GDOT RESEARCH PROJECT 17-23

FINAL REPORT

GDOT ROADMAP FOR DRIVERLESS VEHICLES

Georgia Department of Transportation

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16. Abstract:
This study develops a technology roadmap of the development of driverless vehicles, exploring the likely impacts for the transportation systems of the state of Georgia and the operations of the Georgia Department of Transportation (GDOT). The roadmap consists of two elements. First, a range of contingencies shaping the development pathways for autonomous vehicle (AV) technology is examined through: (a) a review of literature in the research and professional communities regarding AV, and (b) semi-structured interviews with 31 industry and public-sector experts representing a range of development strategies and commercial applications. Second, a range of impacts from AV technology on the transportation systems of Georgia is identified through focus groups with GDOT leadership, managers, and consultants representing the full scope of GDOT operations. By comparing findings between the two elements of the roadmap, implementation strategies to prepare for and manage the deployment of driverless vehicles are developed. Drawing from knowledge gained through these resources, five classes of recommendations were developed that address the following areas of implementation: (1) Developing an Internal AV Organizational Structure; (2) Increasing GDOT Familiarity with AV Technology; (3) Managing External Engagements Related to AV Technology; (4) Data, Analysis, and Performance Indicators for AV Technology; and (5) Managing Outside Activities.

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Final Report

GDOT ROADMAP FOR DRIVERLESS VEHICLES

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LIST OF ABBREVIATIONS

Acronym	Meaning
AAA	American Automobile Association
AASHTO	American Association of State Highway and Transportation Officials
ACES	Autonomous, Connected, Electric, and Shared
ADAS	Advanced Driver Assistance Systems
ADS	Advanced Driving Systems
AEV	All-Electric Vehicle
AI	Artificial Intelligence
ARC	Atlanta Regional Commission
ATA	American Trucking Association
AV	Autonomous Vehicle
AV START	American Vision for Safer Transportation Through Advancement of Revolutionary Technologies
B2B	Business-to-Business
BEV	Battery Electric Vehicle
BSM	Basic Safety Messaging
Caltrans	California Department of Transportation
CAR	Center for Automotive Research
CAV	Connected and Autonomous Vehicles
CV	Connected Vehicle
DMV	Department of Motor Vehicles
DNN	Deep Neural Network
DOT	Department of Transportation
DSRC	Dedicated Short-Range Communications
EDR	Event Data Recorder
EV	Electric Vehicle
FAA	Federal Aviation Administration
FAV	Fully Autonomous Vehicle
FAVP	Federal Automated Vehicle Policy Statement
FCEV	Fuel Cell Electric Vehicle
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
FOI	Freedom of Information
GDOT	Georgia Department of Transportation
GEMA/HAS	Georgia Emergency Management and Homeland Security Agency
HB	House Bill

ICE	Internal Combustion Engine
ICT	Information and Communications Technology
IDOT	Illinois Department of Transportation
IT	Information Technology
ITS	Intelligent Transportation Systems
LaDOTD	Louisiana Department of Transportation and Development
LTE	Long-term Evolution
MAASTO	Mid America Association of State Transportation Officials
ML	Machine Learning
MnDOT	Minnesota Department of Transportation
MPO	Metropolitan Planning Organization
NC	North Carolina
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
ODOT	Oregon Department of Transportation
OECD	Organisation for Economic Co-operation and Development
OEM	Original Equipment Manufacturer
P3	Public–Private Partnership
PennDOT	Pennsylvania Department of Transportation
PHEV	Plug-in Hybrid Electric Vehicle
PwC	PricewaterhouseCoopers
R&D	Research and Development
RPA	Regional Planning Agency
SAE	Society of Automotive Engineers
SB	Senate Bill
SELF DRIVE	Safely Ensuring Lives Future Deployment and Research In Vehicle Evolution
TaaS	Transport-as-a-Service
TNC	Transportation Network Company
TRB	Transportation Research Board
TxDOT	Texas Department of Transportation
U.S.	United States
USDOT	United States Department of Transportation
V2I	Vehicle-to-Infrastructure
V2N	Vehicle-to-Network
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Anything
VMT	Vehicle Miles Traveled

EXECUTIVE SUMMARY

Over the coming years, the Georgia Department of Transportation (GDOT) and other state DOTs will need to prepare for the arrival of driverless vehicles through planning, operations, construction, and research. As a guide to these future efforts, this project develops a driverless vehicle *implementation roadmap*. This roadmap identifies key contingencies in the development path toward driverless vehicles and provides an assessment of the potential technological impacts on the transportation system of Georgia. The developed roadmap will provide guidance to GDOT, allowing for a planned, efficient, and effective approach to addressing developments in driverless vehicle technology.

As a first step, this roadmap provides a synthesis of expert views on trajectories for autonomous vehicle (AV) technology and professional reflections on the types of implementation programs needed to prepare for the arrival of these vehicles. The expert interviews and reviewed literature provide a wide-ranging review of potential AV-technology development trajectories, as well as a review of the impacts that AVs may have on transportation systems and organizations at the state and local levels of government. It is clear that the levels of risk and uncertainty regarding the likely AV technology development paths remain quite high. Critically, while industry experts were able to identify the key characteristics of AV technology that are under development, they were not in a position to recommend to GDOT the likeliest path of development around which the agency can plan. Instead, the outcome from these interviews is that extensive caution must be exercised about early commitments to a particular AV technological path.

Next, the review of potential trajectories of driverless vehicle technology was presented to GDOT leadership, GDOT managers, and consultants engaged with GDOT to reflect on the potential impacts of this technology on the Georgia transportation system and the operational integrity of GDOT. The similarities and differences between the views of industry and outside public experts and the GDOT leadership, managers, and consultants were used to identify key points in the roadmap for AV technology, and the roles that a state DOT may wish to pursue. Drawing from knowledge gained through these resources, five classes of recommendations were developed that address the following areas of implementation: (1) Developing an Internal AV Organizational Structure; (2) Increasing GDOT Familiarity with AV Technology; (3) Managing External Engagements Related to AV Technology; (4) Data, Analysis, and Performance Indicators for AV Technology; and (5) Managing Outside Activities. Briefly, each area may be summarized as follows:

1) Developing an Internal AV Organizational Structure

This class of recommendations includes actions and decisions, seeking to aid in the development of the administrative and support structure for higher levels of autonomous vehicles, including driverless vehicles, within the GDOT organizational structure. Recommendations include:

- Create an internal AV working group drawn from across GDOT
- Define mission statement and objectives
- Determine AV staffing
- Determine GDOT AV promotional role

- Set AV and connected vehicle (CV) organization
- Determine Georgia AV leadership task force

2) Increasing GDOT Familiarity with AV Technology

From the literature, interviews, and focus groups, it was seen that one strong thrust area of the AV working group should be developing processes for expanding the AV knowledge base within GDOT. Recommendations include:

- AV familiarity activities
- AV technology tracking
- Internal AV committees

3) Managing External Engagements Related to AV Technology

AV technology will have an impact throughout Georgia and will include a multitude of stakeholders. Highlighted by the industry experts and seen throughout the literature is that a successful AV deployment will require coordination and cooperation among the many federal, state, local, public, and industry groups that influence or are impacted by AV technology. Recommendations include:

- Develop AV coordination, planning, and actions with other local and state agencies, as well as private industry
- Determine appropriate GDOT involvement in training
- Determine appropriate spokesperson for state AV policy

4) Data, Analysis, and Performance Indicators for AV Technology

Industry experts and the findings from the research and professional literature highlighted that increasing automation technology in vehicles and on the roadway is resulting in a massive increase in data available to monitor and improve the transportation system's safety and performance. It is from the conversion of the massive data streams to performance metrics and actionable information where GDOT will first see tangible impacts of AV, allowing for proactive measures to address other potential impacts and influence the technology deployment. Recommendations include:

- Establish appropriate data scientist staffing levels
- Establish appropriate information technology staffing levels
- Establish data architecture and management system
- Establish AV impact performance indices
- Explore data monetization policies

5) Managing Outside Activities

A number of experts recommended, and other states are involved in, pilot programs and educational and regulatory activities. Several of these activities offer potential opportunities for the GDOT AV program. Recommendations include:

- Initiate involvement in AV pilots, test beds, etc.

- Determine appropriate GDOT involvement in education of public officials regarding AVs
- Determine appropriate GDOT involvement in public education regarding AVs
- Determine the extent of GDOT involvement in regulatory development and enforcement
- Determine whether GDOT approaches to AV technology will focus on freight

The developed recommendations seek to allow GDOT to prepare for the arrival of driverless vehicles, putting in place the internal structures and capabilities necessary to meet the demands of a transportation system evolving to include significant AV participation. When implemented, these recommendations will enable GDOT to anticipate impacts from higher levels of automation (i.e., Level 4 and Level 5, which currently include high and full automation, respectively) and prepare the agency and the state transportation system to best leverage this new emerging technology.

Chapter 1 Introduction

1.1. Project Purpose

Over the coming years, the Georgia Department of Transportation (GDOT) and other state DOTs will need to prepare for the arrival of driverless vehicles through planning, operations, construction, and research. As a guide to these future efforts, this project seeks to develop a driverless vehicle *implementation roadmap*. This roadmap identifies key contingencies in the development path toward driverless vehicles and provides an assessment of the potential technological impacts on the transportation system of the state of Georgia. This report provides a synthesis of the current research and a summary of the state-of-the-art perspectives of experts drawn from across those industries attempting to develop driverless vehicles and the associated complementary technical systems. The review of potential trajectories of driverless vehicle technology was presented to GDOT leadership and GDOT managers to reflect on the potential impacts of this technology on the Georgia transportation system and the operational integrity of GDOT. This research provides a synthesis of expert views on technology trajectories and professional reflections on the types of implementation programs needed to prepare for the arrival of these vehicles. The developed roadmap will provide guidance to GDOT, allowing for a planned, efficient, and effective approach to addressing developments in driverless vehicle technology.

1.2. Background

Transportation has a long history of disruptive technologies. For instance, the electric streetcar opened land up to the first low-density suburbs. The automobile relegated the horse to recreation and vastly increased the distance a traveler could go in a short time frame. Air travel made transcontinental and international travel possible in a matter of hours, instead of weeks or months.

These disruptive technologies of the past have had vast benefits, but they have also had significant consequences. The streetcar was a leading force in defining the form of urban development for the first half of the last century and thus helped to define the accompanying energy demands and environmental impacts. Automobiles resulted in a significant increase in available and affordable personal mobility, leading to unforeseen travel demands and subsequent congestion and safety issues. The speed of airline travel from continent to continent has decreased to mere days the time over which a people and high-value goods can reach every corner of the globe, changing the global economic landscape as well as creating additional risks for a global pandemic.

It has been argued that autonomous (driverless) vehicles (AVs) are poised as the next great disruptive technology. Automobile manufacturers and technology companies are actively testing autonomous vehicles on public roads, and semi-automated driver assist features are already on the market. While significant technological hurdles remain and the timeline for availability to the general public is uncertain, the ultimate arrival of this technology is frequently presented in the professional and research literature as inevitable.

It must be expected that driverless vehicles also hold the potential to remake the transportation landscape in ways both intended and unintended. Nearly every aspect of the transportation system may be influenced by this technology. The Georgia Department of Transportation "plans, constructs and maintains Georgia's state and federal highways." In this role, GDOT will be on the front lines of any widespread implementation of driverless cars on our roadway system, as well as the mitigation of potential negative impacts. While the technical challenges of creating autonomous vehicles have been, and continue to be, deeply studied, the impact of these vehicles on the driver behavior of non-autonomous vehicles remains in many aspects unknown. AVs may require significant new or modified infrastructure, alter traffic operations and flow, impact travel demand, or have unintended negative safety consequences. This is particularly true for the transition period (likely many decades long) as new driverless technologies are introduced into the marketplace.

One of the key contingencies considered in this study is the varying levels of automation currently under development on the path toward driverless vehicles. The standards and definitions of AVs set by the Society of Automotive Engineers (SAE) have been widely adopted. As will be detailed in Chapter 2, they offered 6 levels (Level 0 through Level 5) of automation, ranging from absolutely no automation and full driver control (Level 0) to total automation with no driver control (Level 5). Currently, new vehicles sold in the United States are not available without electronic stability control, meaning that all new automobiles sold have at a minimum Level 1 automation. Over the next few years, manufacturers are expected to continue to introduce Level 2, Level 3, and potentially Level 4 vehicles. For instance, many manufacturers are currently testing Level 3 automated vehicles where drivers are ready to take control but generally defer driving and navigating to the vehicle, and several have begun or are preparing for near-term Level 4 tests.

In this study, respondents were asked to focus on the higher levels of automation associated with a completely driverless vehicle. Interestingly, experts found this a challenging task. The level of uncertainty associated with the technology development paths that will result in a driverless vehicle remains high. Experts did not converge on a limited set of development paths. Instead, they provided a wide array of technological contingencies that are likely to shape the timetables and business cases associated with driverless vehicles. These, in turn, will have significant impacts on the implementation strategies that state DOTs should consider.

As part of this study, the impacts of having a mixture of vehicles on the road that includes driverless vehicles, vehicles with lower levels of automation, and vehicles in which drivers do not have or use automation was explored. Studies that have explored the impact of driverless vehicles tend to start from an assumption of *all* vehicles being autonomous. However, such a future is likely many decades away, if ever, with a long transition period where autonomous and non-autonomous vehicles share the roadway. This transition period will create many of the following challenges:

- Do the system benefits of autonomous vehicles still hold in a system dominated by non-autonomous vehicles?
- What are the impacts of this mixed system?

- Who is responsible for mitigating challenges that arise?

This report reviews the implications of mixed fleets on the implementation strategies that GDOT and other state DOTs could consider in their preparations and strategic planning.

1.3. Project Objectives

GDOT is committed to maintaining safety on Georgia's roadways and providing an efficient, cost-effective system. This research project explores the opportunities and challenges that the driverless vehicle poses toward these values. In this study, the following research objectives are pursued:

1) *Develop a synthesis of current research and thinking on driverless vehicles.* This synthesis incorporates both a literature review and a series of interviews with acknowledged experts in the field to develop an understanding of current knowledge and thinking regarding this technology. A focus of this synthesis is on how various assumptions regarding implementation (e.g., dedicated vs. mixed-fleet lanes, allowable headways, vehicle aggressiveness, behavior of manually driven vehicles, etc.) may impact the anticipated development pathways and potential costs and benefits of these technologies.
2) Develop a roadmap for future actions that should be undertaken by GDOT. This roadmap includes, but is not limited to:
    a. Developing an Internal AV Organizational Structure;
    b. Increasing GDOT Familiarity with AV Technology;
    c. Managing External Engagements Related to AV Technology;

d. Data, Analysis, and Performance Indicators for AV Technology; and
e. Managing Outside Activities.

The developed roadmap will allow GDOT to prepare for the arrival of driverless vehicles, putting in place the internal structures and capabilities necessary to meet the demands of a transportation system evolving to include significant AV participation. When implemented, this roadmap will enable GDOT to anticipate impacts from higher levels of automation and prepare the agency and the state transportation system to best leverage this new emerging technology.

Chapter 2 A Review of the Research and Professional Literatures on Driverless Vehicles

2.1. Introduction – Project Methodology

With automated vehicle technologies nearing market deployment, transportation agencies at all levels of government are recognizing the need to consider their potential impacts and incorporate those insights into their planning processes. As Stanford's Stephen M. Zoepf noted, the United States Department of Transportation (USDOT) had no mention of "self-driving cars" or synonymous terms in any published documentation as recently as 2013 (Zoepf 2018). Since then, however, the USDOT and subunits (e.g., the Federal Highway Administration [FHWA]) have increasingly focused on self-driving cars, both to lay the groundwork for federal policymaking and offer guidance for state and local officials (see section 2.5.2 later in this chapter).

Similarly, GDOT has identified the introduction and scaled deployment of automated vehicles as an upcoming challenge to its future operations and long-term planning objectives, and now seeks a roadmap to help it navigate what could be a decades-long transition period to a driverless future. Though technology forecasting has been a military and corporate practice since at least the middle of last century, only in the past 30 years has a framework for "roadmapping" emerged in academic literature.

While technology roadmapping reviews provide approaches for understanding the factors shaping the development pathways of driverless vehicles, the broader "technology foresight" framework as outlined by Porter (2010) provides more value as a project structure to provide guidance to organizations adapting to technology innovations.

This study incorporates elements of Porter (2010) in the identification of factors and issues related to the implementation strategies that state DOTs should consider in addressing the development of driverless vehicles (Figure 1).

Issues	*Dimension*	*State values*			
Content	Motivation	Extrapolative	Normative		
	Drivers	Science (Research)	Technology (Development)	Innovation	Context
	Scope	Single topic or technology	Multiple technologies	Wide-ranging planning	
	Locus	Institution	Sector	Nation/Region	Global
	Time horizon	Short (1–2 year)	Mid-range (3–10 year)	Long (15+ year)	
	Purpose	Informational	Action-oriented		
Process	Target users	Few; knowledgeable	Diverse		
	Participation	Narrow mix, closed process	Intermediate	Diverse mix, representative process	
	Study duration	Day(s)	Month(s)	Year(s)	

Source: Porter 2010

FIGURE 1

Technology Foresight Typology Relevant Histories of Disruptive Technologies

To develop a scenario-based framework for the development and deployment of driverless vehicles, the introduction of other disruptive technologies from the past two centuries was explored. Much of the industry and consulting literature addressing automated vehicle adoption compares the technology to newer computing devices and infrastructure, such as household Internet, cellular phones, and—most recently—smartphones (Corwin et al. 2016). The comparisons are not completely without merit. As asset management firm Brookfield (2017) noted, the market penetration timeline for these transformative technologies has steadily decreased over time.

Todd Litman of the Victoria Transport Policy Institute (2017) chooses a different approach, labeling automation technology as a cost premium over standard vehicles and comparing it with other automotive innovations such as airbags, navigation systems, and hybrid vehicles. Investment management and market research firm ARK Invest (Keeney 2017) uses another popular comparison: autopilot on commercial planes, which developed in piecemeal fashion from the 1910s through the 1980s. The USDOT considers airplane autopilot an important safety case study for vehicle automation, which is why it included Captain Chelsey "Sully" Sullenberger on its Advisory Committee on Automation in Transportation (Roy 2017).

Each of the aforementioned technologies offers data points useful for assessing deployment timelines and impacts, but three informative case studies are almost completely missing from the literature:

1) Trains and railroads in the early to mid-19th century
2) Automobiles in the late 19th and early 20th centuries
3) Telephone and telecommunications networks in the same time period

The American mentality in the first decades of rail amounted to "get the track laid and the locomotives built, and start running trains as quickly as possible to generate income, even if that means cutting corners that drive up operating costs" (Wolmar 2012). Improvements could be made later, once the line started making a profit. However, rails deteriorated rapidly due to the following: lack of protective fencing led to frequent livestock collisions and derailments, interoperability of proximate lines was frequently impossible, no gauge standard had been set by a regulatory authority, and independent operators eschewed collaboration. Drastically varying state cultures also engendered an uneven deployment of infrastructure and operating models.

Automobiles were at first hardly more useful than horse-drawn carriages and operated on the same roads, but increasingly grew more attractive with technical innovations and the buildout of an infrastructure tailored to support them (Goldstone 2016). They, too, reshaped cities and drove legacy transportation modes into obsolescence. Though early manufacturers of automobiles could operate their vehicles on existing infrastructure built for horse-and-carriage transportation, these roads were overwhelmingly dirt and posed limitations. Only 150,000 of the two million miles of U.S. road in 1904 were considered "improved," (Goldstone 2016) and most of that improved road was gravel. These improved roads were almost exclusively outside major cities, and bridges that could serve automobiles were non-existent.

Finally, telephones introduced the first real-time telecommunications, marking a substantial improvement over the legacy telegraph. However, strong network effects and diseconomies of scale ultimately forced regulators to grant a single provider monopoly power (Wu 2010). Growing the network did not create efficiencies; it created additional complexities that ultimately required rate-setting without competition. This is partially why Bell focused the expansion of his service in East Coast cities, where the density of wealthy customers and businesses made his service more valuable. This story shares significant similarities with the operations of transportation network companies (TNCs) today and likely automated urban fleets of the future.

2.2. Automated Vehicle Technologies

Automation development and research is centralized around “efficiency, productivity, quality, and reliability” (Goldberg 2012; Autor 2015) of systems that are mechanistic and often robotic. Such systems operate autonomously, independent and self-governing, and can be found in transportation, agriculture, security, and many other applications. Of equal importance is the field of robotics, which may be composed of a complex systems integration of components such as sensors, microcontrollers, actuators, processors, and more, yet, can operate autonomously or through human interface (Goldberg 2012).

2.2.1. Levels of Automation

The standards and definitions of AVs set by the Society of Automotive Engineers have been widely adopted by actors developing in this space. Even further, SAE has worked with the National Highway Safety Traffic Administration (NHSTA) to align these definitions with USDOT policies (SAE International 2016; NHTSA 2016). The Eno Center for Transportation demonstrates these definitions (see Table 1), as adapted from SAE and NHTSA (Lewis et al. 2017).

TABLE 1
AV Classification and Definitions

Level of Automation	**Name**	**Automated System Role**	**Human Role**
Level 0	No Automation	No role.	All driving functions of the vehicle.
Level 1	Driver Assistance	Features such as adaptive cruise control or lane centering.	Responsible for all core driving functions.
Level 2	Partial Automation	Conducts some parts of driving such as acceleration, deceleration, and steering.	Responsible for monitoring outside driving environment and ready to take control with or without warning from the system.
Level 3	Conditional Automation	Performs most driving functions in most driving environments. May request human to intervene for specific driving tasks.	Must remain ready to take control and respond appropriately to the AV systems' request to intervene.
Level 4	High Automation	Conducts all driving tasks and monitors environment. Can only operate in certain environments and designed for specific situations, such as pre-defined shuttle routes. No steering wheel, pedals, or mechanisms required for a human.	Human is present but does not need to take back control.
Level 5	Full Automation	Conducts all driving functions in all driving environments without a human driver.	Human controls destination and navigation input but does not control vehicle at any point.

Source: Lewis et al. 2017

2.2.2. Assisted Driving vs. Full Automation

It has become common in popular press and media outlets to use the term "autonomous vehicles" as a blanket term to discuss this technology. SAE and NHTSA have attempted to distinguish driverless vehicles by using the term "automated driving systems" (ADS) to describe full automation at Level 5 (SAE International 2016). Lower levels of automation (Levels 1 through 4) are characterized as "advanced driver assistance systems" (ADAS) (SAE International 2016) and feature technologies that alleviate the driver from specific driving demands. This report adopts the SAE classification scheme throughout this report. The use of the term "driverless vehicle" refers to Level 5 automation. However, many of the respondents demonstrated a tendency to lump levels of classifications together, sometimes using AV to refer to Level 4 and Level 5 collectively.

As drivers begin to grow accustomed to these offered features, there may be a decline in driver skills before refined levels of automation reach the road (Ponsard et al. 2017). A parallel scenario played out with aviation auto-pilot features, reported by the Federal Aviation Administration (FAA), where pilot flying skills diminished over time due to the excessive use of auto-pilot features (Flight Deck Automation Working Group 2013). As a result, the FAA has implemented standards for when pilots are able to access and utilize these advanced features.

2.2.3. Trajectory

Currently, no vehicles featuring greater than Level 3 autonomy are commercially available, though multiple firms are expected to launch ride-hailing services between 2018 and

2021. These services require what would be considered Level 4 autonomy features. Waymo is planning a 2018 launch of its service and GM Cruise has said it will launch an AV ride-hailing service in 2019. (Boudette 2018; Muller 2018). Other firms, including Daimler, Ford, and Uber, are promising first deployments between 2019 and 2021 (Kehnscherper 2018; Boston 2017; Fingas 2018). Other firms have targeted deployments as late as 2030, if they have set public timelines at all (Lewis et al. 2017). Several startups are developing platooning, teleoperations, or trucking-specific automation platforms (Hall-Geisler 2017; Marshall 2018).

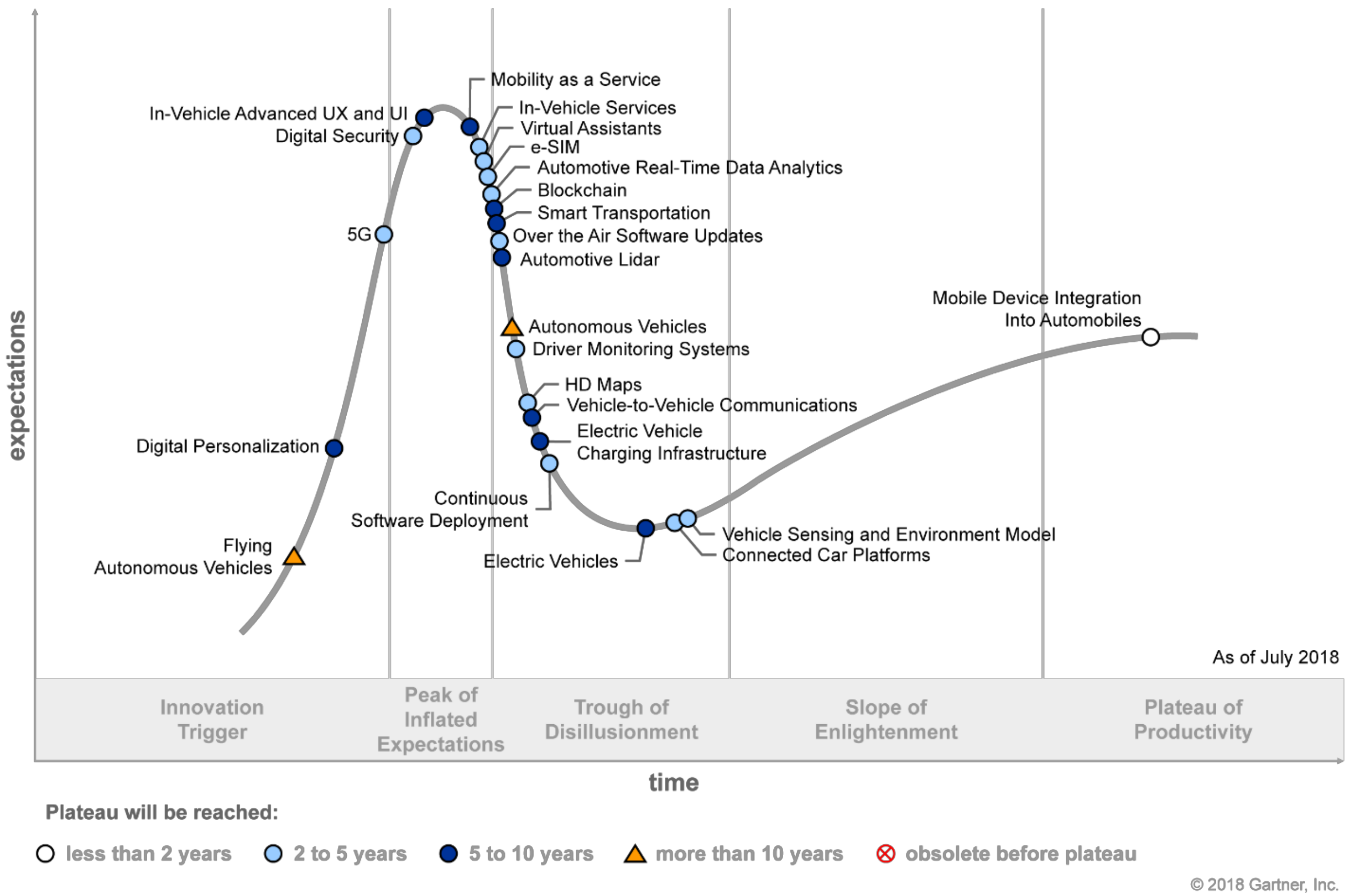
Other insights have been vague, at best, to depict the trajectory for technology deployments. The Organisation for Economic Co-operation and Development (OECD) has examined AV technologies and conducted research to inform policymakers of potential time frames, yet has not given any solidified periods of deployment (International Transportation Forum 2015). Recommendations from the OECD have portrayed private and public transit AV deployments between 2020 and 2030 (International Transportation Forum 2015). RethinkX predictions demonstrate individual ownership of cars gradually declining beginning in 2021, as TaaS (transport-as-a-service, a model that depicts AV on-demand mobile services) participation increases significantly (Arbib and Seba 2017).

Market research firm Gartner publishes annual updates to its “hype cycle” for all emerging technologies, grouped by market sector, and in 2018 moved automated vehicles from the “peak of inflated expectations” to the “trough of disillusionment (Ramsey and Isert, 2018). The hype cycle, as pictured in Figure 2, captures a development cycle that all technologies roughly follow from their “innovation trigger” until they reach maturity. Technologies move to the "peak" when media coverage and investor sentiment is overwhelmingly positive and is mismatched with technical progress and commercial reality. Gartner moved AVs in 2018 due to multiple crashes involving partially automated vehicles and missed deployment timelines from developers, and the analysis still places AVs more than 10 years away from maturity.

2.3. Connected Vehicles

Connected vehicle technologies are those that allow vehicles to communicate with other vehicles, infrastructure, or external devices. The primary function of these capabilities is to provide information to drivers that enables them to make safer driving decisions, which can also augment automated driving systems (Murtha et al. 2017). Connected vehicles fit into the intelligent transportation systems (ITS) framework, which has developed over the past several decades to apply information and communications technology (ICT) to transportation.

Broadly speaking, these technologies fall into two categories: short-range and long-range telecommunications. Long-range technologies include cellular and satellite-enabled communications, and short-range technologies include essentially everything else. Moreover, these technologies fall into several categories of functionality: vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-anything (V2X), which accounts for both V2V and V2I, as well as other devices and cloud networks (V2N).



Source: Ramsey and Isert 2018

FIGURE 2

Gartner 2018 Hype Cycle for Connected Vehicles and Smart Mobility

Since 2006, NHTSA has been working with industry manufacturers to determine the feasibility of dedicated short-range communications (DSRC) as a systemic standard (NHTSA 2014). NHTSA anticipates DSRC will serve as a complement to additional technologies employed for V2X communications, and has limited a potential mandate to basic safety messaging (BSM). This would cover mostly threat detection from other vehicles and road conditions. The agency has pursued the mandate out of concern for interoperability of V2X systems, and acceleration of market penetration (USDOT 2017a). In November 2017, the Trump Administration signaled it would not move forward with a DSRC mandate, though NHTSA has issued no final decision (Estrada, 2017).

Currently, the telecommunications industry standard for cellular service is 4G LTE (long-term evolution), and for several years that standard was considered insufficient to provide serious V2X utility. That changed in 2016, when a new V2X-specific design of LTE was formalized, and the standard released. This standard, called LTE-V 3GPP Rel. 14, provides bandwidth and latency capable of managing all connected vehicle (CV) requirements (Flore 2016).

2.3.1. Cybersecurity

Cybersecurity presents a significant challenge for connected and autonomous vehicles (CAVs) because failure tolerance will be effectively zero. Vehicle security and safety will rely in large part on cyber systems, and therefore public acceptance of CAV technology depends on effective cybersecurity (Murtha et al. 2017; Bordonali et al. 2017). Hackers could disrupt wireless signals or seize control of CAVs, directly threatening any captive passengers (Bordonali et al. 2017; Lewis et al. 2017). They could also compromise vehicles through physical connections, notably at electric vehicle charging stations. Moreover, every connection between vehicles and within their system architecture represents another potential vulnerability (Watney and Draffin 2017).

McKinsey & Company notes that system architecture in today's vehicles is more oriented toward practicality than security. This would need to shift as more features are exposed to external connections (Bordonali et al. 2017). Automakers are aware of their vulnerabilities and lack of preparedness, but face increasing supply chain and architecture complexity challenges that further complicate their cybersecurity efforts. Automotive suppliers are even less prepared than the carmakers themselves, and their hardware represents additional vulnerabilities (Bordonali et al. 2017).

Manufacturers have taken several new approaches to address various cybersecurity threats, including limiting connectivity to reduce vulnerability windows, and proactive threat detection through the use of internal "white hat" hackers (Watney and Draffin 2017).

2.4. Policy Environment

Policies from both the executive and legislative branches of the United States federal government will shape the deployment of AVs. At present, the federal government is also serving as the primary regulatory authority and facilitator of technological development. States will also have a role, though the federal government will preempt states on design and telecommunications issues.

2.4.1. Federal

The NHTSA Federal Automated Vehicle Policy Statement (FAVP) was released in September 2016. An updated version of the FAVP was released in September 2017, now referring to the technology as "Automated Driving Systems" and substantially reducing the size of the document (NHTSA 2017). The most significant change in the guidance was its emphasis on the voluntary nature of the safety self-assessment for AV technology testers, where in the first edition it was mandatory. Two firms have submitted these safety self-assessments to date, Waymo and GM Cruise (Waymo 2017; GM Cruise 2018). USDOT Secretary Elaine Chao has stated that NHTSA will publish a third version of the FAVP in 2018, and it will be "multi-modal." Therefore, the policy will cover all travel surfaces, including ground, air, and water (Rogers 2018).

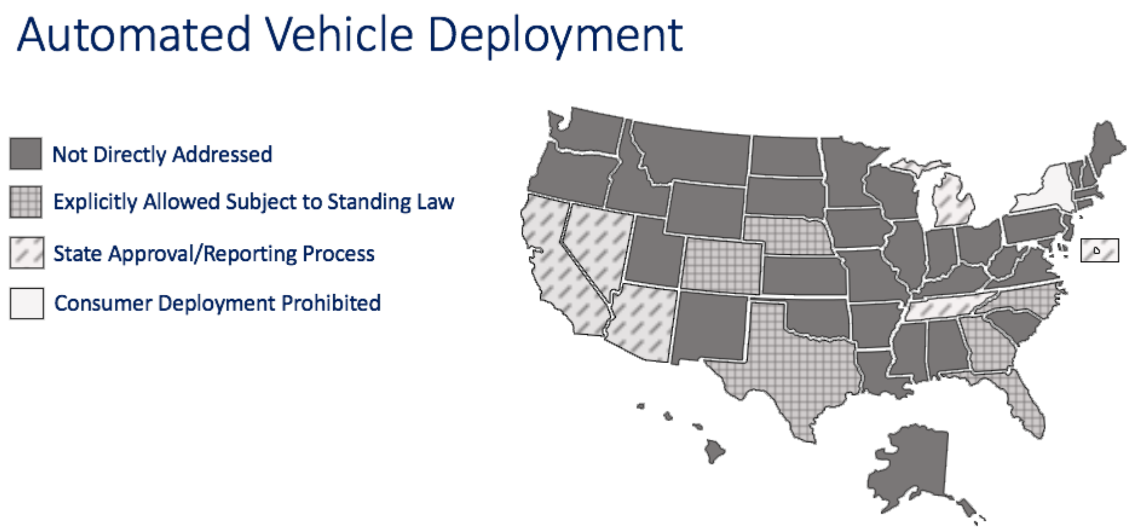
2.4.2. Legislative

Introduced in the U.S. House of Representatives on July 25, 2017, the Safely Ensuring Lives Future Deployment and Research In Vehicle Evolution (SELF DRIVE) Act includes the following points: recommendations on NHTSA and State authority regulation adoption, cybersecurity interests, testing and piloting guidance, consumer awareness and information approaches, data privacy plan, and the creation of a 'Highly Automated Vehicle Advisory Council' (House Bill 3388 2017). This bill was pending at the time of this report.

Another piece of corresponding legislation, the American Vision for Safer Transportation Through Advancement of Revolutionary Technologies (AV START) Act, was introduced in the U.S. Senate on September 28, 2017. The primary components of the bill seek to outline guidance for the following: improve manufacturer safety reporting techniques; encourage manufacturers to work with state and local governments to ensure compliance with respective laws; instruct the USDOT to update motor vehicle safety rules and requirements; develop and adopt cybersecurity policies to address vulnerabilities; identify and develop standards for data procurement, storage, and sharing; and promote consumer awareness (Senate Bill 1885 2017). This bill is still pending further action.

2.4.3. Georgia and Other U.S. States

The state of Georgia introduced legislation related to AVs from 2014–2018. In 2017 and 2018 the state passed GA H 472 and GA S 219, which provided definitions and early licensing standards for operators of AVs in the state. These laws help to identify and define autonomous vehicles, provide guidance on testing and use of the technology, and more. Georgia's law explicitly permits platooning, as do all five of its neighboring states (Florida, Alabama, Tennessee, North Carolina, South Carolina), which means freight operators could legally cross state lines with platooned vehicles. Rather than pass laws requiring the commission of a study on AV implications and legalization of testing, Georgia fully legalized deployment provided the vehicles meet federal design standards and operators are licensed to do so. As shown in Figure 3 (which depicts only legislative activity, and not that of executive orders or other policy strategies), Georgia is one of several states that permit commercial deployments of automated vehicles.



Source: Dennis 2018
*Map does not include executive orders.

FIGURE 3

Map of State Legislation Permitting Automated Vehicle Deployment

2.5. State DOT Activities

Though U.S. research on AVs spans decades, state DOTs started preparing for AV technology relatively recently. Activity was sporadic and confined to just a few states until 2015 and has accelerated significantly since then.

As of this report, at least 35 of 50 state DOTs have engaged in at least some activity organized around AV technology readiness. However, these activities vary greatly in terms of commitments (both financial and human resources), objectives, and outputs. Moreover, most states have bundled automated vehicles and connected vehicles. In some cases, DOTs already had programs aimed at addressing CV technologies, and simply expanded their scopes to include AVs. The DOT activities are organized around the following general classifications:

- Funding of research through university partners
- Commission of a strategic roadmap through consulting firms
- Development of a study or report required per legislation or executive order
- Leading or participating in a standing committee, working group, or advisory council
- Creating programs to organize and/or manage AV-related activities in the state
- Sponsoring or participating in pilot programs for testing AV technology

As of this report, 14 states have published a major strategic roadmap or statewide impacts report focused on AVs: Delaware, Florida, Iowa, Kentucky, Maryland, Massachusetts, Michigan, North Carolina, Oregon, Pennsylvania, Texas, Utah, Virginia, and Wisconsin. These documents range in scope, audience, and depth, but all are intended to inform policymakers at DOTs or in elected government. The DOTs in California, Florida, Texas, Michigan, Oregon, and North Carolina are identified as potentially useful models for GDOT as it considers how to address AV technology.

2.5.1. California

California is widely recognized as a leader in AV technology both in terms of private-sector investment and development, and the public sector's willingness to sponsor research and testing activities. The state has allowed testing of AVs with a safety driver on public roads since 2014, with the California Department of Motor Vehicles (DMV) managing registration and oversight of testing programs (California Department of Motor Vehicles 2018). Each firm registered to test must submit an incident report for any collisions after they occur, as well as a year-end disengagements report itemizing every situation in which the AV's software failed and returned control to the human driver. Because these reports are not properly standardized and are susceptible to strategies by AV developers seeking positive press coverage, some AV industry analysts have questioned their utility (Abuelsamid 2018; Harris 2017). However, as no other private firm's test data is publicly available, these reports have nonetheless become an industry benchmark for performance. As of August 2018, there are 57 firms registered to test in California.

The agency has also sponsored and/or participated in a number of CAV demos over the past decades, including the highly publicized Demo '97 in San Diego. That demonstration was the culmination of a multiyear research initiative called the National Automated Highway Systems Consortium, sponsored by nine organizations, including the California DOT (Caltrans; Auer et al. 2016). Most recently, it was a co-sponsor of the San Diego Association of Governments proposal that USDOT named one of its 10 designated AV proving grounds in January 2017 (San Diego Association of Governments 2017). Though the agency has sponsored very little in the way of academic research and has not developed an AV-specific roadmap to date, Caltrans officials have been active in national AV symposiums and workshops.

2.5.2. Florida

Florida has been at the forefront of automated vehicle research and testing since it passed its first legislation in 2012. The following year, the state hosted its first annual Florida Automated Vehicles Summit, organized in part by the Florida DOT (FDOT), which has consistently featured support and involvement from DOT resources (Florida DOT 2014). FDOT organized three working groups of multidisciplinary stakeholders (Policy, Modal Applications, and Technology & Infrastructure) that published their findings on AV impacts in 2015. Moreover, FDOT has sponsored several pilot programs experimenting with CAV technologies and applications.

FDOT has sponsored multiple research initiatives with university and consulting partners, including the following reports:

- *Enhanced Mobility for Aging Populations Using Automated Vehicles* by Florida State University, which studied AV safety and the technology's ability to enable greater mobility for elderly populations. The study also studied critical public acceptance considerations, and surveyed attitudes toward the technology (Duncan et al. 2015).
- *Surveying Florida MPO Readiness to Incorporate Innovative Technologies into Long Range Transportation Plans* by the University of Florida, which examined the long-range transportation plans of each of Florida's metropolitan planning organizations (MPOs) and surveyed respondents at those organizations to study CAV readiness (Srinivasan et al. 2016).

- *Identification of Autonomous Service Vehicle Requirements* by Embry-Riddle Aeronautical University, which explored potential applications of AV technology for DOT operations, including inspection and maintenance of infrastructure (Coyle et al. 2016).
- *Envisioning Florida's Future: Transportation and Land Use in an Automated Vehicle World* by Florida State University, which assessed AV impacts on the built environment and offered preliminary recommendations for DOT infrastructure investments (Chapin et al. 2016).

The agency has also commissioned other relevant reports through Florida Atlantic University, the University of Central Florida, and Bishop Consulting/HNTB.

2.5.3. Texas

Much like its counterpart in Florida, Texas DOT (TxDOT) has assumed an active role in supporting AV testing and deployment, having already funded several major research projects and supported pilot programs across the state. TxDOT-sponsored research initiatives include the following reports:

- *Implications of Connected and Automated Vehicles on the Safety and Operations of Roadway Networks: A Final Report* by the Center for Transportation Research at the University of Texas, which surveyed consumer acceptance to estimate deployment timelines for AVs, and analyzed potential safety benefits and associated cost reductions from the technology's adoption (Kockelman et al. 2016).

- *An Assessment of Autonomous Vehicles: Traffic Impacts and Infrastructure Needs, Final Report* by the Center for Transportation Research at the University of Texas, a follow-on study that assessed a wide range of potential AV impacts and offered a more comprehensive planning roadmap for the state, including suggested AV truck platooning corridors and test beds (Kockelman et al. 2017).
- *Transportation Planning Implications of Automated/Connected Vehicles on Texas Highways* by the Texas A&M Transportation Institute at Texas A&M University, which specifically addresses commercial vehicle transportation and freight, as well as possible impacts to travel modeling (Williams et al. 2017).

TxDOT is also a leading sponsor of the Texas AV Proving Grounds Partnership, one of the 10 sites to win USDOT designation (U.S. Department of Transportation 2017b). The initiative incorporates multiple university partners and other research institutions, and involves multiple test sites statewide in both urban and rural environments (Texas A&M University 2016).

2.5.4. Michigan

Given Michigan's position at the center of the American automotive industry, much of Michigan DOT's focus on automated vehicle technologies has had an economic development and/or industry collaboration component. The state worked with the Center for Automotive Research (CAR) to identify and detail AV development activities from 2014 through 2016, and published those findings in a report (CAR 2017). Michigan DOT also played a significant role in the establishment of Mcity, a large CAV test facility affiliated with the University of Michigan that opened in 2015 (CAR 2017). The agency partially funded the facility's initial construction, donated out-of-service equipment to support testing operations, and remains a major Mcity partner alongside other public- and private-sector stakeholders (Mcity 2018).

Michigan DOT hired CAR to organize and manage a quarterly working group of industry and public-sector stakeholders (Center for Automotive Research 2018). The agency also recently hired engineering consultancy WSP to develop a strategic roadmap for the agency on connected and automated vehicle technologies, though it has not published the report as of this writing (WSP 2018).

2.5.5. Oregon

Oregon DOT (ODOT) completed a connected vehicle applications roadmap in May 2016 (Bertini and Wang 2016), produced by research partners at California Polytechnic State University and the University of Oregon. This project, while focused on CVs, incorporated substantial research into AV impacts and ODOT's preparedness for the technology's introduction. The report's literature review primarily focused on AV technology as a feature closely tied to CV architecture, and assessed potential impacts of increasing automation on Oregon's roadways (Bertini et al. 2016a). Another report deliverable surveyed more than 100 ODOT employees on their awareness and attitudes toward both CV and AV technologies (Bertini et al. 2016b). While respondents demonstrated a general willingness to embrace CAVs and believed these technologies would improve road safety, they also expressed significant concern around privacy and external threats. They also agreed the agency was unprepared to embrace CAV adoption, as it had neither the technical knowledge in-house, a track record of success in information technology (IT) project implementation, nor financial resources to retrofit infrastructure sufficiently. Finally, they highlighted the urban/rural cultural split within ODOT and noted there may be resistance to adoption from rural offices. Some employees suggested the agency had a role in educating the public about CAV benefits, dispelling unwarranted concerns, and possibly sponsoring demonstration projects to increase public acceptance.

Legislation in 2018 (HB 4063) created Oregon's Task Force on Autonomous Vehicles, charged with developing recommendations for future AV legislation (Task Force on Autonomous Vehicles 2018). HB 4063 charged the Director of Transportation with appointing 27 of the task force's 31 members, drawn from a diverse group of industry, advocacy, and government stakeholders. The bill also required this task force to deliver a report with recommendations for the following policy areas by September 2018: licensing and registration, law enforcement and crash reporting, cybersecurity, and insurance and liability. The task force delivered this report on September 10, addressing permitting for AV testing, and recommendations in the designated policy areas.

2.5.6. North Carolina

North Carolina DOT contracted consulting firm Kimley-Horn to develop an assessment of CAV readiness and strategic roadmap, resulting in a 2016 report titled *NC Readiness for Connected and Autonomous Vehicles* (Kimley-Horn 2016). The report cited Florida and Michigan as model leaders on AVs, as both had already moved forward on legislation, and were investing significantly in AV research and testing. To execute recommendations, Kimley-Horn proposed the creation of three working groups comprising internal resources and external stakeholders: Law and Policies, Infrastructure, and Business. The report recommended DOT action items across seven discrete areas: (1) Group Structure and Organization; (2) Political Leadership, Engagement; (3) Changes to Laws and Motor Vehicle Codes; (4) Long-Range Transportation Plans; (5) Mobility and Access Improvements; 6) Pilot Projects and Research; and 7) Outreach/In-Reach Strategy.

Pursuant to the passage of state AV legislation in 2017, North Carolina's Fully Autonomous Vehicle (FAV) Committee convened for the first time in March 2018. It featured all three of the proposed working groups ("Law and Policies" was renamed "Legislative") and two additional groups: Research and Operations (Kimley-Horn 2018).

2.5.7. Other States

Since the beginning of 2016, legislation and executive orders in multiple states have required DOTs to issue standalone reports or participate in special committees to study AV impacts statewide. Notably, Oklahoma is the only state to geographically limit the scope of its report, requiring only study of the I-40 Corridor (Johnston 2018). Colorado and Ohio have both created formal programs under the direction of their DOTs to coordinate and manage all connected and automated vehicle activities in their respective states (Colorado DOT 2016; Ohio DOT 2018). Among Georgia's other neighbors, the South Carolina, Tennessee, and Alabama DOTs have not engaged in any major AV activities, though they are working on some CV projects that are more limited in scope.

2.6. Development Factors

Outside safety considerations, multiple factors will shape AV development and the technology's deployment timeline. Some of these are social or policy considerations, while others are economic or technological in nature.

2.6.1. Consumer Acceptance

Automated vehicles will need to overcome perception challenges for widespread adoption, and survey data from the past several years shows the technology still has an uphill climb. An American Automobile Association (AAA) poll from January 2017 found that three-quarters of Americans feared riding in a self-driving vehicle, and only 19% of them would trust the technology (AAA 2017). The numbers improved when AAA repeated the survey in January 2018, to 63% fearful and 28% comfortable, but the numbers still skew heavily against acceptance (Edelstein 2018). Reuters found similar results in 2018, with 67% uncomfortable against 27% comfortable (Lienert 2018). The numbers do improve steadily with younger generational cohorts, as both 2018 polls show millennials far more accepting than baby boomers. Both polls show men far more trusting of AV technology than women (Lienert 2018; Edelstein 2018).

2.6.2. Electric Vehicle (EV) Technologies

According to Energy.gov, "there are two basic types of EVs: all-electric vehicles (AEVs) and plug-in hybrid electric vehicles (PHEVs). AEVs include battery electric vehicles (BEVs) and fuel cell electric vehicles (FCEVs). In addition to charging from the electrical grid, both types are charged in part by regenerative braking,…" EVs tend to have a range of 80 to 100 miles, with some up to 250 miles. Charging times range from 30 minutes to a day. PHEVs allow for the extension of range through the use of an internal combustion engine when the battery is depleted (Energy.gov).

Many analyses of automated vehicle adoption assume these vehicles will be battery-powered electric due to lifecycle costs. RethinkX argues higher asset utilization make electric vehicles more attractive for fleet-based services, given their lower maintenance and energy costs. The authors also argue the shift toward electric vehicles will have the double-edged effect of increasing economies of scale in battery and electric vehicle production, while reducing them in gasoline refinement and internal combustion engine (ICE) vehicle manufacture. This dynamic will further increase the attractiveness of electric vehicles (Arbib and Seba 2017). Chen et al. furthers the EV argument for AV by also highlighting the current expectation that AV implementation will likely be through fleets. Fleet management will allow for addressing concerns such as range anxiety and charging found in today's privately owned EVs. In addition, fleet operations increase the potential for optimized charging station locations; although, tradeoffs between optimal charging locations and minimizing user travel times were observed in the study models. Finally, significant advantages were seen in user service provided and reduced demand during peak charging times with Level III fast charging stations (30-minute recharge time for 80-mile range) versus Level II charging (4-hour recharge time for 80-mile range); although, Level III charging incurred additional costs (Chen et al. 2016).

Due to the large number of sensors and cameras, and robust software packages necessary to operate CAVs, energy requirements are so high that internal combustion engines may make little sense. However, current battery technology is also insufficient to support CAV operation at anything but short range (Stewart 2018). Some automakers and AV developers are skeptical BEVs will be capable of supporting AV fleet requirements for the near future.

Finally, regardless of the progress of AV, EV is expected to continue to penetrate the market. Bloomberg's New Energy Finance group predicts that rapidly declining production costs will make EVs cost-competitive with ICE vehicles by 2025, with sales of EVs finally surpassing ICE vehicles in 2038. This trajectory would give EVs a one-third market share of the global auto market by 2040 (Shankleman 2017). Energy Policy Solutions noted the rate of EV adoption is accelerating, and it forecasts EVs will constitute 65% of all light-duty vehicle sales in 2050. High oil prices or technology breakthroughs could push the EV market share as high as 75% (Rissman 2017).

2.6.3. E-Commerce

McKinsey and Company estimates that, by 2026: (1) nearly all package deliveries to homes will be done by fully automated vehicles (including drones); and (2) 80% of all goods will be delivered this way. Larger business-to-business (B2B) customers and high-rise apartments with substantial quantities of packages delivered, and certain specialized goods will likely continue to require human delivery (Joerss et al. 2016). E-commerce firms may experiment with different delivery schemes to improve customer experience (Tamietti and Kim 2017). Cities will need to ensure sufficient curb space to accommodate increased package delivery volume (Henry et al. 2017). However, dedicating facilities for these purposes, as well as for other AV uses, may anger local residents who previously used the space for parking (Zmud et al. 2017).

2.6.4. Data Management, Privacy, and Ownership

The increased flow of data to and from AVs will allow firms to create new revenue streams from the use or sale of that data. The vehicle's developers will want performance data to improve software, but customer information may also be sold for advertising purposes (Lewis et al. 2017; Murtha et al. 2017). There may be no way to travel "off the grid" without having one or more commercial entities tracking an individual's every trip (Henry et al. 2017).

Additional regulatory protections may be necessary for customer privacy in fleet-based operations, and would need to cover any cybersecurity breach (Lewis et al. 2017). As all AVs will be equipped with cameras and sensors, they will likely have enough information to recreate crashes, and will need to retain that data in the case of an incident.

2.6.5. Freight

The Atlanta Regional Commission (ARC) noted in its 2016 transportation technology impacts analysis that contemporary labor challenges in trucking could lead that industry to be among the first widespread adoptions of AV technologies (ARC 2016). McKinsey also cites increasing labor costs as a driver for accelerating freight automation (Joerss et al. 2016). The American Trucking Association (ATA) forecasts a shortage of 75,000 drivers by

2024, and those that continue to drive are overwhelmingly older and male (Henry et al. 2017). Uber argues that fears of massive jobs losses with the introduction of automated trucking are overblown, and that reoriented distribution models and increased demand will create more short-haul jobs than eliminated long-haul roles (Uber 2018).

Automated trucking would almost certainly produce cost reductions in the shipping of goods, through labor cost reductions and improved asset utilization (Tamietti and Kim 2017). One of the key AV implications ARC identified in its report was a reduced cost of freight due to the automation and electrification of trucks (ARC 2016). A PricewaterhouseCoopers (PwC) survey of manufacturers found they expected automating freight would reduce their transportation costs by 30% (Koenig 2018).

Testing to date has generally shown that all vehicles involved in truck platoons achieve fuel savings of varying degrees. Lead vehicles save fuel at an average rate of roughly 4%, and following vehicles receive a greater benefit of anywhere between 8–10% in savings (Henry et al. 2017; Lammert et al. 2014; Faife 2017). Long-haul freight will operate predominantly on highways, which present far less challenging operating environments for AVs than dense urban areas. This should accelerate adoption (Henry et al. 2017). The more limited operating environment combined with the reduced reliance on human driving should also create safer highway environments (Zmud 2017).

2.6.6. Insurance and Liability

ARC expects that driver licensing requirements will need to change with the introduction of personal automated vehicles, depending on the level of technology deployed

(ARC 2016). In a study performed by Detroit-based law firm Miller Canfield and market research firm JD Power, 62% of survey respondents indicated interest in completing additional training to receive a special designation on their driver's licenses that would allow them to operate automated vehicles (Westenberg et al. 2018).

Depending on the degree of automation, liability will shift either partially or completely from personal to commercial product (Tamietti and Kim 2017; Lewis et al. 2017). Low levels of automation place a clear burden of responsibility on the driver, where the highest levels clearly shift that burden to the AV developer or operator. Level 2 and 3 AVs will present more challenging cases, as the lines between human and machine responsibilities are blurred (Lewis et al. 2017). Increasing insurance requirements for AV operators may also prompt them to adopt more robust safety standards and quality-control mechanisms (International Transport Forum 2015).

NHTSA requires that all new vehicles sold in the United States have an event data recorder (EDR) installed to capture the moments leading up to, during, and after a crash (Westenberg et al. 2018). However, the amount of data stored today is minimal compared with that stored in the aviation industry, and it is not standardized. AVs at higher levels of automation will capture and store significantly greater levels of data than current automobiles, though that also complicates torts cases. Legal experts surveyed by Miller Canfield and JD Power expect the discovery phase of product liability lawsuits will grow longer and more expensive as both sides cultivate experts capable of interpreting increasingly complicated data to evaluate fault and depose more witnesses from manufacturers and software developers.

2.7. Impacts

The mere introduction of AVs will impact existing transportation services and infrastructure, and scaled deployments may have transformative economic, social, and political effects. Transportation agencies will need to consider appropriate levels of investment in existing and future assets, including both roadway infrastructure and transit. Vehicles may have completely different interactions with non-motorized modes of transportation, as well as emergency vehicles. Cities will also need to assess their parking policies and data sharing agreements with CAV operators.

2.7.1. Physical Infrastructure

Among the first initiatives the National Cooperative Highway Research Program (NCHRP) launched in its series of AV/CV projects is an evaluation of the requirements for road markings in an age of machine vision (Pike, 2018). The report has not yet been published, but Caltrans, one of the research partners involved in the study, has already acted on initial findings. It announced in January 2017 that it would remove all "Botts' dots" from its roads as it resurfaces them over the coming years (Bizjak 2017). Botts' dots are ceramic bumps installed as lane markings that drivers feel as they switch lanes, though only select states utilize them. Because these bumps are difficult for machine vision systems to see, Caltrans decided to remove them, and move toward more artificial intelligence or AI-friendly standards of lane markings (Bizjak 2017).

Although these enhancements would potentially accelerate adoption, they may be unnecessary long-term. AV operators do not want to remain dependent on perfect infrastructure conditions for reliable operations, and they are developing other mechanisms to safely automate lane-keeping and decision-making. Moreover, with automated lane-keeping and reduced human error, road widths can be narrowed to increase throughput (Public Sector Consultants and CAR 2017). A different NCHRP analysis argued that increased vehicle miles traveled (VMT) would impose greater roadway maintenance costs and, therefore, require greater investment from state and local transportation agencies (Zmud et al. 2017).

2.7.2. Transit Ridership and Interactions

Automated vehicles could have an uneven impact on transit, based in part on local population densities and how effectively transit agencies deploy the technology themselves (Guerra 2016). Transit will likely compete with private AVs, whether personally owned or fleet-based, and the problem will be especially acute in lower-density suburbs. Local governments may need to operate their own AVs or subsidize connections to transit assets to remain competitive (Henry et al. 2017). Automated shuttles of smaller size than existing buses could complement existing transit assets by providing last-mile service at low cost. However, smaller automated transit vehicles may have one or few other passengers in them, and people may not be comfortable riding transit with complete strangers under those circumstances (Lang et al. 2017).

2.7.3. Pedestrians and Bicyclists

Most collisions between vehicles and non-motorized forms of transportation occur at intersections, largely the result of poor driver awareness and detection of pedestrians and bicyclists. Both vehicle automation and connectivity offer potential collision-avoiding and life-saving applications through increased detection and/or notification capabilities (Sandt and Owens 2017). With generally increased awareness over human drivers, CAVs will have fewer collisions with pedestrians and bicyclists (Murtha et al. 2017). V2X applications may also improve vehicular interactions with pedestrians and bicyclists at intersections. One of USDOT's three V2X pilot projects is exploring these interactions in Manhattan (Zmud et al. 2017).

2.7.4. Emergency Vehicles and Law Enforcement

Waymo has been working with law enforcement in Chandler, Arizona, to train its automated vehicles to recognize and respond appropriately to emergency vehicles, using both sound localization and visual detection technologies (Moon 2018). Law enforcement officers will also need mechanisms for communicating and stopping automated vehicles in the instance of a traffic violation. They and emergency responders may be able to use a standardized set of wireless messages to communicate (Public Sector Consultants and CAR 2017).

2.7.5. Travel Demand and Traffic Flow

The impact of automated vehicles on traffic and congestion is highly uncertain due to a number of unknown variables. If fleet-based adoption models prevail, reduced car ownership may induce greater sharing and lead to fewer vehicles on the road. However, improved mobility services for children, the elderly, and the disabled may generate more travel from those groups (Murtha et al. 2017; Zmud et al. 2017). This increased mobility may reduce trip-chaining and create more solo trips, as well as incentivize longer commutes for those in the suburbs due to reduced cost of travel time, all of which would increase VMT (Public Sector Consultants and CAR 2017).

According to the FHWA, roughly 25% of congestion nationally is caused by accidents, and automation has the potential to greatly reduce roadway collisions. Increased AV market penetration could increase roadway capacity anywhere from 25% to 90%, per different estimates (Henry et al. 2017).

2.7.6. Parking

Cities should develop plans for repurposing both on- and off-street parking facilities in the event AVs do reduce parking demand (Arbib and Seba 2017). Cities may be able to reduce or altogether eliminate parking minimums (Henry et al. 2017). However, AVs that are not shared may also weigh operating costs against parking costs and travel greater distances after drop-off to avoid expensive parking fees. This would produce greater VMT (Henry et al. 2017; Public Sector Consultants and CAR 2017). The University of Sydney's David Levinson argues cities will need to price roads to balance against parking costs, otherwise empty vehicles will cruise on roadways rather than pay for parking (Pethokoukis 2017).

2.8. Data Broker

Since state and local transportation agencies own the roads on which AVs will operate, they will have some leverage in negotiating data sharing agreements. Planners would benefit from ridership data, as well as real-time positioning data that these AVs will collect, but will need to identify which data is worth collecting (Lewis et al. 2017; Murtha et al. 2017). Cities and states should launch open data initiatives to ensure planners can utilize this data for public benefit (Arbib and Seba 2017; Henry et al. 2017). State and local agencies can build from existing models for public–private partnerships (P3s) with mapping firms, including Waze, HERE, and INRIX, to establish models for HD mapping and other real-time data requirements (Public Sector Consultants and CAR 2017).

2.9. Conclusions

This review of the research and professional literature helped identify key factors and contingencies shaping the development of AV technology. In this review, it is found that the focus on AV technology development is focused primarily on automation lower than Level 5, i.e., fully driverless vehicles. Instead, as seen in the research literature, the actions of policymakers, and in the studies commissioned by state DOTs, there is broader foci on AVs, inclusive of lower levels of automation, or CAVs, inclusive of connected and autonomous vehicles. While Level 5 may be an ultimate goal, actors in industry and the policy sectors are focused more on the pathways toward Level 5 and the varieties of technologies and automation that inhabit these pathways.

The number of factors and contingencies identified on these pathways toward Level 5 also indicates that the amount of uncertainty associated with this future state remain significant. At the outset, the authors of this study were perhaps also influenced by the “hype cycle” associated with driverless vehicles and had the expectation that there would be a limited number of scenarios likely to lead to Level 5 automation. The review of the literature suggests otherwise. Thus, protocols for both the expert interviews and for the focus groups with GDOT managers were adapted to a broader review of technology contingencies in the development of driverless vehicles, rather than restricting respondents to a narrower range of scenarios.

Chapter 3 Expert Interviews

3.1. Introduction

In this chapter, the research team presents findings from interviews conducted with industry experts and public-sector agents who have experience working with AV technology. Since the focus of this study concerns the impact of driverless cars on Georgia's transportation system, interviewed experts were asked to project forward in two important ways. First, they were asked about the likely path of technology development that will produce Level 5 automation in vehicles. Second, they were asked to consider the consequences of different levels of market penetration of Level 5 vehicles on the roadways. This approach challenged industry experts to go beyond the traditional confines of a technology roadmap exercise (i.e., charting a path for the emergence and commercialization of a technology). Here experts were asked to identify those aspects of the technology that are likely to impact developing, implementing, and maintaining transportation systems. Following this portion of the interview, the experts were asked what roles, if any, they see state and local DOTs playing in the AV development and deployment.

The research team talked with 31 industry professionals and public-sector agents over 25 semi-structured interviews. Respondents were selected to represent a range of perspectives related to AV technology development. Industry experts were drawn from entrepreneurial startups to large corporate research and development (R&D) programs, and also represent companies working in different aspects of AV technology development. During the course of this investigation, interviews were also conducted with two distinct groups of public-sector officials. The research team selected state DOT officials based upon their leadership experience and expertise in AV technology. It also interviewed a set of officials from local DOT offices in the Atlanta metropolitan area. These officials were selected because of their knowledge of Georgia's transportation system, and current patterns of technology adoption and deployment in the Atlanta region.

This chapter presents an analyzed synthesis of those interviews addressing the following topics: interview participant attributes (i.e., academic, career, and technical experience), projections of a timeline for AV development, projections on AV technology impacts, challenges to AV adoption, overstated barriers for AV deployment, complementary and competing disruptive technologies, and industry expectations for the public-sector role in AV development and deployment. Those areas of alignment across the varying industry perspectives are examined, as well as important areas of variance. The question protocol used in these interviews can be found in Appendix C.

3.2. Interview Participants

Experts who participated in the AV interviews covered industry, public, and academic domains, providing significant breadth and depth of insights into the AV industry and its impact on transportation. Experts interviewed varied significantly in educational and professional experience. The earlier part of their careers represented a wide array of experiences, such as line mechanics, logistics, automotive management, technology research and development, software development, telecommunications, AI and machine learning, energy, law, entrepreneurship, think tank research, media, robotics, transportation systems, consulting, and a range of academics (e.g., physical science; biology; psychology; and computer, civil, electrical, and agricultural engineers). Their current roles in AV technology also varied widely, including transportation systems impact analysis, mobility and accessibility, human behavior, energy efficiency, agriculture, parts development for AVs, AV software (e.g., platforms, applications, AI and machine learning, big data, etc.), first- and last-mile transportation, freight, teleoperation, legal issues, policy, as well as others. Appendix B provides a list of the individuals interviewed for this study.

Many of the experts were also engaged with various governments and industry partners locally, regionally, and globally. A number of the experts had at some point worked at or contracted with government agencies. The experts have also participated in a wide array of community outreach activities, symposiums, and organizational committees. They said they saw these engagements as an opportunity to communicate the benefits and progress of AV technologies, as well as address the concerns of public officials and their constituents.

The public-sector experts interviewed performed a variety of roles at public agencies, including general civil engineers, materials personnel, project developers, traffic operations specialists, information technology specialists, and geospatial analysts. Moreover, their organizational experience ranged from lower management to executive leadership. Of the public-sector experts, many had, to varying degrees, begun to engage in strategic planning to better prepare their respective organizations and communities for AV technology deployment.

3.3. AV Timeline

> *"Autonomous vehicles, people have been wanting this since the 1950's, and we think it's going to be remarkable when it starts to roll out and it looks viable, the adoption is going to be crazy" – Interview Participant*

The experts interviewed revealed sharp divisions in opinion over the speed at which AV technology will be deployed commercially. Timelines ranged from a few years, to 10 to 20 years, to several decades. Interviewees also disagreed about the market segments most likely to see initial AV deployments (i.e., fleets vs. freight, etc.). However, most experts readily acknowledged uncertainty in their predictions.

3.3.1. Timeline: Slow Perspectives

A number of the experts saw AV technology developers creating market-ready Level 4 and 5 prototypes in 10 to 20 years. The projections for slower timelines were particularly associated with affordable AVs for passenger use. One expert viewed near-term deployment dates as an overstatement about technological capabilities and likely availability of models for widespread adoption. One expert noted that manufacturers and regulators are still working on benchmarks for demonstrating Level 4 technology is safe for public consumption. Given these conditions, vehicles featuring Level 3 and 4 autonomy are more likely to be the norm rather than Level 5 autonomy. Many experts also closely associated EV technology with AVs, and one expert anticipated that development of AV technology would accelerate as auto manufacturers increase production of EVs.

3.3.2. Timeline: Fast Perspectives

In contrast, several experts had a faster timeline. One noted that AV freight technology is already available and has successfully demonstrated it can operate on long stretches of highway without human input. This expert noted that a startup has been field testing an automated tractor trailer that was able to complete a coast-to-coast journey. Experts projecting a faster timeline for deployment also tended to highlight Waymo, with one expert pointing to Waymo's recent application to California for testing driverless vehicles using Level 4 vehicles. Several experts projecting a faster timeline for deployment claimed that a fully autonomous fleet could provide 50% of rideshare trips within 5 years within a set urban area. A key factor perceived as enabling or hindering a fast timeline for deployment is government policies. These experts noted that jurisdictions aggressive in promoting AV technology are more likely to see faster and more widespread deployments.

One industry expert supporting a faster timeline, who also has decades of experience in the tech sector, said that he had never seen demand so great for a new technology. A key metric for monitoring demand is the number of pre-orders for vehicles equipped with automation technology. Partnerships between Waymo and Chrysler, as well as Waymo and Jaguar, have generated pre-orders of more than 82,000 AVs to date. The expert added perspective by noting that the number of taxicabs in New York City numbers roughly 18,000, accounting for approximately 4% of the total vehicle miles traveled in the city. The expert anticipated that fleet companies could be operating between 40,000 to 50,000 AVs in the next few years.

3.3.3. Timeline: Mixed Perspectives

Other industry experts projected mixed patterns of targeted early deployments, but with wider adoption coming over a longer time horizon. While they saw widespread deployment as more likely occurring by 2045 to 2050, they identified several examples of possible early deployment, including:

- *Ridesharing.* Rideshare was seen as an initial-use case of this mixed timeline group as well, projecting that early AV deployment will occur primarily through fleets designed for ride-hailing applications. Over time (20 to 30 years), people will find it more cost-effective to use ride-hailing and ridesharing services versus personal car ownership. The cost of owning a car and keeping it parked for most of the day will not be competitive with the lower costs offered by mobility services.
- *Synergies with Connected Vehicles.* Another expert, while acknowledging this pattern of deployment in certain sections of the city, also noted that there are synergies at work with CVs that are likely to be deployed earlier than AVs. Thus, AV deployment may also benefit from layering over where CV infrastructure has already been deployed.
- *Buses and Shuttle Buses.* Another example of early deployment (2025 or 2030) offered by industry experts focused on controlled routes for buses and smaller

shuttle buses in urban areas, on college campuses, and airport facilities. These deployments can be enhanced with secondary infrastructure and geofencing that create highly controlled environments where AVs have little interaction with human-driven vehicles.

In further arguing against quick deployment scenarios, one expert noted that many of companies projecting deployment by 2022 are already failing to meet projected AV development milestones. This expert believed that the often-stated comparison to the fast rise of ridesharing companies (e.g., Uber and Lyft) is not meaningful, as those services required minimal new technology development. Significant development is still needed for Level 3 and 4 AVs, let alone fully operational Level 5.

3.3.4. Adoption Location

Industry experts also expect that the timeline for deployment of AV technology may vary by geographic location. This argument was made in a variety of forms:

- *Rural vs. Urban.* Several experts suggested that rural and urban adoption will likely differ, with rural adoption lagging. They noted that given the infrastructure and density of rural environments, the market case for deployment is not as clear.
- *Climate.* Industry experts also indicated that initial deployment will probably favor warm-weather cities that offer less challenging environmental settings for the technology (i.e., less snow, ice, and other forms of inclement weather).
- *Long-Haul Freight.* In addition, industry experts who work in or are closely connected to freight movement also indicated that timelines will likely differ for

passenger vehicles and commercial freight. They noted that commercial vehicles (i.e., class 6 to 8 delivery trucks and tractor trailers) typically lag passenger vehicles by 2 to 3 years in technology development and integration. They anticipated that freight AVs may be deployed first at night, when human traffic is low.

- *Legal Infrastructure.* In considering timelines, one expert also noted that in the majority of states, it remains illegal to operate AV technology on public streets. This expert indicated that as consumers observe AVs in action, their reservations will disappear and remove market barriers to adoption. This would increase pressure on the legal and regulatory environments to adapt to AVs.

3.4. AV Impact

AVs are commonly referred to as a disruptive technology, as their anticipated impacts will be far-reaching. The interviewed experts identified a number of potential impacts, highlighting those anticipated for infrastructure, safety, quality of life, deployment, transit, freight, logistics, vehicle ownership, productivity, licensing, mobility cost, public finance, and vehicle design. However, several industry experts recognized that these only begin to touch the surface of potential AV impacts.

3.4.1. Impacts: Infrastructure

One of the strongest sentiments across industry experts was their view that AV technology needs to adapt to the roads as they currently exist. Most experts stated that for the near future, AV technology must be able to recognize and operate alongside human-driven vehicles, pedestrians, and bicyclists in the current mixed-user environment. Several experts noted that driverless cars should not require any change in existing approaches to building or maintaining transportation infrastructure. However, these sentiments do not necessarily extend to long-term changes in infrastructure design and operations, due to changing demands and use cases resulting from AV technology's increased market penetration.

While there was agreement among industry experts that an AV should not necessarily require infrastructure changes, they differed on how much infrastructure designers should anticipate the arrival of AV technology to accelerate deployment of supportive technology. For instance, one industry expert argued that designers of both transportation systems and vehicles should err on the side of facilitating AV technology through vehicle-to-infrastructure communications, and improved signage and striping. However, one industry expert cautioned that infrastructure designers should hold off on efforts to accommodate AVs until firms are closer to producing Level 4 and Level 5 automation. Until then, anticipated solutions may simply generate new problems. Several experts echoed the sentiment that there is currently too much uncertainty about AV technology to change approaches to infrastructure design.

Many experts did agree that vehicle automation will facilitate reallocation of curb and street space over time—replacing it with multimodal designs. Several examples identified include:

- Wider sidewalks
- Additional opportunities for bike lanes or bus rapid transit lanes

- Road and parking space reclaimed for residential and commercial purposes
- More affordable residential real estate by removing parking costs
- High-density buildings designed to incorporate AV pick-up and drop-off zones through curbside management
- Commercial real estate parking garages designed to allow for future conversion to additional living space
- Narrower roads

Ultimately, experts believed that the use of infrastructure will shift in the long run, as the number of human-driven vehicles drops to zero. Vehicles will be able to travel at higher speeds and closer together, perhaps in tight platoons. Roads may have narrower lanes, less congestion, and increased throughput efficiency. When this occurs, signage, pavement markings, and other types of signals may no longer be needed, or may be redesigned. However, even the most aggressive estimates of universal Level 5 AV adoption are measured in decades, with only limited dedicated AV-only facilities designed in the near future.

Finally, experts highlighted the role of local governments. Several industry experts described having close working relationships with local DOTs, noting that this level of government will best be able to influence the way AVs will impact existing land-use patterns and curbside use. Several of these experts identified parking as a major example of where AV adoption will change existing land use plans, and promoted parking structures that can be converted later to residential or commercial uses.

3.4.2. Impacts: Safety and Quality of Life

Nearly all of the experts were confident that AV technology would greatly reduce fatalities and serious injuries long-term. However, they raised concerns about quality of life impacts, citing a potential that AV could primarily benefit the affluent. Numerous experts stated that how AV is implemented will shape these outcomes, and that government may play a role in guiding implementations. Some industry experts felt the technology could improve equity and transportation access. For instance, some believed that AVs will permit greater mobility for elderly and disabled citizens.

3.4.3. Impacts: Deployment

One expert recounted a demonstration video prepared by Zipcar founder Robin Chase entitled *Heaven and Hell*, illustrating two opposing AV deployment scenarios. The “Hell” scenario featured a high rate of single-occupancy vehicles with Level 4 AVs clogging streets, extending commute distances, and increasing congestion. In “Heaven,” ridesharing is pervasive, mitigating congestion and increasing sustainability. Expert opinions spanned both extremes, and a range of potential outcomes between. For instance, one expert believed the likely impact of AV will be more diverse, with multiple models playing out (between Heaven and Hell), including better coordination with—and sometimes competition with—transit. Other experts similarly noted that technologists will develop platforms and vehicles to meet the variety of mobility and transportation needs in the market. One expert stated that AV technology would be in "carefully constrained domains," with daylight, weather, quality of roads, and complexity of the road use playing significant roles.

3.4.4. Impacts: Transit

As ridesharing is seen as a likely initial-use case, it is not surprising that a number of industry experts viewed AVs as having a large influence upon existing transit services. One acknowledged fears that AVs may “kill” transit. This expert pointed to studies of large urban areas that suggest rideshare services lead to a net decrease in transit ridership. Thus, some early evidence favors competition of technology rather than complementarity of technology. However, several experts also argued that it is too soon to assess how AV ridesharing technologies will interact with transit. For example, AV ridesharing could replace public transit in areas where there are high-cost, low-quality services, allowing transit agencies to focus on high-density routes that serve as a backbone for the transportation system. Therefore, AV ridesharing services would address shorter trip needs, as well as first mile/last mile connectivity to public transit. In addition, the scatter-gather-hub model of public transit in the U.S. will create incentives for AV fleets to focus on first mile/last mile segments rather than replacing public transit. Finally, the urban transit bus operates in high-density areas with large numbers of pedestrians, which is an extremely challenging environment for AV technology. Transit agencies operate on very thin margins, leading several industry experts to the view that AV technology will be slow to compete with urban bus systems.

One industry expert suggested that what is emerging today is a multi-modal transportation environment where ridesharing, bicycles, scooters, and various forms of transit are alternative modes of mobility. However, these modes are operating in a system currently dominated by single-occupancy, owner-operated vehicles; recent surveys found that 80% of drivers never use transit and 75% of drivers commute to work alone every day. As AVs are integrated into fleet operations, they have the potential to change consumer behavior toward access to a wider range of mobility services. For example, studies of ride-hailing customers found them much more likely to also use transit, compared to individuals who drive personal vehicles to work.

3.4.5. Impacts: Freight

Most experts interviewed believed that there will be many impacts to the freight industry, AV technology adds too much economic value for freight and logistics firms not to take advantage of it. However, these impacts will be dependent on the development trajectory of AV technology, and what regulations will permit. Some industry experts interviewed are focused on developing technology solely for the freight industry, and are actively working on pilot projects. A few experts argued that integrating AV technology into the trucking industry will be relatively easy, with the more difficult piece being the refinement of the operating model. However, others believed the trucking industry will not begin to see major impacts from AV technology for another 20 to 30 years, with operators incrementally adding automated driving assistance features over a long period of time. One expert raised a key question around whether freight applications of AVs will operate primarily in highway environments, or also extend to the last mile, bringing goods and services directly to residences.

Several industry experts noted that one impact from AV technology in freight will be to increase incentives for platooning with longer "trains" of vehicles operating at higher speeds and in closer proximity to one another. Several interviewees work for firms that have been piloting truck platooning technology several years, and many of the experts agreed that increased fuel efficiency is one near-certain outcome of the technology. However, other industry experts were skeptical about arguments for platooning, noting there are simpler innovations currently available to trucking companies that would achieve equal or greater fuel savings, but have yet to be adopted.

Industry experts noted that one possible impact from AV technology is in addressing the driver shortage in the freight industry. Even though sensor suites may cost hundreds of thousands of dollars for a fleet of trucks in capital expenditures, eliminating labor costs and boosting asset utilization by running AV trucks around the clock would improve fleet economics. However, other experts expressed a view that while the truck-driving role will fundamentally change and become easier, it will not disappear. One expert noted: “There are a lot of tasks the truck drivers do minute-by-minute and day-by-day that will be very difficult to write code and account for. There will need to be a radical overhaul of the transportation system and trucking regulations for there to be any structured or streamlined automation adoptions.” Another expert said the introduction of AV technology in freight may change the role of the driver (and in some cases, owner-operator) to a model where humans in freight vehicles are providing services and managing logistics. Nonetheless, those interviewed expressed a common view that, in the long term, AV technology will impact the freight industry and its labor force.

Finally, one public-sector expert indicated their state is investigating the impact of AVs on platooning of vehicles, including freight, and raised several concerns. First, state laws will need to be changed to gain efficiencies from increased platooning. Second, there are public safety concerns associated with human-driven vehicles operating in an environment where a train of multiple driverless trucks are operating in close proximity. Third, there are public acceptance concerns for mixed environments of AVs and human-driven vehicles around driverless heavy vehicles. Fourth, there is concern around impacts on the pavement of having essentially a digital rail, where a large train of large load-bearing trucks are traversing a single line of the roadway at high speeds.

3.4.6. Impacts: Logistics

Hand-in-hand with freight, industry experts agreed that there will be major impacts to today's delivery and logistics models. The hub-and-spoke delivery model will be challenged as companies maximize efficiency, reducing idle time and deadheading. Experts speculated about the idea of long-haul platoons featuring a single driver operating up to five trailers, which enter urban areas and hand freight off to local human drivers for last-mile delivery. Additionally, more companies will try to leverage AVs to improve their services, including grocery stores, major logistics companies, auto parts delivery, and others. Once AV technology demonstrates commercial viability, one expert indicated, consumer 'on-demand' services will grow rapidly.

3.4.7. Impacts: Vehicle Ownership

Some experts thought that ownership will ultimately come in the form of large fleets (accessed by individuals as a mobility service) rather than the currently dominant model of individual vehicle ownership. One stated social benefit of AV fleets is that of ridesharing, through which overall VMT will likely decrease. Several experts noted that by the time the personal ownership costs of AVs become widely affordable, consumer preferences will have already shifted to a shared mobility model. That is, AV technology integrated with ridesharing and buses will supplement public transportation to a point where personal vehicle ownership will no longer make sense. Moreover, AV technology complexity and liability concerns were noted as hindrances to personal ownership. However, in rural and suburban areas, the mobility model may not prove economically feasible, with personal vehicle ownership remaining dominant.

One expert identified public policy as a key factor that will shape how society derives social benefits from ride-hailing and AV technology. Policy could continue to encourage private ownership, or it could change to encourage adoption of mobility services. This expert had spoken with major automobile manufacturers and found some firms certain that personal ownership of vehicles would continue, while others are making greater preparations for fleet ownership and mobility service–based transportation.

Similar changes to the ownership model are projected for the introduction of AV in long-haul freight. As stated by an expert, barriers to entry are currently low in the freight industry, and as a consequence, the industry is heavily diffuse in terms of vehicle ownership and employment. AV technology may change the ownership structure among trucking firms and lead to consolidation, due to its capital costs and operating efficiencies.

In agriculture, AVs have made significant progress in in-field operations. AVs may further stimulate an already-emerging trend where farmers are deciding whether to maintain personal responsibility for sowing, spraying, and combining activities. Large farm operations increasingly have incentives to hire commercial applicators to come in with a large set or fleet of machines. AV technology might further accelerate such a trend. The challenge will be continuing to set geofencing AV operations in fields versus rural road interactions with the AV agriculture equipment.

3.4.8. Impacts: Productivity

One major impact of the introduction of a true Level 5 AV is that individuals can reallocate their commute time to other productive purposes. The potential for commuting to become a time for work or socialization could be, as one expert described, a “game changer" for productivity.

3.4.9. Impacts: Licensing

Experts highlighted licensing as another potential AV technology impact for states and localities, in both long-haul freight and personal vehicles. Up through Level 4 automation, industry experts argued there will be a need for licensing individuals to operate vehicles. One expert pointed to the possibility that someone born today may never learn to drive with the advent of Level 5 AV technology.

3.4.10. Impacts: Mobility Cost

Several experts noted that the aggregate costs of AV mobility may be cheaper than current transportation expenditures. Individual user cost savings may be considerable, with no need for licensing fees, insurance, property taxes, vehicle ownership costs, or maintenance and fuel, potentially freeing up significant personal income. Likewise, as fewer people drive their own vehicles, the pool of insured drivers shrinks. This may increase insurance rates, licensing fees, and other socialized costs for people who choose to drive.

3.4.11. Impacts: Public Finance

One expert noted that financing for transportation infrastructure will need to change, since taxes and fee structures are closely tied to individual ownership. However, another also felt that the current fee for EVs in Georgia is set too high and creates a future disincentive for adopting AV technology, as AV and EV are often seen as complementary technologies.

3.4.12. Impacts: Vehicle Design

In the short term, experts mostly agreed that vehicles will maintain their current design, as much of this is driven by federal safety requirements for the cab. Design changes will mostly occur in the vehicle’s interior, corresponding with new AV functionalities. For example, several experts suggested manufacturers may eliminate steering wheels, acceleration and brake pedals, dashboards, and side mirrors. Seats may face each other, as is common in rail cars.

However, if AVs achieve their expected safety performance, policymakers may relax many current regulations, allowing for evolving vehicle designs. Experts mostly agreed that AV appearance will be shaped by business models. If the market shifts from personally owned vehicles to a fleet or subscription model, AVs will evolve to suit more customized needs through a wider variety of form-factors and functionalities. Today, individuals generally purchase one-size-fits-all vehicles to fit their rarest and most extreme needs. One expert added that cars today look similar because they need design compromises to meet mass market demand, but shared AVs can be designed to fit more specific purposes. Vehicles designed to more specific needs may feature a wider array of top speeds, acceleration, and other operational characteristics. For instance, vehicle designs with rear-facing passengers will likely need lower acceleration for passenger comfort, similar to that of a train.

3.5. Challenges to AV Adoption

When considering potential AV timelines and impacts, experts were also asked to identify challenges to AV adoption. They highlighted a number of potential challenges including: public acceptance, economic sustainability, regulatory environment, need for infrastructure, and technological hurdles.

3.5.1. Public Acceptance

The majority of industry experts shared the view that public acceptance is the most critical variable to determine AV deployment types and timelines, and they identified multiple factors as influencers. First, several experts noted the recent (March 2018) AV-related fatality in Arizona where a pedestrian walking with a bicycle was hit and killed. This crash represented the first pedestrian fatality involving an AV and was a setback, leading companies to pull back on public road testing. Second, industry experts noted that people generally have poor judgement of risk, and are unlikely to accurately assess AV risks against human-driven vehicles in spite of (to paraphrase one industry expert) 40,000 fatalities and 2 million injuries annually, mostly due to human error. Third, developers of AV technology and the wider public have yet to reach a consensus on what constitutes sufficient improvement in safety for AV technology to facilitate widespread adoption. Fourth, a more general concern is that Americans have grown accustomed to owning and driving their own vehicles. Industry experts noted that several polls regarding AV technology have found that people are not ready to relinquish control of their vehicles. Even when AV enthusiasts have been asked if they would be willing to have an AV take their child to and from school, the answer is typically and emphatically no.

3.5.2. Economic Sustainability

A second potential barrier identified by experts addresses the business case for AV technology. They expressed a range of views about where the technology would have its earliest market applications, and noted that there remains great uncertainty about who will be the first to produce a viable market strategy with sustainable returns on investment. Several experts observed that currently companies are surviving based on the willingness of investors to explore commercialization of AV technology, with ridesharing and freight as two of the likeliest initial deployments.

As seen in the timeline discussion, numerous experts identified ride-hailing as a highly likely initial use case, primarily driven by the potential market opportunities. Industry experts noted that there are several companies focused on ride-hailing in their business plans. Some are seeking to deploy completely new AV fleets (e.g., Waymo, GM Cruise), and others plan to integrate a percentage of AVs into their existing fleets (e.g., Lyft, Uber). Several experts highlighted the importance of investors in initial deployments, with AV technology following a deployment pattern that traces investor incentives. Investors are already considering risk exposure and margins, with many supporting fleet applications as offering the most significant initial returns. AV companies have the equivalent of heat maps for urban mobility, which they can use to ascertain where to deploy and geofence AV fleets for profitability. As vehicle costs decrease, the viable deployment area will grow. Areas more densely populated with residents and jobs represent the initial deployment targets. Further complicating deployment, one expert suggested that instead of having 10 or 20 large car companies, AV platforms will be supplied to 100 logistics companies producing tailored vehicles to niche needs for a wide variety of mobility requirements.

Experts stated that for a personal ownership model to work with AV technology, the industry must first reconcile cost factors, safety issues, maintenance issues, liability, and insurance. The sensor array alone on Level 4 AV technology currently costs more than $100,000 per car. Fleet operations of AV technology will spread costs across many trips, and therefore AVs will be more cost-effective in a ride-hailing environment. One expert noted that a Level 4 AV costing $150,000 and operating in an urban ride-hailing fleet can be profitable in the near term, perhaps even today. It was noted by several experts that it is expected that costs will drop as AV developers settle on platform and production increases; however, it was anticipated that sufficient reduction in cost for widespread private ownership may be more than a decade away.

When considering freight operations, several experts stated that a stronger business case to fully adopt AV technology is needed. Many firms are enthusiastic and exploring options, but currently there is little imperative for original equipment manufacturers (OEMs) or the freight industry to race for first adopter status. The most attractive segment of freight for AV adoption is in long-haul trucking. Many experts remarked on the decline of available labor in the trucking industry, and the introduction of AV would allow that industry to focus hiring efforts on pick-up and delivery points. In addition, the “driver” position would likely take on additional logistic roles. Another expert argued that freight-only highways are not justifiable economically. They also noted that while removing other vehicles from certain lanes and creating an AV freight-only highway solves some operational challenges, it would create others. These include social challenges, much as flight paths over low-income neighborhoods have generated equity concerns.

3.5.3. Regulatory Environment

A third potential barrier to AV adoption is uncertainty in the regulatory environment. The most common view among industry experts is a preference for limited regulation organized through the federal government (as opposed to state and local regulation). Experts note that to date, government actors have primarily focused on enabling the development of AV technology. However, potential flash points that could spur greater regulation include: negatively perceived interactions between AV technology and human-driven vehicles, liability claims involving AVs, aggressive applications by industry that go beyond operational capabilities of AV technology, and reconciling safety standards across competing technologies. Additionally, experts from the freight industry noted that trucks using AV technology will need permission to cross state lines and have insurance coverage to operate across state lines.

3.5.4. Infrastructure Needs

Most industry experts argued that AV technology will adapt to existing roadway infrastructure, handling any and all conditions. However, a minority view held that public-sector investments will be necessary as the number of AVs on the road grows. One barrier noted by industry experts to securing these investments is achieving consensus and buy-in across diverse states, where political leaders representing urban, suburban, and rural jurisdictions will have different levels of interest in and applications for AV technology.

Some experts also raised increased maintenance needs as another potential issue. While designed to operate under the same conditions as human-driven vehicles, AVs will operate more efficiently where there are clear, well-maintained roadways. One expert highlighted that improvements benefitting human-driven vehicles, such as better maintenance, will also aid AVs.

While not necessarily in the purview of DOTs, industry experts also highlighted the deployment and maintenance cost of communications infrastructure needed to support AVs. For example, one expert cited Verizon and AT&T's claims that an AV would need 250 connections to the cellular network. Preparing this infrastructure will be a significant challenge, as bandwidth demands from AVs will add to already-increasing burdens from other cellular users.

3.5.5. Technological Hurdles

A fifth potential barrier is solving the remaining core technological challenges. One expert described AV technology as consisting of three interrelated packages: (1) the drivetrain of the vehicle; (2) the automation technology consisting of sensors, cameras, LiDAR, ultrasonics, radar, and software; and (3) the cab, which will serve as basis for the user's in-vehicle experience. They stated that there are several competing packages of automation technology that are far from consolidating toward a set of industry standards. There are also multiple combinations of the three aforementioned technology components currently under development in the industry.

Many experts interviewed reported that technological hurdles represented the least risky aspect among factors affecting AV development and deployment. One expert pegged the technology at currently 98% to 99% complete in terms of technical viability.

However, this same expert also noted that the final 1% to 2% could take much longer than most experts anticipate for AVs to achieve broad public acceptance. Moreover, experts were careful to distinguish between applications of the technology in areas that are controlled, and those in more open environments. Controlled environments are characterized by strong geofencing and preferential treatment for AV technology. Open applications are those where the AV technology is adapting to local road conditions and interactions with human-driven vehicles.

Many circumstances continue to emerge in AV testing where the vehicle is confused by weather or road conditions and requires human intervention to navigate the problem. Industry representatives refer to these as "edge cases," implying that these are relatively rare events. However, one industry expert noted that many of these edge cases are not rare at all, but rather common events associated with construction, maintenance, or certain weather conditions. Several experts further noted that edge cases will always exist; however, they will become more limited as the technology evolves. One expert noted that addressing an edge case will be driven by the business model associated with that case. One strategy for overcoming these conditions is through the introduction of remote driving technology. Companies are field testing remote drivers who can step in and assist an AV through conditions on the road. Teleoperation or telepresence will allow human drivers to assist AVs using real-time feedback from the cameras on the vehicle to navigate challenging situations (such as crash or construction sites). They can also interact with passengers in the car to mitigate anxieties that may arise from relinquishing control of the vehicle.

There are also issues in the degree to which the AV follows rules of the road, rather than adapting to driving conditions around the vehicle; or the ways in which the AV may accelerate or operate at higher speeds with closer vehicle following distances that may make passengers initially uncomfortable. A further technological challenge associated with rural applications stems from adaptability of the technology to work in both road and non-road environments. Finally, cybersecurity also poses a technological hurdle. While cybersecurity was not seen as an immediate concern for many of the industry experts, they saw it as a long-term challenge that needs to be addressed. However, industry is currently prioritizing development of core AV functionality.

3.6. Overstated Barriers to AV Deployment

> *"Imagine that in the year 2000 we survey people to ask about their acceptance about what would come to be the common smartphone. Divulging that apps and services provided bring out questions of data and privacy security. Knowing that there are risks, people would indicate their reluctance to use these devices, yet we know today that they are fundamental pieces of our daily lives"* – Interview Participant

While the experts identified a number of challenges to AV adoption, they also identified several barriers to adoption that they considered overstated. Many pointed to mass media as the source of these overstated concerns. They argued media coverage of AVs is hyperbolic, with headlines inducing fear of the unknown, and hyping flaws that generate overreaction. For instance, one interviewee noted that a single AV incident makes major headlines, while dozens of fatal human-error vehicle crashes garner little attention. Additionally, media have overhyped the immediacy of AV technology, and it will likely see a slower development and adoption curve.

3.6.1. Public Acceptance

While a majority of experts saw public acceptance as a challenge, nearly one in four interviewed felt that public acceptance was an overstated barrier to deployment. Similar to other technologies, public acceptance will develop over time and reflect technological progress. Several experts expressed greater concern with 'over-acceptance' of the technology. They expect people will become comfortable with the technology after a few rides, and grow complacent about its capabilities. Multiple interviewees pointed to Tesla's Autopilot technology, and how consumers have quickly adopted it. In addition, one interviewee suggested that public acceptance will grow with fewer setbacks if AVs are deployed in coordination with local authorities, such as DOTs.

A few experts indicated that public acceptance challenges are due to media portrayals or polling that occurs immediately after an AV crash. One expert used the smartphone analogy presented at the start of this section, arguing these surveys are a 'distraction' because they gauge consumer acceptance of a technology that is not yet available. To counter public acceptance challenges, one expert indicated that their pilot projects surveyed consumer sentiment before and after the deployment of their vehicles, and found that public acceptance increased significantly after the deployment of the AVs.

3.6.2. Liability

Several experts identified liability as a major potential barrier during the interviews. However, others did not find it to be a significant barrier. One expert noted that the American insurance system has always been able to account for emerging technologies, and has generally done so rationally. Though the tort liability system is not currently equipped to handle AVs, experts are comfortable that this will change over time as the technology develops. They also rejected the need for urgent change, arguing that not all issues need be resolved before the technology arrives, as this has not been the case in any other technology domain. Interviewees said developers tend to think that regulators cannot quickly adapt to the pace of technological change, but this is not true. States are working with developers to test policies, adopt technology, and learn what works best, so regulators and insurance companies can adapt and successfully integrate AVs.

3.6.3. Safety

Experts had differing views on AV safety as a potentially overstated barrier. One interviewee challenged a common argument that AVs will be safer than human drivers: "Until the AV has driven in every scenario, environment, developers cannot accurately state that they are safer." However, experts also indicated that these vehicles will have redundancies in their computing platforms to add layers of security. Therefore, if primary driving algorithms fail for any multitude of reasons, the AI will have secondary and possibly tertiary mechanisms to reconcile issues to avert any dangerous situations. Overall, most interviewees agreed that AVs will be safer than human-driven vehicles, but they will have limitations; the complete elimination of crashes is not possible. Furthermore, AV technology may also limit the severity of crashes that are unavoidable. Public-sector managers agreed that perceptions of safety are inaccurate, and need to be reframed. They understand that there will not be ‘zero’ crashes, and such promises to public agencies and policymakers are not beneficial for developing partnerships and trust.

3.6.4. Weather

Experts developing AV technology mostly noted minor concerns about weather and an AV’s ability to navigate inclement conditions were not significant issues at this time. Though weather introduces additional complexity, “they are not unmanageable,” one expert stated. As the technology matures, developers see deployments of shared fleets, working in geofenced locations, as the first of many stepping stones to expanding deployments into locations with unfamiliar conditions. Interviewees believed that if the business case permits deployment, weather would not be a serious deterrent. Developers recognize that access to weather data will become a necessary component of their operations, but also see an additional advantage to using operational vehicle platforms to potentially capture weather data. This may include hotspots where ice patches are located, wind speed on roadways, and even vision in inclement weather. The idea of having a fleet of vehicles simultaneously transmitting weather data and providing greater and more accurate coverage of a local area seems plausible. Overall, if AVs are to be operated in areas where weather poses a hazard, many of the experts agree that the viability of that operation will depend on the quality of the roads (and maintenance) and state of the technology. The short-run deployment of AVs in extreme weather conditions, such as snow, appears to be a non-viable venture and has limited developers from testing their vehicles in those regions.

3.6.5. Connection to the Built Environment

Experts sought to dispel the idea that AVs require connectivity to the built environment. While the vehicle computing capacity and operational efficiency may be improved with such connections, they are not necessary for core AV functionalities. According to one expert, digital infrastructure will not play a role in the early deployment of these vehicles. Also, developers are hesitant to encourage public agencies to spend money on these investments at this stage of development, as standardization has not yet occurred.

3.6.6. Cost

One expert stated that the cost of AV technology and associated components is "a complete red herring." Technology costs should not be a concern in the short term, as AVs are still largely in their R&D phase. Once the business case has been made, and there are thousands of these vehicles on the road, the costs will exponentially decrease. Moreover, in a fleet-based mobility service model, the technology's economics will likely provide a compelling business model.

3.7. Other Potentially Influential Technologies

During the interviews, experts were also asked to identity other potential emerging technologies that may influence the trajectory of AV development and deployment. The primary identified technologies included electric vehicles, connectivity and data sharing, and artificial intelligence.

3.7.1. Electric Vehicles

Many industry experts highlighted the connection between automated vehicles and electric vehicles. Both technologies are currently developing rapidly, and a number of experts saw them as complementary. Some believed that vehicle electrification will be facilitated by the ease of self-parking to charge, removing the need of relying on a human to start and finish the process. The greatest concern expressed about electric vehicles was the impact they may have on gas taxes and other revenue streams supporting the DOT.

3.7.2. Connectivity and Data Sharing

Many experts see a need to prepare for improved connectivity (V2V, V2I, and V2X) and communication between AV passengers, vehicles, and the surrounding environment. They did not agree on any single communications technology, with some envisioning a mix of 5G and DSRC. To operate AVs with these technologies, experts saw the need for effective data-sharing mechanisms, possibly enabled by a cloud computing platform or service. Sensor fusion—the enhanced relationship and communication abilities among several types of sensors on a single vehicle platform that allows for determination of conditions based on multiple sensor inputs and types— is another aspect of connectivity and telecommunications that several experts agreed would impact AV deployments.

3.7.3. Artificial Intelligence

The influence of AI, machine learning (ML), and deep neural network (DNN) technologies were mentioned by several experts, and the development of these technologies may heavily influence the rate of AV deployment. Neural networks and deep learning are expected to impact how AVs interact with other roadway users.

3.8. State DOTs and AV Deployment

As part of the interviews, experts were asked how they believed a state DOT should respond to the introduction of AVs. The following summarizes their responses, with a significant theme being that DOTs should primarily be in a fact-finding and education mode, not yet trying to actively change roadway design or operations. Significant evolution in the technology needs to occur before changes to the built environment should be considered. Experts highlighted that industry hype and excitement around a technology that has yet to be fully realized or developed may lead regulators and policymakers to waste resources on frivolous projects. Experts suggested that government agencies should not be too anxious to accept media portrayals of AV technology, nor should they assume that any individual company will provide any singular AV solution for their city. However, they noted that departments of transportation will likely need to innovate and develop new operating practices. While many current functions are important and not likely to go away, AV technology presents new opportunities and capabilities, and perhaps new missions for agencies. The following discussion presents guidance from the interviewed industry and public-sector experts.

3.8.1. Industry Experts

3.8.1.1. Industry Expert Views of a State DOT

Industry experts were asked to first describe the functions of a state DOT in order to get some context for their answers regarding the role of a state DOT in AV technology. Most industry experts described the role of the state DOT as owning, operating, planning, and maintaining the transportation infrastructure system. Several highlighted the importance of roads that are well-maintained (i.e., limiting potholes, and quick response to roadway disruptions) and well-marked with clear, unambiguous signage and paints for AVs to use as guidance. Other industry experts emphasized the role of state DOTs in ensuring safe transportation systems, facilitating traffic flow through the transportation grid, and assuring transportation services to all segments of the population, including low-income groups.

Industry experts were not always clear about which activities fell under the domain of state versus local DOTs. For example, transit systems, licensing, enforcement of traffic laws, economic development, and driver's education were included in the domain of the state DOT. Industry experts also highlighted the state DOT's role in informing legislative and other political processes within the state, and providing guidance on competing technologies that are vying for both authorization to operate within a jurisdiction and, in some cases, support from the public sector. Finally, several experts noted that the role of transportation authorities in other countries can be very different than in the U.S., creating some confusion for international AV industry firms in understanding U.S. agency roles at all levels of government.

3.8.1.2. Infrastructure and Operations

Many industry experts echoed a common theme that it would be a mistake for DOTs to take significant actions at this point in the AV technology deployment cycle, as there are too many open questions. They argued for DOTs to continue what they are already doing, monitoring technology development and maintaining dialogue with leading industry experts. By speaking with advocates and detractors of the technology, not just its developers, DOTs will build a more informed viewpoint of how this technology will deploy and change the existing transportation system. Experts argued that states should not overinvest in infrastructure while the technology is still being tested and public acceptance is still uncertain.

Experts also agreed that there is no immediate or near-term need for agencies to purchase equipment, special paints, or other devices specifically to aid AVs. Experts noted it is possible that any changes intended to aid AVs could, in the long run, further complicate AV implementation due to additional costs of maintenance and the rapidly changing nature of the technology. Technology developments could render certain devices, features, and standards obsolete, especially with CV infrastructure. However, a small group of industry experts did believe that secondary infrastructure will be needed to support this technology once it becomes an established mode of transportation. They argued that making early infrastructure investments can ensure safer deployment. For example, there may be a need to consider additional roadside devices, and communicating the data they collect to AVs. Several industry experts also argued that agencies may need to install their own data collection equipment because AV developers are very protective of their data.

Experts generally noted that if the DOT were to take a high-level managerial approach to the deployment of AVs, rather than a hands-on operating role, it might reduce cost burdens for the agency and reduce overall risk. Any investments in the short term should focus on infrastructure that is also useful to human drivers, including signage and striping. Industry experts agreed that any infrastructure investments beneficial for human drivers (e.g., signing and pavement markings) will also benefit the machine vision systems enabling AVs. However, several industry experts considered AVs that utilized pavement markings as old technology, with more advanced AV systems not requiring markings.

3.8.1.3. Safety

One of the most common themes mentioned across different industry sectors was the need for the DOT to implement safety measures and monitor their effectiveness. By monitoring available traffic data and implementing regulations that protect AV owners and occupants, the DOT can exercise greater control over how AV technology is deployed.

3.8.1.4. Pilot and Testing

Some experts suggested that for the DOT to fully understand AV impacts on existing roadways and traffic flow, it should engage in controlled testing of the technology. By implementing small-scale pilot programs, DOTs can identify early risks from the technology and make appropriate adjustments. Some experts stated that local DOTs have the most agency in this type of deployment because they have the ability to geofence AV technology at a reduced scale. However, others warned against DOTs investing directly in pilot projects. Agencies can contribute resources other than funding, which may already be limited, including personnel and data.

3.8.1.5. Transit

Several experts argued that transportation agencies should not give up on public transit options for their communities. Even though many AV developers are working toward transit-like solutions, or ways to augment gaps in transportation accessibility, public service providers possess local knowledge that these companies do not have. Experts said they can see industry partnerships with public agencies as useful and sometimes critical mechanisms to address gaps in transportation accessibility, congestion, and other issues. Simultaneously, several experts argued that agencies should not facilitate adoption of AVs that encourage users to choose single-occupancy vehicles over mass transit or active transportation. Some experts with more experience in transportation systems believed that doing so would lead to otherwise avoidable secondary impacts such as greater VMT and more congestion.

3.8.1.6. Regulation

Experts agreed that legislation and regulation should be minimal and set at the federal level. Overregulation, or blindly following other states without considering future federal regulations, can impede technological progress and deter development and testing. For instance, some states have already begun to consider new insurance requirements that would make it very difficult to scale operations for AVs in that state, likely preventing deployment outright.

Industry experts advised flexibility in regulation once AV market penetration reaches a critical mass of AVs. When considering regulation, industry experts believed the DOTs should primarily focus on safe roadway operations. By assuming the role of safety advocates, DOTs can leverage existing technical expertise as AV technology is integrated into the current mix of vehicles. They should also avoid erecting barriers, and remain supportive of technology development through testing and pilot programs. Finally, several experts noted that state governments and agencies need to address federal regulation in a collaborative and coordinated fashion, so as to not hinder AV development.

3.8.1.7. Workforce

Industry experts noted the need for DOTs to improve the technical skills of their staffs, adding expertise in robotics, data sciences, and IT so they understand the functionality of AV technology, and can incorporate this knowledge into their design, construction, and maintenance operations.

3.8.1.8. Data

Industry experts noted that there should be ways in which AV technology enables improved DOT operations, once DOTs have the skill sets in-house to capitalize on new data sources. Experts recognized the challenge this presents, as DOTs will need to work with a higher volume and more diverse set of data from multiple sources than they have been accustomed. For instance, AVs and CVs are likely to generate real-time data for monitoring road conditions, allowing DOTs to react more quickly to maintenance needs. However, a few industry experts mentioned that data was seen as a potential revenue source by industry, and could cost DOTs to procure. Several industry experts argued the DOT should not pay companies for their data, since the public sector has already made value-added contributions in the form of infrastructure. In addition, experts raised concerns about proprietary data generated by AVs, as well as privacy. For instance, data valuable to the public sector for social good and transportation system performance improvement could also be valuable to industry competitors for commercial reasons.

3.8.1.9. Public–Private Partnerships

Industry experts noted that there may be reasons to have public–private partnerships associated with the rollout of AV technology. One possible focus is in the area of data management and creation of data exchanges; however, industry experts viewed this prospect with a great deal of caution. One noted that any information shared with a public-sector partner will likely be subject to Open Daylight and Freedom of Information (FOI) laws, raising the aforementioned issues of data privacy and competitive concerns. Experts also highlighted P3s as important for the public sector in supporting technology development, testing, and demonstration. However, one industry expert cautioned that while P3s generally sound attractive, their value in this context is uncertain.

3.8.1.10. Education and Public Acceptance

Several experts expect that the DOT will assume an educational role with the general public, explaining AV technology's benefits and emphasizing the quality of life improvements it offers. One potential path is the development of partnerships with industry groups such as the Chamber of Commerce, which may have more resources to devote to education campaigns. Experts differed on which groups the DOT should prioritize in terms of education, with only some saying the DOT should focus on garnering public acceptance of this technology. Other experts believed that the DOT's technical expertise is needed to educate policymakers. Moreover, such education initiatives would positively signal to developers that those states should be targeted for operations, bringing potential economic development impacts. Many experts also encouraged individuals at the DOT to attend AV-oriented conferences and symposiums to "proactively get their hands dirty." This engagement allows the DOT to open dialogue directly with industry, and increase preparedness for AV deployment.

3.8.2. Public-Sector Experts

State and local DOT experts saw AVs as part of a collection of technologies that could produce major changes in how they organize and fund operations. One state manager used the common ACES (i.e., autonomous, connected, electric, and shared) branding to describe this collection of technologies. These experts noted that while current efforts directed to AV technology at their agencies is relatively low in some instances, amounting to additional news monitoring for some, AVs have become their own mission-driven program for others. Experts noted that some DOTs have already created AV-specific divisions in their organizations; developed new AV-oriented working groups or committees; and launched research initiatives to look at the technological, policy, and economic impacts of AVs. Some of these projects include joint efforts with other government agencies at both the local and the state levels, as well as some private companies. One DOT official noted that their government had just commissioned its new five-year strategic transportation plan, and it requires considering CV and AV technology impacts for the next 25 years.

Experts noted that some states are taking a wait-and-see approach to AV technology legislation, citing changes in both public acceptance and the technology itself. However, other states have taken a more active role, passing legislation to legalize the technology on state roads. These states do not see many limitations to deploying AV technology today. One state official noted that it is currently legal to deploy AV on their roads, and anticipates the passage of laws that legalize riding in an AV without a license in the near future.

State and local DOT experts tended to see the deployment of AV technology as a consumer-driven phenomenon. One expert made the analogy that AV technology would likely deploy in a similar manner to iPhones, with early iterations of the technology leading to wider public acceptance of the technology. Some officials raised concerns about industry expectations that state DOTs can adapt quickly to AV technology as deployments increase. Examples include coordination of interoperable signal technology with the various AV platforms currently in development, or designing roads for dedicated AV and/or truck platooning lanes. They expressed additional concerns that if AV companies achieve rapid deployment, then state DOTs will be stretched by the demands placed upon the transportation grid. The following sections provide insights from the public-sector interviews on various topic areas.

3.8.2.1. Infrastructure and Operations

Public-sector officials shared many themes similar to those of industry experts. In the short term, they believed the DOT should focus on signals, signage, and pavement markings that benefit all road users, human and machine. They stated that working with industry partners can help determine what types of signage and striping will be needed, noting that although all major thoroughfares have striping, that may not be sufficient to accommodate all AVs.

In addition, public-sector experts believed that AV technology will open new avenues and opportunities for existing infrastructure operations, continuing an already emergent trend. The integration of digital technology with physical infrastructure is already occurring in state and local DOTs, and this transition is likely to continue over the next several decades. However, some officials believed that government agencies should refrain from acquiring new technologies to support AVs and maintain their focus on core functions already performed today. They preferred the private sector determining technology requirements, and then presenting solutions to public agencies.

In describing AV impacts on infrastructure, one expert used the analogy of a storm tracker, highlighting the significant potential for variability. This expert provided the example of redeveloping major facilities such as existing bridges. Their DOT considered adding two feet of width, leaving open the possibility to restripe and add two more lanes in the future, if AVs were proven capable of operating in narrower lanes. However, this expert also noted that perhaps AVs will platoon, eliminating any need for extra lanes. They said there was no way of knowing the correct course of action.

One state expert distinguished between the demands of AVs and CVs. Cities and states are already investing in transportation infrastructure that can facilitate and interact with CV technology. To the extent that AV technology builds upon and integrates CVs, then it may have some impact on the design and maintenance of transportation infrastructure. But, this is a continuation of trends in CV technology, rather than a direct impact from AVs.

Additionally, other state DOTs are incentivizing AV developers to operate in their states by offering proving grounds, or cordoned areas within the state where they can test their technology. Officials argued that these projects open collaboration and dialogue opportunities for both private and public interest groups in those states. Several experts highlighted that proving grounds can help achieve the objective of low-cost, low-risk partnerships that offer learning opportunities in the short term and aid in long-term strategic planning.

3.8.2.2. Regulations

Several experts noted that state governments and agencies need to be careful about applying new laws and regulations without considering impacts to local governments. The state can assist in facilitating education and community activities needed to ensure smooth AV adoption in local communities.

3.8.2.3. Data

Public-sector experts identified data and asset management as becoming increasingly important with the concurrent introductions of CVs, EVs, and AVs. CVs were seen as particularly important, as officials anticipated that CV technologies will play a large part in AV integration. They believed that DOTs are in a position to collect, process, and share data with private-sector partners where appropriate. Connected infrastructure systems will potentially have the ability to share crash reports, construction-zone information, operations data, and more. Additionally, as also noted by the industry experts, data will play a critical role in safety monitoring and improvements.

3.8.2.4. Safety

Several public-sector experts stated the primary role of the DOT in the deployment of AVs is to promote safety. Experts noted that since many agencies do not have statutory authority to fully examine impacts of AV technology on the existing transportation system, they advised DOTs to monitor early areas of deployment, such as freight. Experts highlighted that safety and data must be strongly correlated DOT activities.

3.8.2.5. Transit

Public-sector experts noted that MPOs and state DOTs have been encouraged to begin planning for AV deployment through the Moving Ahead for Progress in the 21st Century (MAP-21) and Fixing America's Surface Transportation (FAST) Acts. Therefore, some of these groups have already been engaged in planning that considers AVs and transit. Some local governments have also been considering land use relative to the need to incorporate more, less, or different types of parking. There has also been consideration of coordination between transit and ride-hailing. However, one expert quipped that all they know is these plans are wrong because governments are planning with too little information and cannot accurately project AV developments.

3.8.2.6. Public Finance

Public-sector experts expressed concerns that the combination of AVs and EVs will require an entirely different model for financing transportation services and infrastructure. Several stated that these technologies render current finance models incapable of supporting operations. Thus, public-sector experts also note that they may be able to translate agency resources into alternative sources of revenue for local or state governments. Some agencies are considering rights of way, pavement, and ITS as assets that could possibly generate revenue from industry.

3.8.2.7. Interagency Cooperation

These experts also highlighted the need for state DOTs to work with USDOT and local DOTs. One state DOT expert indicated they were currently working with local DOTs to educate them on CV and AV technologies. Part of this exercise involves listening to local DOTs voice their concerns about AV applications impacting their operations. For example, how do CVs and AVs influence the maintenance of snow plow operations or other types of local services? Another example noted the testing of platooning technology across state lines requires cooperation between neighboring state agencies.

One state manager mentioned their deference to the federal government for guidance on all issues related to vehicle safety of AV technology. They stated that neither state nor local agencies have the expertise to determine whether particular technology platforms or specific vehicles are safe to operate. Experts observed that some states are willing to participate in federally sanctioned initiatives that explore safety capabilities and requirements for AV technology. In taking this position, they are continuing a long-standing separation of roles within the U.S. federal system on safety, and the evaluation of new approaches or new technologies. However, the experts said that state and local DOTs will still seek to be responsible for infrastructure, traffic laws, and licensing vehicles within their jurisdictions.

State experts provided examples of how states are working with each other and the federal government in preparing for likely impacts of AV technology. Two examples include:

1) The 10 Midwestern states that form the Mid America Association of State Transportation Officials (MAASTO) regional chapter have coordinated studies and information-sharing on platooning using AVs, so they can go back to their legislators (federal and state) to propose relaxation of laws on following distance for freight AVs.
2) Iowa has a USDOT-designated proving ground for AV technology, as does Wisconsin. The University of Iowa called a conference of states that have these

proving grounds so they can share information with one another, and better prepare for the deployment and impacts of AV technology.

One expert encouraged Georgia to incorporate the term "seamlessly" into their planning for AVs, particularly with regard to freight applications, as long-haul shipping companies using this technology need to be able to move from one state to another without encountering significant interruptions due to policy differences or technological capabilities.

A local DOT manager noted how AV technology may create new coordination challenges between state and local agencies in transportation administration, as both levels will be adapting to companies rolling out a variety of AV platforms. Key questions will include how quickly and in what direction these agencies adapt. This expert gave the example of the state changing direction on which traffic signal technology will be used on a state road. If it shifts from a cellular system to a fiber system without appropriate notice, it can create significant confusion between departments in the local DOT when they plan signals on non-state roads.

3.8.2.8. Workforce

Both state and local DOT managers expressed concerns that as AV technology achieves greater market penetration, certain jobs and functions that are currently performed by their agencies will become obsolete. DOTs have been heavily oriented toward the construction of infrastructure, and the DOT's organizational structure reflects this emphasis on engineering and construction. However, as AV technology becomes more widespread, DOTs will shift from building infrastructure to managing and operating infrastructure. It is likely that state and local DOTs will continue to have design and construction operations; however, emphasis may shift to redesign and redevelopment of existing infrastructure, rather than building new capacity. Furthermore, multiple experts highlighted the challenge of hiring tech-savvy staff with the necessary data management and IT skills to manage the increase in data and technology demands. They noted that salaries of public employees are uncompetitive for those individuals with data management and programming skills.

3.8.2.9. Organizational Changes

The types of organizational changes stimulated by AV technology may differ from agency to agency, in part because today's state and local DOTs have varying levels of integration and coordination of systems. AVs and CVs present opportunities for greater data coordination and data management between the levels of government. However, state DOTs have different working relationships with local DOTs. For instance, one expert stated that in states such as North Carolina, the state DOT has more control over roads in local jurisdictions, whereas in a state like Georgia, local governments often have more control.

3.8.2.10. Education and Public Acceptance

Similar to industry experts, many public-sector officials believed the DOT would assume a greater role in educating the public by promoting public awareness of AV technology and advocating its case for improving road safety. Through increased opportunities for interaction with the technology, experts expected the public would be more willing to embrace AVs. One expert proposed that the DOT create geofenced test beds as a way to introduce people and policymakers to the technology, and improve their perception of it.

3.9. Conclusion

The expert interviews provide a wide-ranging review of the trajectories of development for AV technology, as well as a review of the impacts that AVs may have on transportation systems and organizations at the state and local levels of government. The level of risk and uncertainty regarding the likely development paths for AV technology remain quite high. While industry experts were able to identify the key characteristics of AV technology that are under development, they are not in position to recommend to GDOT the likeliest path of development around which the agency can plan. Instead, the outcome from these interviews is that extensive caution must be exercised about early commitments to a particular technological path.

The expert interviews represent the first step toward developing a technological roadmap for GDOT. In the next chapter, the perceptions and positions that GDOT managers currently hold regarding AV technology are examined. Then, similarities and differences between the views of experts in the field and GDOT managers are used to identify key points in the roadmap for AV technology, and the roles that a state DOT may want to pursue.

Chapter 4 Exploring Potential Impacts of Driverless Vehicles

4.1. Introduction

A technology roadmap builds upon two bodies of knowledge. In the previous chapter, alternative paths for the development of AV technology were explored based upon the perspectives of experts drawn from industry, research institutions, and the public sector. A second critical component for building a roadmap is understanding the current perspectives of AV technology held by professionals in the GDOT community. To capture these perspectives, the research team conducted four focus groups. Each focus group was designed to capture current AV technology perceptions and projections from different elements of GDOT. Two focus groups were conducted with mid-level and upper-level managers, representing a wide cross section of GDOT operations. A third focus group was conducted with the senior executive leadership of GDOT. The final focus group comprised representatives of the consulting community actively engaged with GDOT in the delivery of transportation infrastructure and services. Table 2 provides a description of the composition of the focus groups.

The research team's approach was to present focus group participants a variety of AV technology development paths and performance characteristics identified during the interviews with industry experts. Participants were asked to reflect on two major themes: (1) what are the likely impacts of these AV technology characteristics on Georgia's transportation infrastructure, and (2) what are the likely impacts of these AV technology characteristics on GDOT operations. In this chapter, GDOT's perspectives on AV technology are reviewed by comparing and contrasting the perspectives shared in each of the focus groups.

TABLE 2
Description of Focus Group Participants

	Number of Participants	Types of Units Represented
GDOT Manager Focus Groups	15	Traffic Operations, Intermodal, Pedestrian/ Bicycle Path Engineer, Engineering, Communications, and Construction
GDOT Leadership Focus Group	9	Engineering, Communications, Construction, Permits and Operations, Program Delivery, and P3
Consultant Focus Group	12	Construction, Technical Services, Engineering, Architecture, Transportation, Information Technology, and Management Firms

4.2. Level of Engagement with AV Technology

GDOT managers, leadership, and consultants demonstrated a high level of awareness of AV technology developments. As the research team reviewed different developments in AV technology characteristics, there were few surprises reported by participants about the likely AV technical capabilities. Participants in the GDOT leadership and the GDOT manager focus groups reported of riding in AV test cars, monitoring AV technology trends in the professional literature, and learning about AV as part of professional conferences. However, none of the mid-level and upper-level management focus group participants reported being tasked with officially engaging in issues related to AV technology development on behalf of the agency.

While AV technology is clearly on the professional radar of GDOT managers, they had less certainty about the leading companies and public agencies in this field. GDOT leadership demonstrated greater awareness of the public transportation agencies in the U.S. that are testing AV technology. GDOT managers pointed to the DOTs in California and Michigan as leaders in AV. They also pointed to Germany as doing the most work in testing heavy truck AV technology.

In contrast, several of the consultants working with GDOT reported that their organization is actively engaged in examining and planning for AV technology. The types of AV technology work that consultants are engaged in include:

- Working with AV developers
- Working with public agencies preparing for AV technology
- Hiring AV technology subject matter experts
- Working with other countries on AV preparedness
    - Europe and East Asia were the most commonly reported locations for international projects

4.3. Timeline

GDOT leadership and managers share the view that AV technology will take time to achieve widespread acceptance. They projected that Level 4 automation is over 10 years away. One of the key factors that leadership intends to monitor are those industries that are able to put together a viable business case for adopting AV technology. At this time, leadership has yet to see a viable business case emerge around this technology. Furthermore, leadership anticipates that even with a viable business case the introduction of AV technology will require the marketplace to successfully work through numerous edge cases to achieve widespread acceptance and deployment of the technology.

There was a strong consensus amongst GDOT managers in the focus groups that the timeline for AV technology deployment is not a factor in their planning for infrastructure needs. From their perspective, AV will not substantially change roadway design, construction, or maintenance. GDOT managers were aware of claims from industry that AV technology should be able to adapt to existing road conditions. GDOT managers also pointed out that, whatever the timeline for AV deployment, there will be a long period of time (10+ years) when there will be a mixed fleet of human-driven vehicles and AVs. As long as the fleet mix includes a significant percentage of human drivers, the design and operations of infrastructure will focus on the needs of humans to manage the roadways.

GDOT managers noted that there will be a tipping point where the level and mix of AV will be sufficiently high that GDOT operations will adapt more to the capabilities of the prevailing automation levels. GDOT managers provided some examples of the types of adaptations that might be considered in the future, including:

- Re-striping roads to make lanes narrower
- Creating AV-only lanes
- Deploying autonomous street sweepers to maintain the roads

GDOT managers also noted that all of these adaptations are things that are within GDOT's capabilities today. Consequently, whatever the timeline for AV deployment, the agency will have the ability to adapt.

Consultants were split in their views of the timeline for AV deployment. The majority view was in line with the perceptions of the GDOT leadership and GDOT managers; that is, that significant deployment of Level 4 and Level 5 automation is over 10 years away. However, there was a minority view amongst the consultants that Level 4 and Level 5 are closer to the market than others perceive.

During the consultant focus group, a previous technology innovation was identified as a potential model of AV technology deployment. Some of the consultants noted that the introduction of cruise control was initially met with concern by state and local DOTs, engineers, and policy professionals. Ultimately, cruise control technology had a slow and incremental integration into the fleet. Some of the consultants expect that a similar pattern will play out with AVs.

Consultants also encouraged GDOT to consider more efficient ways to respond to new technology. As AVs come online, there will be a variety of other technology components concurrently coming to market. AV is likely to be a sufficiently disruptive technology to the prevailing patterns of ownership and demand for mobility services that the agency needs to greatly strengthen its capacities for technology forecasting and foresight. GDOT needs to quickly analyze the cost/benefit of each technology as it emerges and make strategic, forward-thinking decisions. This means there needs to be a larger working group within the agency monitoring technology innovations and developments.

4.4. Challenges to AV Adoption

Across the focus groups there were several factors identified as potential challenges to the deployment and acceptance of AV technology in the marketplace. However, each class of focus group (i.e., GDOT leadership, GDOT managers, and consultants) focused on a different set of challenges.

GDOT leaders indicated that customer acceptance will likely take longer than anticipated by industry. People prefer to be in control of their time, controlling their own commutes, and having the ability to run errands on their own schedule. Members of leadership anticipate that people may retain one car for these types of errands and for days when they need more commute flexibility. It will take a while for people to grow comfortable with not being in control of their mobility. One leader pointed to the lack of adoption of mass transit in spite of many education efforts by transit agencies as a reason to expect this lengthy time period for acceptance and incorporation of AVs.

GDOT managers focused more on the behavioral challenges that may occur during the period of time when there will be a mix of human-driven vehicles and AVs on the roads. GDOT managers expressed concern that human drivers will start to "game the system" by adapting to AVs, which are more likely to be law-abiding actors. This may prevent the transportation system from achieving the full efficiencies that AV technology may offer. For example, GDOT managers noted that increasing levels of automation in vehicles may allow for increasing driving speeds, narrowing lanes, and narrowing following distances between vehicles. However, during the interval of time marked by mixed fleets, AVs will need to operate accounting for other human-driven vehicles, reducing the potential benefits.

GDOT managers noted that there will likely be a period of time in which multiple AV platforms are operating on the roadways. There is also likely to be considerable experimentation with different vehicle types as companies try new approaches to freight, goods delivery, fleet operations, and passenger mobility. It will be challenging for DOTs to achieve higher levels of transportation system efficiency until industry reaches some level of AV technology standardization. GDOT managers noted that ultimately industry would provide standardized technical information to transportation agencies on vehicle operations. The public sector can then use this information to adapt infrastructure design as necessary and/or appropriate. One example noted by GDOT managers is adapting guardrail heights to adjust to variability in AV sizes.

Consultants also mentioned the uncertainties associated with the development and deployment of AV technology. They noted that many industry players are currently looking for places to deploy AV technologies. "Smart city" technologies have been a frequent discussion topic, and how they can assist AV deployments, but the private sector does not appear to have a consensus on the appearance of smart city infrastructure. There is considerable speculation by industry around the technology cities will invest in, deploy, and manage. Relatedly, consultants noted the growing divide involving mobility and transportation services between rural and urban areas. They observe that the industry focus on the development of smart cities may well exclude consideration of the needs of rural communities.

This uncertainty related to AV technology development and deployment led consultants to recommend that GDOT move away from the practice of requiring the adoption of specific hardware requirements. Consultants noted that GDOT has encountered this issue previously with signal systems. GDOT should focus more on prescribing performance specifications for the software and system operations rather than hardware. This change would provide more flexibility to those tasked with keeping up with AV deployments and other technological advances. Consultants argued that technology components change so quickly that obsolescence is a perpetual risk, as was the case with signals the state once procured that are no longer supported by any industry firm.

An additional challenge identified by one consultant is the possibility of competition between mass transit and AV technology. For example, when considering rail expansions, agencies must go through a balloting process, and after success must often defer the vast majority of funding across decades. Once AVs are introduced, they may siphon off riders from mass transit. In this circumstance, agencies may have issues repaying bonds and could be confronted with an under-utilized rail system. This consultant recommended investing in digital, software, and technology capabilities that can be incrementally upgraded and may be a better course of action for public agencies, rather than building new mega-projects.

4.5. Impacts

During the focus groups, a wide variety of impacts were identified from the development and deployment of higher levels of AV technology. Table 3 provides a summary list of the major impact areas and which focus groups highlighted that impact. In this section, a summary is provided of each impact area.

TABLE 3
Areas of Impact from AV Technology

Impact Areas	Leadership Focus Group	Manager Focus Groups	Consultant Focus Group
Design & Infrastructure	√	√	√
Maintenance	√	√	√
Freight	√	√	√
Data Management	√	√	√
Intergovernmental Coordination	√	√	√
Edge Cases	√	√	√
Capacity	√	√	√
Public Finance	√	√	
Rural		√	√
Safety & Liability		√	√
Human Capital		√	√
Socioeconomic Impacts		√	

4.5.1. Impacts: Design & Infrastructure

One of the strongest points of consensus across the expert interviews and the various focus groups is that state DOTs should be taking a wait-and-see approach with regard to the potential impacts of AV technology on the design and adaptation of the transportation infrastructure. At present, GDOT managers indicate that they intend to treat an AV just like any other vehicle on the road. This means there are no plans to change the pavement, signal design, signage, or maintenance operations.

The wait-and-see approach assumes a long period of time over which automation will be increasing on the roads and a mixed fleet exists between AV and human-driven vehicles. GDOT leadership noted that as long as there is such a mixed fleet on the roadways, state and local DOTs will default to the safety needs of human drivers. However, GDOT leadership and managers recognized that one future scenario sees the AV fleet eventually supplanting the human-driven fleet. This led one GDOT manager to suggest monitoring the proportion of vehicles on the roads that are human-driven and those that have higher AV levels (i.e., Levels 4 and 5) as a metric to understand whether such a tipping point is approaching. Managers taking this perspective argued that the greater the percentage of AVs on the road, the greater the likelihood that design, construction, and maintenance strategies will need to adapt to the automated environment.

The wait-and-see approach is also reinforced by the mixed signals that GDOT managers perceive in their interactions with industry regarding the ways in which AV and infrastructure design are likely to interact. A central source of the mixed signals stems from uncertainty regarding the capabilities of AV technology at different stages of deployment. GDOT managers reported the following conflicting signals:

- *Signage and Signals.* On one hand, GDOT managers have heard AV companies indicate a need for improving signage, striping, and stricter maintenance operations to ensure efficient AV operations. However, GDOT managers have also heard presentations from industry that signage and striping may not be needed for vehicles that know their precise location at all times and operate in geofenced environments.
- *VMT.* GDOT managers also note industry reports that present starkly different outlooks with regard to VMT. In one version, the VMT decreases as people shift away from personal car ownership to ridesharing and mobility services. In another version, the VMT increases if the personal ownership model continues and people's cars travel to parking areas to wait until they are called upon again.
- *Lane Width and Lane Restrictions.* In one scenario AV technology will allow designers to re-purpose the existing infrastructure and add narrower lanes because AVs will hold lane position better than human-driven vehicles. For instance, this may allow for converting a four-lane road into a six- to eight-lane road through restriping for narrower lanes. In contrast, the demand for constructing additional dedicated AV lanes will become great in order to limit the inefficiency introduced by mixing AVs with human-driven cars.
- *Secondary Infrastructure.* While industry frequently promotes the message that the roads will not need to adapt, there are conflicting stories about optimizing the

capabilities of AV technology through the creation of secondary infrastructure to serve needs such as: dedicated lanes for automated freight or goods-delivery vehicles, or controlled routes or lanes to support geofencing. GDOT leadership reports that adapting infrastructure to AV technology will likely be more difficult than industry is anticipating. The lead time for creating such infrastructure is longer than industry anticipates, and there is little evidence that the public is willing or able to support secondary infrastructure expansion.

Consultants concurred with a wait-and-see approach with respect to the relationship between AV technology development and the design and development of infrastructure. For example, consultants recommended that GDOT should not dedicate funding or other resources to creating AV-only lanes. They argued that AV technology is developing at such a fast rate that the benefits from dedicated AV lanes for freight or passenger vehicles may be short-lived. Consultants further noted that the utility of dedicated lanes disappears once AV technology integrates more effectively into the traffic system.

4.5.2. Impacts: Maintenance

GDOT leaders and managers both noted that some of the greatest impacts from AV technology development may be felt in GDOT's maintenance operations. The following possible impacts were identified:

- *Striping, Signage, and Signals.* AV technology is sensitive to striping, signage, and signals. This means that the demand for maintaining these resources at a high level are likely to escalate with AV technology. In the consultant focus group, respondents noted that these resources are concentrated in higher traffic zones. One potential impact may be the expansion of the range of roads in which striping, signage, and signals are deployed.

- *Road Impediments.* AV technology is also sensitive to debris in the roadway. The deployment of this technology is likely to increase demands for quick response times from GDOT maintenance operations. The source of this demand is also likely to change as AV companies assume more responsibility for mobility services.
- *Maintenance Vehicles.* GDOT managers and consultants noted that industry is likely to have strong incentives to develop AVs designed explicitly to support maintenance efforts to clear debris. This will free maintenance crews to focus their efforts on tasks requiring human intervention.
- *HERO Unit Technologies.* Managers and consultants described the development of complementary technologies that may become available to assist HERO (Highway Emergency Response Operator) units in identifying the location and extent of incidents. One consultant described the development of iCone technology, which marks the location of an incident response and notifies routing services of the potential impacts on traffic flow.
- *Fewer Crashes.* While AVs will still break down and get flat tires, consultants and GDOT managers noted that they are likely to result in fewer crashes. This will have an impact on maintenance by reducing the number of debris-generating events on the roadways.

- *Freight Operations.* GDOT managers and consultants noted that one source of uncertainty for maintenance operations comes from the impact of autonomous freight vehicles. Several possible examples of maintenance impacts were identified: (1) the increased stress on road maintenance stemming from AV freight operating in platoons at high speed, (2) longer duration of operations of AV freight as driver rest requirements may be relaxed, and (3) changes in times in which maintenance services are in demand as the patterns of use for AV freight shifts to times of day when the travel volumes are low.

4.5.3. Impacts: Freight

GDOT leadership and GDOT managers identified freight as the place that the AV technology business case would most likely first emerge. They indicated that freight had the most to gain by adopting AVs in terms of cost reductions, labor augmentation, and general efficiency. Several managers shared the expectation that within the next 5 years they anticipate that freight applications of AV technology will be commercially deployed. This GDOT perspective contrasts sharply with the views expressed during the expert interviews, which identified ridesharing and fleet operations as the most likely places for the deployment of AV technology in the next 5 years.

There are two distinct classes of market applications for freight discussed in the focus groups: long-haul trucking moving goods across country, and short-haul trucking delivering goods to homes and businesses within a community.

4.5.3.1. Long-Haul Trucking

GDOT leaders and managers noted several impacts from AV freight operations on transportation systems.

- Respondents envisioned that during a typical cross-country trip, a freight vehicle can be on the road the entire time without stopping, as the AV will not have to satisfy regulations concerned with driver alertness and performance. This will save time in the delivery process. Even if companies opt to retain a human in the vehicle, their roles will shift to load management and vehicle maintenance.
- AV freight may produce cost savings through the platooning of vehicles. Platooning may come in the form of a single cab with multiple trailers or a group of vehicles drafting behind one another. Respondents indicated that this would allow freight to draft in tight formations with only a foot of separation between vehicles.
- As AV freight increases, urban areas will have an incentive to encourage companies to travel in off-peak hours through their jurisdiction. GDOT managers and consultants had two distinct views. Some respondents suggested companies will have an incentive to shift to off-peak travel in order to avoid congestion. However, other respondents indicated that AV freight might reduce the degree to which companies will care about off-peak travel. If firms are indifferent to congestion, then urban areas may need to charge fees to encourage travel through their areas during off-peak times.

4.5.3.2. Short-Haul Trucking

GDOT leaders described how this industry has been steadily building the case for new modes of goods delivery. They noted several new delivery mechanisms including: (a) building upon ridesharing platforms for meal delivery, (b) renewed interest in grocery delivery services, and (c) alternative meal preparation services. GDOT leadership noted how this industry is pouring money into discovery of business cases in the goods delivery sector. Leaders who saw goods delivery as a likely AV model anticipated that industry may approach GDOT about creating facilities for them to pilot deployment programs, promising new revenue streams if GDOT altered some infrastructure for their service.

Consultants also identified short-haul trucking and goods delivery as a market segment in which AV technology is likely to have an early impact. Some consultants noted that goods delivery has the added benefit of exposing consumers to AV technology and more diverse options for mobility. Consultants also noted that goods delivery is likely to incorporate complementary technologies, such AI and drones, to create sophisticated delivery systems.

Consultants were not as bullish as GDOT leadership and managers on AV freight applications in the long-haul markets. Consultants acknowledged the same potential market advantages for early adoption by long-haul trucking as identified by GDOT leadership (see above). However, they expressed concern that GDOT might over-invest in infrastructure for freight at too early a stage of technological innovation with AVs.

4.5.4. Impacts: Data Management

AV technology will generate an enormous volume of data regarding vehicle status, vehicle location, and conditions on the surrounding roads. GDOT leaders noted the incentives for companies to monetize data regarding vehicle performance in traffic; the more effectively these systems can be monetized, the quicker they will deploy into the transportation grid. AVs may also provide real-time updates of the transportation system's performance. A key question is how the data management strategies and systems of state and local DOTs might work with AV companies who will own this data.

Several GDOT managers noted that the current practices of broadcasting GDOT data on road conditions and transportation system performance may be inadequate to the needs of AV companies. It will be important for GDOT managers to take stock of existing GDOT databases and understand how these sources may be of value to AV companies. New data exchange methods will have to be developed, whether over a cloud platform or otherwise, as there will be too much data for any single DOT to manage and effectively distribute. In such exchanges GDOT will need to incorporate sufficient IT security systems to protect any data applications associated with the privacy and identity of AV company customers.

Over time, as the penetration of AVs on the roads increases, that value of GDOT data may diminish due to the expansion of real-time AV data. The new volume of data from vehicles may create opportunities for crowdsourcing real-time transportation system performance data. GDOT managers and consultants indicated that there may need to be federal regulations requiring all vehicles, including those from utilities, industry, and individuals, to have the capability to automatically send a signal when they break down or are doing work that requires traffic diversion.

4.5.5. Impacts: VMT and Capacity

One question that generated considerable disagreement across focus groups was the question of whether the VMT will increase or decrease. GDOT leaders indicated a need for a better understanding of how AV technology will impact VMT and traffic volume before they will be able to effectively choose strategies for public investments. One leader noted that much of the discussion about adding capacity through dedicated infrastructure for AVs is serving the needs of a limited phase of the AV technology evolution. A key question for the DOTs is whether a particular state of AV development is sufficiently stable to warrant a long-term public investment by the state. State DOTs need to be able to adapt as the technologies evolve and develop capacity strategies that are also adaptable.

GDOT manager perceptions of VMT trends revolved around questions of ownership. If AVs continue to be owned as personal vehicles, then it is more likely that VMT will increase over time. However, if AVs spur greater interest in ridesharing and transportation as a mobility service, then the VMT may decrease. For example, one GDOT manager noted that people may cease to make trips to stores or to complete other chores, but instead rely upon AVs to deliver these goods to them as a scheduled service. Another GDOT manager anticipates that traffic congestion will increase due to increases in goods and services deliveries.

Consultants tended to frame this issue in a different fashion. They largely agreed that VMT will decrease over time because citizens will likely live in denser urban areas. However, the impact of AVs in reducing VMT is uncertain. The total number of trips per person is likely to increase, as mobility opportunities open up for more people, including those with limited access or who are unable to drive themselves. If AVs generate new trips, and if they are cheaper and more convenient, then VMT may increase. Additionally, 'dead-head trips' may also increase, with delivery vehicles possibly bringing a single package of toothpaste to a customer on a Sunday, or a single consumer generating orders that set multiple vehicles on the road at once. The consultants seemed to go back and forth on this point, and agreed that in the short term, public agencies, private industry, and citizens will struggle to figure out how AVs will integrate into regular commercial activity. However, in the long term, wider adoption and managed fleets may mitigate VMT issues.

GDOT managers and consultants agreed that the introduction of AV technology is likely to lead individuals and companies to travel at off-peak times. One GDOT manager noted that Level 4 and Level 5 AV will effectively spread peak travel time across a longer time frame as commuters shift their travel times to off-peak hours. This pattern, coupled with freight traveling in off-peak hours, will make traffic management easier. Consultants also noted that businesses will shift goods and service delivery to off-peak hours.

4.5.6. Impacts: Public Financing of Transportation Agencies

One of the biggest potential impacts posed by AV technology to state and local DOTs is the potential erosion of their revenue base. Currently, funding for transportation agencies is tied primarily to gasoline taxes. Several industry experts noted that AV technology development would also correspond with increased reliance on electric vehicle propulsion systems. Experts noted some of the advantages of electric vehicles, which operate on a single electric drive functioning in one gear. This means there are fewer moving parts to break down. If AVs and EVs become complementary technologies, then states may need an alternative financing system to raise adequate revenues for the infrastructure. Although, GDOT leadership noted that the current fees paid by electric vehicles in Georgia exceed the gasoline taxes paid by similar vehicles.

4.5.7. Impacts: Intergovernmental Coordination

GDOT leaders noted that the state DOT is only responsible for the portion of the transportation system that it owns. The federal government and local governments have ownership positions as well. The AV industry will want to use these transportation systems as an integrated grid. While these systems are physically integrated, political boundaries between jurisdictions are significant. Industry will need all infrastructure owners to agree to systems that allow AVs to operate across all jurisdictions. GDOT leadership anticipates that as the levels of automation grow, so too will the need for greater integration of data management and system processes across the levels of government. GDOT leaders identified several areas where there needs to be improved coordination and standardization across jurisdictions in order for AVs to operate efficiently including:

- Standardization of stripes, signage, and guidance on when to use these tools
- Resolution of DSRC vs. cellular V2X, which will be an eventual issue
- Planning programs for roadway capacity as the trends on AV use, VMT, and capacity become clearer

GDOT leaders also pointed out that a number of AV issues are in the local government domain, particularly on topics such as curbside management, striping, signage, parking, and incentive pricing programs. However, the costs and variability associated with developing regulations at the local level may lead industry to push for more state and national level involvement in standard setting and regulation.

GDOT managers noted the important potential role of the federal government regarding AV technology. For example, federal support could significantly impact how states build infrastructure for AV. Federal funding could also allow states to design projects that consider AVs, while federal regulations on AV operations would ensure interstate operability.

Consultants also discussed how AV technology is likely to increase pressure for intergovernmental coordination. They argued that GDOT focuses primarily on moving vehicles, while local transportation officials focus on moving people. For GDOT to optimize mobility on state roads, it may need to revisit the management of those roads from a governance perspective. Consultants suggested that GDOT needs to be prepared to communicate more frequently with local authorities in order for the transportation system to adapt to the introduction of AV technology. Some consultants also suggested that GDOT may want to prepare for bottom-up (from local governments) pressure to quickly change policies, assist with new projects, or even completely cede control to local authorities.

The perception that GDOT must manage the introduction of AV technology may be overwhelming for the agency. Consultants suggested that GDOT should consider allowing local agencies to proceed on small projects deemed necessary. Several consultants argued that local governments will lead more on AV deployments than the state agency appreciates. Some of these local governments are innovative and have the funding to experiment. GDOT needs to prioritize jurisdictions with little or no capacity to adapt to AVs due to limited resources.

4.5.8. Impacts: Edge Cases

Edge cases are conditions that disrupt the normal flow of traffic and, consequently, can challenge the programming of an AV. During the focus groups, several edge cases were identified and discussed.

- *Work Zone Management.* Some GDOT leaders noted that one important role they may play is continuing to be responsible for work zone management. They described how the DOT collects information on disruptions to normal traffic flow and broadcasts the locations of these sites for public use. Other leaders thought GDOT might consider handing this role over to contractors who would send the work zone management information to GDOT's traffic operations center for broadcasting.

- *Bicyclists and Pedestrians.* GDOT managers noted that recent field tests have found that AVs continue to be confused by bicyclists and pedestrians. This is particularly true when these types of actors weave in and out of the dedicated lane markings on the roads. Many pedestrians will not walk more than 200 feet to a crosswalk (one respondent indicated that more than 50% of pedestrians exhibit this behavior). That means human behavior will not improve, even if vehicles do. GDOT managers were doubtful that AVs will change pedestrian and bicyclist behavior.
- *"Cold Driving" and Teleoperation.* GDOT managers also noted the problem of "cold driving", i.e., when the AV needs to have some intervention by a human to resolve an uncertainty on the road. As AVs approach Levels 4 and 5, the "driver" will become less engaged with driving. GDOT managers expressed concern about the speed and quality of transition from AV control to human control. Industry experts have developed solutions involving teleoperation where a remote driver steps in at a signal from the vehicle. GDOT managers expressed skepticism about teleoperation altogether, suggesting the technology seemed too far-fetched or would not be sufficient to remotely operate a vehicle.

Consultants suggested that to truly account for edge cases, people need to be better informed on the difference between "autonomous" vehicles and "driverless" vehicles. For quite some time, vehicles will depend on human assistance (i.e., Level 4 automation) when they encounter edge cases, including construction sites, accidents, and wildlife in the road, among other challenging situations. Level 5 automation (i.e., the driverless car) seemed like a remote development to both GDOT managers and consultants when discussing adaptation to edge cases.

4.5.9. Impacts: Rural

GDOT managers and consultants noted the differential impacts of AV technology on urban and rural settings. There is strong consensus among industry experts that AV technology will be deployed in urban areas first where the business case is most likely to be successful. However, there was also strong consensus among the focus group participants that the needs of rural areas should not be ignored. However, rural settings present several challenges to AV deployment.

First, consultants noted that, in Georgia, there are many rural roads that are not paved, lack signals/signage, have no cellular connection, and are not near any major human settlements. If AV technology were to fail in these environments, it raises questions about how the vehicle and the passenger/occupants will respond. If communications are sufficiently poor, then teleoperation may not be a viable option. In addition, maintaining adequate striping in those environments presents new challenges, especially when considering roads that GDOT controls (state and interstate) versus rights of way that GDOT does not control.

Second, one consultant noted the ripple effects that may arise from the introduction of AV in rural settings. The Georgia state legislature has been working on a bill that expands broadband connectivity to rural communities in the state, and once this occurs there will be more opportunities for AV to reach these places.

Third, consultants and GDOT leadership noted that there is strong representation of rural areas in the General Assembly. This means that strategies supporting AV deployment should not be overly concentrated in the largest markets; they also should account for the needs of the rural areas

4.5.10. Impacts: Safety & Liability

One of the chief selling points for AV technology made by industry experts is that it will be a safer means of transportation. As the technology matures, there will be fewer and less-severe crashes because AVs can hold a position on the road with greater certainty and can monitor conditions without the lapses in concentration that human drivers exhibit. Both GDOT managers and consultants acknowledged that these advantages would likely emerge as AVs grow in numbers on the roads. For instance, AVs will help mitigate two of the most common crash types: lane-departure crashes and rear-end collisions. However, both groups also expressed that the evidence of these safety advantages has yet to be clearly established in road tests.

- GDOT managers discussed the Arizona incident where an AV was involved in a fatal crash. One of the conditions of that crash site was a missing guardrail, damaged in a crash 11 days earlier. The state DOT had not yet repaired the guardrail. Under conditions such as the Arizona example, there are concerns that

AV companies will attempt to shift liability to the state DOT. Focus group participants indicated this to be a likely scenario, similar to many crashes today.

- GDOT managers noted that it is unlikely that a state DOT could ever react quickly enough to sufficiently mitigate all problems. Some of the focus group participants suggested that AV systems need to be sufficiently robust to avoid these types of problems. However, others wondered how the large volumes of data generated by AVs might be used in a court of law. This uncertainty led others to suggest that legislation will be needed to shield state DOTs from this new form of liability. Consultants also suggested GDOT find a way to protect itself from firms attempting to shift fault to public agencies due to lane markings, signals, or other infrastructure issues.

Several consultants suggested that the price for human drivers to secure automobile insurance will increase as the number of human-driven cars decreases. This may create market pressures to push individual drivers off the roads. Consultants were of the view that one of the chief sources of uncertainty associated with AV technology is the liability landscape and identifying who will be responsible for vehicle performance.

4.5.11. Impacts: Human Capital

GDOT managers discussed the implications on state and local human capital needs of a successful dissemination of AV technology into the marketplace. As the share of AV technology grows on the roads, there will be an enormous increase in the volume of digital information generated. GDOT will need computer engineers, data scientists, and electrical engineers. Focus group participants indicated they are already running into these staffing challenges as IT departments try to assist traffic engineers in signal system maintenance and ongoing operations. At present, there is a significant mismatch between IT and traffic engineering skills. Similarly, the career ladders for IT personnel in traffic engineering are not well established.

One GDOT manager posed the following questions regarding job security: (a) Why do you need message boards over the highways with AVs? (b) Why would you need ramp meters if you could set a geofence that measures and meters itself? and (c) What happens if there is no viable benefit/cost ratio for GDOT to maintain a navigator-style system? The concern among GDOT managers is that AV technology may reduce a significant portion of their operations.

Consultants also identified the need to hire new talent to help its current workforce understand AV technology. Consultants noted that their organizations had concluded that civil engineering experts are not well equipped regarding a number of important potential AV impacts. New knowledge experts will bring significant value to GDOT.

Consultants recommended that GDOT begin hiring personnel with expertise in data analytics, software development, and other skill sets that will help the agency respond to AV technology. At present, GDOT cannot afford to pay these types of professionals their market value, so it may need to address skills gaps by hiring consultants. Participants in the consultant focus group noted that they are already hiring people who can fill these roles.

Additionally, consultants noted that traffic engineering jobs will change, though exactly how is still an unknown. A traffic engineer's education and training prioritize human safety. Data scientists and software developers may not understand the intricacies of designing safety into traffic systems. One consultant indicated that the role of traffic engineers will change as AI improves. There is likely to be less demand for these experts to actively monitor systems and make decisions in real-time. The role of traffic management will largely shift to computers. This may allow traffic engineers to move away from this tedious role and focus on other value-added tasks.

4.5.12. Impacts: Socioeconomic

GDOT managers noted that there will be impacts for AV technology beyond the operations of the transportation system and beyond impacts on the GDOT organization. Several socioeconomic impacts of AV were identified, including the following:

- The price tag on AVs will be so high, particularly in the early years, that there will be groups that will not have access to this transportation mode. One GDOT manager expressed concern that AVs may force segments of the population to rely more on pedestrian or bike travel because they will not be able to afford mobility in an AV-dominated system.
- There may also be health impacts as the system shifts to door-to-door travel, eliminating walking from parking spots to destinations.
- If AVs are introduced through ride-hailing fleets, much will depend on the price. What if Uber goes from $5 per ride to $1 per ride? Another respondent noted that

under these conditions, people may stop owning cars and instead access services. They also would no longer need auto insurance. Under these conditions, they might use vehicles more than they do today.

- GDOT managers noted that a number of aspects of deployment and use will depend on how policymakers regulate access to AVs. This technology may increase access for everyone, or it could serve as a factor that further divides society along income lines.
- AVs may also eliminate jobs, including those of taxi drivers, truck drivers, or "half the people in this room" (GDOT operations). The focus groups discussed the relative political power of groups like the Teamsters and how such groups will react to and adapt to AV technology. They noted that AVs may have political as well as techno-economic aspects to deployment.

4.6. Role of State and Local DOTs in AV Technology

One of the most consistent judgments made by GDOT leaders and GDOT managers is that AV technology development is unlikely to generate increased demand for greater capacity in the transportation infrastructure of the state. Furthermore, they do not believe that GDOT should be trying to anticipate which of the competing AV technologies will emerge as the industry standard. Nor do they believe that it is timely for the agency to adapt the roadways in anticipation of the deployment of AV technology.

In addition, GDOT leaders are monitoring initiatives at the federal level and in other states that are laying the groundwork for adaptations to AV technology deployment.

An example includes consideration by the State of California to adopt wider roadway stripes, which should be easier for AVs to recognize. Similarly, USDOT has asked GDOT to think about I-75 as an AV corridor and develop strategies to make the corridor truck lanes CAV-ready.

GDOT managers indicated that their role is to keep doing what they already do for human drivers. For AVs, they said they will stay focused on striping and maintaining an appropriate quality of striping on the Interstate until industry tells them it is unnecessary. From a traffic operations perspective, they expect to shift to a role of monitoring activity on the roads and highways. Managers did not see the DOT as responsible for routing individual vehicles and expressed concerns about government overreach on individuals' mobility decisions.

As consultants reflected on the role of state and local DOTs in AV technology, they shared many of the views expressed by industry:

- AVs should operate efficiently with minimal help from the built environment.
- State and local DOTs should simply stay out of the way of the private sector. This will allow AV developers to continue to innovate and improve their systems and not have to respond to a patchwork of local regulations. One consultant argued that state and local DOTs should focus on keeping people safe and let the developers figure out everything else.
- AV technology will find a natural path to the market. One area where state and local DOTs can best utilize their expertise is through public policy opportunities for articulating the common good for their region.

One of the chief concerns that consultants expressed about the role of state and local DOTs stems from the mismatch between the pace of change and innovation with AV technology and the longer time horizon associated with transportation planning and processes of public-sector decision-making. Transportation planners tend to work on time horizons as long as 25 years, which may present a problem for AV technology. The public sector is not equipped to handle the rapidly changing technology landscape. Consultants believed public officials would seek the expertise of AV industry professionals, who can directly address or educate existing staff on unfamiliar aspects of technology.

Consultants noted that AV technology will not deploy as an 'overnight' shift. Rather, consultants believed there would be small breakthroughs that encourage AV adoption in different ways. State and local DOTs need to recognize that they cannot accommodate every potential development in their long-term strategic planning. Agencies need to maintain a rational approach, or too much turbulence will stress the agency. This led several consultants to recommend that DOTs wait and see what types of technologies emerge rather than proactively attempting to pick likely paths of technology development.

Consultants highlighted an "adaptable" infrastructure strategy that has been adopted by clients in other states DOTs for planning the built environment. One example can be found among North Carolina cities requiring that projects for parking garages be designed for convertibility into office or residential spaces in 20 or 30 years. In doing so, these cities are incorporating one possible future state from AV technology where the demand for parking close to destinations diminishes.

4.6.1. Role of State and Local DOTs in AV Technology: Education

Several industry experts indicated that an important role for state DOTs is education of the public and policymakers so they may be better prepared for AV technology's introduction. GDOT leadership acknowledged that it does provide some education on road conditions and safety issues. However, there was strong pushback from GDOT leadership and GDOT managers regarding this education role. One leader noted that industry commonly thinks state DOTs have special access to policymakers. However, Industry often has better lobbyists, who are better received by policymakers. GDOT managers thought that such education efforts were more likely to be a role for Georgia's Governor's Office of Highway Safety.

Other leaders thought that any effort devoted to the education of policymakers and the public will need to be tied back to the business case for AV technology. Those in industry who are able to create viable business models will also have the resources to lobby and run information campaigns aimed at both the public and policymakers. Until that business case emerges, it makes little sense for GDOT to attempt to educate policymakers or the public on the likely direction of the technology's evolution.

4.7. Conclusions

GDOT leadership and managers demonstrated a high degree of awareness of current developments in AV technology. However, the organization's level of active engagement with the technology lags the levels observed amongst GDOT's consultant community and the levels of engagement exhibited by state DOTs who have created more formal means for monitoring, exploring, and engaging with innovations in AV technology.

In many ways, GDOT's current position toward AV technology is quite reasonable. As observed in the previous chapter and in the focus group with GDOT's own consultants, industry experts are advising state and local DOTs to take a wait-and-see strategy, citing longer time horizons for Level 5 automation to be viable and road-ready. GDOT leadership also shares the perspective of industry experts that the best factor to monitor for early deployment of AV technology is the quality of the business case put forward for commercialization. To date, this viable business case has not emerged. However, industry experts and GDOT's consultants also note that the range of technology developments associated with fully autonomous vehicles, assisted driving, and connected vehicles is rapidly changing. The level of innovation is intense, and whether driverless vehicles emerge quickly or slowly, aspects of this technology are already being deployed into the population of vehicles on the road. Under these conditions, it is important for DOTs to move beyond passive monitoring toward developing internal capabilities to effectively engage with developments by industry in the marketplace and on the roads.

The focus groups provide ample evidence for a more active engagement strategy with driverless vehicles and the associated technological developments. GDOT leadership and managers identified a dozen major areas of GDOT operations that will be significantly impacted by this technology (see Table 3). For most of these topics, there is consensus across each class of focus group regarding the likelihood and the importance of impacts occurring. Each of the focus groups noted how AV technology is likely to impact the mix of human capital working inside GDOT and with the agency. Each of the focus groups noted how AV technology is likely to be a stimulus for greater intergovernmental coordination between state and local DOTs. Each noted the ways in which data management will become a core element of DOT operations and may require different forms of partnerships and work flows for the agency. Each focus group noted how AV technology has the potential to disrupt the current funding mechanisms for DOT operations.

The focus groups also revealed some real differences of perspective between GDOT personnel and industry. For example, industry experts and GDOT's consultant community do not share the widely held perception amongst GDOT leadership and GDOT managers that freight will be the most likely venue for early deployment of driverless vehicles. Industry experts viewed ride-hailing and -sharing, last-mile transit, and local goods delivery as the most likely early adopters of AV technology. In a similar vein, industry experts see education of policymakers and the public as critical roles for state and local DOTs. In a post focus group survey of GDOT managers, it was found that 64% disagreed with the idea that GDOT should take on an educational role. This sentiment was even more pronounced amongst GDOT leadership, where 80% disagreed with the proposition that GDOT should assume responsibility for educating policymakers and the public.

By comparing the findings from the review of the literature, the expert interviews, and the focus groups of GDOT and their consultants, the types of issues relevant to an implementation strategy for managing GDOT's engagement with AV technologies begins to be seen. In the next chapter, a detailed set of actions and decisions based on these findings is presented.

Chapter 5 Technology Roadmap Recommendations

5.1. Recommendations

To develop the GDOT roadmap for driverless vehicles, the researchers first identified the key contingencies shaping the technology development pathways leading to Level 5 automation. They identified these contingencies through review of the literature, review of state DOT AV plans, and through interviews with industry experts drawn from a wide range of companies developing AVs or AV-related technology (see Chapters 2 and 3). To help identify implementation strategies for adapting to driverless vehicles, they compared the guidance from industry experts with the reflections of GDOT leadership and managers on AV technology's likely impacts on the Georgia transportation system and on GDOT operations (see Chapter 4). Drawing from knowledge gained through these resources, the research team developed classes of recommendation that address the following areas of implementation: (1) Developing an Internal AV Organizational Structure; (2) Increasing GDOT Familiarity with AV Technology; (3) Managing External Engagements Related to AV Technology; (4) Data, Analysis, and Performance Indicators for AV Technology; and (5) Managing Outside Activities. Each thrust contains both actions and decisions. Within these recommendation areas are specific actions that GDOT should undertake, as well as decisions with several potential alternative actions (or non-actions) or policy positions that GDOT should consider.

In developing these recommendations, the researchers note one area of significant difference in this report from many similar documents developed for other state DOTs: recommendations regarding CV. Many of the reviewed state plans combine CV and AV, with generated recommendations and action plans addressing both topics. While one of the recommendations in this study does include CV, and some of the recommendations contained below may also be applied to CV (and other technologies), this study’s focus is AV technology, particularly on the challenges associated with driverless vehicles.

At the beginning of this study, the authors had an expectation that the developed roadmap recommendations would contain a greater degree of implementable design, operations, and policy recommendations that focused on specific technologies. However, throughout the expert interviews and focus groups, it became starkly clear that while the ultimate deployment of driverless vehicles is generally agreed upon, the timeline, form, and deployment of the technology remains highly uncertain. Many experts agree that insufficient information exists today for prudent regulatory, policy, or design changes. Thus, the developed recommendations seek to allow GDOT to prepare for the arrival of driverless vehicles, putting in place the internal structures and capabilities necessary to meet the demands of a transportation system evolving to include significant AV participation. When implemented, these recommendations will enable GDOT to anticipate impacts from higher levels of automation (i.e., Level 4 and Level 5) and prepare the agency and the state transportation system to best leverage this new emerging technology.

1) **Developing an Internal AV Organizational Structure**

Internal AV organizational structure actions and decisions seek to aid in the development of the administrative and support structure for higher levels of autonomous vehicles, including driverless vehicles, within the GDOT organizational structure. Without a clear understanding of the goals and person(s) or unit(s) responsible for AVs within GDOT, the likelihood for a successful integration of AV activities within the department is greatly diminished.

a. **Create an Internal AV Working Group Drawn from Across GDOT (ACTION)** – As seen in both the expert interviews and the literature, AVs have the potential to affect nearly all sectors of GDOT. This working group should help set the direction of internal GDOT AV activities, within the limits of the GDOT organizational structure. This group should not focus exclusively on Level 5 automation but consider the impending development pathway from Level 2 through Level 5.

b. **Define Mission Statement and Objectives (ACTION)** – The AV working group should define a mission and objectives for AVs in the context of GDOT. While the mission statement and objectives should be flexible and reviewed periodically, it is critical they be developed and utilized. Lacking these, there exists an increased likelihood that GDOT AV activities will become unconnected and ad hoc, inefficiently utilizing staff time and resources with limited results. The threat of this behavior was observed by several of the public experts on AV technology as they discussed effective and ineffective responses by state and local DOTs.

c. **Determine AV Staffing (DECISION)** – GDOT should determine if it will create a formal AV position or group within a unit (or as a unit). Similar positions have been created at other state agencies. Alternatively, primary guidance may be derived from the AV working group with AV tasks and roles distributed across existing positions. The appropriate decision will be based on the GDOT organizational structure and culture, needing to determine whether a person(s) having "ownership" of the topic is more likely to advance it (i.e., champion it) throughout GDOT or isolate the topic to that person(s).

d. **Determine GDOT AV Promotional Role (DECISION)** – A number of state DOTs to some degree maintain dual roles, actively preparing for AVs, as well as promoting AVs within their respective states. While GDOT will certainly undertake AV preparations (e.g., infrastructure design, operations, etc.), it should affirmatively decide if it will also maintain a promotional role.

e. **Set AV and CV Organization (DECISION)** – Most states consider connected vehicles and autonomous vehicles within the same framework, setting a connected and autonomous vehicle program. GDOT should determine if AV technology will be a standalone topic (e.g., an AV working group), interacting with CV strategies, or be considered together (e.g., a CAV working group). Combining the two technologies leverages potential synergies between the technologies. However, combining them increases the potential that one of the technologies may consume most of the available resources (e.g., staff time, funding, etc.), leaving the other technology without a champion and failing to advance.

f. **Determine Georgia AV Leadership Task Force (DECISION)** – Many states have developed an AV strategy committee or task force that incorporates leadership from across the state. In several instances, the DOT has been tasked (often by a legislative or executive directive) with leading or administrating this group. The state government, with input from GDOT, should determine if this is an appropriate action (potentially including establishing statutory authority) for the state and GDOT.

2) Increasing GDOT Familiarity with AV Technology

From the literature, interviews, and focus groups, one strong thrust area of the AV working group should be developing processes for expanding the AV knowledge base within GDOT. GDOT staff at multiple levels should be given opportunities and encouraged to learn about AV technology. As GDOT staff become more familiar with AVs, they will also become increasing likely to self-identify AV benefits, issues, and challenges specific to GDOT and their areas of responsibility and expertise.

a. **AV Familiarity Activities (ACTION)** – Specific formal and informal activities should be developed to increase internal GDOT knowledge and understanding of AV technology, and its potential uses and impacts.

There are a number of possible activities that could be undertaken; examples include:

i. An AV primer
ii. Seminars (seeking outside speakers from industry, other states, academia, etc.)
iii. Recommended AV reading list
iv. Encouragement of travel to AV conferences and participation on national AV working groups
v. Biweekly (every two weeks) AV news article email
vi. Internal training sessions
vii. Development of AV discussion material for outside presentations

b. **AV Technology Tracking (ACTION)** – GDOT should have an individual(s) for whom a part of the job responsibility is to track the current state and advances in AV technology, and distribute this information to the wider GDOT audience.

c. **Internal AV Committees (DECISION)** – As part of the familiarization, GDOT may set up small internal committees, considering specific aspects of AV technology and its potential impact on the transportation system and GDOT. For instance, one activity of these groups may be to consider different possible AV scenarios and how each would impact GDOT. For example, what would be the impact on pavement life cycle of significant truck platooning versus limited truck platooning? Internal groups could be either specific to an area or cross-cutting. AVs would serve as a good topic for engagement in the various workforce development programs that have been initiated by GDOT, including efforts to train and retain young engineers, as well as the leadership training programs.

3) Managing External Engagements Related to AV Technology

AV technology will have impact throughout Georgia and will include a multitude of stakeholders. As highlighted by the industry experts and seen throughout the literature, a successful AV deployment will require coordination and cooperation among the many federal, state, local, public, and industry groups that influence or are impacted by AV technology.

a. **Develop AV Coordination, Planning, and Actions with Other Local and State Agencies, as well as Private Industry (ACTION)** – One item that has been clear across the expert interviews, literature, and other state agencies' AV plans is that local governments and departments of transportation will play a critical role in the integration of AVs into the transportation system. GDOT should begin working with local and other state agencies in considering AV impacts and guiding potential responses.

   i. **Engage with local departments of transportation (ACTION**) – As seen in the expert interviews and focus groups, it is highly likely that much of the impact of AV will fall within the purview of local DOTs. Strong coordination and cooperation between GDOT and local DOTs will help ensure an effective integration of AVs throughout Georgia. Example engagements include:

1. Working committees
2. Joint scenarios analysis
3. Memoranda of understanding

ii. **Engage with a wide array of external stakeholders (ACTION)** – For example, the Georgia Emergency Management and Homeland Security Agency (GEMA/HSA) is responsible for developing disaster plans, such as coastal evacuations. Distressed or non-standard conditions may present barriers to AV operation (i.e., debris on roadway, contra-flow lanes, etc.). Significant AV planning and coordination between GDOT and GEMA/HSA will allow the highest degree of preparation and response. GDOT should seek engagement with a number of stakeholders, such as:

1. Law enforcement
2. Fire and EMS
3. Municipalities and local governments
4. Metropolitan planning organizations and regional planning agencies (RPAs)
5. Association of County Commissioners of Georgia
6. Other state agencies and offices, e.g., Governor's Office of Highway Safety, GEMA/HSA, etc.

7. Business groups, e.g., chambers of commerce, etc.
8. Road user groups, e.g., AAA, Road Safe America, etc.
9. Others

The AV working group (recommendation 1a) could be tasked with developing the form of these engagements.

b. **Determine Appropriate GDOT Involvement in Training (DECISION)** – Some other states have engaged in the training of law enforcement and emergency responders for incidents involving AVs. In addition, states have undertaken items such as providing edits to the state driving manuals or other similar documents. GDOT should determine if and to what level it will engage in these or similar activities and how to implement those chosen actions.

c. **Determine the Appropriate Spokesperson for State AV Policy (DECISION)** – GDOT should engage with other state agencies, the governor's office, the State Transportation Board, and others to determine who the appropriate spokesperson is for state AV policy.

4) Data, Analysis, and Performance Indicators for AV Technology

Industry experts and the findings from the research and professional literature highlighted that increasing automation technology in vehicles and on the roadway is resulting in a massive increase in data available to monitor and improve the transportation system's safety and performance. GDOT will need to advance its ability to collect, store, process and interpret, and convert the data into actionable information. This data will be significantly greater in volume and velocity than currently seen, and will be drawn from a wide variety of internal, public, and private sources.

Data becomes actionable only after it has been converted into information that can be used to inform future decisions. An important step in the process of decision-making is the development of performance metrics that indicate the impact of various technologies on the various aspects (e.g., safety, delay, reliability, travel times, etc.) of transportation system safety and operational performance. While AV technology is disruptive and will likely have vast impacts on the transportation system, many experts interviewed agreed there exists significant uncertainty in the technology's form and deployment rate. It is not currently possible to make reliable AV predictions upon which infrastructure or operational design changes could be based.

Most industry experts also agreed there will be an evolution in transportation system safety and operational performance as the technology deploys and progresses. This is due not only to Level 4 and 5 AVs, but also Level 2 and 3 AV capabilities, such as collision avoidance, lane departure warnings, blind spot detection systems, etc. *It is from the conversion of the massive data streams to performance metrics and actionable information that the DOT will first see tangible impacts of AVs, allowing for proactive actions while the impacts can still be addressed and the technology deployment influenced.* As highlighted by one expert, these technologies will eventually reach a "tipping point" or critical mass.

It is from the use of data, analysis, and performance indicators that GDOT will first identify these points. Thus, it is critical that GDOT develop the computational and data storage infrastructure and workforce skills necessary to conduct these technology impact analyses.

a. **Establish Appropriate Data Scientist Staffing Levels (ACTION)** – GDOT should employ additional data scientists tasked with converting data streams for the development of performance metrics, as described above. A critical aspect of these positions would be developing the data quality standards necessary for producing actionable information. While some portion of these efforts may also occur through contract efforts, it is important that GDOT maintain the knowledge and program guidance of this core capability internally.

b. **Establish Appropriate Information Technology Staffing Levels (ACTION)** – Maintaining the massive new data streams will require significant information technology expertise and capacity. GDOT should explore both internal and contracting methods to gain and retain this expertise.

c. **Establish Data Architecture and Management System (ACTION/DECISION)** – GDOT will need to increase its capability to store and archive significant volumes of data. GDOT should explore both internally and externally (e.g., third-party cloud) based solutions. This should include a central repository for data, meta-data, and derived information.

d. **Establish AV Impact Performance Indices (ACTION)** – Utilizing the data science and IT expertise, GDOT should develop performance indices and metrics to help gauge the deployment and impacts of AVs. As seen in the literature, expert interviews, and focus groups, there are a wide variety of potential deployment scenarios and impacts. Thus, the developed metrics should expand well past traditional operational measures (i.e., flow, travel time, safety, VMT, etc.) and include items such as AV ownership rates, percentage of trips served by mobility services, changes in facility capacity due to vehicle technology, trends in vehicle characteristics (i.e., acceleration rates, top speeds, size, etc.), rural- and urban-specific metrics, and differences between metrics, etc. Finally, this analysis should incorporate economic considerations, as many experts interviewed strongly indicated that AV deployment and impacts will be highly tied to use cases with viable business models.

e. **Explore Data Monetization Policies (DECISION)** – Along with data collection, archiving, processing, and analysis, GDOT will need to determine policies and procedures regarding data monetization. This includes both opportunities for GDOT to monetize their data, as well as for private firms that seek to sell data to GDOT.

5) **Managing Outside Activities** – A number of experts recommended, and other states are involved in, pilot programs and educational and regulatory activities. Several of these activities offer potential opportunities for the GDOT AV program.

   a. **Involvement in AV Pilots, Test Beds, etc. (DECISION)** – GDOT must determine the level of activity it seeks in AV pilot projects, test beds, etc. The experts, literature, and other states are mixed on this type of activity. Active involvement in AV test beds can serve to help promote AV technology among policymakers and the public, and create hands-on AV experience for GDOT staff. However, AV test beds can also entail significant financial investment with little perceived return on investment, and appear to be more of a promotional activity. A key activity of the proposed AV working group should be to explore the potential of such projects.

   b. **Determine Appropriate GDOT Involvement in Education of Public Officials Regarding AVs (DECISION)** – Many of the experts, literature sources, and other state DOTs see educating and familiarizing public officials with AV technology as an important state DOT activity. The state DOT is commonly perceived as a trusted source for transportation information. GDOT will need to decide if this is an appropriate role for GDOT, or if it should reside within some other state agency.

c. **Determine Appropriate GDOT Involvement in Public Education Regarding AVs (DECISION)** – Many of the same experts, literature sources, and other state DOTs see educating and familiarizing the public with AV technology as an important state DOT activity, as the DOT has significant experience and public trust. Given the differences among states, GDOT may choose not to undertake such a role.

d. **Determine GDOT Involvement in Regulatory Development and Enforcement (DECISION)** – In several states, the DOT leads or is heavily involved in defining AV testing regulations and operations and in developing draft legislation. The USDOT's *Automated Driving Systems 2.0: A Vision for Safety* provides extensive discussion and recommendations for state highway officials opting for an oversight role in AV testing. GDOT should determine if it has the authority and/or desire to play such a role. At a minimum, GDOT should stay apprised of activities within the state.

e. **Determine Whether GDOT Approaches to AV Technology Will Focus on Freight (DECISION)** – One of the biggest differences of opinion between industry experts and GDOT leadership and managers is on the question of where driverless vehicles are likely to be deployed first. Numerous GDOT managers viewed freight, particularly long-haul freight, as the earliest adopter of AV and driverless technology. This view was not shared by industry experts—even those in the freight industry. In this study, several external forces that are focused on freight (e.g., USDOT guidance on freight and CAV readiness of I-75 corridor development, and freight-focused policies of the states surrounding Georgia) are identified. However, GDOT should avoid decision-making processes that drift in favor of freight without doing a strategic review to understand why industry thinks this is the wrong focus for early deployment and for infrastructure investment decisions.

5.2. Summary

The preceding five thrusts—(1) Developing an Internal AV Organizational Structure; (2) Increasing GDOT Familiarity with AV Technology; (3) Managing External Engagements Related to AV Technology; (4) Data, Analysis, and Performance Indicators for AV Technology; and (5) Managing Outside Activities—entail a series of recommendations that enable GDOT to best anticipate, prepare for, and leverage AV technology for a safe and efficient transportation system. One omission from these recommendations is mid- and long-term AV implementation plans. While found in plans of other states, this is not included as a recommendation because current uncertainty in deployment and impacts precludes the ability to make actionable long-term plans. However, the value of this exercise of developing such plans is recognized, and may be accomplished within the given recommendations. For instance, recommendation 2c provides for internal AV committees, and 4d establishes AV impact performance indices. Thus, as trends develop, internal committees can conduct scenario-planning analyses that consider the mid- and long-term impacts of these trends or significant divergence from these trends. As trends and indices begin to converge, it is anticipated that GDOT will be able to produce actionable policy, infrastructure, and operational decisions.

Appendix A State AV Activity Report

Table A 1: State AV Activities

State	Activities	AV Study / Roadmap	Description
Alabama	Yes	No	State legislation set up Joint Legislative Committee to study self-driving vehicles. No completed product to date.
Alaska	No	No	N/A
Arizona	Yes	No	Governor Ducey authorized testing and study; directed all state agencies to assist. No completed product to date.
Arkansas	No	No	N/A
California	Yes	Yes	California DMV administers robust AV testing program with private sector. Caltrans coordinates with multiple test beds and also State Highway Patrol. Multiple studies funded through various research partners.
Colorado	Yes	No	Created RoadX program to oversee various test and research activities. However, no study to date.
Connecticut	Yes	No	CTDOT sponsors Connecticut Transportation Research Center at UCONN, which created The Autonomous Vehicle Research Group. This group has several research projects in progress.
Delaware	Yes	Yes	Governor Carney signed order creating CAV advisory council to research CAV impacts. First report assessing impacts published in April 2017.
Florida	Yes	Yes	Florida passed first AV legislation in 2012. Has hosted Florida AV Summit since 2013. Created first working groups in 2014. Multiple reports published through research partners.
Georgia	Yes	Yes	Georgia Institute of Technology undertaking Roadmap Study.
Hawaii	No	No	N/A

Idaho	Yes	No	2018 executive order created the Autonomous & Connected Vehicle Testing & Deployment Committee.
Illinois	Yes	No	Illinois Center for Transportation (IDOT research partner) identified CAVs as research need in July 2018.
Indiana	Yes	Yes	Report due June 2018. Has not been published yet. Another report in works around Economic Development.
Iowa	Yes	Yes	Published "Vision Document" in 2017 as part of a broader project coalition, including university partners.
Kansas	No	No	N/A
Kentucky	Yes	Yes	University of Kentucky policy analysis of AVs funded by Kentucky Transportation Cabinet.
Louisiana	Yes	No	Study in progress. LaDOTD contracted with Arcadis to provide a strategic roadmap for addressing AV impacts
Maine	Yes	No	Legislature created a State of Maine Commission on Autonomous Vehicles in 2018. Meets monthly.
Maryland	Yes	Yes	Published CAV strategic plan in December 2017. Created working group on CAVs in 2015. MDOT submitted an application for a federally designated proving ground and failed.
Massachusetts	Yes	Yes	Autonomous Vehicle Working Group created in October 2017. Draft report for working group published September 2018.
Michigan	Yes	Yes	Center for Automotive Research runs a quarterly CAV working group on behalf of DOT. MDOT also works closely with industry. MDOT also provided some funding for construction of MCity at U-Michigan and works closely with the test bed. WSP recently completed a strategic plan, but has not been published.

Minnesota	Yes	No	Has sponsored a driverless shuttle pilot. Governor Dayton formed an advisory council in March 2018 with policy recommendations due in December 2018 (expected completion early 2019). Council is co-chaired by MnDOT commissioner. Also formed an interagency CAV team to manage AV programs. Also created an I-94 test bed that MnDOT manages. Also published a survey for the public to offer input on AV concerns.
Mississippi	No	No	N/A
Missouri	Yes	No	Surveyed residents about long-range concerns and priorities around AVs. Has funded a research project titled: "Leader-Follower TMA System" that looks at platooning for maintenance vehicles.
Montana	No	No	N/A
Nebraska	No	No	State legislature published a policy primer in 2017. Also, no DOT involvement
Nevada	Yes	No	Nevada DOT collaborating with multiple local partners, including Northern Nevada Intelligent Mobility Living Lab. Has also hosted policy workshops. Nevada DMV has created self-certification for testing. Nevada DOT has hired CH2M to do a CAV policy roadmap as of November 2016, but no publication to date.
New Hampshire	No	No	Appears to be leveraging research findings from neighboring states in New England.
New Jersey	No	No	N/A
New Mexico	Yes	No	Legislature passed a bill requiring NM DOT to create a committee to study AV impacts and issue report.
New York	No	No	N/A

North Carolina	Yes	Yes	Kimley-Horn produced short-range roadmap published in November 2016 that proposed activities to prepare NC DOT and other state agencies for AV impacts. State AV committee also operating.
North Dakota	Yes	No	State legislation requires DOT to provide task force report in 2019.
Ohio	Yes	No	Ohio DOT has created DriveOhio to lead testing/study. Organizes all test beds/projects in the state. Ongoing "Connected Vehicle Analysis in Connected Marysville Pilot" set to conclude in October.
Oklahoma	Yes	No	State DOT has convened AV task force to study I-40 corridor and will report by December 2018.
Oregon	Yes	Yes	ODOT presented report to Oregon State legislature on September 10, 2018. Report published online.
Pennsylvania	Yes	Yes	Published a report in 2014. Has hosted annual AV summit since 2017 (3rd year). PennDot convened Autonomous Vehicle Policy Task Force starting in spring 2016 to develop a state AV testing policy. It released its recommendations in December 2016.
Rhode Island	Yes	No	Launched the Rhode Island Transportation Innovation Partnership challenge in 2018 to explore AV models.
South Carolina	No	No	N/A
South Dakota	No	No	N/A
Tennessee	No	No	N/A
Texas	Yes	Yes	Published first report in October 2016, second in March 2017. Signed MOU with TTI (Texas A&M) in 2017 to design test protocols for AVs. Published another report through TTI in April 2017.

Utah	Yes	Yes	Policy report delivered to legislature in October 2016.
Vermont	Yes	No	Minor report issued to legislature in January 2018.
Virginia	Yes	Yes	Plan for establishing testing and deployment programs in Virginia, and organizational roles for administration. Published fall 2017.
Washington	Yes	No	Governor Inslee creating a working group by executive order in June 2017. Washington Legislature created another in May 2018.
West Virginia	No	No	N/A
Wisconsin	Yes	Yes	Governor Walker created a special steering committee in 2017 to study CAVs, report published June 2018.
Wyoming	No	No	Wyoming has one of three federally designated CV pilots, but no AV activity.

Appendix B List of Interview Participants

Table B 1: List of Interview Participants

First Name	Last Name	Organization	Professional Position	Education
Philip	Aiello	United Parcel Service (UPS)	Director, Automotive Advanced Technology Group	Industrial Automotive Technology (B.S.); Business Management (B.S.)
John	Avery	Panasonic Automotive	Engineering Group Manager	Electric Engineering (B.S.E.E.)
Ronald	Barrett	City of Marietta, GA	Director of IT	Geography & GIS (M.S.)
Austin	Brown	Policy Institute for Energy, Environment, and the Economy, at UC Davis	Executive Director	Biophysics (Ph.D.)
Tom	Byron	Florida Department of Transportation (FDOT)	Assistant Secretary, Strategic Development	Civil Engineer (B.S.)
Henri	Cordon	Navya Group	Chief Business Development Officer	Business & Economics (MBA)
Eric	Dennis	Center for Automotive Research (CAR)	Senior Transportation Systems Analyst	Environmental Engineering (M.S.); Master Urban Planning
Johan	Engström	Virginia Tech Transportation Institute (VTTI)	Group Leader, Human Factors and Advanced Systems Testing	Evolutionary & Adaptive Systems (Ph.D.)
Corey	Ershow	Lyft	Transportation Policy Manager	Law School (J.D.)
Ravi	Godbole	AgCo Corporation	Global R&AE Manager	Agriculture Engineering & Statistics (Ph.D.)
Chris	Heiser	Renovo	Co-Founder & CEO	Mechanical Engineer (B.S.)
Jay	Hietpas	Minnesota Department of Transportation (MnDOT)	Connected and Automated Vehicle Director	Civil Engineer (M.S.)

Vineet	Jain	Drive.ai	Head of North American Deployment	Finance & Strategy (B.S.)
Aravind	Kailas	Volvo Group	Manager of Research & Innovation	Electrical & Computer Engineering (Ph.D.)
Elliot	Katz	Phantom Auto	Co-Founder & Chief Strategy Officer	Law School (J.D.)
Ankit	Kaushik	Independent Consultant (software developer)	Current Student	Electrical & Computer Engineering (M.S.)
Kirsten	Korosec	Tech Crunch	Senior Reporter	Journalism & Communication (M.A.)
Jane	Lappin	Toyota Research Institute (TRI)	Director of Government Affairs & Public Policy	Business (MBA)
Scott	Marler	Iowa Department of Transportation (IowaDOT)	Director, Operations Bureau	Civil Engineer (B.S.)
Donna	Matulac	Iowa Department of Transportation (IowaDOT)	Assistant Director, Office of Traffic Operations	Civil Engineer (B.S.)
David	Montanye	Cobb County Department of Transportation, GA	Traffic Operations Divison Manager	Civil Engineer (B.S.)
Brook	Martin	Cobb County Department of Transportation, GA	ITS Manager	Civil Engineer (B.S.)
Nick	Reed	Robert Bosch LLC.	Head of Mobility R&D	Pyschology (Ph.D.)
Jordan	Sanders	Phantom Auto	Director of Business & Operations	Economics (B.A.)
Stefan	Seltz-Axmacher	Starsky Robotics	Co-Founder & CEO	International Business & Marketing (B.S.B.A)

Tom	Sever	Gwinnett County Department of Transportation, GA	Deputy Director, Traffic Engineering, Operations and Maintenance	Civil Engineer (B.S.)
Jason	Stinson	Renovo	Co-Founder & Chief Technology Officer (CTO)	Electrical Engineering (M.S.)
Eric	Tanenblatt	Dentons	Principal, Global Chair of Public Policy & Regulation	Economics (B.A.)
Chris	Urmson	Aurora Innovation	Co-Founder & CEO	Robotics & Computer Engineering (Ph.D.)
Jeff	Zimmerman	AgCo Corporation	R&D Strategy Manager for AV	Agriculture Engineering (M.S.)

Appendix C Protocols

Georgia Tech | Office of Research Integrity Assurance

Protocol Number: H18169
Funding Agency: GEORGIA DEPT OF TRANSPORTATION
Review Type: Expedited, Category 7
Title: GDOT Roadmap for Driverless Vehicles - Semi-structured Interview
Number of Subjects: 60

May 4, 2018
Michael P Hunter
Civil Engr
michael.hunter@ce.gatech.edu

Dear Dr. Hunter:

The Institutional Review Board (IRB) has carefully considered your proposal referenced above. The proposed procedures afford reasonable protection to the human subjects involved and therefore you are granted approval.

Minimal risk research qualified for expedited review in accordance with 45 CFR 46 expedited category # 7

Per 45CFR46.117(c) (2) this study qualifies for a waiver of documentation of consent.

Your approval and stamped consent form(s) are effective **05/04/2018** with an expiration date of **05/03/2019.** Thereafter, continued approval is contingent upon submission of a continuation form/progress report that must be reviewed and approved prior to the expiration date.

Approval is contingent upon your agreement to obtain informed consent from your subjects, to abide by the Georgia Institute of Technology Assurance of Compliance for the Protection of Human Subjects, and to keep appropriate records concerning your subjects.

You are required to submit to the IRB for review any changes in procedures involving human subjects prior to the implementation. Adverse events and unanticipated problems must be reported to the IRB within ten days of their occurrence. These may be reported via the Adverse Event Reporting tool in your protocol in IRBWISE. Very serious adverse events must be reported immediately to the IRB by telephone; a full report must also be submitted via IRBWISE as soon as practicable.

Please note that all correspondence or e-mail you send to the IRB regarding this topic must include the full title and Protocol Number (shown in the upper right corner of this letter).

If you have any questions concerning this approval or regulations governing human subject activities, please feel free to contact me at 470-572-3581.

Sincerely,

Steve J. Anzalone, MS, CIP
Compliance Officer
Office of Research Integrity Assurance
Steven.anzalone@gtrc.gatech.edu
470-572-3581

Unit of the University System of Georgia   An Equal Education and Employment Opportunity Institution

FIGURE C 1

IRB Approval Letter

Consent Form for Focus Groups

CONSENT TO PARTICIPATE IN A RESEARCH STUDY
Georgia Institute of Technology

Project Title: GDOT Roadmap for Driverless Vehicles
Investigator(s): (Person(s) conducting interview, to be completed when focus scheduled.)
Principal Investigator: Michael Hunter, Ph.D.

You are being asked to be a volunteer in a research study.

Purpose: This project will seek to develop a driverless vehicle implementation roadmap for the Georgia Department of Transportation (GDOT). The roadmap will provide a synthesis of the current research regarding the potential impacts of driverless vehicles on transportation systems. The developed roadmap will provide guidance to GDOT allowing for a planned, efficient, and effective approach to addressing this rapidly approaching technology. The research team anticipates that up to 60 individuals will participate in this research based upon their expertise in autonomous vehicle technology or the transportation systems of the State of Georgia.

Exclusion/Inclusion Criteria: Study participants must be 18 years of age or older with professional experience working as an employee of GDOT or as a consultant providing professional services to GDOT.

Procedures: Participation will be in the form of a focus group. Each focus group will take between 90 minutes to 2 hours to complete. During the focus group participants will be presented with alternative scenarios regarding the development of autonomous vehicle technology. Participants will be asked to discuss the likely impact of each scenario on the transportation infrastructure of the State of Georgia and the demands this will place on the organizational structure, processes, and human capital of the Georgia Department of Transportation. The focus group will be recorded and a transcript made for research purposes. Both the recording and the transcript will be stored in a de-identified file (i.e. the data of your interview will not be associated with your name to ensure confidentiality. With your consent the research team will store and analyze your de-identified interview data.

Confidentiality: The following procedures will be followed to keep your personal information confidential in this study: The data collected about you will be kept private to the extent required by law. Your records will be kept in secure files and only study staff will be allowed to review them. Your privacy will be protected to the extent allowed by law.

The Georgia Institute of Technology IRB, and the Office of Human Research Protections, may look over study records during required reviews.

APPROVED *Consent Form Approved by Georgia Tech IRB: May 04, 2018 - May 03, 2019*

FIGURE C 2

Consent Forms for Focus Groups

Benefits: There is no immediate, direct benefit to the participants. There may be a social benefit from this project as the information may assist the Georgia Department of Transportation to better plan for the impacts of autonomous vehicle technology on the transportation and mobility systems of the State of Georgia.

Costs to You: There are no costs to you, other than your time, for being in this study.

Risks or Discomforts: Participation in this study may carry the possibility of breach of confidentiality in the case of malicious external activity. The risks involved are no greater than those involved in daily activities such as email correspondence or user registration via a secure website.

Storing and Sharing Information: Your participation in this study is gratefully acknowledged. It is possible that your information/data will be enormously valuable for other research purposes. By signing below, you consent for your de-identified information/data to be stored by the researcher and to be shared with other researchers in future studies. If you agree to allow such future sharing and use, your identity will be completely separated from your information/data. Future researchers will not have a way to identify you. Any future research must be approved by an ethics committee before being undertaken.

Questions about Your Rights as a Research Participant:

- Your participation in this study is voluntary. You do not have to be in this study if you don't want to be.
- You have the right to change your mind and leave the study at any time without giving any reason and without penalty.
- Any new information that may make you change your mind about being in this study will be given to you.
- You will be given a copy of this consent form to keep.
- You do not waive any of your legal rights by signing this consent form.

If you have any questions about your rights as a research participant, you may contact:

Ms. Melanie Clark, Georgia Institute of Technology
Office of Research Integrity Assurance, at (404) 894-6942.

If you have questions about the focus group or the overall goals and objectives of the research project then contact:

Dr. Michael P. Hunter
School of Civil and Environmental Engineering
Georgia Institute of Technology at (404) 385-1243

APPROVED *Consent Form Approved by Georgia Tech IRB: May 04, 2018 - May 03, 2019*

FIGURE C 2

(Continued)

If you sign below, it means that you have read (or have had read to you) the information contained in this letter and would like to be a volunteer in this research study.

____

Participant Name (printed)

____

Participant Signature

____

Signature of Research Team Member Obtaining Consent

Date:

Consent to Store and Share your Information (check one option):

______I agree that my de-identified information/data may be stored and shared for future, unspecified research.

______I do not allow my de-identified information/data to be stored and shared for future, unspecified research. These may be only used for this specific study.

APPROVED *Consent Form Approved by Georgia Tech IRB: May 04, 2018 - May 03, 2019*

FIGURE C 2

(Continued)

Consent Form for Interviews

CONSENT TO PARTICIPATE IN A RESEARCH STUDY
Georgia Institute of Technology

Project Title: GDOT Roadmap for Driverless Vehicles
Investigator: (Person conducting interview, to be completed when interview scheduled.)
Principal Investigator: Michael Hunter, Ph.D.

You are being asked to be a volunteer in a research study.

Purpose: This project will seek to develop a driverless vehicle implementation roadmap for the Georgia Department of Transportation (GDOT). The roadmap will provide a synthesis of the current research and understandings of the potential impacts of driverless vehicles on transportation systems. The developed roadmap will provide guidance to GDOT allowing for a planned, efficient, and effective approach to addressing this rapidly approaching technology. The research team anticipates that up to 60 individuals will participate in this research based upon their expertise in autonomous vehicle technology or the transportation systems of the State of Georgia.

Exclusion/Inclusion Criteria: Study participants must be 18 years of age or older with expertise in the transportation or autonomous vehicle field.

Procedures: Participation will be in the form of a semi-structured interview. During the interview we will seek your perspectives on how this technology might develop over the next couple of decades, and the potential impact to a State DOT's planning and operations. The interview will be by phone and will last between 30 minutes to 1 hour of your time. This interview will be recorded and a transcript made for research purposes. Both the recording and the transcript will be stored in a de-identified file (i.e. the data of your interview will not be associated with your name to ensure confidentiality. With your consent the research team will store and analyze your de-identified interview data.

Confidentiality: The following procedures will be followed to keep your personal information confidential in this study: The data collected about you will be kept private to the extent required by law. Your records will be kept in secure files and only study staff will be allowed to review them. A list of all interview participants and their professional association may be included in the final report; however, your responses will not be associated with your name. Your privacy will be protected to the extent allowed by law.

The Georgia Institute of Technology IRB, and the Office of Human Research Protections, may look over study records during required reviews.

Benefits: There is no immediate, direct benefit to the participants. There may be a social benefit from this project as the information may assist the Georgia Department of Transportation to

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FIGURE C 3

Consent Forms for Interviews

better plan for the impacts of autonomous vehicle technology on the transportation and mobility systems of the State of Georgia.

Costs to You: There are no costs to you, other than your time, for being in this study.

Risks or Discomforts: Participation in this study may carry the possibility of breach of confidentiality in the case of malicious external activity. The risks involved are no greater than those involved in daily activities such as email correspondence or user registration via a secure website.

Storing and Sharing Information: Your participation in this study is gratefully acknowledged. It is possible that your information/data will be enormously valuable for other research purposes. By signing below, you consent for your de-identified information/data to be stored by the researcher and to be shared with other researchers in future studies. If you agree to allow such future sharing and use, your identity will be completely separated from your information/data. Future researchers will not have a way to identify you. Any future research must be approved by an ethics committee before being undertaken.

Questions about Your Rights as a Research Participant:

- Your participation in this study is voluntary. You do not have to be in this study if you don't want to be.
- You have the right to change your mind and leave the study at any time without giving any reason and without penalty.
- Any new information that may make you change your mind about being in this study will be given to you.
- You will be given a copy of this consent form to keep.
- You do not waive any of your legal rights by signing this consent form.

If you have any questions about your rights as a research participant, you may contact:

Ms. Melanie Clark, Georgia Institute of Technology
Office of Research Integrity Assurance, at (404) 894-6942.

If you have questions about the focus group or the overall goals and objectives of the research project then contact:

Dr. Michael P. Hunter
School of Civil and Environmental Engineering
Georgia Institute of Technology at (404) 385-1243

If you participate in the interview, it means that you have read -- or have had read to you -- the information contained in this letter and would like to be a volunteer in this research study. By continuing with this interview, you indicate your consent to be in the study. Thank you.

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FIGURE C 3

(Continued)

Expert Interview Protocol

Project: Georgia Department of Transportation (GDOT) Roadmap for Driverless Vehicles

Purpose: Over the coming years, GDOT and other State DOTs will need to prepare for the arrival of driverless vehicles through planning, operations, construction, and research. As a guide to these future efforts, this project will seek to develop a driverless vehicle implementation roadmap. The roadmap will provide a synthesis of the current research and understandings of the potential impacts of driverless vehicles on the transportation system from a GDOT perspective. A potential research, design, and implementation program will be proposed to prepare for the arrival of these vehicles. The developed roadmap will provide guidance to GDOT allowing for a planned, efficient and effective approach to addressing this rapidly approaching technology.

[Introduction] *"I would like to ask you about AVs, first a few questions in relation to your position and general thoughts on what the future transportation system with AVs might look like, followed by a few questions on the role of a department of transportation in a transportation system with widespread AV use."*

Expert Interview Questions – Part 1 – General Industry Questions

1. [Personal Background] Tell me a little about yourself. What is your professional background?
    - How did you become involved in AV?
    - How much experience do you have in this area?

2. [Industry specific AV view – participant will be asked a., b., or c.]
    a. [Technology developer]
        - What does an AV need from the built environment, i.e. what are the requirements of an AV beyond the needs of a manually driven vehicle, i.e., dedicated lanes vs mixed use, connectivity (cellular, DSRC), nothing, etc.?
        - Will vehicles look like today's cars and trucks?
        - Do you expect the operating characteristics to be different than manually driven vehicles, i.e., platooning, AV headways?

    b. [Industry user]
        - How do you see automated vehicle (AV) technologies impacting your industry?

    c. [combined developer / user]

- What does the AV need from the built environment, i.e. what are the requirements of an AV beyond the vehicle itself: dedicated lanes vs mixed use, connectivity (cellular, DSRC), etc.?
- Will vehicles look like today's cars and trucks?
- Do you expect the operating characteristics to be different than manually driven vehicles, i.e., platooning, AV headways?
- How do you see automated vehicle (AV) technologies impacting your industry?

3. [Major transformations] I would like to learn more about your vision of the characteristics of AV integration into the transportation system. What are the characteristics of the transportation system that you believe will be transformed by AV?
    - What is the impact on Transit?
    - How do you see the tradeoff between ridesharing vs single occupancy vehicle (SOV) vs no-occupancy vehicle?
    - Will AV be owned primary through fleet management (mobility as a service), private ownership, or some other model?
    - What do you see as the role of AV in Freight?
    - Other?

4. [Timeline and challenges] What do you perceive as the AV implementation timeline and challenges to implementation?
    - What development timeline do you see as most likely for AV technology? When will a company or person be able to buy an unrestricted AV?
    - What do you see as the greatest challenges to AV adoption, either technical, policy, regulatory, infrastructure, etc.?
    - Is there an implementation hurdle you see as overstated or do you see any significant misconceptions about the technology and its likely deployment path?
    - What do you see the government's role in facilitating the development and deployment of AV technology? Do you see that role changing over time?

5. [Other disruptors] Is there a major development you can envision that may completely reshapes the trajectory of AV development?
    - Sensor breakthrough?
    - Drones?
    - 3D printing?
    - Etc.

6. Is there a critical aspect relative to the impact of AV on transportation that I have failed to ask?

Expert Interview Questions – Part 2 – GDOT Specific Questions

1. [Participant view of a State DOT] Broadly speaking, what do you see as the role of a State Department of Transportation?
    - Do you or your firm currently interact with a State DOT, and if so, how?

2. [Participant view on what a State DOT should and should not do] Based in on your industry knowledge,
    - What do you see as the role or critical activities that a State DOT is, or should be, conducting to facilitate the transition from a non-AV fleet to roadways with AVs?
        i. Signing and Striping
        ii. other
    - Is there a specific aspect of facilitating AV that a state DOT should not do?
    - Are there any functions or roles performed today that you see as unnecessary in a future with automated vehicles?
    - How do you see automated vehicles changing the management of transportation system infrastructure? Traffic signals, ramp meters, reversible lanes, etc.
    - Do you see any major shifts in the make-up or role of a state DOT?
    - What are key issues that AV technology poses for the following functions:
        i. Design of highways, roads, and bridges?
        ii. Traffic operations?
        iii. Construction of infrastructure?
        iv. Maintenance?

v. Infrastructure planning?
vi. The types of skills sets hired by state DOTs?
vii. The types of partnerships needed by state DOTs?

Focus Group Protocol

Objective: We are using a combination of focus groups and scenarios as a foresight exercise designed to stimulate forecasts by public transportation professionals of the impact of autonomous vehicle (AV) technology development and deployment. Each focus group will explore the impact of AV technology on 1) the demand for transportation infrastructure for the State of Georgia and 2) the organizational design of GDOT in terms of operations and human capital needs. We will use scenarios as a "treatment" designed to stimulate discussion amongst each panel of respondents. The advantage of focus groups is that they allow interviewers to observe responses of professionals engaged in a more natural conversation pattern regarding a topic likely to have a significant impact on their work lives. Mini-scenarios are interspersed through the focus group protocol designed to achieve two objectives. First, each mini-scenario will introduce information to respondents that we have gathered from the expert interviews and from our review of the research and professional literature. Second, each mini-scenario will also frame a question for the respondents to discuss. There are four focus group events planned for the summer of 2018. Each event will focus on one of the following groups: 1) GDOT leadership; 2) GDOT mid-level employees; 3) external consultant professionals with extensive experience working with GDOT.

Key Theoretical Framing:

The focus groups aim to provide insights directly from community of professionals currently engaged in delivering the GDOT program of transportation services. The use of scenarios allows us to explore the following:

1. Expectations and assessments of current personnel regarding the likelihood of each scenario transpiring within the state.
2. Identification of key barriers and facilitators associated with scenario.
3. Identification of current capabilities for adapting to this technology. Since this technology will develop largely outside of GDOT's control the agency will be in an adaptive posture rather than controlling the pace of innovation and change.
4. Projection of demands upon existing infrastructure associated with each scenario. In this line of questions, we will be seeking professional assessments of how the demand for the existing infrastructure is likely to change.
5. Projection of demands on the organizational and operational structure of GDOT. What should be the organizational and operational design of GDOT to adapt to AV technology?
6. Projection of demands on the human capital needs of GDOT. Is the current mix of personnel within the agency capable of adapting to alternative scenarios of

technology deployment? What skill sets need to be added to the agency? What skill sets will no longer be needed?

Procedures for Conducting the Focus Groups:

1. Preparation for the focus group
    a. All focus groups will be conducted on GDOT facilities. Prior to the focus group, team members should check the availability and accessibility of audio-visual equipment presenting visual cues to respondents.
    b. A list of all invited and confirmed respondents should be compiled prior to the day of the focus group.
        i. Check responses to the invitation survey each day leading up to and including the focus group.
        ii. If additional individuals from the relevant community of respondents show up to the focus group they should be accommodated.
        iii. Bring blank copies of the consent form for signature.
2. To Do List for the day of the focus group
    a. Get to the site early to set up and test audio-visual equipment
    b. Have name tents for all confirmed respondents. Number each of the name tents as well. The number will make it easier for note-takers to keep track of the flow of the conversation.
        i. Have additional blank name tents along with assigned numbers.
    c. Set up a check-in area for respondents as they arrive. At check in you will:
        i. Note who participates in the focus group
        ii. Distribute the name tent
        iii. Consent forms should be provided and collected prior to the beginning of the focus group.
        iv. Distribute any supporting material we might have such as hand-outs
3. Observer responsibilities -- team members should be designated with responsibility for each of the following activities:
    a. Recording the focus group
    b. Advancing the audio-visual support. We should have hard copies of these slides for distribution in case the audio-visual equipment is not working.
    c. Taking a running tally of who is talking when. The transcriptionist will not be able to identify each respondent. We need a record of who is talking when so we can accurately match responses to respondents.
    d. Taking notes of the conversation

e. Taking notes of major themes in the discussion and also unobtrusive observations of the tone and body posture of respondents.
f. Conducting the interview and maintaining the flow the conversation.

Themes and Questions

Focus group begins with a general introduction of the team and the project. We then collect:

- Consent forms
- Notify group that we are recording for research purposes, not for attribution.

Provide an overview of how the session will be conducted. The following points should be raised:

- This project is a look forward about the potential impacts of AV technology on GDOT
- Over the past two months we have been speaking with experts in the various fields and industries working on the development and deployment of autonomous vehicle (AV) technology.
- We are going to share a series of characteristics of AV technology. These are grouped into four clusters of attributes regarding AV technology development. My colleague will provide a brief description of the characteristics. We will then ask you to reflect on two broad questions:
    - How these attributes of AV development are likely to impact Georgia's transportation infrastructure?
    - How might this change the role and activities of GDOT?

We will begin by focusing in on a set of attributes of that describe the development of the vehicle itself. I will now turn this over to Mike to describe this cluster of attributes.

[Cue slide on AV technology classification levels]
[Vehicle Slides 2-7]

<u>AV Characteristic 1 [Cue the Slide on Operational Mode]:</u> Experts have noted that individuals may access AV technology through a variety of operational modes. These include:

- Personal vehicles: predominately individual trips
- Mobility as a Service: rideshare, i.e. AV taxi, Uber and Lyft pools
- Micro-transit: 6 to 12 passenger vehicles servicing a fixed area

<u>AV Characteristic 2 [Cue Slide on AV types]:</u> We would like you to consider a variety of different vehicle types in which AV will be deployed. Experts describe a future in which a wide variety of AV technology may be deployed ranging from:

- Limited to characteristics of today's vehicles

- Today's vehicles with more operational variability, platooning, tighter headways, reduced acceleration, etc.
- Wide diversity of AV technology of different sizes and characteristics including small single item delivery, single person vehicles, multi-user vehicles, large freight.

AV Characteristic 3 [Cue Slide on Ownership]: Experts projected a variety of scenarios for vehicle ownership associated with vehicles using AV technology. They clustered into three distinct groups:

- Private/individual ownership of vehicles
- Mixed private and fleets
- Fleet

AV Characteristic 4 [Cue Slide on Power]: Experts projected a variety of scenarios for the power train associated with vehicles using AV technology. They clustered into three distinct groups:

- Current fuel mix
- Predominately EV
- Wide mix of power sources

AV Characteristic 5 [Cue Slide on Timeline]: Experts projected a variety of scenarios for the timeline associated with vehicles using AV technology. They clustered into three distinct groups:

- Tomorrow
- Next decade
- Many decades

Questions:

- **How might this cluster of AV attributes (associated with vehicle development) impact Georgia's transportation infrastructure?**
- **How will this change the role or activities of GDOT?**

Prompts:

A. Experts begin to imagine the wide variety of vehicle mixing utilizing infrastructure difference, i.e. split a single 10 ft. into two 6 ft. lanes.
B. Operating characteristics of vehicles may differ significantly in terms of top and operating speed, acceleration and deceleration, ability to be detected, etc.
C. How will these modes interact with pedestrians and cyclists?
D. Experts all noted the variety of current tests of AV technology for personal vehicles. Experts describe the states of California, Arizona, Pennsylvania and Florida as particularly active in this area.
E. Another vehicle type projected by experts are micro-delivery vehicles for goods and business services. These will be used primarily in urban centers.

F. What challenges/opportunities are created for GDOT if transportation becomes a service provided by fleet operators?

[Infrastructure Slides 8-13] Experts also described AV uses on infrastructure. We will now turn to my colleague for a brief description of this cluster of attributes of AV technology development.

AV Characteristic 6 [Cue Slide on AV Location and Use]: Experts also describe a variety of locations in which AV technology will be deployed. These range from the following:

- Constrained: narrow geofenced area
- Wider zones: usage with safety driver and/or tele-operation backup
- Anywhere: no constraints on use area

AV Characteristic 7 [Cue Slide on Infrastructure Use]: Experts have noted that the full capabilities of AV technology can only be used in controlled settings with limited to no interactions with human driven vehicles. Future states of AV deployment and use include:

- Dedicated: AV only facilities
- Both: Mix of dedicated AV and non-AV facilities
- Mixed: All facilities mixed use

AV Characteristic 8 [Cue Slide on Vehicle Miles Travelled]: Experts projected a variety of scenarios for the amount of vehicle miles travelled (VMT) using AV technology. They clustered into three distinct groups:

- Reduced: ridesharing and multi-purpose trips
- No change
- Greater: demand for new trips, longer trips, and new uses (goods).

AV Characteristic 9 [Cue Slide on Capacity]: Experts projected a variety of scenarios for the capacity of vehicles on the roads using AV technology. They clustered into three distinct groups:

- Reduced: larger headways, reduced acceleration, and lower speeds
- Same: drives like a person drives today.
- Greater: platooning, reduced headways, higher speeds, and V2X.

AV Characteristic 10 [Cue Slide on Interaction of VMT and Capacity]: Experts projected a variety of scenarios for the interaction of VMT and capacity of vehicles on the roads using AV technology.

Questions:

- **How might this cluster of AV attributes (associated with AV uses on infrastructure) impact Georgia's transportation infrastructure?**

- **How will this change the role or activities of GDOT?**

Prompts:

A. Many experts agreed that initial deployments need to be in constrained areas, that are well and consistently maintained and monitored, i.e., signing and striping, limited construction, etc. Limiting variability is key to initial deployments.
B. Experts have also noted the development micro-transit (i.e. small buses). They note that this has already started on fixed circulatory routes in work complexes, universities, etc. However, they project wider deployment with more adaptive routes within a 10 year timeframe.
C. Many experts predict that the earliest deployment of AV technology will come in freight. They also note that the taking full-advantage of the technology in freight (such as platooning, speed of service, and coordination of services) will depend on greater control of the transportation infrastructure (i.e. limited interaction with manned vehicles).
D. Arterial environments provide many challenges to separating modes. How do experiences with other mode separations, such as bike lanes, inform your thoughts/concerns with separating out AV. When considering increasing or decreasing ADT how does that influence GDOT approach to roadway operations and maintenance.
E. Would increasing the proportion of long distance trips being served influence operation of the roadway?
F. Would increasing the proportion of multi-stop trips being served influence the operation of the roadway?
G. AV may change the capacity of a location over time as the proportion of AV increases. How would GDOT respond to changing capacities? How would GDOT measure or know if capacities are changing.
H. How might GDOT adapt to the interaction between VMT changes and capacity changes?

[Interaction Slides 14-18] Experts described human interactions with AV. We will now turn to my colleague for a brief description of this cluster of attributes of AV technology development.

<u>AV Characteristic 11 [Cue Slide on Access and Egress from the Vehicle]:</u> Experts projected a variety of scenarios for access and egress from the vehicle using AV technology. They clustered into three distinct groups:

- Enter and exit vehicle from dedicated parking spaces
- Dedicated drop-off and pick-up locations
- Free-for-all

AV Characteristic 12 [Cue Slide on Parking]: Experts projected a variety of scenarios for parking needs associated with vehicles using AV technology. They clustered into three distinct groups:

- Limited parking needed as we shift to mobility as a service
- Reduced parking & parking while traveling
- Similar to today

AV Characteristic 13 [Cue Slide on Routing]: Experts projected a variety of scenarios for the routing and demand management associated with vehicles using AV technology. They clustered into three distinct groups:

- AV will lead to optimized travel times, utilizing all roadway assets
- AV technology will lead to routes priced for travel time and road utilization, allowing use of local and collector roads for a premium
- Vehicles geofenced to limit use of roads based on destination; commuters will be prohibited from local roads

AV Characteristic 14 [Cue Slide on Edge Cases]: Experts projected a variety of "edge" scenarios for operation of the vehicle using AV technology. They clustered into three distinct groups:

- Vehicles capable of handling all cases of driving
- Driver takes over in some cases, i.e. construction, police instructions, etc.; instances when the vehicle may stop.
- Tele-remote option for special cases, i.e. construction, police, etc. Vehicle may stop for longer period.

Questions:

- **How might this cluster of AV attributes (associated with human interactions with AV technology) impact Georgia's transportation infrastructure?**

- **How will this change the role or activities of GDOT?**

Prompts:

A. If the zone in front of an office building looked like an airport drop-off zone, spilling into roadway lanes, how might GDOT address this?
B. If AVs tended to have circulatory travel patterns while waiting for pick-up existing O- D patterns, i.e. turning movement rations, may change dramatically.
C. To allow for drivers to take over or tele-control vehicles may stop in place or seek to pull to the side of a roadway. Time until supervised operation may be seconds to minutes of a vehicle stop in place.
D. How might consistency in construction zone personnel interaction with vehicles be improved?
E. If additional technology is added work zones for dedicated interaction with AVs who would be responsible of it operation, maintenance, and costs.

F. Will DOT's need to provide real-time response to edge cases – e.g. edge case HERO vehicles?

[Interaction Slides 19-24] Experts described AV technology as a system. We will now turn to my colleague for a brief description of this cluster of attributes of AV technology development.

<u>AV Characteristic 15 [Cue Slide on Safety]:</u> Experts projected a variety of scenarios for safety associated with vehicles using AV technology. They clustered into three distinct groups:

- Increase in crash numbers, increase in crash severity due to risk compensation
- No net benefit
- Decrease in crashes, decrease in crash types, decrease in severity

<u>AV Characteristic 16 [Cue Slide on Data Management]:</u> Experts projected a variety of scenarios for data management associated with vehicles using AV technology. They clustered into three distinct groups:

- No Data Exchange with Vehicle
- Passive Data Exchange: Maps, Road Closures, Pavement Condition, Historic Speeds, etc.
- Active Data Exchange: Signal Control, Current Location, Crash, Current Speed, Tele- Driving, etc.

<u>AV Characteristic 17 [Cue Slide on Communications]:</u> Experts projected a variety of scenarios for communications among vehicles using AV technology. They clustered into three distinct groups:

- None required
- Cellular & V2V: improve efficiency, safety, tele-control
- DSRC & V2X: Communication with infrastructure

<u>AV Characteristic 18 [Cue Slide on Public Private Partnerships]:</u> Experts projected a variety of scenarios for the public private partnerships associated with vehicles using AV technology.

They clustered into three distinct groups:

- Collaborations lead to controlled pilots and city-wide deployments; benefits accrue for public agencies and the private firms involved
- Minimal collaboration with little information sharing; eases some processes and begins to set operation standards
- No collaboration leads to haphazard and uncoordinated deployment efforts creating a hectic environment for public agencies and private firms

Questions:

- **How might this cluster of AV attributes (associated with AV technology systems) impact Georgia's transportation infrastructure?**

- **How will this change the role or activities of GDOT?**

Prompts:

A. Industry representatives strongly assert that AV will reduce the number of deaths and accidents associated with transportation simply by reducing the number of human drivers. Do you think this is likely in a mixed transportation environment of AV and human-driven vehicles?
B. What capabilities will a state DOT need to have to achieve potential safety gains from AV technology?

<u>Summary Assessment of Characteristics of AV Technology [Cue Summary Slide of AV Technology Characteristics]:</u>

Question: We have now reviewed 18 characteristics of AV technology that experts have identified as likely to influence transportation systems. In your view which of the 18 characteristics is most likely to influence your work? (Note: Select all that apply, if any)

Question: Are there aspects of AV technology not covered in our 18 characteristics that are likely to be impactful on your work?

If respondents engage in an active discussion around the questions then there will be less need to use the scenarios. However, if discussion is limited use scenarios 1 and 2 to attempt to generate deeper engagement.

[Present Scenarios 1 & 2]

Attempt to re-engage on our core questions:

- **How might these scenarios of AV technology development impact Georgia's transportation infrastructure?**

- **How will this change the role or activities of GDOT?**

- **What are the strategic implications for GDOT?**

Theme 2: Impact on respondent's work

Question: How do you see the work of your office changing in response to the development and deployment of AV technology?

Prompts:

- How might AV technology change the way your office interfaces with other offices in GDOT?
  - What about organizations outside of GDOT?
  - Contractors and consultants?
  - Local governments?
- What skill sets do you think you will need to have within your unit to adapt to AV technology?
  - Are you more likely to buy or hire these skill sets?

Theme 3: Impact on GDOT operations

Question: In what ways should GDOT adapt as an organization in preparation for the development and deployment of AV technology?

Prompts:

- Will AV technology require GDOT to rethink key missions?
- Will there need to be any changes to the organization design of the agency?
- Does GDOT need to develop a new division/position that coordinates AV efforts/collaborations?
- Should GDOT consider new forms of public transportation (i.e., first and last mile options)?
- How can GDOT capture new revenue markets (e.g., public transportation, VMTs, driver usage, etc.)?
- Should GDOT consider building public-private partnerships with AV firms?
- To what degree does GDOT interaction with local governments change?

Focus Group Closing Survey:

As we wrap-up our focus group we ask that you complete the short survey that has been distributed to you. Please do NOT put your name on the survey. Thank you for your participation.

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
***Human driver* monitors the driving environment**						
0	**No Automation**	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	**Driver Assistance**	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	**Partial Automation**	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
***Automated driving system* ("system") monitors the driving environment**						
3	**Conditional** [illegible]	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task [illegible] appropriately to a *request to intervene*	System	**System**	Human driver	Some driving [illegible]
4	**High Automation**	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	**Full Automation**	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

https://www.engineering.com/DesignerEdge/DesignerEdgeArticles/ArticleID/15478/Driverless-Cars--The-Race-to-Level-5-Autonomous-Vehicles.aspx

Vehicle

AV Operational Mode

Personal Vehicle
Predominately individual trips

Mobility as a Service
Rideshare, i.e. AV taxi, Uber Pool

Micro Transit
6 to 12 passenger vehicles, fixed area service

Vehicle

AV Designs

Today's designs
Limited to characteristics of today's vehicles

Moderate differences
Today's vehicles with more operational variability

Highly variable
Wide diversity in sizes and characteristics

https://www.retailcustomerexperience.com/articles/grocery-on-wheels-may-be-supermarket-delivery-game-changer/

Vehicle

Ownership

Private / Individual

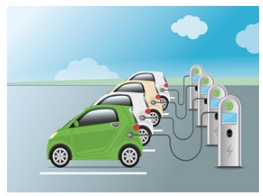
Mixed
Private and fleet

Fleet

https://www.motor1.com/news/234385/ford-autonmous-car-test/
https://www.gettyimages.com/detail/photo/fleet-of-cars-in-a-row-royalty-free-image/529173785

Vehicle

Power

Current fuel types	Predominately EV	Wide mix of power sources
		

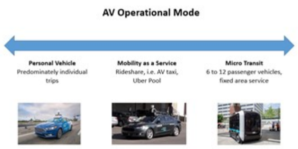
https://auto.howstuffworks.com/fuel-efficiency/alternative-fuels/nitrogen-enriched-gasoline.htm
https://frontera.net/news/global-macro/the-5-biggest-electric-vehicle-manufacturers-in-brics-nations/
http://www.hybridcars.com/mercedes-and-bmws-future-emphasizes-fuel-cell-vehicles-over-battery-electric-cars/

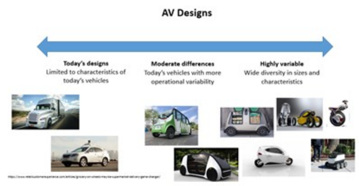
Vehicle

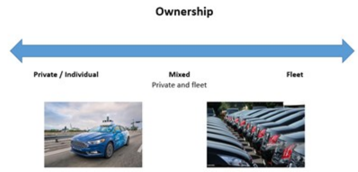
Timeline

Tomorrow	Next decade	Many decades
		

Vehicle



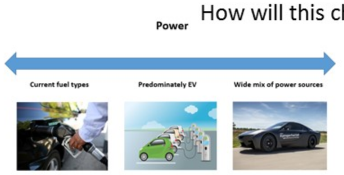




Has GDOT taken steps to prepare for upcoming developments in AV?

How may these AV attributes impact Georgia's transportation infrastructure?

How will this change the role or activities of GDOT?



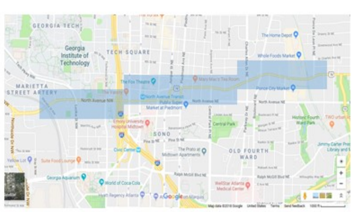
Integration

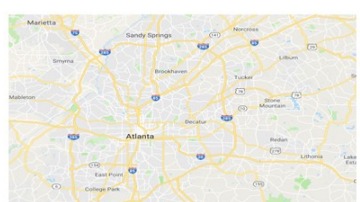
AV Location Use

Constrained
Narrow geo-fenced area

Wider Zones
Usage with safety driver or tele-operation backup

Anywhere
No constraints on use areas





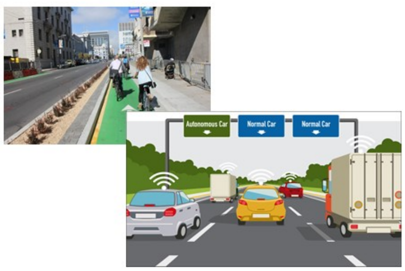
Integration

Infrastructure Use

Dedicated
AV only facilities

Both
Mix of dedicated
AV + non-AV facilities

Mixed
All facilities mixed use



1) https://www.nzta.govt.nz/walking-cycling-and-public-transport/cycling/cycling-network-guidance/designing-a-cycle-facility/between-intersections/separated-cycleways/
2) http://nwnewsnetwork.org/post/dedicated-lanes-i-5-self-driving-cars-get-ear-washington-state-officials
3) http://www.clarksvillesmartgrowth.com/Sec3-TransportationAnalysis.htm
4) http://www.clarksvillesmartgrowth.com/Sec3-TransportationAnalysis.htm

Integration

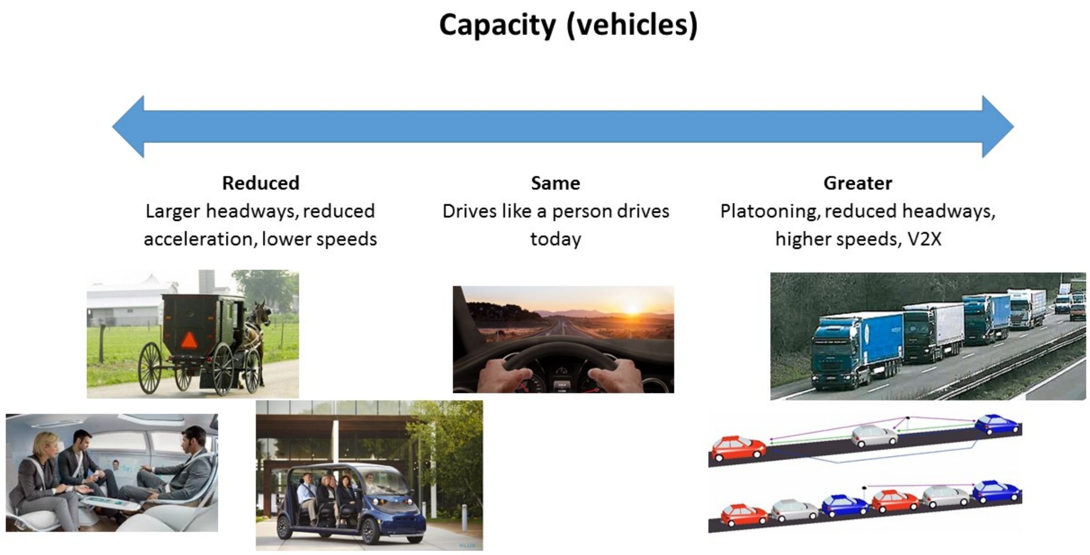
VMT

Reduced
Ridesharing, multi-purpose trips, etc.

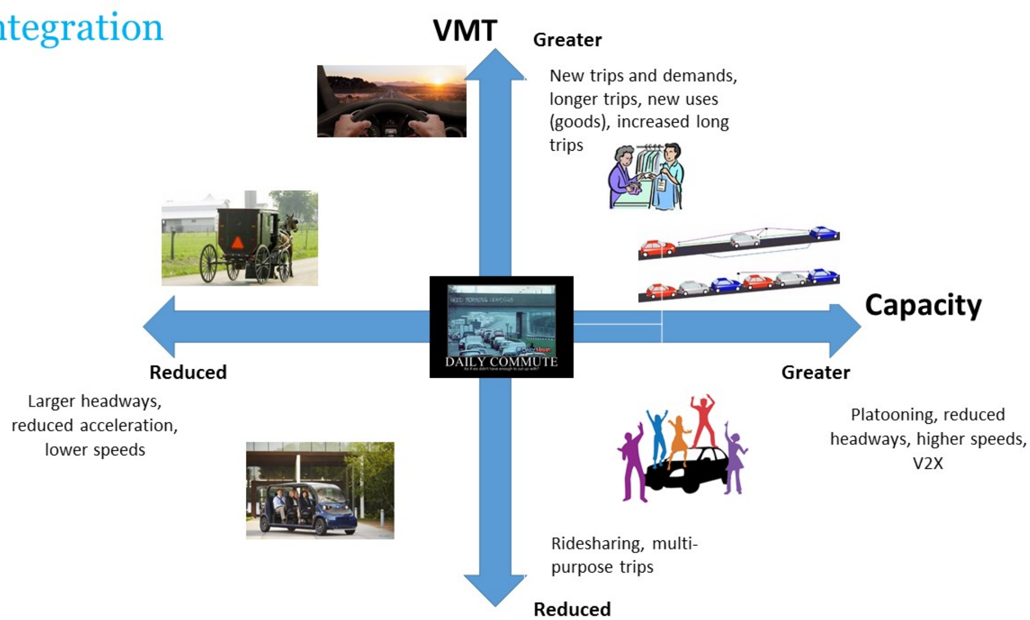
No change

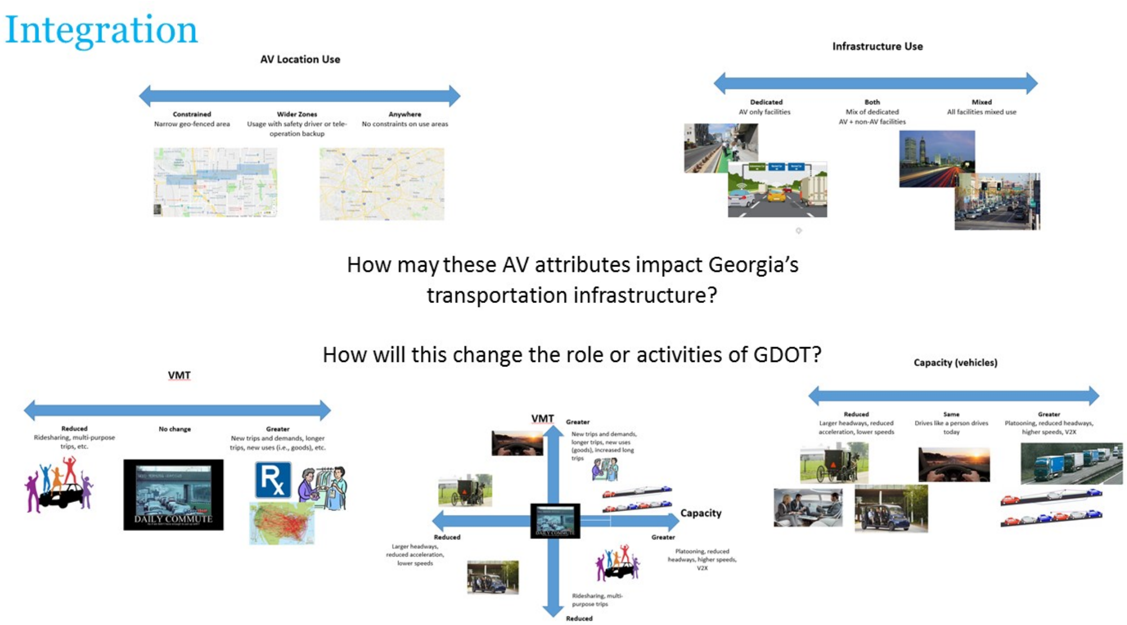
Greater
New trips and demands, longer trips, new uses (i.e., goods), etc.

Integration



Integration




Integration
AV Location Use
Constrained
Narrow geo-fenced area
Wider Zones
Usage with safety driver or tele-operation backup
Anywhere
No constraints on use areas
Infrastructure Use
Dedicated
AV only facilities
Both
Mix of dedicated AV + non-AV facilities
Mixed
All facilities mixed use
How may these AV attributes impact Georgia's transportation infrastructure?
How will this change the role or activities of GDOT?
VMT
Reduced
Ridesharing, multi-purpose trips, etc.
No change
DAILY COMMUTE
Greater
New trips and demands, longer trips, new uses (i.e., goods), etc.
Rx
VMT
Greater
New trips and demands, longer trips, new uses (goods), increased long trips
Capacity
Reduced
Larger headways, reduced acceleration, lower speeds
Greater
Platooning, reduced headways, higher speeds, V2X
Ridesharing, multi-purpose trips
Reduced
Capacity (vehicles)
Reduced
Larger headways, reduced acceleration, lower speeds
Same
Drives like a person drives today
Greater
Platooning, reduced headways, higher speeds, V2X


Interaction
Access and Egress From the Vehicle
Enter and Exit vehicle from dedicated parking spaces
Dedicated drop-off and pick-up locations
Free-for-all
RESERVED FOR YOU!
1) https://mjcs.org/product/mjcs-parking-spot/
2) https://inside.ptsem.edu/Community/Security/Content.aspx?id=15237957
3) https://www.bizjournals.com/losangeles/news/2016/01/21/uber-cleared-to-pick-up-passengers-at-lax.html
4) http://money.cnn.com/2017/11/16/technology/uber-lyft-designated-pickup-spots/index.html
5) https://universeinform.com/category/mobile/page/10/

Interaction

Parking

Limited parking needed
mobility as a service

Reduced parking
parking while traveling

Similar to today

http://web.mit.edu/francov/www/citycar

Interaction

Routing

User based
Each AV set its own route

Mixed
AV sets on route but provided data that encourages certain paths

System based
AVs are assigned routes that optimize system performance, minimize disruption

Interaction

Edge Cases

Fully capable
Vehicles capable of handling all case

Limited takeover
Driver takes over in some cases, i.e. construction, police, etc. Vehicle may stop

Remote operation
Tele-remote option, i.e. construction, police, etc. Vehicle may stop for longer period.


1) https://www.safewaytms.com.au/tmp/

Interaction

Access and Egress From the Vehicle

Enter and Exit vehicle from dedicated parking spaces | **Dedicated drop-off and pick-up locations** | **Free-for-all**

Parking

Limited parking needed mobility as a service | **Reduced parking** parking while traveling | **Similar to today**

How may these AV attributes impact Georgia's transportation infrastructure?

How will this change the role or activities of GDOT?

Routing

User based
Each AV set its own route

Mixed
AV sets on route but provided data that encourages certain paths

System based
AVs are assigned routes that optimize system performance, minimize disruption

Edge Cases

Fully capable
Vehicles capable of handling all case

Limited takeover
Driver takes over in some cases, i.e. construction, police, etc. Vehicle may stop

Remote operation
Tele-remote option, i.e. construction, police, etc. Vehicle may stop for longer period.

System

Safety

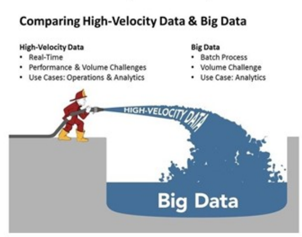
Increase in crashes / severity	**No net change**	**Decrease in crashes / severity**
Increase in crash severity due to risk compensation		Decrease in certain crash types, decrease in severity

1) http://www.presentermedia.com/index.php?target=closeup&id=2498&categoryid=139&maincat=clipart
2) http://www.airliners.net/forum/viewtopic.php?t=770653
3) http://www.treemagineers.com/blog/out-of-step/
4) https://pixabay.com/en/road-winding-highway-curve-travel-184283/
5) https://en.wikipedia.org/wiki/Side_collision

System

Data

No data exchange	**Passive data exchange**	**Active data exchange**
Vehicle require no outside data	maps, road closures, pavement condition, historic speeds, etc.	signal control, current location, crash, current speed, tele-operation, etc.

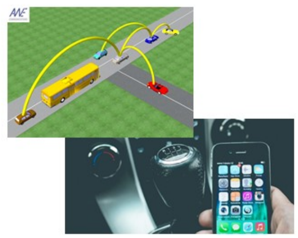


1) http://03e24ad.netsolhost.com/wp-content/uploads/2015/01/bigdata.jpg
2) https://www.quora.com/Real-time-Analytics-Where-can-I-find-sources-of-high-volume-firehose-like-streaming-data

System

Communications

None Required	Non-Standardize	Standardized
	Cellular & V2V, improve efficiency, safety, tele-control	DSRC & V2X, Communication with infrastructure

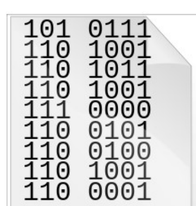


1) https://www.thegreenhead.com/2007/12/carcapsule-inflatable-car-storage-bubble.php
2) http://krisaru.com/car-to-car-communication-system-to-get-a-massive-road-test/
3) https://www.trafficsafetystore.com/blog/vehicle-to-vehicle-communication/
4) https://www.trafficsafetystore.com/blog/vehicle-to-vehicle-communication/

System

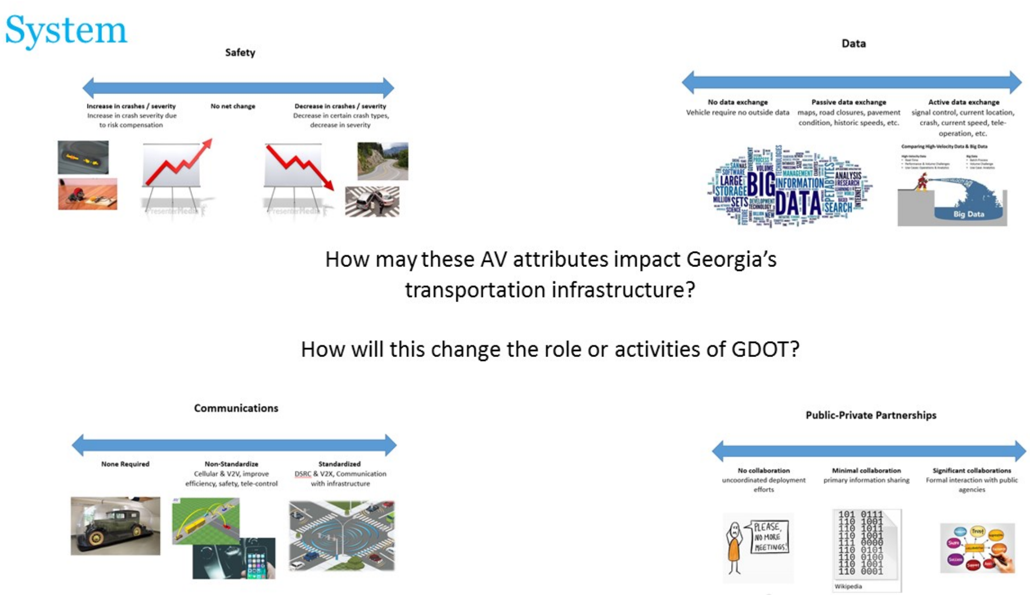
Public-Private Partnerships

No collaboration	Minimal collaboration	Significant collaborations
uncoordinated deployment efforts	primary information sharing	Formal interaction with public agencies



Wikipedia

https://usaidlearninglab.org/lab-notes/two-steps-strategic-collaboration-how-be-more-collaborative-without-scheduling-one-more-0
https://www.knowledgedesk.com/collaboration-trumps-management/
https://en.wikipedia.org/wiki/Information


System
Safety
Increase in crashes / severity
Increase in crash severity due to risk compensation
No net change
Decrease in crashes / severity
Decrease in certain crash types, decrease in severity
Data
No data exchange
Vehicle require no outside data
Passive data exchange
maps, road closures, pavement condition, historic speeds, etc.
Active data exchange
signal control, current location, crash, current speed, tele-operation, etc.
BIG DATA
Comparing High-Velocity Data & Big Data
Big Data
How may these AV attributes impact Georgia's transportation infrastructure?
How will this change the role or activities of GDOT?
Communications
None Required
Non-Standardize
Cellular & V2V, improve efficiency, safety, tele-control
Standardized
DSRC & V2X, Communication with infrastructure
Public-Private Partnerships
No collaboration
uncoordinated deployment efforts
Minimal collaboration
primary information sharing
Significant collaborations
Formal interaction with public agencies
PLEASE, NO MORE MEETINGS!
Wikipedia

Focus Group Protocol II (GDOT Leadership) Objective:
We are using a combination of focus groups and scenarios as a foresight exercise designed to stimulate forecasts by public transportation professionals of the impact of autonomous vehicle (AV) technology development and deployment. Each focus group will explore the impact of AV technology on 1) the demand for transportation infrastructure for the State of Georgia and 2) the organizational design of GDOT in terms of operations and human capital needs.

We will use scenarios as a “treatment” designed to stimulate discussion amongst each panel of respondents. The advantage of focus groups is that they allow interviewers to observe responses of professionals engaged in a more natural conversation pattern regarding a topic likely to have a significant impact on their work lives.

Mini-scenarios are interspersed through the focus group protocol designed to achieve two objectives. First, each mini-scenario will introduce information to respondents that we have gathered from the expert interviews and from our review of the research and professional literature. Second, each mini-scenario will also frame a question for the respondents to discuss.

There are four focus group events planned for the summer of 2018. Each event will focus on one of the following groups: 1) GDOT leadership; 2) GDOT mid-level employees; 3) external consultant professionals with extensive experience working with GDOT.

Key Theoretical Framing:
The focus groups aim to provide insights directly from community of professionals currently engaged in delivering the GDOT program of transportation services. The use of scenarios allows us to explore the following:

1. Expectations and assessments of current personnel regarding the likelihood of each scenario transpiring within the state.
2. Identification of key barriers and facilitators associated with scenario.
3. Identification of current capabilities for adapting to this technology. Since this technology will develop largely outside of GDOT’s control the agency will be in an adaptive posture rather than controlling the pace of innovation and change.
4. Projection of demands upon existing infrastructure associated with each scenario. In this line of questions, we will be seeking professional assessments of how the demand for the existing infrastructure is likely to change.
5. Projection of demands on the organizational and operational structure of GDOT. What should be the organizational and operational design of GDOT to adapt to AV technology?
6. Projection of demands on the human capital needs of GDOT. Is the current mix of personnel within the agency capable of adapting to alternative scenarios of technology deployment? What skill sets need to be added to the agency? What skill sets will no longer be needed?

Procedures for Conducting the Focus Groups:

1. Preparation for the focus group
    a. All focus groups will be conducted on GDOT facilities. Prior to the focus group, team members should check the availability and accessibility of audio-visual equipment presenting visual cues to respondents.
    b. A list of all invited and confirmed respondents should be compiled prior to the day of the focus group.
        i. Check responses to the invitation survey each day leading up to and including the focus group.
        ii. If additional individuals from the relevant community of respondents show up to the focus group they should be accommodated.
        iii. Bring blank copies of the consent form for signature.
2. To Do List for the day of the focus group
    a. Get to the site early to set up and test audio-visual equipment
    b. Have name tents for all confirmed respondents. Number each of the name tents as well. The number will make it easier for note-takers to keep track of the flow of the conversation.
        i. Have additional blank name tents along with assigned numbers.
    c. Set up a check-in area for respondents as they arrive. At check in you will:
        i. Note who participates in the focus group
        ii. Distribute the name tent
        iii. Consent forms should be provided and collected prior to the beginning of the focus group.
        iv. Distribute any supporting material we might have such as hand-outs
3. Observer responsibilities -- team members should be designated with responsibility for each of the following activities:
    a. Recording the focus group. [NOTE: for leadership focus group we will not record the event.
    b. Advancing the audio-visual support. We should have hard copies of these slides for distribution in case the audio-visual equipment is not working.
    c. Taking a running tally of who is talking when. The transcriptionist will not be able to identify each respondent. We need a record of who is talking when so we can accurately match responses to respondents.
    d. Taking notes of the conversation

e. Taking notes of major themes in the discussion and also unobtrusive observations of the tone and body posture of respondents.
f. Conducting the interview and maintaining the flow the conversation.

Themes and Questions

Focus group begins with a general introduction of the team and the project. We then collect:

- Consent forms

Provide an overview of how the session will be conducted. The following points should be raised:

- This project is a look forward about the potential impacts of AV technology on GDOT
- Over the past two months we have been speaking with experts in the various fields and industries working on the development and deployment of autonomous vehicle (AV) technology.
- We are going to share a description of the characteristics of AV technology based on our interviews with experts. We will then ask you to reflect on three broad questions:
    - How these attributes of AV development are likely to impact Georgia's transportation infrastructure?
    - How might this change the role and activities of GDOT?
    - What are the strategic implications for GDOT?

We will begin by focusing in on a set of attributes of that describe the development of the vehicle itself. I will now turn this over to Mike to describe this cluster of attributes.

[Cue slides on AV technology: Slides 1-4]

Questions:

- **Do you have any questions regarding the information provided by experts in the fields associated with AV technology development?**

- **How might these attributes of AV technology development impact Georgia's transportation infrastructure?**

- **How will this change the role or activities of GDOT?**

- **What are the strategic implications for GDOT?**

Prompts

A. Experts all noted the variety of current tests of AV technology for personal vehicles. Experts describe the states of California, Arizona, Michigan, Pennsylvania and Florida as particularly active in this area. Which states do you view as leaders in the field of AV technology?
B. Many experts agreed that initial deployments need to be in constrained areas, that are well and consistently maintained and monitored, i.e., signing and striping, limited construction, etc. Limiting variability is key to initial deployments.
C. Many experts predict that the earliest deployment of AV technology will come in freight. They also note that the taking full-advantage of the technology in freight (such as platooning, speed of service, and coordination of services) will depend on greater control of the transportation infrastructure (i.e. limited interaction with manned vehicles).
D. AV may change the capacity of a location over time as the proportion of AV increases. How would GDOT respond to changing capacities? How would GDOT measure or know if capacities are changing.
E. How might GDOT adapt to the interaction between VMT changes and capacity changes?
F. If the zone in front of an office building looked like an airport drop-off zone, spilling into roadway lanes, how might GDOT address this?
G. Will DOT's need to provide real-time response to edge cases – e.g. edge case HERO vehicles?
H. Industry representatives strongly assert that AV will reduce the number of deaths and accidents associated with transportation simply by reducing the number of human drivers. Do you think this is likely in a mixed transportation environment of AV and human-driven vehicles?
I. What capabilities will a state DOT need to have to achieve potential safety gains from AV technology?

If respondents engage in an active discussion around the questions then there will be less need to use the scenarios. However, if discussion is limited use scenarios 1 and 2 to attempt to generate deeper engagement.

[Present Scenarios 1 & 2]

Attempt to re-engage on our core questions:

- **How might these scenarios of AV technology development impact Georgia's transportation infrastructure?**

- **How will this change the role or activities of GDOT?**

- **What are the strategic implications for GDOT?**

Theme 2: Impact on respondent's work

Question: How do you see the work of your office changing in response to the development and deployment of AV technology?

Prompts:

- How might AV technology change the way your office interfaces with other offices in GDOT?
    - What about organizations outside of GDOT?
    - Contractors and consultants?
    - Local governments?
- What skill sets do you think you will need to have within your unit to adapt to AV technology?
    - Are you more likely to buy or hire these skill sets?

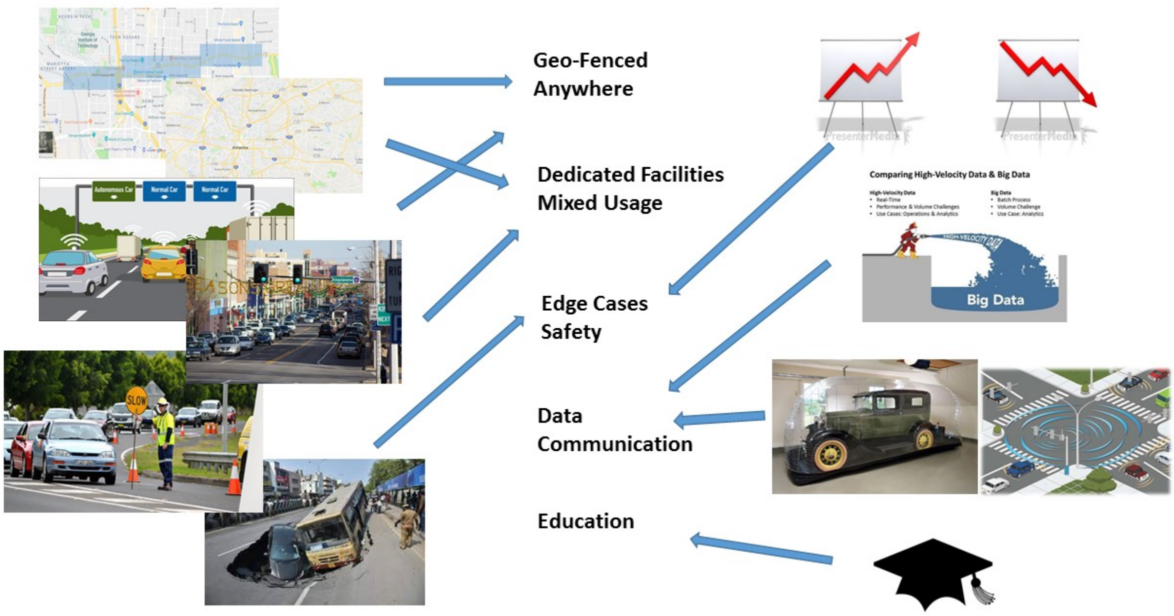
Theme 3: Impact on GDOT operations

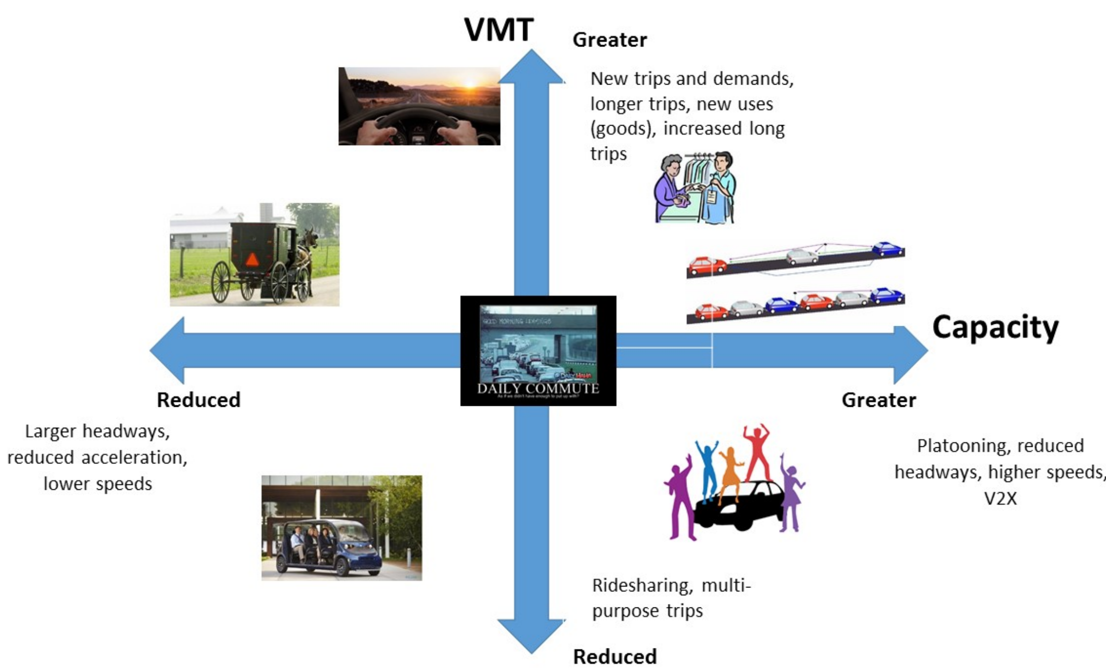
Question: In what ways should GDOT adapt as an organization in preparation for the development and deployment of AV technology?
Prompts:

- Will AV technology require GDOT to rethink key missions?
- Will there need to be any changes to the organization design of the agency?
- Does GDOT need to develop a new division/position that coordinates AV efforts/collaborations?
- Should GDOT consider new forms of public transportation (i.e., first and last mile options)?
- How can GDOT capture new revenue markets (e.g., public transportation, VMTs, driver usage, etc.)?
- Should GDOT consider building public-private partnerships with AV firms?
- To what degree does GDOT interaction with local governments change?

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
***Human driver* monitors the driving environment**						
0	**No Automation**	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	**Driver Assistance**	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	**Partial Automation**	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
***Automated driving system* ("system") monitors the driving environment**						
3	**Conditional Automation**	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the human driver will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	**High Automation**	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	**Full Automation**	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

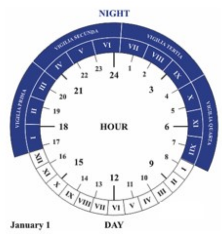
https://www.engineering.com/DesignerEdge/DesignerEdgeArticles/ArticleID/15478/Driverless-Cars-The-Race-to-Level-5-Autonomous-Vehicles.aspx


Geo-Fenced
Anywhere
Dedicated Facilities
Mixed Usage
Edge Cases
Safety
Data
Communication
Education
Comparing High-Velocity Data & Big Data
Big Data
SLOW


VMT
Greater
New trips and demands, longer trips, new uses (goods), increased long trips
Capacity
Greater
Platooning, reduced headways, higher speeds, V2X
Reduced
Larger headways, reduced acceleration, lower speeds
DAILY COMMUTE
Ridesharing, multi-purpose trips
Reduced

Timeline

Tomorrow	Next decade	Many decades



Is the technology ready?
Will the public accept AV?
Is there a business case?

- How may these AV attributes impact Georgia’s transportation infrastructure?
- How will this change the role or activities of GDOT?
- What are the strategic implications to GDOT?

Scenario #1

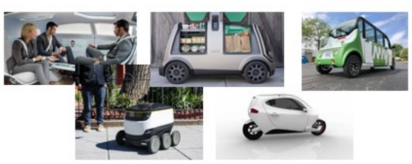
Capacity increases by 25% on freeways
Capacity stable on arterials, collectors, local roads
Drive anywhere – edge cases through tele-operation
AV and Non-AV mix

VMT / Demand increases in excess of 100%
25% of vehicle fleet is AV
75% of all VMT is AV

90% of AV are in commercial fleets
Mobility as a service dominate use
AV fleet is electric

Freight is an early adopter
200% increase in truck miles
Significant presence of platoon

Scenario #2



Wide variety in types, sizes, and performance characteristic
Numerous task specific vehicles
Deployment urban and rural
Re-orientation of freight and distribution center siting

Mixes of controlled and non-controlled zones
Dedicated and mix facilities
Increasing demand for secondary infrastructure

Ridesharing balances increased personal travel, no new net VMT
Significant increase in last mile goods, service based trips
Over 50% of VMT does not include a person in vehicle

Data is a commodity, transportation agency may buy and sell
75% of all trips receive dynamic routing from 3rd party services

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