and will play a significant role in the evolution of automated vehicles.

**Example CV Functions:** Curve speed warnings, forward-collision warnings, and advisories and warnings of deteriorating/hazardous driving conditions.

**Automated Vehicles (AV)** encompass a spectrum of vehicles at progressing levels of automation. AVs at lower levels perform some driving functions, but require a human to monitor the road. AVs at higher levels perform some driving functions, as well as monitor the road in some to all situations.

**Example AV Functions:** Pre-emptive braking systems, parking assistance systems, adaptive cruise control, and lane centering systems.

*SAE Levels of Automation*

0 1 2 3 4 5

**Highly Automated Vehicles (HAV)** refer to automated vehicles at higher levels of automation, and are distinguished by the capability to monitor the driving environment. HAVs monitor the road in some to all situations and conduct some to all driving functions.

**Example HAV Functions:** Performs all driving tasks in specific situations; and performs all driving tasks in all situations/no steering wheel or pedals.

*SAE Levels of Automation*

0 1 2 3 4 5

<sup>7</sup> <https://www.youtube.com/watch?v=x6ePtBPwZE0&feature=youtu.be>.

<sup>8</sup> <http://www.autonomoustractor.com/>.

<sup>9</sup> <http://www.freightlinerinspiration.com/>.

<sup>10</sup> <http://ot.to/>.

(Footnote continued on next page...)

scenarios, where a variety of users and modes interacts with each other, and where safety for all system users is paramount.

As the private sector continues to advance research, the Federal Government has become actively involved. The U.S. Department of Transportation (U.S. DOT) released the Federal Automated Vehicles Policy (FAVP) in September 2016. This policy seeks to set out a “proactive safety approach that will bring life-saving technologies to the roads safely while providing innovators the space they need to develop new solutions.”<sup>11</sup>

The specific technological innovations, timing, and implications for transportation in the future remain speculative. However, given current trends, it is possible to define several general expectations. As technology develops, competition among stakeholders in the private sector involved will continue to grow. The State can expect to see new stakeholders in the race to be the first provider of HAV mobility, and new partnerships will continue to develop.

### Understanding Levels of Automation

SAE J3016™ levels of vehicle automation can be briefly summarized as follows:

0	<b>No Automation</b>
1	<b>Driver Assistance</b> – Some driving tasks supported by automation
2	<b>Partial Automation</b> – More automation though human driver monitors driving environment
3	<b>Conditional Automation</b> – Automated driving system monitors environment but human is prepared to intervene
4	<b>High Automation</b> – Automated driving system handles all aspects of driving task even if human is unprepared to intervene
5	<b>Full Automation</b> – Automation replaces functions of human driver

See <https://www.sae.org/news/3544/> for more details on each level.

The transportation community has issued widely varying timelines as to when users can expect the remaining levels of automation. Experts in the field have made various predictions of AV adoption rates. The range among predictions is wide. In 2016, Serbjeet Kohli and Luis Willumsen presented the results of a Delphi survey on the field of AV transportation.<sup>12</sup> The results show that, on average, transportation experts expect that AV technology will be available in the U.S. by 2021 (with a two-year standard deviation); and that there will be a 20-percent penetration rate in the U.S. market by 2033 (with a six-year standard deviation). Although it is not clear when Level 5 AV technology will be adopted, one thing is for certain—AVs are coming, and the time is ripe for public agencies to embrace these uncertainties and plan for a range of possible scenarios and impacts.

AVs are expected to disrupt mobility as society knows it. It is easier to understand these impacts if they are clustered into three main categories: 1) transportation; 2) built environment/land use; and 3) social.

The first category, **transportation impacts**, refers to the expected changes for intrinsic physical characteristics of AV technology. Highly automated vehicles are capable of utilizing more of the transportation network’s capacity by allowing vehicles to travel closer together and possibly at higher speeds, depending on adapted driving rules set for the technology and the AV’s penetration rate. Impacts

<sup>11</sup> <https://www.transportation.gov/AV-factsheet>.

<sup>12</sup> “Traffic Forecasting and Autonomous Vehicles,” Serbjeet Kohli and Luis Willumsen, European Transport Conference 2016, <http://www.steerdaviesgleave.com/sites/default/files/elfinder/Traffic-forecasting-and-automated-vehicles-Kohli-Willumsen.pdf>.

on transportation agency-defined performance measures are expected, but the direction of those impacts (positive/negative) will depend on many combined factors, such as if expected vehicle miles traveled (VMT) increases might be counterbalanced through a vehicle-sharing economy, or through more efficient use of transportation capacity and vehicles on the transportation system. Furthermore, it is expected that AV technology will increase safety by reducing incident rates significantly, as more than 90 percent of incidents are a result of human error.<sup>13</sup>

Another important impact is the effect on public transportation. It is possible that AV mobility could replace the need for less productive public transportation services with low ridership or low frequency; on the other hand, public transportation could be promoted by easing the “last-mile” problem for its users. Bicycling and walking could become safer through safer interactions with vehicles; and right-of-way (ROW), which currently are used for parking, could possibly be reallocated to nonmotorized uses.

The second category of impacts relates to the effect these vehicles could have on **built environments**. AV technology could have as big an effect on urban landform as the introduction of the first automobile. There is a current debate on how AV technology will affect land uses. Experts have considered that AV technology could exacerbate suburbanization by allowing people to live in areas further away from major employment centers without experiencing the inconvenience of unproductive commutes. However, some experts expect AV technology will help make urban living more attractive and affordable by reducing parking needs, time spent looking for parking, or reducing the need for car ownership. If changes in roadway capacity allow for ROW reallocation to nonmotorized uses, the built environment in urban areas could not only be safer, but also could transition to urban design that is focused increasingly more around people than cars.

The third category of impacts relates to **social parameters**. Paramount to this topic is to understand how AV will impact the environment, and how equity can be considered to ensure vulnerable populations benefit from mobility improvements. If AV and shared mobility are implemented in tandem, and ride costs are affordable, there might be positive impacts on low- and very low-income households’ transportation costs, as families



<sup>13</sup> National Motor Vehicle Crash Causation Survey (NMVCCS).

that currently need to buy, maintain, and insure vehicles might be able to avoid these costs. AV adoption strategies need to consider current users' needs and environmental conditions, and be resilient to possible upcoming changes.

Paradigm changes in mobility can have a ripple effect on other areas, such as the economy. Furthermore, current social changes are transforming urban living and mobility needs. Agencies need to take different evolving issues, such as climate change, "Big Data," energy prices, automation, the rise of alternative economies, and the needs and desires of upcoming generations into their plans for the future.

The expected impacts of AVs are bound to have a significant effect on the status quo of governing. It is only through planning that agencies can truly prepare for these types of changes. According to the National League of Cities, in 2016, only 6 percent of regional plans in the U.S. consider the potential effect of driverless technology, and only 3 percent are taking into account private transportation network companies (TNC), despite that TNCs operate in the vast majority of these regions.<sup>14</sup>



## The Public Agency Perspective

As technology evolves and transforms mobility solutions, public agencies need to start thinking how these technologies can affect their everyday work—both individually and collectively—and continue planning for these changes. State and local governments cannot turn a blind-eye towards these upcoming impacts, as their response to these changes can significantly affect the region, positively or negatively.

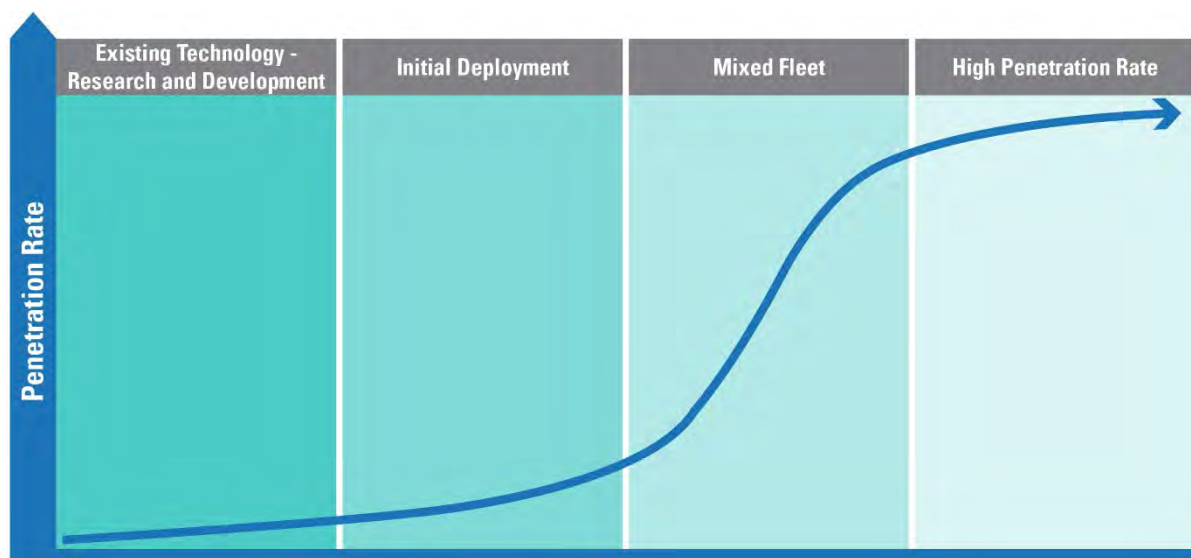
The public agency role in transportation automation will evolve over time. A discussion of four stages of AV technology development and deployment follows. Each phase will bring its own challenges and opportunities.

- **Research and Development.** This stage includes current technology deployment and the continuous development of AV technology. Pilots and test beds will continue to be developed to gather data and performance measures that will help evaluate technology costs and benefits, shaping technology towards implementation. Major breakthroughs can be expected during this phase, as different designs and system architectures will be tested thoroughly, helping shape a product viable for deployment. Public agencies will need to finance and conduct research, support partner research

<sup>14</sup> <http://www.nlc.org/Documents/Find%20City%20Solutions/Research%20Innovation/City%20of%20the%20Future/City%20of%20the%20Future%20FINAL%20WEB.pdf>.

efforts, and keep an eye on evolving technology to understand possible impacts and plan ahead of deployment.

- Initial Deployment.** This stage considers the initial small-scale roll out of AV technology to the general public. This initial deployment could take different shapes, such as public technology available for purchase, or small-scale deployment exclusively for taxi and ridesharing services. Public agencies will need to have robust plans to adapt to these disruptive, initial deployments to accommodate different types of deployments in their operations, and to help these initial deployments to operate safely and in consideration to other road users.
- Mixed Fleet.** If AV technology is proven useful, the penetration rate of such technology could increase at a rate that will depend on the operational performance of the technology and the effectiveness of its use. Many issues can be expected during this phase. For instance, current domestic and internationally accepted traffic rules may need to be revisited, and privacy and ethical issues may need to be addressed. It is during this phase that public agencies will need to be prepared to consider different policy and operational changes, such as lane usage, parking requirements, transit services, and traffic control operations, among many other possible impacts.
- High Penetration Rate.** If AV technology is proven beneficial to society and are available at a price point acceptable to the general public, AV penetration rates will represent the majority of vehicles in the market. During this stage, public agencies will need to be prepared to guide and promote infrastructure changes to accommodate for different mobility patterns, and the needs and demands of new generations of users accustomed to these new transportation technologies.



Moreover, as AV technology matures, developers will seek a clearly defined path to include their vehicles in the transportation system, which requires licensing, vehicle registration, and other regulatory components. As more AVs come into contact with Nevada's drivers and citizens, the NDOT will need to address these new requirements to ensure the safety and convenience of all travelers.

## A.2 *Background on Connected Vehicles and Smart Infrastructure*

### Description

Connected vehicles and “smart” infrastructure use mechatronics, telematics, and artificial intelligence technologies to interact with the environment to provide greater safety, comfort, entertainment, and most of all, a “connected-life” experience. With the appropriate communication network in place, vehicles with onboard communications (whether it uses Dedicated Short-Range Communications (DSRC), cellular, WiFi, satellite, Bluetooth, etc.), can send vehicle information such as location and speed to roadside units (RSUs).

### Anticipated Evolution

Mainstream adoption of connected vehicles and smart infrastructure has the potential reduce traffic deaths and help achieve the goals put forth by Federal Highway Administration’s Towards Zero Deaths initiative. Although there exists a fair amount of transportation data available from public agencies and private industry, the interval at which the data is collected currently does not support real-time decision-making. The advent of connected vehicles and smart infrastructure will greatly enhance the quantity, quality, and velocity of data available for enhanced collision warning systems. Connected vehicle safety applications will enable drivers to have 360-degree awareness of hazards and situations that they cannot even see.

On the operational side, real-time roadway conditions, congestion levels, travel times, and incident-related information of roadway users can be used to predict travel times and augment current traveler information systems. The data also can be used to provide transportation operators with more timely and accurate performance data to better manage their systems.

In December of 2016, the NHTSA published their notice of proposed rulemaking (NPRM) which is likely to require manufacturers would be required to install dedicated short-range communication (DSRC) radios into new vehicles, probably starting in about 2020.<sup>15</sup> Despite the potential for changes to the ruling, this signifies an aggressive timeline for new vehicle adoption of CV technologies. Gartner predicts that by 2020, more than 250 million vehicles will be connected globally.<sup>16</sup> Most long-range scenarios on vehicle trends expect the population of equipped vehicles to exceed 90 percent by 2050.<sup>17</sup>

There are ongoing debates regarding whether DSRC or 5G cellular networks should become the wireless technology standard for vehicular communication. Proponents of DSRC assert that it is able to support all vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) use cases and modules already are commercially available for installation. U.S. DOT has dedicated a significant amount of resources into connected vehicle pilots to determine the capabilities of this technology in terms of safety benefits,

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<sup>15</sup> <https://www.nhtsa.gov/press-releases/us-dot-advances-deployment-connected-vehicle-technology-prevent-hundreds-thousands>.

<sup>16</sup> <https://dupress.deloitte.com/dup-us-en/focus/Internet-of-things/iot-in-automotive-industry.html>.

<sup>17</sup> AASHTO, “National Connected Vehicle Field Infrastructure Footprint Analysis,” Publication No. FHWA-JPO-14-125, June 2014.

*(Footnote continued on next page...)*

robustness, interoperability, and practicality. Proponents of 5G insist that the advancement of cellular technology will eventually be able to provide the many of the basic functions offered by DSRC, in addition to additional in-car features that passengers want, such as mobile entertainment. Vehicles also may act as roving hotspots, redistributing Internet connectivity to nearby users as they travel.<sup>18</sup> On the downside, 5G is still very much in the development phase with no working prototypes or standards available yet and DSRC would not reach full functionality without widespread adoption of the technology.

In the meantime, AASHTO has issued a Connected Vehicle Deployment Challenge, urging every State to equip at least one corridor (roughly 20 signalized intersections) with DSRC infrastructure to broadcast Signal Phase and Timing (SpaT) information by January 2020, and maintain operations for at least 10 years.

The standard of vehicular communications will most likely be a combination of DSRC and 5G. As 5G cellular technology standards are developed in the near future, in-vehicle infotainment may be realized, with the advent of interactive in-car surfaces for controlling these systems. It will become clearer which use cases are better served by DSRC or 5G, and from this experience, vehicular communication standards will be developed.



The connectivity necessary for providing connected vehicle features pose privacy, data security, and physical safety vulnerabilities of connected vehicle computer systems. If digital messages sent or received by connected vehicles and smart infrastructure are not authenticated or encrypted properly, they can be susceptible to remote hacking of vehicle controls, location data or payment card data through the vehicles' wireless and phone components. In the long term, the approach by Congress and the courts of governance of Connected Vehicles will likely guide the development of standards and practices across the Internet of Things (IoT) spectrum.<sup>19</sup> The IoT encompasses the ecosystem of everyday products and services that are equipped with "smart" technology that allows them to communicate and transfer information via a wireless network.

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*"As one of the earliest entrants into and faster-growing components of the Internet of Things,, Connected Cars represent a testing ground for the development of consumer privacy rights and security standards for the IoT."*

*—Data Privacy Monitor*

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<sup>18</sup> <http://spectrum.ieee.org/cars-that-think/transportation/self-driving/autonomous-driving-experts-weigh-5g-cellular-network-against-shortrange-communications-to-connect-cars>.

<sup>19</sup> <https://www.dataprivacymonitor.com/cybersecurity/legal-developments-in-connected-car-arena-provide-glimpse-of-privacy-and-data-security-regulation-in-Internet-of-things/>.

## Notable Innovators

- U.S. DOT Connected Vehicle Safety Pilot Program:** The Connected Vehicle Safety Pilot Program is part of a major research effort run jointly by the U.S. DOT and its research and development partners in private industry. The Safety Pilot is designed to determine the effectiveness of safety applications based on vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) DSRC communications systems at reducing crashes and to show how real-world drivers will respond to these safety applications in their vehicles. The test will include many vehicles with vehicle awareness devices, others with integrated safety systems, and others that use aftermarket safety devices to communicate with surrounding vehicles. The Safety Pilot includes multiple vehicle types such as cars, trucks, and transit vehicles.
- 5G World Alliance:** In response to the U.S. DOT's focus on DSRC technology for connected vehicles, the 5G World Alliance aims to integrate the fixed and wireless networks and build new technologies such as IoT, Cloud Computing, and SDV-NFV (software-defined networking, network functions virtualization), all based on Ipv6 (instead of DSRC). They want to promote 5G as the Neutral Next Generation World Wide Wireless Internet and define the standards to be used by all sectors (including transportation) for wireless Internet solutions.<sup>20</sup>
- Peloton:** Peloton's Truck Platooning System uses V2V communication, radar-based active braking and vehicle-control algorithms to improve safety and fuel efficiency. Collision mitigation systems help detect stopped or slowed vehicles far down the road to alert the driver and apply brakes when needed. Electronically coupling heavy trucks using V2V communications allows trucks to accelerate and brake together and operate at closer distances to form a platoon. Fuel savings of 4.5 percent can be achieved for the lead truck and 10 percent for the following truck. Peloton's cloud-based Network Operations Center can either plan pairings ahead of time or notify drivers en-route of potential pairings based on their location and anticipated route.<sup>21</sup>
- AT&T:** AT&T Mobility has partnered with the most car companies to build cellular technology into over 1 million connected cars so far. AT&T is focusing more on the "connected life" experience—enabling services such as Internet radio, video streaming, web browsing, connected media, automotive app store and more. Remote services such as parking lot location, sending directions to the vehicle, and starting it remotely to warm up on a cold day allow customers to control their connected vehicle from their wireless device.
- NXP and Cohda Wireless:** NXP and Cohda Wireless developed the RoadLINK platform which exchanges messages reliably across an extended range at high speed, reducing reaction time in safety-critical scenarios. RoadLINK supports both DSRC (IEEE 802.11p) and Wi-Fi (802.11abgn) wireless standards and can upload and access data via home Wi-Fi and hotspot connections. Manufactured DSRC modules that are approximately half the size of a credit card and sell for \$100–\$200. General Motors will be using NXP's RoadLINK chipset with Cohda Wireless's IEEE 802.11p software for use in their Cadillac CTS V2V modules.

<sup>20</sup> <http://www.5gworldalliance.org/>.

<sup>21</sup> <http://peloton-tech.com/>.



## Potential Impacts

Connected vehicle research simulations have consistently shown significant mobility and safety benefits. Connected vehicle technologies can improve roadway capacity by 20 percent with relatively low market penetration.<sup>22</sup> In a separate study, connected vehicles with a market penetration rate of 33 percent or more are shown to be able to support V2I applications and significantly reduce delays at urban intersections.<sup>23</sup> Traffic-light-to-vehicle communication systems can help drivers avoid braking and accelerating maneuvers and reduce fuel consumption 8 to 22 percent.<sup>24</sup> In terms of safety, one research study indicated that connected vehicle warning systems and autonomous emergency braking could reduce fatalities by as much as 57 percent.<sup>25</sup>

A recent study by Pennsylvania Department of Transportation (PennDOT) assessed the implications of CAVs on the management and operation of the State's roadway system.<sup>26</sup> CV technology will transform the way that transportation agencies provide traveler information. Messages which currently are displayed through dynamic message signs and radio communications may be rendered obsolete. Instead, traveler information would be disseminated directly to the vehicles using V2I or V2X technologies and onboard units (OBU). In the longer term, full penetration of CAV technology also may eliminate the need for infrastructure such as traffic signals. Intersection movement can be coordinated in real time based on situational awareness of current traffic conditions.

Connected transit may improve the collection of operational and asset data in transit corridors (e.g., travel speeds, parking availability, weather conditions, bus capacity, and onboard condition), increasing the reliability of its service, which in turn facilitates more inter- and intramodal trips. Routes with authorized transit signal priority intersections can help reduce travel time, making transit trips faster than vehicle trips. Connected transit vehicles have the ability to provide desirable amenities to commuters, such as in-vehicle entertainment. Increased mobile data consumption from infotainment services is a potential avenue for additional revenue for transit agencies. Together, these benefits may outweigh the benefits of driving and cause an increase in transit ridership.

The term "connected" is often misunderstood. Some may think that a vehicle is connected simply because there is a smartphone in it. However, any messages sent from the vehicle (e.g., speed, route, location, road conditions, wear and tear on its components, incident notification, etc.) must be received by an entity on the other end who is ready to store and process the message for decision-making and analytics (e.g., travel time prediction, collision warning, real-time vehicle performance monitoring,

<sup>22</sup> <http://www.itsknowledgeresources.its.dot.gov/ITS/benecost.nsf/0/70212CAA6C95BA5D85257B510055CD6E?OpenDocument&Query=Home>.

<sup>23</sup> <http://www.itsknowledgeresources.its.dot.gov/ITS/benecost.nsf/0/844389AFAC48AA4B85257EEB00642F90?OpenDocument>.

<sup>24</sup> <http://www.itsknowledgeresources.its.dot.gov/ITS/benecost.nsf/ID/0/DBE1DFA0628439685257EF30061BF96?OpenDocument&Query=Home>.

<sup>25</sup> <http://www.itsknowledgeresources.its.dot.gov/ITS/benecost.nsf/ID/458522B76F5CF56885257D890073621E?OpenDocument&Query=Home>.

<sup>26</sup> [http://www.dot7.state.pa.us/BPR\\_PDF\\_FILES/Documents/Research/Complete%20Projects/Planning/CMU%20WO%20001%20-%20Connected%20and%20Autonomous%20Vehicles%202040%20Vision%20-%20Final%20Report.pdf](http://www.dot7.state.pa.us/BPR_PDF_FILES/Documents/Research/Complete%20Projects/Planning/CMU%20WO%20001%20-%20Connected%20and%20Autonomous%20Vehicles%202040%20Vision%20-%20Final%20Report.pdf).

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emergency responder dispatch, etc.). Each connected vehicle has the potential to push 25 GB of data to the cloud every hour.<sup>27</sup> This will require systems with immense storage and computing power.

Additionally, from a public agency operations perspective, CAV technology can be thought of as advanced and mobile component of and ITS. The following table shows how existing ITS strategies may evolve to provide greater benefit as CAV technology matures and enters the vehicle fleet in greater volume and capacity. NDOT and the numerous transportation agencies in the state that implement and maintain ITS equipment could benefit from a shared understanding and vision for the transition to greater CAV focus.

**Table 8. Examples of ITS Technology Applications in CV.**

ITS Technology	Traditional/Existing Solutions	CAV Potential
<b>Dynamic Message Systems</b>	Electronic signs provide real-time travel information to motorists.	Motorists can directly receive information inside vehicle.
<b>Travel Time System</b>	In-pavement or roadside-mounted point-to-point sensors read a unique signal and estimate travel time. Existing probe data systems (primarily using Bluetooth technology) provide travel time data to both agencies and private customers.	DSRC can, in the short term, increase the density of probe data and potentially transition to replace current methods. Benefit can be extended to motorcyclists and bicyclists. This is effective even with low market penetration.
<b>Signal Coordination Study</b>	Pretimed signals allow traffic to flow freely through a corridor based on a manual field survey.	Field survey data can be automatically collected through DSRC. This requires medium to high penetration for data accuracy.
<b>Intersection Monitoring and Detection</b>	This technology converts signals from pretimed to actuated logic, where signals will skip approaches when sensors detect no vehicle and the pedestrian push button is not active.	Mitigate negative impacts on motorcyclists and bicyclists who are not detected by complementing sensor data with DSRC signal data.
<b>Adaptive Traffic Signal Technologies</b>	These technologies allow signal logic to change based on traffic condition information collected by sensors.	Traffic conditions data can be collected through DSRC instead of sensors. This would require medium to high market penetration for data accuracy.
<b>Traffic Signal Interconnect</b>	The interconnect slaves traffic signals to a common clock for executing pretimed plans via fiber optics or wireless communication.	DSRC can serve as the wireless communication medium for intersections that are within a 400 meter line of sight of each other.
<b>Close Circuit Television (CCTV) Cameras</b>	CCTV cameras provide real-time visual monitoring of a road facility requiring a high-capacity communications network.	Existing CCTV would help CV deployment, as the existing backhaul communications can be utilized.

<sup>27</sup> <http://qz.com/344466/connected-cars-will-send-25-gigabytes-of-data-to-the-cloud-every-hour/>.

ITS Technology	Traditional/Existing Solutions	CAV Potential
<b>Transit Signal Priority (TSP)</b>	Transit vehicle requests extend green to clear intersection.	DSRC can serve as a wireless communication medium and provide a response to the vehicle advising whether priority has been granted.
<b>Emergency Vehicle Preemption</b>	An emergency vehicle requests overrides of signal timing to provide green lights.	DSRC can serve as a wireless communication medium and provide a response to the vehicle advising whether preemption has been granted.
<b>Pedestrian Push Buttons and Countdown Signals</b>	Pedestrians request walk signals (particularly for adaptive traffic signals) and are provided with a visual countdown of remaining crossing time left.	Disabled or senior pedestrians can request a walk signal and/or extended green time through a DSRC-enabled smartphone.

Source: Adapted from *Connected/Automated Vehicle Impacts on Transportation Planning: Primer*, prepared by CS for U.S. DOT Joint Program Office, 2016.

# APPENDIX B. USER ADVISORY GROUP RECRUITMENT FLYER



*Help shape the future of autonomous vehicles in Nevada.*

Autonomous vehicles (AV) are coming to Nevada. How would a dedicated connected and autonomous vehicle (CAV) roadway between the Tahoe Reno Industrial Center (TRIC) and Reno/Sparks impact your agency, business, and employees?

The Nevada Department of Transportation is conducting a study to determine if a CAV roadway could help minimize congestion on I-80, reduce travel times for TRIC commuters and improve road safety in the area.

To understand how a CAV roadway would affect businesses in the area, we need your help. Join the User Advisory Group to provide feedback on:

- Proposed solutions and improvements.
- AV roadway user needs.
- Operational scenarios.
- Potential pilot tests.
- Business partnership opportunities.

*Signing up for the User Advisory Group is easy.*

Simply email Manju Kumar at [mkumar@dot.nv.gov](mailto:mkumar@dot.nv.gov) to let us know you'd like to participate.

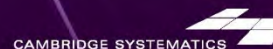
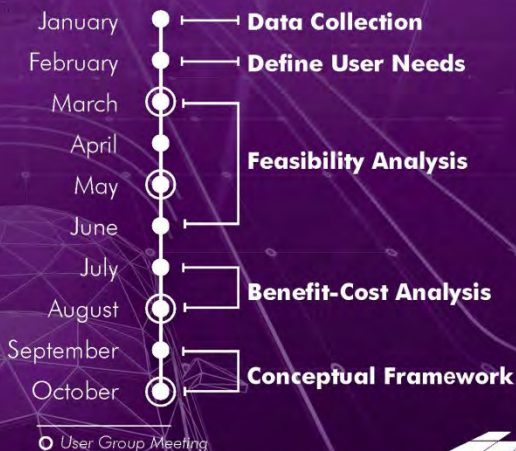
**Joining the User Advisory Group gives you an opportunity to:**

- Advance your business' technology goals.
- Attract employees with high-tech perks like taking an AV shuttle to work.
- Have a voice in the transportation changes coming to Nevada.

*Upcoming meetings focused on emerging technologies in Nevada.*

The User Advisory Group will meet five times throughout the year. You can participate in person or over the phone, whichever works better for you. After joining the group, we will send you a schedule with the proposed dates, times and meeting locations.

Below is a snapshot of the group's activities and meeting schedule:



## APPENDIX C. USER ADVISORY GROUP INTERVIEWS

### *March 12, 2019 Meeting in Reno*

**DATE:** March 12, 2019

**LOCATION:** RTC of Washoe County, 1105 Terminal Way, Reno, Nevada

**ATTENDEES:**

- Gary Bayer, Blockchains
- Sarah Johns, Blockchains
- Chad Anson, CA Group
- Dan Andersen, Cambridge Systematics
- Alice Chu, Cambridge Systematics
- Mark Jensen, Cambridge Systematics
- Thomas Martin, DMV
- Bryan Amenyro, FedEx
- Mike Madden, FedEx
- Juan Balbuena, FHWA—Nevada Division
- Kandee Bahr Worley, NDOT
- Scott Bohemier, NDOT
- Lucy Koury, NDOT
- Manju Kumar, NDOT
- Lewis Lem, NDOT
- Carlos Cardillo, Nevada Center for Applied Research—UNR
- Aimee Chesebrough, Nevada Highway Patrol
- William Murwin, Nevada Highway Patrol
- Chris Walach, Nevada Institute for Autonomous Systems
- Mark Brady, Nevada State Office of Energy
- John Fairman, Nevada State Office of Energy
- Jeff Brigger, NV Energy
- Joel Grace, Reno Land, Inc.
- Kathy Canfield, Story County
- Brynne Merkley, Tesla

## General Discussion

- Nevada Institute for Autonomous Systems—Urban air vehicles:
  - Testing in TRIC, Reno, Las Vegas, Henderson. Also testing passenger drone travel.
  - Want to connect TRIC to Reno.
  - Drones will be dependent on the same infrastructure as Avs.
  - Drones can be used to monitor traffic, air commerce.
  - States with air/ground integration have economic advantage.
- What Avs would you be catering to?
  - Assume Avs will be available to the public for purchase by the mid-2020s. Most likely be integrated into mixed-use conditions.
- How many Avs are there in Nevada today?
  - According to the DMV, there are approximately 100 registered Avs (mostly in Las Vegas).
- Where are the job growth projections from the presentation slides coming from? They seem low.
  - EDAWN projections—may be more conservative than others.
  - Rumor has it that Blockchains alone will hire around 20,000 employees in the next 10 years.
- Traffic conditions:
  - 2016 traffic conditions are not too congested, but during the time it took to complete the traffic study, traffic already grew by another 7,000 vehicles/day.
  - In general, I-80 operates well until there is an incident, in which case the inadequate shoulders exacerbate delays.
- Alignments:
  - Potential to decrease stopping sight distance requirements on an AV roadway from 2 seconds.

## Individual Discussions

- Which alignment is the most attractive may be decided by taking an inventory of the location of existing infrastructure. Switch already invested a lot of money to install fiber. Ground and air vehicles and both tap into this communication system.
- Changing design criteria of a roadway may require getting FHWA involved. States are dependent upon Federal funds for maintenance so they need to follow Federal regulations.

- Concerned with how emergency vehicles, snow plows, etc. will use the roadway alongside Avs.
- Prohibiting trucks seems to be limiting economic development. Is this necessary?
- Perhaps consider only allowing AV technology that meets a certain maturity level to access the corridor. Many companies developing AV technology now are using existing roadways for testing.
- An AV roadway would benefit Nevada Center for Applied Research (UNR) by offering additional opportunities for workforce development. UNR can help define the technology and maintenance requirements. Currently they have people working on LIDAR implementation, using fiber optics, etc. Switch currently is hosting their data center.
- Most agree that TRIC employers would most likely hire 3<sup>rd</sup> party AV shuttles to use the AV roadway (over private passenger vehicles).
- If there is private ownership of the road, we need to consider the ownership of the AV data. There may be benefits of it being a public road.
- Teslas only use camera-based sensors, which are not known to do well in inclement weather conditions.

## Main Points

- Skepticism on cost savings for one-lane bridges.
- Would there be any travel benefits if there ends up being too many Avs?
- Need to consider road damage from AV buses.
- Examine offramp needs.
- Estimated 50–80 percent of employees would use this route.
- Highly suggests southern alignment.
- Does this need to be ahead of AV development? Perhaps this roadway can be used in the short term for non-AV commuter buses until AV technology matures.
- Will we look into air travel/aviation corridor in this study?—We will mention, but not study in-depth.
- South Meadows route would encounter a mountain.

## March 18, 2019 Webinar

**DATE:** March 18, 2019

**LOCATION:** Webinar

### ATTENDEES:

- Chad Anson, CA Group
- Dan Andersen, Cambridge Systematics
- Alice Chu, Cambridge Systematics
- Mark Jensen, Cambridge Systematics
- Jude Hurin, Department of Motor Vehicles
- April Sanborn, Department of Motor Vehicles
- Dan Langford, Governor's Office of Economic Development (GOED)
- Francis Julien, Keolis
- Rob Pyzel, Lyon County
- Kandee Bahr Worley, NDOT
- Scott Bohemier, NDOT
- Ken Chambers, NDOT
- Manju Kumar, NDOT
- Chruszhet Ledesma, NDOT
- Lewis Lem, NDOT
- Bill Story, NDOT
- Bill Thompson, NDOT
- Michael Fuess, NDOT District II
- Jeff Brigger, NV Energy
- Joel Grace, Reno Land, Inc.
- Amy Cummings, RTC of Washoe County
- Julie Masterpool, RTC of Washoe County
- Blaine Petersen, RTC of Washoe County
- Xuan Wang, RTC of Washoe County
- Jasmine Fletcher, Tesla



## General Discussion

- This work is a research project looking at the feasibility of a lower-cost AV roadway.
- AADT has gone up around 7,000 vehicles/day in just two years.
- If I am using my own personal AV. If this study could show the savings over a 6-month period. Mini-bus AV may have more benefits compared to a personal AV.
- Has anyone reached out to the trucking companies to see their interest?
  - Benefits will be deferred costs for trucks. We are limiting vehicles of shuttles, will not build reinforced concrete to support heavy-duty trucks.
- Is there a specific width you have come to calculate for this roadway?
  - This is part of our next steps, how far we can go to reducing roadway width. Will be working on this in the next month.
- Concerns of weather conditions—dust/snow/ice—what considerations are being discussed regarding that—snow plows/EMS/emergency vehicles being able to get in.
  - Our high-level concept proposes 3 lanes with the center lane as an access lane.
- Private or public roadway?
  - All are options. Could be PPP, toll road, etc.
- Do you have any idea how an AV roadway would be any more efficient than a roadway that allows all vehicles?
  - Reduced headways (fitting more vehicles into the same amount of space), reduced infrastructure to support the roadway. We anticipate a lot of people to have Avs by the 2020s.
- Avs are anticipated to increase the number of vehicles on roadways.
  - If Avs are not communicating to each other, then you probably are creating more trips. But there should be benefit if they are communicating with each other.
- If this becomes a significant investment, you do not want to design it for a single purpose.
  - We are not necessarily designing something that NDOT will be building in the next few years.
- Are you considering a new lane to I-80 that is AV only?
  - Needs to adhere to Federal standards, so we rejected that idea.

- You made a comment controlling access to the route.
  - You do not want a non-AV on the roadway. You need to have some sort of toll road-type access to the roadway. Emergency vehicles would need some sort of transponder to get access to the roadway.

## Discussion Questions

### *How Would You Use and Benefit from the AV Roadway?*

1. How would an AV roadway benefit your agency, business, or employees?
2. How would an AV roadway support your business/organization goals? (e.g., reduce commute time, attract talent, support innovation, etc.)
3. How would your organization utilize an AV roadway along this study area?
  - a. Personal AV commuting?
  - b. Employee AV shuttle bus?
  - c. AV parcel delivery truck?
  - d. Other uses?

### Feedback

- If Avs break down, will they be able to be towed out?
  - Yes, 3 lane facility with the extra lane for access of emergency vehicles.
- Would be used by production associates, Monday–Sunday, 24 hours/day?
- In the future, mobility is not only for people, but also for goods. Why not open this to autonomous trucks? Or utilizing the roadway for people in the daytime and freight in the afternoon.

### *What Might Be the Level of Use of the AV Roadway?*

1. The year is 2025 and AV's are now commonplace on Nevada roads. In this new environment, please make a "guesstimate" on what level of usage might your base of employees be expected to use the AV roadway (either in a personal AV or an employee shuttle bus AV)?
  - a. Small (<10 percent of employees).
  - b. Medium (between 10 percent and 30 percent of employees).
  - c. Large (over 30 percent of employees).

### Feedback

- With base model of Model 3 starting at \$35k, by 2020, we definitely see more Tesla employees purchasing Avs.
- What level of autonomy/SAE level are we talking about here?
  - Level 3 and above. May not require a driver.
  - Level 3 to 5
- Our current shuttles are limited to a low speed, but we currently are in the works with something that can handle highway speeds.
- Level 3 will not be appropriate for the type of headways you want to achieve. You will not achieve the level of density you want to achieve in the short term.
  - Level 3 would be a starting point.
- If we have a high percentage of vehicles going to work—should we have 3 lanes going to TRIC and then change back to one lane in either direction, etc.? Reversible lanes.
  - Yes, we would support that flexibility. Helpful that it will not have signage.

### *How Would an AV Roadway Be Implemented?*

1. How could your organization assist in the development of an AV roadway? (e.g., infrastructure, policy, ridership, technology, etc.)
2. Who else would be an important partner or stakeholder to include?
3. Are there any policy constraints to consider?

### Feedback

- Most definitely would be interested in being involved.
- We will be supportive, but it will be dependent upon whether it is a public road or private road. If public, local and State laws need to be considered.
  - For this research project, we are not going to consider local and State laws since we want to do something innovative and different.
- We would like to continue being involved, with our travel demand model.
- Is there any type of legislative person that would need to be involved?
  - Dan Langford is with the Governor's Office of Economic Development (GOED)

- Recommend contacting Michelle White (Chief of Staff of Governor's office), Chris Brooks (Senator)—would be good points of contact on the legislative side.
- I'm trying to wrap my mind around if we have a totally AV roadway, are we trying to bridge a gap. Why not try to convert existing roadways to gain this benefit? There are some companies that have technology that can be implemented into existing roadways. That could be the technology that bridges.
- If we are looking at the future of AV technology, it is easier to assume in 2040 that all vehicles would be Avs. The harder point is the mix that we are going to have in the next 10–15 years. One way to accelerate the benefits is to have corridors like this, in places where NDOT is a pioneer.

## Aptiv

**DATE:** *Thursday, April 25, 2019, 11:30–12:30 p.m. PST*

**LOCATION:** *Conference Call*

### ATTENDEES:

- Dan Andersen, Cambridge Systematics
- Alice Marecek, Cambridge Systematics
- Keir Opie, Cambridge Systematics
- Chad Anson, CA Group
- Steve Bird, CA Group
- Abe Ghabra, Aptiv

### Discussion Questions

- Aptiv background
  - Currently operating in Boston, Singapore, Shanghai, Pittsburg, Las Vegas.
  - Does not operate in Northern Nevada right now.
  - Aptiv's Avs consist of a fleet of retrofitted BMW 5 series vehicles, which will soon be transitioning to a new AV platform.
  - Aptiv Avs have driven over 1 million AV miles without an incident.
- If NDOT were to build a separate CAV-only roadway, which use cases would you be most interested in testing on this facility?
  - Aptiv anticipates that Avs will not have high penetration rates until 2050–2060s, so CAV-only roadways are not their focus right now. Right now, their high-priority use cases (same as the ones shared with City of Las Vegas), all involve interfacing with non-CAVs.
  - What Aptiv *is* interested in is a closed course test track to test their use cases. Today, Aptiv conducts their testing through simulation first before doing real-world testing. Once their unbranded vehicles passes all tests, then they will put their Aptiv labeling on it.
  - In Las Vegas, Aptiv has a test track that includes traffic circles, winding roads, freeways, on-/offramps, and all other situations you would see on public roads.

- A dedicated Point A to Point B roadway/lane would be less useful to Aptiv since it is more limiting in the number of test cases they can use the facility to test.
- What does the ideal test facility look like?
  - Aptiv engineers have the layout of the Las Vegas test track, but an NDA would need to be signed before they can share it.
- What is the accuracy of AV lane keeping algorithms (for potential lane width reduction and shoulder removal/reduction)?
  - If there is a cyclist present, you need to provide them at least 3 feet for comfort.
  - Aptiv Avs can localize down to 1 centimeter because they map out the roads they use in their routes in advance. There are many situations where you may want extra lane width when you need to avoid debris.
- Do your Avs support vehicle-to-vehicle and vehicle-to-infrastructure communications? If so, within what distance would the V2V communication effectively operate?
  - Yes, all vehicles are equipped with DSRC modules and are capable of V2X communications. Currently they can communicate with traffic lights.
  - The distance the V2V communication effectively operates follows CV industry standards.
- If your Avs currently do not support vehicle-to-vehicle and vehicle-to-infrastructure communications, would you be interested in the future in exploring with the State of Nevada the testing of this technology on a Nevada dedicated CAV roadway/testbed?
  - It costs a few hundred thousand dollars to install county-approved traffic lights in Aptiv's test track. They currently are in the process of installing some right now.
  - Right now, when you use cameras to detect traffic light colors (green, yellow, red), the camera is not 100 percent confident, especially when it is sunny in Las Vegas. So Aptiv wants to use V2I communications as a redundant information source to cameras for traffic light status.
  - In the future, when we do not have drivers in the cars, V2V and V2I communications will be much more valuable.
  - In Las Vegas, there are over 100 intersections that are DSRC equipped which Aptiv can use as part of their testing.
- If your Avs support V2I communications, would there be any cases in which the AV would still rely on roadway signage to make decisions, assuming information from traditional roadway signs would now be replaced by "messages" from the roadside equipment installed on CAV roadway?
  - We use our cars to map the roadways using perception systems and sensors to get a high-definition view of road signage and lane markings. We augment the maps with the rules of the

road. The rules break when there is roadway construction, which caused us to start using artificial intelligence. Now our AV system uses a combination of rules-based planning and machine learning.

- Aptiv Avs can operate on non-premapped roads, just not to the high-level degree of confidence as when the roads are premapped. The vehicles can see and feel their way around the world, just not with 100 percent confidence.
- Vehicle characteristics—Are they still going to be the vehicle we see today or will they change in the future?
  - Today's vehicles are built around the driver experience. In the future, it will be designed with the passenger in mind.
- Sight distance—reducing or eliminating the reaction time for sight distance?
  - With Avs, you can get rid of the susceptibility to human errors and distractions.
  - Reaction time can be decreased because Avs can respond in microseconds. An additional half-second reaction time would reduce 60 percent of roadway incidents.
- Given the fact that you are reducing the human error component, do you foresee that you can push the envelope on acceleration/deceleration rates based on the kinematic nature of the vehicle itself?
  - Vehicles on the road today do not represent AV vehicles of the future. They are just retrofitted existing vehicles which allows them to be quickly deployed. This does not change the kinematic nature of the vehicle itself. However, future Avs may be able to push the envelope on acceleration/deceleration rates.
- On an CAV-only roadway, would we be able to reduce following distances/headways? Does it matter if the vehicle in front of you is an AV or non-AV?
  - You do not know what mishap will happen due to human error.
  - Even if you have a dedicated CAV roadway, what if there is an object on the road? Then you are setting yourself up for a crash. If you can ensure that there will not be those types of surprises, then you could platoon with reduced headways.
- Does platooning require both AV sensors and V2V or one or the other?
  - Aptiv would prefer having both for redundancy, but from a technical standpoint, it is possible to use one or the other.
- How do Avs work with passing sight distance?
  - A combination of short-range LIDAR, long-range LIDAR, cameras with different ranges, medium-range radar, and articulating radar (looking over shoulder) provide 360 degree visibility.

- We implement algorithms to determine whether the vehicle is able to pass or not.
- Are manual controls allowed? If so, what are the thresholds/criteria that manual takeover is required and/or allowed?
  - Safety. The driver will disengage any time they do not feel like the vehicle can handle a situation safely. Then Aptiv will simulate the same situation to see what the AV would have done had the system not been disengaged.
  - Aptiv Avs have driven over 1 million AV miles without an incident.
  - We always disengage when we go onto private property out of respect for the property owners.
  - If there is a serious hardware failure in the compute platform, one or more sensors will issue audible commands for the driver to take over. When cars are driverless, there will be a NASA-like mission control center that will monitor the status of the entire AV fleet.
- Does the AV driving logic encourage cooperative behavior at onramps?
  - If the road consists of all Avs, they can be programmed to follow the zipper pattern.
- Is cooperative behavior at onramps still feasible with mixed traffic?
  - We do that today. Non-AV drivers assume Avs will be the most conservative vehicle on the road, so they try to take advantage of that.
- What roadway infrastructure can be eliminated?
  - Would need to keep roadway markings.
- What improved vehicle headway would you feel comfortable with?
  - Abe cannot provide that right now.
- How do you think Avs will impact design speed standards?
  - I would think it could be increased if the roadway contains all Avs.
- What use cases are included in your high-priority product roadmap?
  - Interactions with emergency responders—need to be planned and standardized—This was the use case highlighted in the RTCSNV/City of Las Vegas ADS grant application.
  - How do we communicate our intentions to other roadway users—external facing signage on the vehicles.
  - Same general high-priority roadmap as shared with RTCSNV/City of Las Vegas.



Use Case	Description
External Human Machine Interface	Testing AV road interactions with other road users, including pedestrians, drivers, and bicyclists.
Airport Pick Up/Drop Off	Testing AV-specific airport pick up/drop off (e.g., dedicated pickup spot, less busy roadway, constrained pickup time).
Curb Pick Up/Drop Off	Pilot AV-specific dedicated curbside pick up/drop off using AV-hailing kiosk, allowing Avs to use bus stops outside of bus arrival times.
Construction Materials	Training Avs to recognize construction marking materials and then infer the intent (lane diversion, keep-out areas, or yield instructions).
Post-takeover Resimulation	Use of simulation to determine what would have happened after a human safety driver takes over from the AV if the safety driver had not taken over.
Emergency Vehicles: Detection, Behavior, Access	Training Avs to distinguish emergency vehicles from other traffic in various situations and respond in the preferred, programmed maneuver(s).
Quantification of Risk Level in Operational Design Domain Elements	Help cities/DOTs determine which operational design elements (e.g., signage, obstacles, etc.) should be avoided in future infrastructure planning to in order to support Avs.
Simulation Capabilities	Development of innovative methods to enhance simulation engine capabilities for safety testing and validation.
Validation of Simulation Engines	Research involving the design and conduct of tests on a closed course to evaluate how well autonomous vehicle simulation engines model the behavior of these vehicles in the real world.
Subsystem Safety Requirements	Develop methods and models to decompose an overall system safety goal into subsystem safety requirements for some sample AV architectures.

- With only Avs on the roads, would we be able to remove shoulders?
  - You would probably want to keep them for emergency purposes.
- Do you want us to omit mention of Aptiv in our final reports and just speak in general terms?
  - If you want to mention Aptiv specifically, just provide the materials to Aptiv ahead of time for review.

## EdgeConneX

**DATE:** *Friday, April 26, 2019, 7:00–8:00 a.m. PST*

**LOCATION:** *Conference Call*

### **ATTENDEES:**

- Dan Andersen, Cambridge Systematics
- Alice Marecek, Cambridge Systematics
- Keir Opie, Cambridge Systematics
- Chad Anson, CA Group
- Miguel Payan, EdgeConneX
- Pack Janes, EdgeConneX

### **Discussion Questions**

- EdgeConneX background:
  - EdgeConneX is a private data center developer and manager. They build warehouse data centers which they lease to other companies to host their content. They have built 36 data centers over the past 8–10 years, mostly focused on edge processing. Now they are focused on the road ahead.
  - Miguel is EdgeConneX's mobility leader. He worked on strategy for Samsung and a lot of other large companies. Now he focuses on how CAVs will impact EdgeConneX's business.
  - Pack Janes is on the business development team. His focus is on emerging technologies. Looking into how emerging trends can impact EdgeConneX's business.
  - Currently working on a connectivity proof of concept, where the data CAVs transmit to RSUs get wirelessly transferred to a remote data center.
- Why is edge computing necessary?
  - Edge computing helps reduce the cost involved with transferring CAV data to the warehouse. Data will be processed and then sent to somewhere else. The step where you upload the data to the edge computing node, and then organize/synthesize the data at the edge computing node takes a lot of work.
  - Right now, even getting data off the vehicle is a challenge. AV companies will not trust the infrastructure outside of the vehicle. Right now the latency is being tested.

- Is the edge computing device integrated with the RSU?
  - Right now, RSUs are not that smart. They do not do computing within the RSU themselves. You will want to have a server near the RSU (distance to be determined based on latency, bandwidth, cost) that will serve as the 5G edge computing box.
- Are edge computing boxes agnostic to DSRC or cellular vehicle communications?
  - Yes. Most likely it will be the RSU that receives the data directly from the vehicles and then the RSU will send the data to the edge computing box.
- Is edge computing dependent upon 5G deployment?
  - No, but 5G deployment may help. Edge computing boxes are basically a server at an intersection that may be connected to a fiber cable. The boxes help to move the data through the cloud.
- In an AV-only roadway facility what challenges would we anticipate?
  - Challenges with data transmission (flow and volume).
  - Standardization of the virtual driving system (Tesla, GM, etc. all have their own). How will systems from different AV manufacturers/developers communicate with each other? Can a GM vehicle communicate with a Tesla and with a Ford? That is not happening today. Regulators have not set standards for how that may happen.
  - An AV-only roadway is maybe 10 years out.
  - Long-haul trucking use case is an easier one than passenger Avs.
  - Mcity and another testing lab in Michigan are doing a similar thing.
- There are some standards around BSM transmissions. Is the concern that vehicle companies are not designed to play nice with each other?
  - It is more of a timing issue. The concern is more **when** will that happen. AV companies are fully aware of the need to play nice with each other. In the software, they would have to ensure certain commonalities in the virtual driving systems.
  - But a major problem will be **how** regulators determine how vehicles will communicate with each other and determine what constitutes a safe AV environment. Regulators do not want to squash innovation, but AV developers are looking for direction from regulators.
- If NDOT were to build a separate CAV only roadway, which use cases would you be most interested in testing on this facility?
  - Highly interested in testing the data operational challenges and using edge computing to address challenges such as:
    - How to get AV data off the vehicle in a cost-effective manner?

- How to handle CAV data from the vehicle to the cloud?
- Right now, when Avs reach the maximum storage limit in their vehicle, some AV developers take the disks from the trunk of the car and either FedEx the data to a central location or downloads the data off the disks.
- A lot of companies are developing algorithms using artificial intelligence to determine what CAV data is important and what is considered distracting.
- The edge needs to understand what data needs to be processed. The power required to process the data generates a lot of heat. There is a whole stack of things that needs to happen at the edge in order to support high penetration rates of CAVs.
- There are companies such as NVIDIA that are working on semiconductors/chip sets that have the power to process the data (e.g., NVIDIA Xavier)
- Next steps
  - EdgeConneX wants to participate in as many proof of concepts as possible.
  - EdgeConneX wants to send us their proof-of-concepts to work into this project. We would first need to sign their NDAs.
  - EdgeConneX will send over NDA to Alice. NDOT, CA Group, CS would have to sign it. They are flexible in which NDA we use. They want us to keep them in mind for any city that might be interested in their services/technology.

## Keolis

**DATE:** *Thursday, May 2, 2019, 9:00–10:00 a.m. PST*

**LOCATION:** *Conference Call*

### ATTENDEES:

- Dan Andersen, Cambridge Systematics
- Alice Marecek, Cambridge Systematics
- Keir Opie, Cambridge Systematics
- Chad Anson, CA Group
- Steve Bird, CA Group
- Chris Barker, Keolis Mobility VP

## Discussion Questions

- Keolis background:
  - Chris is based in Phoenix and covers new mobility services in North America for Keolis. He worked at U.S. DOT before working for Keolis. He spent the last two years launching autonomous shuttle service and microtransit options in new areas. Keolis services can be utilized as last-mile connector services. Currently, Keolis has upwards of 35,000 riders.
  - Last year, Keolis launched ondemand microtransit service in Orange County.
  - Keolis' focus is on low-speed environments (25 mph or less).
- Chris—Is the TRIC area a higher speed environment?
  - Yes, the proposed CAV-only roadway would need to operate at at least 45–60 mph to compete with travel times along I-80, which operates at 65–70 mph.
  - Chris knows of tests going on with autonomous buses that can operate at higher speeds.
- What is included in microtransit?
  - Vans that carry 15–20 passengers and are ADA accessible.
  - Some microtransit options (such as the service recently launched in Orange County), include the ability to select origin and destination.
- Are your microtransit vehicles autonomous?
  - Not currently, but in time, they may be. Navya is the manufacturer of the autonomous shuttles. Currently we have one demonstration. May offer as a service for transit service that does not operate at full capacity.
  - Keolis does all day-to-day maintenance of the shuttles. Keolis does planning for ideal routes, infrastructure planning, DSRC signal planning, and wireless communications. They work with a number of shuttle manufacturers.
- Who are you working with in regards to autonomous buses?
  - There are several companies looking to convert buses to autonomous buses, such as Proterra. Keolis will be operating their buses in Reno and already are operating their buses in Orange County, and some in Europe.
  - Autonomous Proterra buses may support 45 mph and up. They currently do not have maximum speed cap.
- If NDOT were to build a separate CAV only roadway, which use cases would you be most interested in testing on this facility?

- Keolis focuses mainly on transit operations.
- Chris anticipates that HOV lanes may turn into autonomous vehicle-only lanes.
- The focus of high-speed buses right now is on moving a lot of people through urban areas.
- Chris—There is not much in terms of fixed-route transit options in that Reno/Sparks-TRIC study area.
  - Keolis will kickoff bus service with Reno in July 2019.
  - Chris thinks the first step is to set up transit services before considering autonomous services. Would need to capture ridership levels first to determine which transit service makes the most sense (e.g., Express buses). This region is going through hypergrowth. Need to figure out where the biggest influx of vehicles is coming from. Express buses may eventually evolve into autonomous buses.
- Chris—Do you know how many employees TRIC is moving back and forth to their campuses on a daily basis?
  - Chad—Depends on who you want to believe. Currently, probably pushing over 10,000 employees and construction workers. With the build-out, we are looking at maybe an increase to 50,000.
- Chris—How near to completion is the Gigafactory?
  - Phase I is complete. It currently is fully operational. They currently are manufacturing Tesla engines.
  - Tesla is a big proponent of avoiding single-occupant vehicles. Approximately 15 percent of survey participants use some sort of carpool to get to work, which makes environmental and business sense. Employers do not want to aggravate employees with poor commute times.
- What is the accuracy of AV lane keeping algorithms (for potential lane width reduction and shoulder removal/reduction)?
  - Depends on a number of factors, including environmental conditions (e.g., snow, rain), speed, etc.
- Do your Avs support vehicle-to-vehicle and vehicle-to-infrastructure communications? If so, within what distance would the V2V communication effectively operate?
  - Our low-speed autonomous shuttles operate at 5–6 minute headways. They can communicate with one another and the infrastructure. There are four different traffic lights that we traverse on the route. The shuttles can understand the difference between red/yellow/green traffic signals and can maintain a certain headway. At higher speeds, this would be different.
- In downtown Las Vegas, how often do AV operators have to take over manual controls?

- Right now, the Navya autonomous shuttles do not recognize hand gestures. If you have obstruction in the roadway, then the operator will take over. In time, you will get to a point where the AV will be able to detect potholes, debris, obstacles, etc. and would be able to alert other vehicles on the road.
- How far in advance do you plan your product roadmap?
  - This is impacted by public policy, what the vehicles are designed to do today and in the future, and user acceptance.
  - We spend a lot of time making sure we do not go too far too fast.
  - We take a lot of user surveys to get feedback on how users feel about the service (safety, comfort, reliability).
  - Keolis is one of the biggest operators of metro service all over the world. Trains are the ideal scenario for autonomous vehicles and western USA is ripe for this type of service. This topic is not discussed much but would be effective in moving a lot of people quickly.
    - Chad—That may work for part of the trip, but the last 3 or 4 miles at TRIC would be an issue.
    - Chris—You would need ideally three to four modes of transit available for any trip.
- Chris—Keolis is interested in how you pull parked cars and vehicles out of urban areas. Our cities are overrun with parked cars. We want to dedicate whole parts of the city to be car-free zones. In one of our service areas, AV shuttles are the only ones allowed to operate in the heritage area. People walk across the street and take an AV shuttle, which are quiet and electric. This improves traffic going to storefronts. The brain today is trying to determine how best to reconfigure land use.
  - High speed is not the highest priority right now, until get the intercity model figured out.
  - In San Antonio, there is a project looking at a high speed AV roadway between San Antonio and Austin from a freight and shipping point of view. A dedicated lane for freight may later be converted for autonomous passenger vehicles.
    - Chris can send us some contacts for this project.

## HNTB

**DATE:** *Friday, May 17, 2019, 10:00–11:00 a.m. PST*

**LOCATION:** *Conference Call*

### ATTENDEES:

- Mark Jensen, Cambridge Systematics
- Alice Marecek, Cambridge Systematics
- Keir Opie, Cambridge Systematics
- Robert (Bob) James, HNTB

### Discussion Questions

- HNTB background:
  - Bob is the National Chief Engineer of Emerging Mobility for the HNTB. He covers the whole country and is located in New York.
  - Some of the projects he is working on include:
    - A bus project for the PANYNJ through the Lincoln Tunnel. It will involve dedicated bus lanes for approximately 3,600 connected buses at any given time. Autonomous features will come over time. Bob is hoping to do a pilot this fall as part of this project.
    - Working with several airports to replace people movers with automated systems.
    - Looking to implement automated rail on Dumbarton Bridge in the Bay Area.
    - Bus Rapid Transit (BRT) corridors around the world. Dedicated corridors in some areas. Manual vehicles have been retrofitted to stay in lanes automatically.
    - Boring tunnel—running automated vehicles.
    - Treasure Island, Detroit, etc.
    - Main focus is on dedicated lanes, shuttles/circulators.
- Did VISSIM modeling for some of the projects.
  - Lincoln Tunnel—Reduced 5.5 second headways to 4.5 second headways based on the assumption that we can have 30 percent of the vehicles retrofitted for automation. This project involves mixed-use traffic. Some of the buses will be autonomous, all will be connected but only a fraction are automated.



- Is it an issue that there is no GPS in the tunnel?
  - Yes, piloting a different technology. Looking to use ultra wide band technology.
- What is the accuracy of AV lane keeping algorithms (for potential lane width reduction and shoulder removal/reduction)?
  - Based on sensors used. Ultra wide band sensors are important to increase accuracy.
  - Do you want to go on the same tire tracks all of the time? For some of the BRT corridors, they are only paving under the tire tracks. There is potential to use loose grade materials and lighter weight structures in between the tire tracks to save cost. For elevated structures, you can allow drainage to go through the lighter weight structures.
- Do your AVs support vehicle-to-vehicle and vehicle-to-infrastructure communications? If so, within what distance would the V2V communication effectively operate?
  - 300 meters for V2V—achievable even with high penetration of connected and autonomous vehicles.
  - With 5G, there will be some change in that area.—Will decrease to approximately 150 meters.
- How would you keep non-AVs off the AV-only facility?
  - AV systems will have to account for non-cooperating objectives and vehicles to some extent.
  - You may want to design entry points that have exit points right after, to try to get non-cooperating vehicles to exit the facility.
  - You will need to include signage to deter non-AVs from entering the facility or use RSUs to notify AVs and enforcement of non-compliant vehicles.
- Are there any reports that you have published that you can point us to?
  - Can send links to articles.
- Would you be willing to confirm our simulation assumptions?
  - Yes.
- Bob knows Jodie Bare, thought that NDOT would be interested in what Vegas has been doing.

## Qualcomm

**DATE:** *Tuesday, May 28, 2019, 9:00–9:45 a.m. PST*

**LOCATION:** *Conference Call*

### ATTENDEES:

- Mark Jensen, Cambridge Systematics
- Alice Marecek, Cambridge Systematics
- Keir Opie, Cambridge Systematics
- Jim Misener, Qualcomm

### Discussion Questions

- Qualcomm background
  - Jim is the Senior Director of Technical Standards at Qualcomm.
  - He leads automotive and transportation standards activities for Qualcomm, with expanded role to include development and executing strategies to establish cellular V2X ecosystems and foster global deployment. This ecosystem shift includes adaptation of ITS standards and application protocols, compliance and certification, trade association strategy and industry/Government acceptance.
- If NDOT were to build a separate CAV only roadway, which use cases would you be most interested in testing on this facility?
  - In the industry right now, AV sensors are so cost prohibitive, that it only makes sense to install them on trucks and high-value vehicles. Need to consider this if you want to increase demand on this roadway in the near future.
  - Qualcomm is interested in two different use cases:
    - 1) 5G New Radio (NR) C-V2X Sidelink Deployment”
      - Sidelink is a 5G-based direct vehicle-to-everything communication
      - At the end of this year/early 2020, 3GPP, the global standards organization for 5G, will complete the next phase of the global 5G NR standard, Rel-16, to include the first specification for 5G NR C-V2X.
      - 5G NR C-V2X has several fundamental enhancements at the radio level that are unique to the technology. Rel-16 will be the first 5G standard to include sidelink—a 5G-based direct vehicle-to-everything communication.

- You can do cooperative maneuvers with other vehicles based on a function of distance all using radio—which guarantees lower latency and higher reliability.
- Anticipates ranges much higher than 300–400 meters.
- Only works with 100 percent market penetration of connected vehicles.
- Will take 4–5 years to come out with a Level 4 AV.
- What physical/ITS infrastructure is needed to deploy Sidelink?
  - 5G compatible chipset installed in the vehicle.
  - RSUs.
  - Point tolling.
  - Minimal physical/ITS infrastructure since it consists mostly of V2V communications.
  - Emergency vehicles that access the AV roadway can be connected but not autonomous.
  - Mainly need to wait for vehicles to support sidelink. Can deploy with PC5 right now, but it is not as reliable as 5G.
  - Would use 40 MHz of the 70 MHz spectrum. If DSRC also exists, then would be fight for spectrum.
- 2) Mobile Edge Computing (MEC)/Multi-access Edge Computing Deployment
  - Network operators (T-Mobile, AT&T, etc.) say that latency issues are caused by the round trip needed to send CAV data to the cloud.
  - To remedy this, more of the intelligence needs to be located at the edge. You can put an edge computing box around 30–50 miles away from the RSUs, which would help to reduce latency dramatically. However, you would need to pay for every transaction to use operator spectrum.
  - What physical/ITS infrastructure is needed to deploy Sidelink?
    - For the Reno/Sparks-TRIC corridor, one MEC located at TRIC should be enough to cover 20 miles of RSUs.
  - Jim can connect us with Julius Meuller at AT&T who is a MEC expert and local if needed.

## APPENDIX D. ACRONYMS AND ABBREVIATIONS

3GPP	3rd Generation Partnership Project
AAA	American Automobile Association
AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
ADA	Americans with Disabilities Act
ADS	Automated Driving Systems
AV	Autonomous Vehicle
BRT	Bus Rapid Transit
BS	Back sight
BSM	Basic Safety Message
C-V2X	Cellular Vehicle-to-Everything
CAGR	Compound Annual Growth Rate
CAV	Connected and Automated Vehicle
CCTV	Closed-Circuit Television Cameras
CUPC	California Public Utilities Commission
CV	Connected Vehicle
DMV	Department of Motor Vehicles
DOT	Department of Transportation
DSRC	Dedicated Short-Range Communications
EDAWN	Economic Development Authority of Western Nevada
EIA	Environmental Impact Assessment
FAVP	Federal Automated Vehicles Policy
FHWA	Federal Highway Administration
FOV	Field of View
FS	Fore Sight
GM	General Motors
GOED	Governor's Office of Economic Development
GPS	Global Positioning System
HAV	Highly Automated Vehicles
HCS	Highway Capacity Software
HNTB	Howard, Needles, Tammen & Bergendoff
HOV	High-Occupancy Vehicle
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of Things
ITS	Intelligent Transportation Systems
LIDAR	Light Detection and Ranging
LTE	Long-Term Evolution
MEC	Mobile Edge Computing

NASA	National Aeronautics and Space Administration
NDA	Nondisclosure Agreement
NDOT	Nevada Department of Transportation
NHTSA	National Highway Traffic Safety Administration
NPRM	Notice of Proposed Rulemaking
NR	New Radio
OBL	Occupation/Business Licensing
OBU	Onboard Units
ODD	Operational Design Domain
OEDR	Object and Event Detection and Response
PANYNJ	Port Authority of New York and New Jersey
PLC	Public Limited Company
PPP	Public-Private Partnerships
PST	Pacific Standard Time
PTV	PTV VISSIM traffic simulation software
ROW	Right-of-Way
RSU	Roadside Unit
RTC	Regional Transportation Commission
RTCSNV	Regional Transportation Commission of Southern Nevada
SAE	Society of Automatic Engineers
SD	Standard Deviation
SDV-NFV	Software-Defined Networking, Network Functions Virtualization
TNC	Transportation Network Companies
TRIC	Tahoe Reno Industrial Center
TSP	Transit Signal Priority
UAG	User Advisory Group
UNR	University of Nevada, Reno
UPRR	Union Pacific Railroad
UPS	United Parcel Service
USDOT	United States Department of Transportation
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything
VMT	Vehicle Miles Traveled



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