



# Autonomous Vehicles in Delaware:

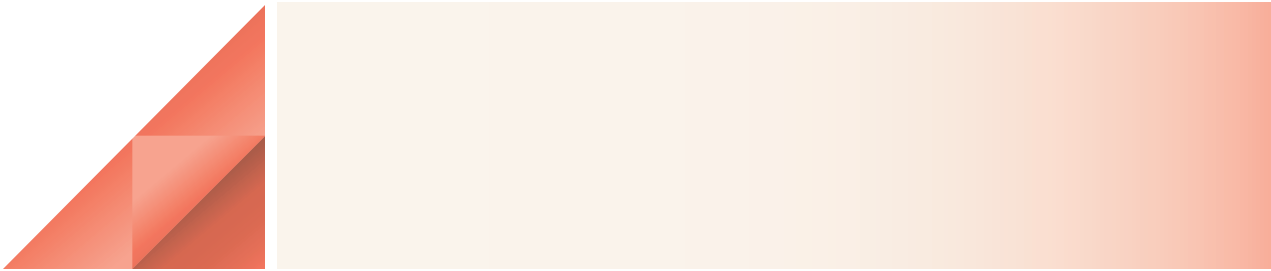
Analyzing the Impact and  
Readiness for the First State

*Written By*  
Philip Barnes, Associate Policy Scientist  
Eli Turkel, Graduate Public Administration Fellow

*Published by*  
Institute for Public Administration  
School of Public Policy and Administration  
University of Delaware  
[www.ipa.udel.edu](http://www.ipa.udel.edu)

*In collaboration with*  
The Delaware Department of Transportation





# Autonomous Vehicles in Delaware: Analyzing the Impact and Readiness for the First State

April 2017

*Written by*

**Philip Barnes**, Associate Policy Scientist  
**Eli Turkel**, Graduate Public Administration Fellow

*Edited by*

**Lisa Moreland**, Policy Scientist  
Institute for Public Administration

*Design and Layout by*

**Sarah Pragg**, Policy Specialist  
Institute for Public Administration

*Published by*

**Institute for Public Administration**  
School of Public Policy and Administration  
University of Delaware  
[www.ipa.udel.edu](http://www.ipa.udel.edu)

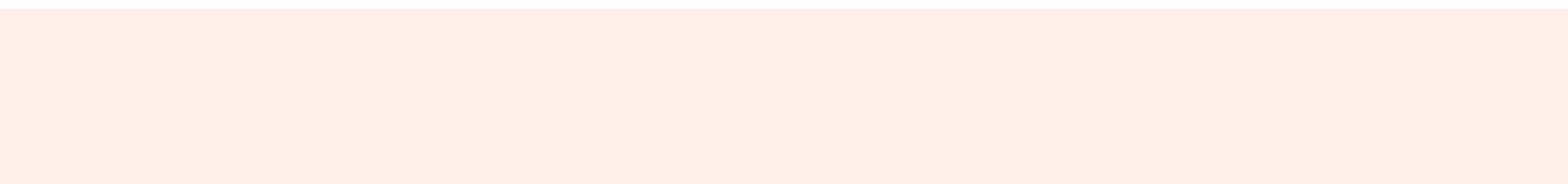
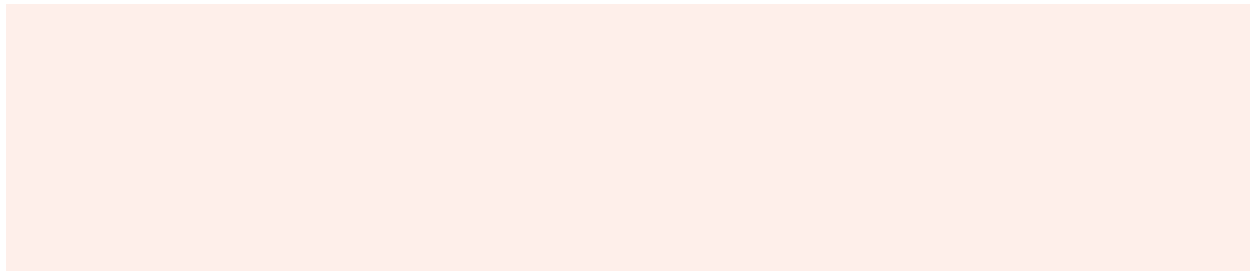
*In collaboration with*

The Delaware Department of Transportation



**Institute for  
Public Administration**





# Preface



Autonomous vehicles—long part of the futuristic frontier—are justifiably receiving a great deal of media attention. These vehicles are currently being tested in many cities and states around the country, and the expected timeline for commercial sales is shortening. The transformative potential of this emerging technology is significant.

As the Director of the University of Delaware’s Institute for Public Administration (IPA), I am pleased to provide this timely report, *Autonomous Vehicles in Delaware: Analyzing the Impact and Readiness for the First State*. This report anticipates autonomous vehicle deployment in Delaware and evaluates the possible consequences of across a wide range of focus areas—from vehicle ownership projections to local fiscal impacts and transportation equity. The analysis demonstrates that successful integration of autonomous vehicles into the First State’s transportation system is not necessarily a technological challenge, but rather an administrative one. Socially beneficial outcomes are possible with the proactive, collaborative involvement of state and local governments, citizens, the business community, research partners, advocacy organizations, and other relevant stakeholder groups.

This report continues IPA’s legacy of practical research on Delaware’s transportation challenges and opportunities. It leverages our expertise to advance the administrative and policy conversations and it responds to emerging trends in transportation systems and urban affairs. It complements our past research for the state on intermodal transportation, paratransit services, and complete communities. Looking forward, this report will form the foundation to advance smart city scholarship and total urban mobility research in Delaware.

IPA is grateful for funding from the Delaware Department of Transportation that supported this research. I would like to thank the lead researchers and authors—IPA’s Philip Barnes and Eli Turkel. Additional thanks go to IPA staff members Lisa Moreland for editing support and Sarah Pragg for designing and formatting the document.

Jerome R. Lewis, Ph.D.

Director, Institute for Public Administration



# Table of Contents

- Acronyms ..... 1**
- Executive Summary .....2**
- Introduction .....4**
- Autonomous Vehicle Technology .....6**
  - History and Technology ..... 6
  - Connected Vehicles ..... 6
    - V2V Technology ..... 7
    - V2I Technology..... 8
  - Taxonomy of Autonomous Vehicles ..... 8
  - Current Availability ..... 8
  - Deployment Scenarios and Timeline ..... 10
  - Costs ..... 11
- Administrative and Citizen Issues ..... 12**
  - Regulations and Vehicle Testing ..... 12
  - Liability..... 12
  - Insurance..... 13
  - Cybersecurity and Privacy..... 14
- Planning and Policy Impacts ..... 16**
  - Roadway Safety..... 16
  - Ownership ..... 16
  - Parking Demand..... 17
  - Vehicle Miles Traveled..... 18
  - Roadway Congestion and Capacity..... 18
  - (Sub)Urban Development Patterns ..... 19
  - Infrastructure Design and Upgrades ..... 20
  - Jobs and the Economy ..... 20
  - State and Local Fiscal Impacts ..... 21
  - Modal Shifts ..... 21
  - Fuel Economy and Carbon Emissions ..... 22
  - Transportation Equity ..... 23
- Delaware’s Readiness ..... 24**
  - Technological Readiness..... 24
  - Administrative Readiness ..... 24
- Conclusion ..... 26**
- References ..... 28**

# Acronyms



<b>ACC</b>	Adaptive Cruise Control
<b>AV</b>	Autonomous Vehicle
<b>CACC</b>	Cooperative Adaptive Cruise Control
<b>CAN</b>	Controller Area Network
<b>CV</b>	Connected Vehicle
<b>DeIDOT</b>	Delaware Department of Transportation
<b>DMV</b>	Division of Motor Vehicles
<b>DSRC</b>	Dedicated Short Range Communication
<b>FTC</b>	Federal Trade Commission
<b>GPS</b>	Global Positioning System
<b>HAV</b>	Highly Autonomous Vehicle
<b>ITMS</b>	Integrated Transportation Management System
<b>LIDAR</b>	Light Detection and Ranging
<b>NHTSA</b>	National Highway Traffic Safety Administration
<b>RSE</b>	Road Side Equipment
<b>SAE</b>	Society of Automotive Engineers
<b>V2I</b>	Vehicle to Infrastructure
<b>V2V</b>	Vehicle to Vehicle
<b>VMT</b>	Vehicle Miles Traveled





# 01 Executive Summary

The sci-fi reality of self-driving, networked, autonomous vehicles is nearly here. Ford claims it will sell these vehicles within five years, and most analysts expect modest sale numbers by the late 2020s and widespread adoption throughout the 2030s and 2040s. The consequences of the impending autonomous vehicle revolution for Delaware's economy, its residents, and visitors are significant. Public and private stakeholders will need to adapt current practices and processes to accommodate the new advancement in transportation. State regulations that govern vehicles and drivers will need to evolve with the technology. Cybersecurity and privacy limits will be tested. The insurance industry will be required to develop new products and actuarial models. Claims of liability will be argued and settled in the courts.

There will also be impacts, both positive and negative, to important transportation and urban planning areas, especially roadway safety, ownership, parking demand, vehicle miles traveled, roadway congestion and capacity, development patterns, infrastructure design, jobs and the economy, state and local budgets, fuel efficiency and carbon emissions, and transportation equity. The authors of this report attempted to preview the possible impact that autonomous vehicle deployment would have on each area. Major information gaps exist on autonomous vehicles, and there are complex interactions among areas that render such previews extremely challenging and uncertain.

Despite these difficulties, the table summarizes the report's findings. The findings are based on a long-term view and assume full, widespread penetration of autonomous vehicles across all Delaware roadways with a corresponding decline in manually-driven vehicles. A confidence measure was added to articulate the level of certainty/uncertainty for each area. Entries in the table should not be accepted as absolute truths, but rather as starting points for preliminary discussions on policy and administrative options to minimize negative impacts and amplify positive ones.

In terms of readiness to accept autonomous vehicles, the state is well prepared technologically. The Delaware Department of Transportation (DelDOT) possesses an extensive telecommunications network that can be leveraged for autonomous vehicle integration, and DelDOT is proactively upgrading its systems in anticipation of autonomous vehicle deployment. DelDOT plans to install a transportation-specific wireless network in Dover, test signal timing and traffic light priority in Smyrna, and develop software to partially automate decision-making at the state's Transportation Management Center. These are positive steps that will make Delaware attractive for vehicle testing, operation, and deployment. From an administrative standpoint, the state could accelerate the evolution of its governance systems and institutions to align with the technological advance. If action is taken now, Delaware could position itself to be a leader in the autonomous vehicle area.





## Possible Impacts of Autonomous Vehicles for Delaware

Impact Area	Possible Impact	Confidence
Roadway Safety	Decrease accidents, injuries, fatalities	High
Ownership	Decrease percent of Delawareans owning a vehicle	Medium-High
Parking Demand	Decrease demand for parking	Medium
Vehicle Miles Traveled	Increase state-wide vehicle miles traveled	Medium
Congestion/Capacity	Increase highway capacity and urban core congestion	Low
Development Patterns	Increase sprawl and urban densification	Medium
Infrastructure Design	Decrease lane width, increase roadside technology	Medium-High
Jobs/Economy	Decrease driving-related jobs short-term/long-term increase in overall economic activity	High/Medium-Low
Fiscal Impacts	Decrease revenue for state and local governments	Medium-Low
Modal Shifts	Decrease use of public transportation	Medium
Fuel Economy/Carbon Emissions	Increase fuel efficiency/decrease carbon emissions	High/Low
Equity	Increase transportation inequities	Medium-High





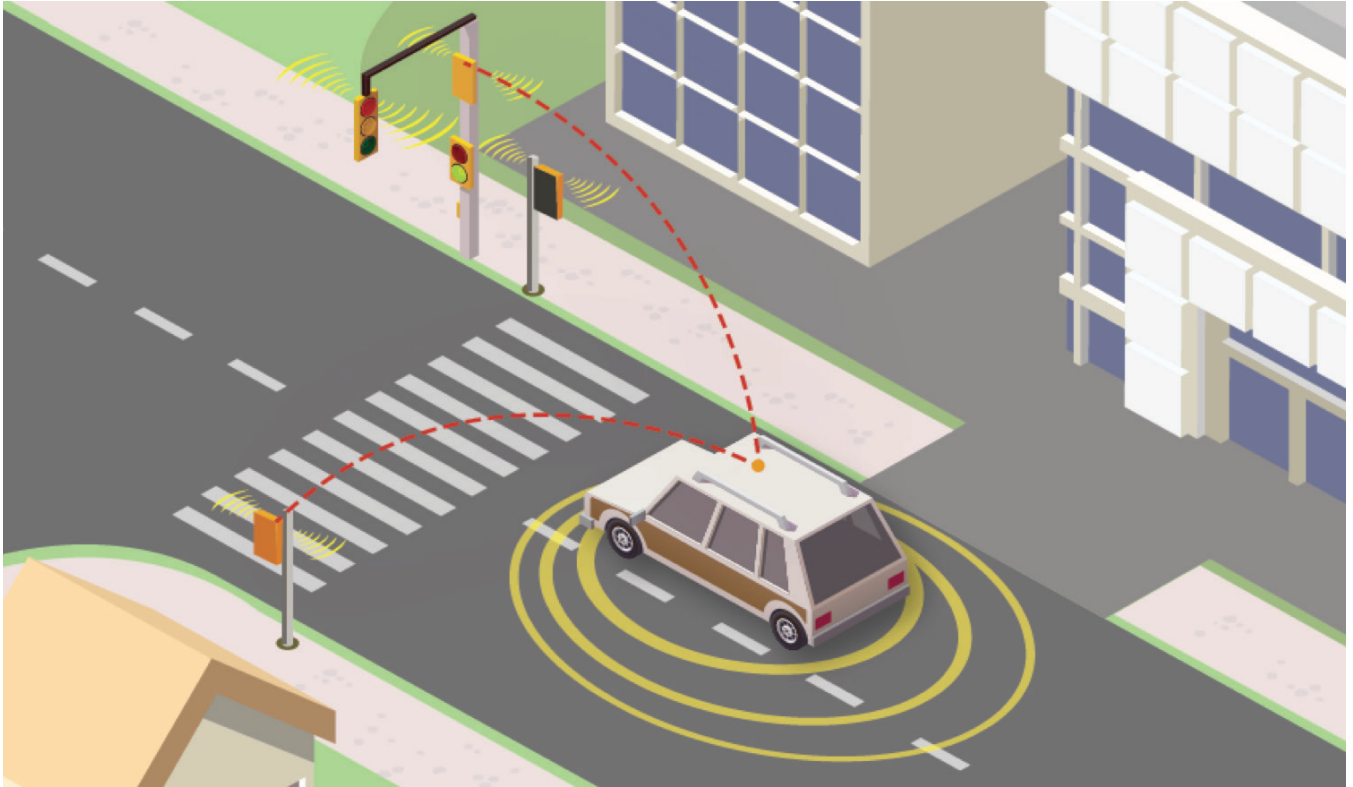
## 02 Introduction

Self-driving autonomous vehicles (AVs) will transform America. The transportation-related impacts are the most apparent, as AVs will enable safe mobility for those individuals who are currently unable to drive such as children and the visually impaired. These vehicles will converge with ridesharing services (e.g., Uber, Lyft, etc.) and upend longstanding traditions of vehicle ownership, particularly in dense, populated areas. They will undoubtedly reshape urban and suburban development, shift demand for parking, and impact roadway congestion and capacity. Significant economic and social consequences of AVs are also expected. As with all disruptive technologies, some job markets will be made redundant, with truck and bus drivers likely bearing the brunt of AV deployment. While the ultimate impact of AVs is uncertain due to many complex variables that will influence the technology's development and deployment, analysts are confident that the transformations to transportation and economic systems will be significant and long lasting.

State departments of transportation such as DeIDOT must anticipate and adapt to the many planning and policy implications of AVs. At a recent Delaware Center for Transportation (2013, p. 47) forum, it was recommended that Delaware transportation professionals “engage in the primary stages of [autonomous] vehicle technology in order to guide its development and to position DeIDOT for expedited integration.” To facilitate that effort—and to provide reliable information to decision-makers at DeIDOT as

well as policymakers, planners, and state administrators in Delaware—this report presents research results that highlight the relevant issues with AV technology. The intent of the report is to lay the foundation for a future policy and planning framework and ensure the timely integration of autonomous vehicles into the state's transportation network. The information gleaned through the research process will also be useful for budget forecasters and policy analysts who must weigh the merits of various AV policy options.

The report is divided into five major sections. First, it reviews the technology behind AVs and degrees of vehicle autonomy. Predictions on the timing of AV deployment are also reviewed. The second section covers administrative and consumer issues, namely regulation of the new technology, liability, insurance, and cybersecurity/privacy. Third, the report investigates a number of planning and policy areas in Delaware that will be impacted by AVs: roadway safety, ownership, parking demand, vehicle miles traveled, roadway congestion and capacity, development patterns, infrastructure design, jobs and the economy, state and local budgets, fuel efficiency and carbon emissions, and transportation equity. Despite the significant uncertainty involved in prognosticating, an attempt is made to predict the future impacts of AVs in each area. Fourth, the report reviews Delaware's current level of technological and administrative readiness to test and operate AVs on the state's roadways. The report concludes with possible next steps for the state.



## Vehicle to Infrastructure (V2I) Interaction

*Source: DelDOT*





# 03 Autonomous Vehicle Technology

Also known as driverless or self-driving cars, the vision of developing autonomous vehicles entered the public's imagination at the "Futurama" exhibit for the 1939 World Fair in New York City. A utopian-inspired display sponsored by General Motors and designed by Norman Bel Geddes depicted radio-controlled, electromagnetically propelled vehicles (O'Toole, 2010). More recently in the past decade, the maturation and convergence of the internet and artificial intelligence created technological foundation to transform Geddes's larger vision of driverless transportation into reality. This section quickly reviews the recent history of AV development, the hardware and software systems comprising AV technology, and identifies a spectrum of AV functionality that helps classify varying degrees of vehicle autonomy. It then reviews the current status of the AV industry before reviewing a number of AV deployment scenarios, many of which anticipate commercial availability within the next decade.

## History and Technology

The United States Congress initiated a push to develop military grade AVs between 2003 and 2007 with a series of contests, known as Grand Challenges. With each successive contest, large advances in AV technology were made and committed private-sector efforts began shortly thereafter. Google leveraged its resources to become a major innovator and accelerated development of fully autonomous vehicles, while the traditional automobile manufacturers began to integrate elements of autonomous technology into their commercial offerings (Anderson et al., 2014).

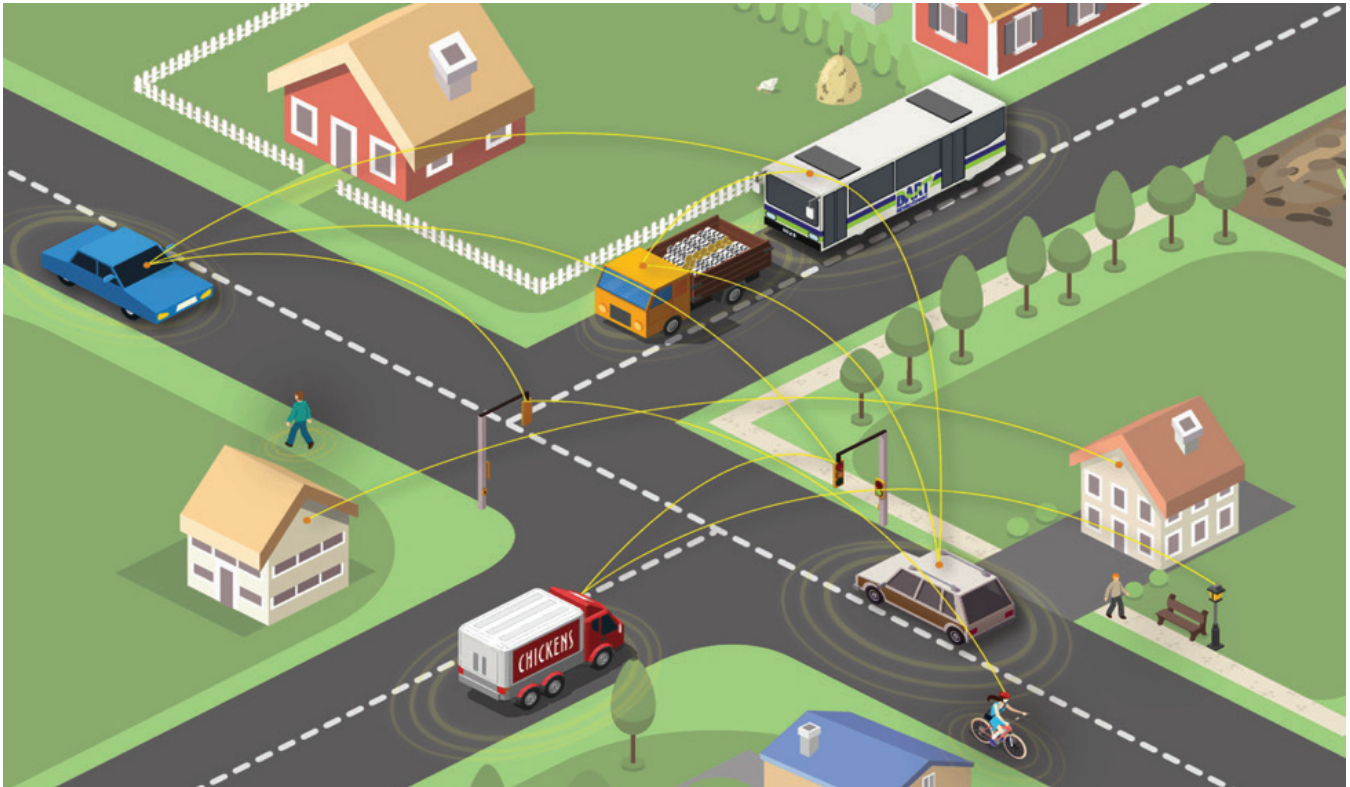
The technology that provides functionality for AVs is based on three related systems. First, just like a smart phone uses the global positioning system (GPS) to provide driving directions, GPS is necessary for AV technology to allow vehicles to roughly identify their positions relative to the transportation infrastructure and journey starting and ending points. To navigate

real-time in an environment that features detours, pedestrians, and other obstacles, a second system of sensors is integrated into the vehicle. Lasers such as Light Detection and Ranging or LIDAR that can "see" in the dark and low-visibility situations, radars, and cameras are common sensors that provide information for vehicle situational awareness. The bulb on the top of Google's AV prototype is a range-finding LIDAR unit that rotates rapidly while sending and receiving signals to detect distances between itself and surrounding environmental features. Cameras and radar units, which are already common on today's vehicles with features such as adaptive cruise control (ACC) or backup parking assistance, are also frequently mounted on AVs. The third system includes the software and algorithms that process the GPS and sensory data to execute movements through space by delivering instructions through the vehicle's Controller Area Network (CAN) bus. The algorithms are designed for machine learning, meaning that while certain rules of the road can be hardwired (e.g., stop at red lights), other non-determined human behaviors such as pedestrian movements are analyzed and continually improved with each successive experience (Madrigal, 2014).

## Connected Vehicles

While autonomous vehicles receive most of the media and research attention, connected vehicles (CVs) are an associated automobile technology seen as precursors and prerequisites to full AVs. The major distinguishing characteristic separating AVs and CVs is the presence of an active, involved driver in CVs. CVs enhance and improve driver decision-making, whereas AVs have the potential to replace the driver altogether.

CVs are equipped with communication technologies that relay and receive information among vehicles, near-road infrastructure, and drivers. The exact type of communication technology that will be dominant is still a matter of debate, but two possible versions



## Combined V2V and V2I systems

Source: DelDOT

exist: dedicated short-range communication (DSRC) and wireless technology similar to that used in smart phones (e.g., 5G technology under development). DSRC is WiFi-like and enables CVs to rapidly transmit and receive signals to specialized roadside infrastructure up to 1,600 feet away, allowing constant monitoring of surrounding environmental conditions. The 5G version may not be as fast as DSRC, but it could utilize the existing infrastructure currently used by mobile devices (Bradbury, 2016). In either case, a vehicle equipped with CV technology can analyze internal and external data to alert drivers about potential hazards and risks that are hidden from their direct view (Arseneau, Roy, Salazar, & Yang, 2015). The anticipated impacts of CVs are mostly similar to AVs, with a key difference related

to the importance of state spending to create the “smart” infrastructure that is required for CV operability (see subsection titled “Infrastructure Design and Upgrades”). CV technologies and systems are generally classified according to the type of connectivity. If they connect vehicles to each other, they are referred to as vehicle to vehicle (V2V) technologies. If they connect to public infrastructure, the systems are referred to as vehicle to infrastructure (V2I) technologies.

### V2V Technology

V2V technology consists of components integrated into automobiles that effectively allow them to communicate with other V2V-equipped vehicles. The





main application of V2V technology involves vehicles wirelessly interacting with each other to monitor conditions and send alert signals to drivers when risks and hazards arise. For example, a vehicle equipped with V2V technology can receive and analyze data from nearby V2V-equipped vehicles to detect rapidly decelerating traffic in the road ahead, giving the driver advanced warning to slow down. Another example of a V2V application involves left-turning assistance that alerts the driver not to execute a left turn because an oncoming vehicle poses an immediate collision risk. Thus, a major benefit of V2V technology is improved on-road safety and traffic flow. The National Highway Traffic Safety Administration (NHTSA) estimates that nearly 600,000 crashes could be avoided with intersection turn assistance (Harding et al., 2014).

### V2I Technology

Like V2V systems, V2I technology is also predicted to improve safety and reduce on-road risks, yet unlike V2V where signals are sent between vehicles, the communication in V2I CVs occurs between the vehicle and the surrounding fixed infrastructure. In a V2I network, roadside equipment (RSE) will transmit communication signals to vehicles that then analyze the information and relay warnings to drivers. One of the many applications of V2I systems involves RSE connected to traffic signals that would alert drivers if they are about to run a red light. Other applications include speed-limit advice along highways to optimize traffic flow and ease congestion. V2I systems also could be integrated to traffic control and planning centers that would monitor and analyze the incoming information and make adjustments to existing intelligent transportation system assets such as message signs and intersection signals. In other applications of V2I technology, it is also possible to envision traffic signal priority for particular vehicles such as buses, police, and emergency responders (Government Accountability Office, 2015).

## Taxonomy of Autonomous Vehicles

Determined to bring a sense of order to the rapidly advancing field, NHTSA (2013) created an initial AV classification system defined by five levels of autonomy, from zero to four, with each successive level exhibiting greater vehicle self-control. With the release of the 2016 policy guidance, NHTSA adopted the Society of Automotive Engineers (SAE) International Standard J3016 that defines vehicles on a 0-to-5 scale. The taxonomy standard is reproduced in the table (right). While there are gray areas between each level, the SAE classification system is useful for understanding and analyzing the implications of a spectrum of AV technology.

An important distinction in the SAE taxonomy involves the difference between Level 2 and Level 3 vehicles. At Level 2 or below, the human driver is required to be fully engaged and continuously monitoring conditions, whereas at Level 3 and above the vehicle is expected to perform monitoring functions and the driver can be disengaged. Safety risks increase significantly at Levels 3 and above, and are characterized as Highly Autonomous Vehicles (HAVs).

## Current Availability

Level 1 automation is currently available and offers assistance to drivers under certain road conditions. For instance, ACC controls a vehicle's speed in response to changes in the traffic environment (Youngs, 2012). Electronic stability control will apply brakes if the vehicle is taking a turn too fast to help prevent roll-overs (Barth, 2015). Emergency dynamic brake support will apply more pressure to the brake if the driver is not braking hard enough in an emergency situation (Ecarma, 2015). Traffic jam assist technology, which adjusts vehicle direction and speed for lane centering while maintaining constant distances between





vehicles ahead and behind, is capable of operating in low-speed, high-traffic situations. BMW, Mercedes, Volkswagen, and Volvo all offer models with traffic jam assist.

Vehicles that combine ACC with lane centering to control all steering, braking, and throttle in high-speed situations also satisfy Level 2 criteria. Tesla's Model S with the added Autopilot feature is an example of high-speed Level 2 autonomy. Autopilot is available as a software download on the Model S and the semi-autonomous feature allows hands- and pedal-free driving in conditions where the road is clearly marked and the weather is good. After downloading Autopilot, the vehicle will change lanes and self-

operate on winding roads, yet Tesla advises the driver to stay engaged by keeping one hand on the wheel at all times. If the Autopilot system detects an unmanageable situation, it signals to the driver with a blue message on the dashboard, audible alerts, and self-braking (Kessler, 2015).

The General Motors SuperCruise system is under development and will be available on certain Cadillac models in 2017. Like Tesla's Autopilot, SuperCruise-equipped vehicles will combine lane centering and ACC and will be capable of driving on highways without the driver holding the steering wheel or putting their foot on the pedal (Naughton, 2015).

## SAE (2014) and NHTSA (2016) taxonomy of autonomous vehicles

Autonomy Level	Description
Level 0: No Automation	The human driver does everything
Level 1: Driver Assistance	An automated system on the vehicle can sometimes assist the human driver conduct some parts of the driving task
Level 2: Partial Automation	An automated system on the vehicle can conduct some parts of the driving task, while the human continues to monitor the driving environment and performs the rest of the driving task
Level 3: Conditional Automation	An automated system can conduct some parts of the driving task and monitor the driving environment in some instances, but the human driver must be ready to take back control when the automated system requests
Level 4: High Automation	An automated system can conduct the driving task and monitor the driving environment, and the human need not take back control, but the automated system can operate only in certain environments and under certain conditions
Level 5: Full Automation	The automated system can perform all driving tasks under all conditions that a human driver could perform them





There are no Level 3 or 4 AVs available on the commercial market, although prototypes from Audi and Delphi have completed lengthy trips with minimal manual driver control (Davies, 2015a, 2015b). In Level 3 autonomy, situations arise where vehicle control must be quickly transferred between the automated system and an inattentive or distracted driver (Markoff, 2016). This amplifies risk, as the driver must immediately control the vehicle while simultaneously gaining situational awareness, a process that could take considerable time and lead to an accident. Consequently, some manufacturers are opting instead to leapfrog directly to full AV functionality to avoid “mode confusion” between the vehicle and driver (Davies, 2015; Golson, 2016; Marinik et al., 2014).

Several manufacturers have developed and are testing Level 5 prototypes. Google’s bubble-like driverless car, named the “Koala,” is undergoing on-road testing in California and receives a great deal of media attention (Bergen, 2015). The vehicle, which has no steering wheel or pedals, is equipped with cameras, sensors, and a roof-mounted LIDAR system. Volvo plans on testing their Drive Me Level 5 system in 2017 with 100 prototypes on the streets of Gothenburg, Sweden (Ziegler, 2015). Unlike Tesla, which is taking incremental steps through the autonomy spectrum, Volvo and Google are intent on bypassing intermediate levels of autonomy and are aiming to leapfrog directly to fully autonomous Level 5 technology (Golson, 2016; Markoff, 2016).

## Deployment Scenarios and Timeline

Major questions concerning AVs center around the expected timeline for vehicle sales and the extent of market penetration. While it is difficult to accurately

predict the deployment of advanced technologies, particularly those with uncertainty around public acceptance and regulatory development, a number of analysts have tried to anticipate when Level 5 AVs would be available for purchase. While analysts differ on the exact timing, they consistently anticipate AVs will follow a standard technology diffusion curve in which a small number of early adopters make initial purchases followed by period of rapid growth before leveling off near a saturation point. These predictions are summarized here to arrive at a range of possible deployment scenarios.

Todd Litman (2015) predicts an optimistic scenario in which AV sales begin in the next ten years, reach 50 percent of all vehicles sold in the 2040s, and achieve nearly 100 percent market penetration by 2060. A report by McKinsey & Co. (2016) offers a similarly optimistic adoption curve, with 15 percent of all vehicle sales by 2030, a quick rise to 50 percent in 2035, and a topping out at 90 percent by 2040. In terms of aggregate number of vehicles sold, a paper delivered at the 2016 Transportation Research Board Annual Conference predicts 1.3 million AVs sold in the United States by 2030, 36 million in 2040, and 84 million in 2050 (Lavasani, Jin, & Du, 2016). Similarly, the consulting firm IHS (2016) recently updated their AV deployment predictions with faster rollout scenarios based on increased research and development commitments by manufacturers, forthcoming regulatory harmonization, and new mobility developments such as ridesharing systems. IHS now anticipates around 300,000 AVs sold in the United States by 2025 and 1.6 million by 2030. Initial rollout could come even sooner, as Ford recently announced they would release an AV for the ridesharing market in 2021 (Boudette, 2016). These analyses indicate that AVs will be commercially available within ten years and will comprise half of all vehicle sales within 20 to 30 years.





## Costs

Cost estimates are available for the price premium that AVs will command due to the advanced computing and sensing technologies that are required for functionality. One estimate places an initial \$10,000 premium on AVs, falling to around \$3,000 several decades later after the technology improves and becomes ubiquitous (Fagnant & Kockelman, 2015). Another study predicts

similar figures, with a \$7,000 to \$10,000 price premium initially and dropping to \$3,000 ten years later (IHS Automotive, 2014). The average cost of a new car in 2015 was \$33,000, so a \$10,000 AV option would increase the price by approximately 30 percent, which would place the product out of range for many consumers. It is therefore likely that AVs will debut with luxury makers that already enjoy an affluent customer base who can afford the added cost (Kelley Blue Book, 2015; Tannert, 2014).



## Google's Koala Car

*Image credit: Marc van der Chijs under Creative Commons license*



# 04 Administrative and Citizen Issues

The design, testing, and deployment of autonomous vehicles will introduce a number of wrinkles to traditional forms of vehicle administration and governance, such as the regulatory boundaries between federal and state governments. Answers to questions about accident liability will be contentious, and the insurance industry will need to create new products for citizens and manufacturers alike. Also, related to citizens, AVs will generate enormous amounts of geolocated data that could be used to track passengers, thus raising concerns about corporate/government surveillance and privacy. These challenging administrative and citizen-related issues are discussed in the following sections.

## Regulations and Vehicle Testing

NHTSA's 2016 policy document contains a section that defines the division of AV regulatory authority between federal and state governments with the goal of ensuring the "establishment of a consistent national framework rather than a patchwork of incompatible laws" (National Highway Traffic Safety Administration, 2016, p. 7). The stated objective of NHTSA's guidance is to provide regulatory clarity to the industry and thus accelerate the development, testing, and deployment of AV technology. Division of regulatory authority for AVs closely mimics the current framework for traditional vehicles. The federal government still retains its ability to establish and enforce vehicles safety standards, regulate vehicle equipment (including computer hardware and software), issue product recalls, and communicate safety-related information to the public. States are still responsible for vehicle licensing, registration, setting and enforcing traffic laws, and establishing insurance and liability standards. New authorities that NHTSA is exploring to ensure AVs safety benefits include new tools to regulate vehicle software updates as well as data collection and storage.

States are encouraged to develop regulations to authorize AV testing and NHTSA offers guidance on the barriers that will need to be overcome. Delaware should appoint a lead agency to handle AV administration and all applications to test AVs within the state's jurisdiction should be submitted to that agency. The agency would review applications, in consultation with state law enforcement, to either grant or refuse authorization to test in Delaware. If authorization is granted, the Delaware Division of Motor Vehicles (DMV) would issue a permit to the applicant for each testing vehicle. Each vehicle should be properly licensed according to Delaware state law. NHTSA recommends that only drivers designated and properly trained by the manufacturer should be allowed to operate AVs during testing trials. These operators should hold a Delaware license and be subject to all state rules of the road. They should also bear responsibility for any traffic offenses that occur during testing (National Highway Traffic Safety Administration, 2016, pp. 40–43).

## Liability

A critical, unresolved legal question hangs over fully autonomous vehicles: who is liable for an incident, the user or the manufacturer? Answers to this question depend on many variables and, at this point, are purely speculative because the courts have not been forced to rule. In certain instances, it is likely to assume that users will be liable for an accident if they are negligent under a standard of reasonableness, for instance if a user knows he needs new brakes, fails to obtain them, and the faulty brakes directly lead to an incident (Anderson et al., 2014). On the other hand, if a user is disengaged from the road in a full Level 5 vehicle that experiences internal software or system failure and is involved in an accident, it could be reasonably argued that the manufacturer should be held liable for damages (Silberg & Wallace, 2012). There is an even stronger case for manufacturer liability when an AV is empty, for



---

## *...some manufacturers are announcing that they will simply accept responsibility if there are incidents involving their autonomously operated vehicles...*

---

example if an accident occurs while the AV is picking up a rideshare. Questions may arise over who was in control of safety critical functions at the time of an incident—human driver or vehicle software—but this situation could be mitigated if manufacturers create “black boxes” that store real-time diagnostic data (Bose, 2015).

To avoid some uncertainty and clarify the liability landscape that will evolve in U.S. courts, some manufacturers are announcing that they will simply accept responsibility if there are incidents involving their autonomously operated vehicles. Volvo, for example, committed to accept liability in an effort to avoid lengthy regulatory and legal battles that could delay the development and eventual release of AVs (Korosec, 2015). Google and Mercedes have made similar pronouncements (Whitaker, 2015). This position helps explain why these manufacturers are also avoiding semi-autonomous technology and leapfrogging direct to Level 5 full autonomy.

While clarification of liability will take time to sort out, NHTSA’s guidance document offers a first-step recommendation. They argue that states should explicitly define what is meant by “drivers” of AV for the purpose of traffic laws and enforcement. NHTSA recommends that when the AV systems are monitoring the roadway, the surrounding environment, and executing driving tasks (autonomy Levels 3 through 5), the vehicle itself should be classified as the driver,

with licensed humans operators classified as drivers for Levels 1 and 2 functionality (National Highway Traffic Safety Administration, 2016, p. 39). If adopted across all states, the classification would set an initial standard of liability that will undoubtedly be refined in the future through successive legal challenges.

### **Insurance**

The automobile insurance marketplace will need to adapt with the deployment of AVs. The anticipated reduction in the number of accidents (see section titled “Roadway Safety” above) will lower expected losses for insurers and those savings will likely be passed on to consumers in the form of lower premiums (Albright, Bell, Schneider, & Nyce, 2015; Buhayar & Robison, 2015). Yet while the number of claims are expected to decline, the cost per claim is anticipated to increase due to the expensive hi-tech components integrated into AVs. Furthermore, if AV manufacturers are deemed liable in incidents caused by product mal function, insurance claims will likely need to originate from the manufacturer rather than the owner/operator of the vehicle. While some insurance claims such as theft and hail damage will still be required, it is clear that AVs—and particularly ride-sharing AVs—will force a dramatic transformation of today’s automobile insurance industry. Insurers will need to anticipate these changes and develop new products and actuarial models.



One possible innovation for insurers is to use speed and location data collected from the vehicle (see next section) to generate a usage-based, driving mode-based, or trip-based insurance product (PricewaterhouseCoopers, 2015). This new product could be targeted at an urban or casual driving demographic that rarely uses their vehicles. Several insurers, such as the San Francisco-based Metromile, offer a usage-based insurance option for low-mileage drivers through a USB-like dongle that plugs into the vehicle and tracks movements. Another innovation would involve creating new commercial and product liability lines for manufacturers if they are required to (or voluntarily) accept liability for accidents (Albright et al., 2015).

## Cybersecurity and Privacy

Autonomous vehicles will introduce a new layer of complexity into growing concerns over cybersecurity. To function properly, AVs must be connected to various digital networks such as GPS systems and possibly wireless and cellular networks. Each digital connection creates a potential gateway and vulnerability for remotely generated malicious intent (Anderson et al., 2014). The magnitude of cybersecurity risk is amplified with autonomous vehicles because the internal vehicle software, which in normal vehicles is already notorious for being “buggy” and requiring recalls, will be designed to adjust safety-critical functions (Gelles, Tabuchi, & Dolan, 2015). A hacker could access an AV’s software system and remotely control steering, braking, and acceleration, as recently demonstrated on a Tesla Model S operating in Autopilot mode (Clark, 2016). The possibility of a system-wide attack also exists. If roadside communication units and ultra-connected V2I and V2V networks become embedded in the U.S. transportation system, a coordinated large-scale cyberattack could exploit that vulnerability and potentially cripple vehicular transportation in the country. Traffic Management Centers also need to exercise caution against being spoofed by malicious

and invalid AV traffic data being relayed through their connected networks. Responding to these hacking concerns, U.S. Senators Richard Blumenthal (D-CT) and Edward J. Markey (D-MA) introduced the Security and Privacy in Your Car Act (SPY Act) in 2015 that would instruct NHTSA and the Federal Trade Commission (FTC) to develop security standards for vehicle software and networked controls. The bill is currently in committee but unlikely to proceed further. In August 2016, the Transportation Research Board (2016) initiated a research effort to understand these threats and create a cybersecurity primer for state DOTs. These efforts are warranted as surveys show that potential users are reluctant to adopt AVs because of hacking concerns (Kyriakidis, Happee, & de Winter, 2015).

Citizen privacy is another issue amplified by AVs. As with smartphones, AVs will generate tremendous amount of tracking data that will prove valuable for advertising and marketing purposes. A study conducted by Senator Markey’s staff found that even at today’s level of vehicle connectivity and partial autonomy, half of the automobile manufacturers generate, transmit, and store on-board data on vehicle movements and diagnostics (Markey, 2015). This data is frequently stored in third-party data centers, sometimes indefinitely, and citizens remain unaware that their movements are being monitored. The aforementioned SPY Act also instructs NHTSA and FTC to develop privacy standards that would force manufacturers to be more transparent in how vehicle data is collected, stored, and used. It would also prohibit data collection by default and would require users to opt in without compromising critical AV capabilities such as self-navigation. NHTSA’s (2016) AV policy guidance reiterates many of these recommendations to vehicle manufacturers. For instance, it asks manufacturers to allow AV owners to opt in to data collection rather than having it collected by default. The policy guidance also suggests that citizens need clear, plain language for what data will be collected, how it will be stored, for how long, and how it will be protected.





*“Does your car have any idea why my car pulled it over?”*

*Paul Noth, The New Yorker © Condé Nast*



# 05 Planning and Policy Impacts

Delaware's transportation planners, urban planners, and policymakers will need to adjust their models and analyses to account for the tremendous impacts that AVs portend. Decision-makers must consider the changes that AVs will cause to variables such as passenger safety, ownership, parking demand, vehicle miles traveled, roadway congestion, development patterns, infrastructure design, employment, state and local budgets, fuel economy, carbon emissions, and transportation equity. In this section, the variables listed above are investigated, and an attempt is made to predict an increase or decrease for each one. Delaware-specific predictions are made for each variable by using data, when available, and logic based on assumptions about the state's transportation and development environment.

This effort is complicated by the inherent uncertainty surrounding the development, uptake, and deployment of an advanced technology such as AVs. There are countervailing social, economic, political, environmental, and technological forces that impact each variable discussed in this section, and untangling their magnitudes to arrive at a final result is an incredibly complex procedure. So, just as early developers of the internet in the 1980s could only speculate as to the network it would become and how it would transform society four decades later, prognostications surrounding AVs are, at this point, educated best guesses. With that caveat, some variables (safety impacts) benefit from greater certainty than others (carbon emissions).

## Roadway Safety

Every year in the United States there are approximately 5.5 million reported vehicle crashes and 33,000 fatalities, with annual economic losses of \$300 billion (Cambridge Systematics, 2011). More than 90 percent of these traffic accidents are caused by human driver error, and analysts predict that many these incidences

will be eliminated with driverless vehicles (Fagnant & Kockelman, 2015; Silberg & Wallace, 2012). Indeed, a decrease in fatalities and injuries is one of the most often-cited benefits of the technology. Analyses of accident data indicates that even semi-autonomous crash avoidance technology—such as forward collision warning systems and automatic braking—featured in current vehicles decreases the frequency of incidents (Highway Loss Data Institute, 2015). However, it is not certain that AVs will deliver totally accident-free transport, especially during the transitional period when AVs and manually-driven vehicles share the road (Sivak & Schoettle, 2015). Assuming full AV saturation, a conservative estimate of a 50 percent reduction in accidents would still yield an overall decrease of approximately 12,000 crashes in Delaware annually, based on 2015 crash data (Hyland, 2016). This would avoid \$320 million (in 2015 dollars) in economic losses for the state.

A more realistic state-level estimate for improvement in safety can be found by examining crashes in which humans were impaired and distracted, such as accidents that involved alcohol and texting. In Delaware from 2005 to 2015, there was an average of 106 fatal crashes per year. Drivers under the influence of drugs and alcohol were responsible for 20 percent of those fatal crashes, while distracted drivers accounted for 8 percent (Hyland, 2016). The figures are similar for total crashes (which averaged 20,700 annually): 5 percent are due to impaired driving and 23 percent to distracted driving. Therefore, a 28 percent decrease in fatal accidents and overall accidents in Delaware is an extremely conservative estimate for the expected traffic safety benefits of AVs.

## Ownership

A confluence of factors are prompting analysts to question the historical trajectory of ever-increasing vehicle ownership, with some suggesting that the



United States has reached “peak car” (Rosenthal, 2013; Sivak, 2013, 2015). One factor is rural-to-urban migration, which decreases demand for vehicles because urban areas are generally better equipped with alternative transit options and offer greater access to essential services. From 2000 to 2010, the portion of Americans living in urban areas increased by 2 percent while there was an equivalent 2 percent decline in the portion of Americans living in rural areas (Lambert, 2012). A second major factor is a partial rejection of American car culture by the younger Millennial generation. With increasing student loan burdens, stagnant wages, and rising rents in urban areas, Millennials do not have as much disposable income to participate in car ownership (Badger, 2014; Davis, Dutzik, & Baxandall, 2012). There is also evidence that younger Americans value minimizing the environmental impacts of their transportation choices and hence avoid high-polluting options like cars (Sakaria & Stehfest, 2013). The third and, perhaps, most important factor depressing vehicle ownership is the rapid ascension of transport/mobility service providers within the “sharing economy.” Uber, Lyft, and Zipcar are the well-known companies operating in this space, and Uber is currently testing AV rideshares in Pittsburgh (Chafkin, 2016). For many urban residents, it is cheaper and more convenient to hail on-demand transport than struggle with driving, parking, vehicle maintenance, insurance, and other costs associated with owning and operating a vehicle (Hampshire & Gaites, 2011; Shaheen & Cohen, 2013). These costs are already significant for Delaware, which ranks in the top third of most expensive states to own a vehicle (Kirkham, 2016).


The fusion of AVs with ridesharing services is an explicitly stated goal of Uber and Lyft. Not only do these companies anticipate replacing their presently commissioned drivers with AVs, they are seeking to upend the traditional model of vehicle ownership and replace it with on-demand, autonomous transportation (Gilbert, 2015). Uber CEO Travis Kalanick said that his company wants to “make car ownership a thing of the

past” (Rulsi, 2014). In the future, those who own an AV can ride to work, then release it to Uber or Lyft during working hours. They will receive compensation as the vehicle shuttles customers around until the owner calls back the vehicle to return home. The impact on vehicle ownership and parking (see next section) could be significant, with one study predicting that each shared AV can effectively replace 12 privately owned vehicles (Fagnant & Kockelman, 2014).

The common thread that ties together the downward pressures on vehicle ownership is population density. Urban migration, changing cultural values, and ridesharing all require population density. Delaware, therefore, may experience more rapidly declining vehicle ownership in New Castle County where urban density amplifies these factors, while the sprawling development patterns of Kent and Sussex Counties could limit the impact of AVs on private-vehicle ownership. Nevertheless, aggregated across Delaware, it is reasonable to expect a “peak car” scenario after Level 5 AVs diffuse.

## Parking Demand

Deployment of Level 5 AVs will likely reduce the need for parking spaces in urban areas for two main reasons. First, because AVs have the ability to function without a human present in the vehicle, AV owners can be dropped off at their destinations and send their vehicles to free parking spaces outside of the city (Anderson et al., 2014). Second and perhaps more significantly, shared-use AVs that engage in Uber-like services may never need to park. Instead of an owner getting dropped off and sending the vehicle outside the city to park, the owner may choose to lend it to Uber and receive compensation for each fare. This scenario has been modeled and the results predict a 50- percent to 90-percent reduction in urban space dedicated to parking (Fagnant & Kockelman, 2014; Skinner & Bidwell, 2016). For Delaware, the impacts



on parking may not be noticeable in rural areas, but in denser urban areas and locations where parking is constantly at a premium, significant space can be freed up for alternative uses.

## Vehicle Miles Traveled

There is a consensus among researchers that AVs will increase vehicle miles traveled (VMT) due to a rebound effect, whereby riders choose to travel more because of reduced travel costs (Anderson et al., 2014; Fagnant & Kockelman, 2015; Litman, 2015). AVs have the potential to reduce the time-related costs of transportation due to the enabled ability to work, sleep, or play while riding. In addition, with reduced congestion (see next section), the cost of transportation declines further. AVs also offer individuals who were previously unable to drive—elderly, children, disabled—greater mobility, with one industry estimate predicting that AVs will increase the number of vehicle operators by 32 million nationwide (Winterhoff, Mishoulam, Shirokinskiy, Chivukula, & Freitas, 2015). The newfound ability of populations who were previously unable to drive could therefore result in increased VMT. There is also the distinct possibility that owners could send their AVs on nonessential trips and errands. For example, a family flying to Vermont for a ski trip could conceivably load their AV with all their gear and program the vehicle to drive itself to their final destination. Analysts therefore estimate that AV deployment could increase nationwide VMT by 9 percent or more, with similar expectations for Delaware (Fagnant & Kockelman, 2015).

## Roadway Congestion and Capacity

Evidence suggests that AVs, especially those equipped with V2V technology, could reduce congestion by decreasing traffic accidents and increasing vehicle capacity on highways by smoothing traffic patterns. For instance, it is estimated that 25 percent of

congestion is attributable to traffic incidents, around half of which are crashes (Cambridge Systematics, 2004). With the full deployment of AVs, crashes related to certain factors such as operating under the influence are expected to decline and therefore reduce congestion by significant margins. V2V technology, in the form of Cooperative Adaptive Cruise Control (CACC), could reduce congestion even further. CACC technology is similar to standard ACC but with the added function in which vehicles can communicate with each other and adjust their speeds in unison. It is predicted that with widespread deployment of CACC, time gaps between platooning vehicles can be shrunk safely, which would increase traffic density. In addition, highway traffic flows, lane merges, and intersections will be coordinated and smoothed, with more laminar queues and less stop-and-go (Lee & Park, 2012; Tachet et al., 2016). One analysis suggests that when all vehicles become equipped with CACC technology, it is possible to effectively double lane capacity (Shladover, Su, & Lu, 2012). Even at moderate levels of V2V technology deployment, lane capacity is expected to increase (Tientrakool, Ho, & Maxemchuk, 2011).

As with the other impacts of AVs, however, there are countervailing user preferences that could force a trend in direction of increased congestion (Barnard, 2016). For instance, if a perception of enhanced safety exists, operators may program their vehicles to take greater risks, which could possibly lead to more traffic accidents. There also are fears about induced traffic and increased VMT, which will neutralize some of the congestion benefits highlighted above (Fagnant & Kockelman, 2015; Litman, 2015). Increased congestion, particularly in denser urban areas, might also occur if owners get dropped off at their destination and then order their vehicle to circulate until they are ready to be picked up. Owners could also send their AVs on delivery or pick-up errands without the inconvenience of having to actually sit in the vehicle.





Even physiological factors become relevant, as one recent study finds that vehicle passengers tend to be more sensitive to acceleration than drivers. So when occupants use travel time to work or rest, it is plausible that, for comfort's sake, users will program their vehicles for lower acceleration/deceleration characteristics, leading to reductions in total urban roadway capacity (Le Vine, Zolfaghari, & Polak, 2015).

After accounting for both sets of congestion and capacity dynamics, it is difficult to anticipate if the induced risk-taking and travel demand will overwhelm the safety and traffic smoothing benefits of AVs, and what impact that would have on congestion and Delaware's roadway capacity. Some overall benefits might be realized on high speed throughfares such as highways, while denser urban areas could become more clogged and congested with empty AVs.

## (Sub)Urban Development Patterns


As with many of the potential impacts of AVs, the consequences for (sub)urban development and density is influenced by countervailing forces and analysts disagree on the ultimate outcome. On the one hand, as noted in the previous section, AVs will likely decrease parking requirements in cities, which will free up land for high-density residential or mixed-use development. One study anticipates a 15 percent to 20 percent increase in urban land that will be made available through this process (Skinner & Bidwell, 2016). As a result of this land-use change, a number of analysts argue that urban densification is a likely outcome of AV deployment (Skinner & Bidwell, 2016; The Economist, 2015). On the other hand, there is a real possibility that AVs could catalyze another round of sprawl beyond the fringes of today's suburban communities. This is due to the fact that AVs reduce the opportunity cost of transportation because the operator is now free to

engage in other activities such as work, entertainment, or even sleep. Longer commutes become more tolerable. In addition, as noted above, congestion will likely decrease. In this way, a vehicle will be able to cover a greater distance for any give length of time. For these reasons, many analysts anticipate that AVs will increase residential demand beyond the current fringes and generate more suburban sprawl (Fox, 2016; Gill, Kirk, Godsmark, & Flemming, 2015; Glancy, 2015; Litman, 2015; McDonald, 2016).

The end result may likely be a mix of the two processes: densification in urban centers coupled with sprawl beyond the urban fringes. With the natural increase in overall population and the rural-to-urban migration mentioned earlier, people will need to find somewhere to live in urban environments. AVs could offer residents a choice to live in urban centers and not have to own a vehicle and, by the same token, they could make it desirable to live outside those cores. For Delaware, which is experiencing sprawling development patterns as well as densification of urban areas like Newark and Wilmington, these dual trends could continue with AVs.

## Infrastructure Design and Upgrades

AVs could generate changes into the way that engineers design and operate transportation infrastructure. To start, it is possible that AV operation will be so precise, traffic lanes could become narrower (Blumenauer, 2016). Richard Biter, the assistant secretary of Florida's DOT suggested that 12-foot lanes could be reduced, and it may be possible to "get by with 9 ½- or 10-foot lanes. We could turn that four-lane express highway into a six-lane express highway with literally the same right-of-way footprint" (McFarland, 2105). Traffic lights could also become redundant by designing a "slot-based intersection" where rights-of-way are optimized by a connected



vehicle platooning model that coordinates groups of vehicles to pass through intersections at variable rates while still enhancing overall efficiency (Tachet et al., 2016). Pedestrians and cyclists introduce a degree of uncertainty and complexity into the slot-based intersection strategy, so it also may be necessary to design grade-separated intersections that place vehicles on one level and pedestrians and cyclists on another, thus optimizing AV traffic flow while preserving non-motorized access to city spaces (Alpert, 2012).

In terms of Delaware needing to install RSE statewide to enable V2I functionality, it is still uncertain what will be required. RSE could relay information between vehicles and the Transportation Management Center where it would be analyzed to monitor and optimize traffic flows. But RSE will need to compete with other forms of communication that AVs utilize. Low-latency DSRC channels between vehicles and RSE operate within the 5.9 GHz spectrum regulated by the Federal Communications Commission, but it is not certain that such short-range networks and the associated hardware will be necessary. Some new vehicles already come equipped with 4G LTE capacity that could replace aspects of DSRC, effectively transmitting and receiving information over the existing mobile network rather than through dedicated on-board and roadside infrastructure (Glancy, 2015). Looking ahead, the 5G systems currently under research development will likely compete with the low-latency DSRC option for

V2I communication (Bradbury, 2016). AV manufacturers also use their own closed private wireless networks to send and receive vehicle information to monitor vehicle diagnostics, update vehicle software, and perform other real-time functions. While the networks and information are proprietary, they too could be used as channels to replace DSRC and enable V2I functionality.

## Jobs and the Economy

The consequences of AVs for the country's and Delaware's labor markets will be profound (Solon, 2016). There are nearly 10,000 Delawareans employed as heavy and light truck drivers, bus drivers, taxi drivers, and chauffeurs, and many of these workers could be made redundant as vehicle automation reduces demand for traditional behind-the-wheel employment (Bureau of Labor Statistics, 2015). At the same time, there is some evidence that over long-enough timeframes, labor-displacing technologies stimulate economic growth in unintended and unanticipated ways, such that jobs lost in certain sectors are partially compensated for with new employment opportunities in others (Pianta & Vivarelli, 2003). Uncertainty surrounds the extent to which AVs will stimulate new markets, grow companies, and increase overall labor productivity. What is clear is that there will be initial job losses, particularly the behind-the-wheel type, as AVs become commercially available. What is less clear is whether or not those displaced workers are able to translate their skills into employment elsewhere.

---

***Ridesharing services are seeking to upend the traditional model of vehicle ownership and replace it with on-demand, autonomous transportation.***

---



## State and Local Fiscal Impacts


Approximately one quarter of the Delaware Transportation Trust Fund revenue comes from motor vehicle fuel tax (Delaware Department of Transportation, 2013; Transportation Trust Fund Task Force, 2011). A number of factors will impact the ability of the state to continue to produce this amount of revenue through this vital source. First, in 2012 the federal DOT and the EPA finalized a fuel efficiency standard of 54.5 miles per gallon for cars and light-duty trucks by 2025, which is predicted to reduce nationwide oil consumption by two million barrels per day in 2025 (National Highway Traffic Safety Administration, 2012). Vehicles are also becoming electrified, running on grid-charged batteries instead of liquid fuels. The United States is already the largest market for electric vehicles, and by 2040 they are predicted to comprise 25 percent of all vehicles on the road, further displacing 13 million barrels of oil per day globally (Bloomberg New Energy Finance, 2016).

AVs could put further downward pressure on fuel consumption and consequently gas tax revenue for Delaware. For instance, AVs will reduce accidents and related congestion. Vehicles can platoon and smooth traffic flows through heavy volume. They can also utilize GPS and traffic-sensing technology to navigate along optimally efficient routes (Litman, 2015). AVs are also predicted to be lighter (and hence more fuel efficient) than a standard vehicle due to the reduced collision risk they will provide to passengers. The ultimate impact that AVs will have on fuel consumption and gas tax revenue is uncertain, however, due to countervailing factors such as a possible increase in VMT (see section “Vehicle Miles Traveled” above). Nonetheless, it is important to consider that AVs could depress critical sources of transportation-related revenue for Delaware at a time when those sources are predicted to decline due to vehicle electrification and federally mandated improvements to fuel economy.

For Delaware’s local governments, AVs could also have a significant impact on revenue generation. For example, from FY13 to FY15, Wilmington generated \$5 million in net revenue from red light traffic cameras alone (City of Wilmington, 2014, 2015). In Dover and Newark, net revenue from red light cameras was \$3.5 million and \$2.4 million between 2010 and 2015 (Cohan, 2016). Because AVs will be programmed to avoid these types of traffic violations, this source of revenue will almost certainly decrease as the technology diffuses. Citations for other common driving-related offenses—speeding, failure to stop, cell phone usage, driving under the influence—will also decline. Additionally, municipal parking revenue generated through meters and fines will decline if the demand for parking decreases in urbanized areas (see section “Parking Demand” above) (Desouza et al., 2015).

## Modal Shifts

Public transportation advocates are concerned that AV deployment will be used to rationalize policy choices to defund (or fail to invest in) more communal transit options. The International Transport Forum (2015, p. 6) argues that in “small- and medium-sized cities it is conceivable that a shared fleet of self-driving vehicles could completely obviate the need for traditional public transporter [because]...self-driving car fleets will compete with public transportation services, as currently organised.” There is some evidence that that this is already occurring. In Pinellas County, Florida, the impending mobility afforded by AV was used as an excuse by opponents to lobby against and eventually defeat a plan to build light rail in the area (Morris, 2014). Light rail has also been placed on the backburner in Columbus, Ohio, after the city won a major \$40 million federal Smart City Challenge grant to enhance the municipality’s intelligent transportation system (Knox, 2016). However, some analysts predict that AVs could help solve the first- and last-mile problem of public transit, effectively making it more



---

*Affluent drivers who can afford AVs would receive the full benefit of enhanced speed and safety in dedicated lanes, while the less affluent are resigned to slower, more dangerous conditions.*

---

convenient to take transit and therefore boosting demand (Freemark, 2015). Municipalities are exploring hybrid models of public-AV transit services, like Beverly Hills, California, where the city council recently accepted a funding request to study the possibility of having publicly owned AVs close first- and last-mile gaps for residents (Mirisch, 2015; Vincent, 2016). This model would preserve the long-standing idea that public transportation services are funded and delivered by local and regional governing bodies.

If the cost of shared-use AV services becomes affordable for all Delaware residents, short-distance DART routes could face competition for riders. State-sponsored paratransit services could also experience decreased demand because AVs could easily be modified to comply with Americans with Disabilities Act requirements to enhance mobility for physically and mentally impaired users.

## **Fuel Economy and Carbon Emissions**

It is widely expected that AVs will have positive impacts on average vehicle fuel efficiency. There are several reasons for optimism. First, as noted earlier, the reduction in crashes and congestion that AVs will likely

offer will smooth traffic flows and decrease inefficient idling and stop-and-go traffic (Anderson et al., 2014; Tientrakool et al., 2011). Second, further fuel efficiency gains can be achieved through platooning in which a series of vehicles follow in the draft of a lead vehicle. The reduced wind resistance for all vehicles in the series can increase fuel efficiency by up to 10 percent (Brown, Gonder, & Repac, 2014). Third, analysts predict that AVs will be lighter—and hence more fuel efficient—than current vehicles because of the enhanced safety and crash-avoidance benefits they will offer users (Anderson et al., 2014; Mattow et al., 2014).

The impact of AVs on carbon gas emissions is less certain. Despite the high confidence that overall vehicle fuel efficiencies will increase, the possible increase in overall VMT (see section above) could offset the reduction in fuel consumed per mile and lead to an increase in annual per-vehicle carbon emissions (Wadud, MacKenzie, & Leiby, 2016). However, the potential fusion of AV technology with ridesharing services could reduce the number of vehicles on the road, thus catalyzing a net decrease in carbon emissions (Greenblatt & Shaheen, 2015). Several studies analyzed the potential for shared-use AVs to impact carbon emissions and they concluded that life-cycle reductions are possible in urban areas despite the expected increase in VMT (Fagnant & Kockelman,



2014; Greenblatt & Saxena, 2015). If overall decrease in emissions is realized, this would be encouraging news for Delaware, which has seen aggregate transportation-sector emissions decrease only slightly in the past twenty-five years (personal communication, February 7, 2016).

## Transportation Equity

The anticipated safety and speed benefits of AVs will increase as more and more AVs appear on the road, displacing manually operated vehicles that add uncertainty and risk into the optimally efficient transportation network. Some commentators and analysts suggest that AV- and manually operated conflicts can be avoided by creating dedicated infrastructure that is only accessible with automated technology (Kurczewski, 2014; Litman, 2015). For instance, it would be possible to set aside existing lanes—or build new lanes solely dedicate for AV use—a situation similar to the current system of high-occupancy/carpool lanes.

Dedicated AV lanes could generate significant transportation equity concerns. From a socio-economic standpoint, AVs are predicted to attract a price premium of \$10,000 and will be financially unfeasible for low-income individuals (Mosquet et al., 2015). Consequently, affluent drivers who can afford to purchase AVs would receive the full benefit of enhanced speed and safety in dedicated lanes, while the less affluent are resigned to slower, more dangerous conditions. The result would be speed and safety disparities among socio-economic levels and raise serious questions of transportation equity. Even without dedicated AV lanes, early adopters who can afford the technology would still experience enhanced safety and speed benefits.

There are additional scenarios whereby low-income communities do not receive the full benefits of AVs.

For instance, AV access could be limited for low-income individuals who do not have a smart phones or methods of electronic payment that are necessary to use ridesharing services. The infrastructure upgrades, RSE installations, and system maintenance to enable AVs could be concentrated in wealthier communities, effectively creating an unequal geography of AV functionality.

Other equity concerns are possible when looking at transportation funding. Fuel efficient AVs will pay a smaller share of gas tax revenue even though they are likely to travel greater miles compared to conventional vehicles. If the current pay-at-the-pump transportation funding system continues, non-AV vehicles will effectively be subsidizing AV users. Again, because AV ownership will be partially separated along a socio-economic spectrum, the current transportation funding model would become a regressive policy structure (Blumenauer, 2016).

Finally, depending on policy and regulatory frameworks that develop around AVs, urban mobility could decline for low-income urban residents. Because AVs, particularly shared-use AVs, will compete with public transportation alternatives, the potential for bus route closures and would have negative mobility impacts on low-income commuters if they are unable to afford to ride in shared-use AVs (Arieff, 2013; Litman, 2015). It was noted above that public transportation proposals in Pinellas County, Florida, and Columbus, Ohio, were defeated because of the prospect of stiff competition from AVs (Knox, 2016; Morris, 2014). Again, transportation equity concerns are raised due to negative AV outcomes falling on socio-economic groups that already experience limited and unequal access to mobility options.

For certain populations, AVs will enhance transportation access. The blind, elderly, minors, and those unable to obtain a conventional driver's license will all experienced greater access to mobility options.



# 06 Delaware's Readiness

The pace of AV innovation within the private sector is remarkable, and the public sector needs to accelerate its efforts in order to successfully integrate AVs on the roads in ways that amplify the positive benefits of the technology while minimizing the costly outcomes. Two areas are particularly noteworthy for Delaware's public institutions, the current capacity of the state's transportation system technology and the state's ability and capacity to govern AVs successfully.

## Technological Readiness

Delaware is well positioned, technologically speaking, to expedite the integration of AVs. For several decades, DeIDOT has been building communications capabilities such as high-speed fiber optic broadband and Wavetronix hardware into the state transportation infrastructure and is already capable of managing traffic in real-time. The Integrated Transportation Management System (ITMS), which comprises these communication technologies and the human resources that manage them, is an integral part of the department, from planning and design to operations, maintenance, and services. ITMS is built into planning, capital project development, and design so that every program and project, when appropriate, incorporates the necessary technology and telecommunications. Currently there are 300 miles of fiber optic cable in the state, with another 300 miles planned. The system is designed to be resilient to damage because it employs a redundant signal routing process, meaning that if a fiber cable gets cut in one area the network can still transmit information from point to point. The result is a state-owned telecommunications system—a backbone for AV functionality and success—that is highly advanced with regard to existing and planned coverage, bandwidth and performance. For instance, DeIDOT's computerized traffic signal system is a useful tool for daily transportation management, and it integrates with other data systems such as traffic monitoring, incident management, and transit

operations. Furthermore, with its ITMS, DeIDOT already collects several types of data (signal timings, delays, travel times, volumes) that connected and autonomous vehicles will need for full functionality. Data collection is processed through an open-architecture, state-owned database that can be readily amended and adapted to incorporate emerging data.

In anticipation of connected and autonomous vehicle deployment, DeIDOT is taking additional proactive steps to facilitate integration these advanced transportation technologies by extending the reach and capacity of the state's ITMS. Three projects that are scheduled for 2017 are particularly noteworthy. First, DeIDOT will enhance ITMS in Dover by installing a state-owned 4.9 GHz wireless system that will eliminate the need to lease circuits from mobile carriers. A second project designed to test signal timing will see an upgrade to signal controllers at 11 intersections along U.S. 13 in Smyrna, installation of networked roadside equipment on the same corridor, and installation of on-board units in select DeIDOT vehicles. The third project involves DeIDOT partnering with the Federal Highway Administration to develop an artificial intelligence system for northern Delaware that will analyze real-time data gathered through remote traffic detectors and semi-automate decision-making and operations in the area.

## Administrative Readiness

From a technological feasibility standpoint, the preceding section demonstrates that Delaware is proactively preparing the state for testing, operation, and deployment of connected and autonomous vehicles. This advancement in transportation infrastructure and technology must parallel a similar effort to augment the state's administrative and policy structures so that timely testing, deployment, and the associated AV impacts are appropriately managed. DeIDOT is already engaged in several AV-related





regional and national partnerships. For instance, the state participates in the I-95 Corridor Coalition's Connected and Autonomous Vehicles Leadership Team and the American Association of State Highway and Transportation Officials's AV Working Group. DelDOT should continue to leverage these partnerships as they will prove fruitful for information sharing, policy development, and the creation of standardized frameworks as well as standardized infrastructure designs across state lines (e.g., pavement markings, traffic signs, signals, lights).

NHTSA's (2016, sec. II) guidance document offers a number of recommendations to states for creating decision-making bodies that will oversee and advise on AV issues. They suggest that a lead agency be appointed to oversee AV administration, especially early testing. The lead agency would identify possible gaps or legal issues in current state regulations, such as the definition of "driver" within state statutes, and propose necessary changes to permit AV testing and operation. The agency would also examine state laws

for barriers in the areas of licensing and registration, driver education and training, insurance and liability, traffic law enforcement, and vehicle inspection. For testing AVs on public roads, procedures and protocols would be developed for accepting and reviewing applications from manufacturers. This may include designation of prohibited areas (near schools, construction zones, etc.) and the submission of applications for testing to a review by state law enforcement representatives.

Two important pieces are in place to advance and accelerate AV governance in Delaware. First, DelDOT owns 90 percent of the roads and most of the traffic signals, and it operates the transit system. Second, the state's small size generates a level of familiarity among stakeholders, legislators, and administrators, meaning that action can occur quickly. The combination of these two factors could create a fertile environment for public and private investment in a flexible transportation system that is well positioned to accommodate AV testing, operation, and deployment.

---

***Delaware is well positioned, technologically speaking, to expedite the integration of AVs.***

---



## 07 Conclusion

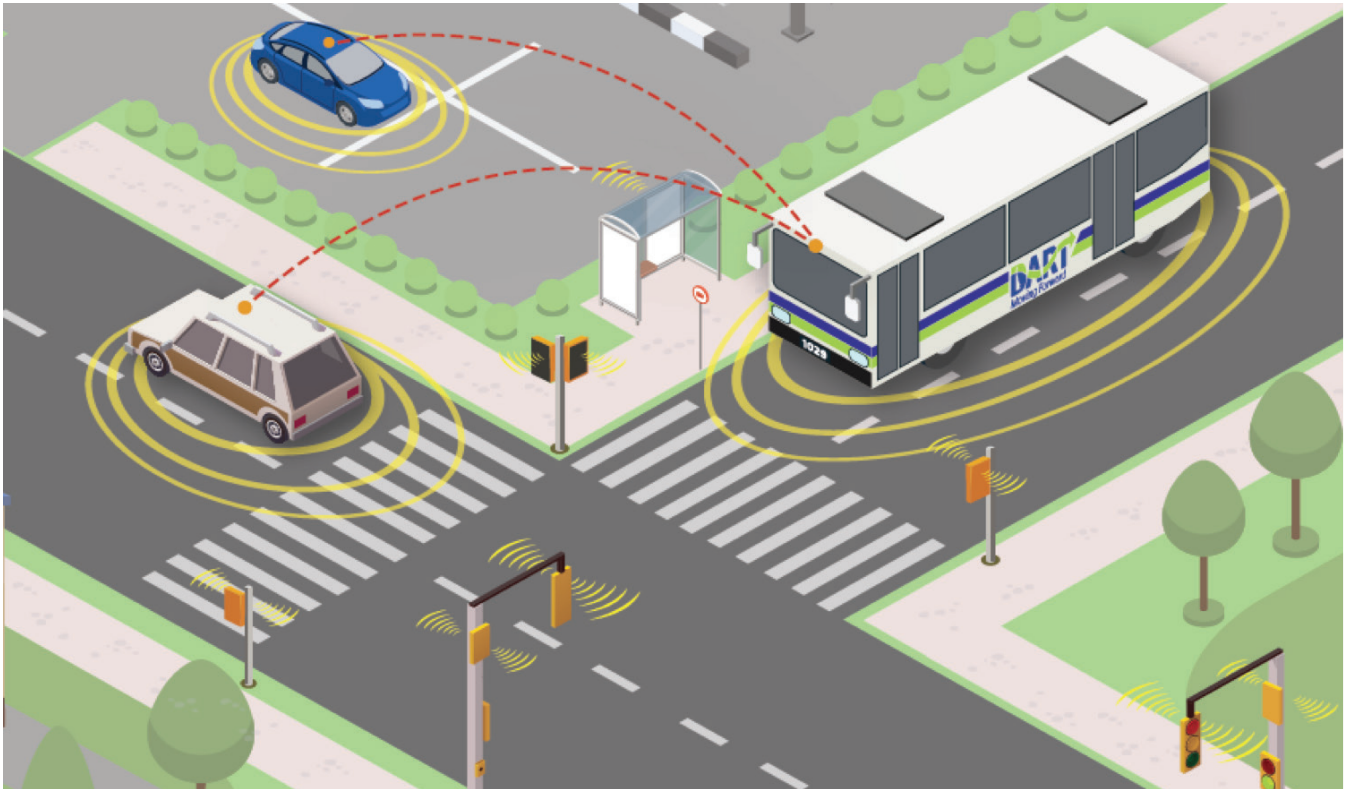
AV technology is rapidly advancing, and when these vehicles become commercially available, they will disrupt traditional forms of transportation behavior and associated socio-economic outcomes—both positively and negatively. The impacts will be long lasting as urban development and policy structures become embedded on Delaware's landscape. If, because of the pace of AV technology advancement, the new form of transportation is accepted passively without an effort to manage and direct its consequences, then the likelihood of Delaware experiencing greater negative impacts increases significantly.

The negative and costly consequences that Delaware could experience if AVs are not managed properly include cybersecurity and hacking threats, erosion of citizen privacy, increased VMT, continued sprawling development beyond the already-extensive urban fringe, costly upgrades to state's transportation infrastructure, job losses for Delaware drivers and vehicle operators, loss of revenue for state and local governments, declining public transportation ridership, increased carbon emissions, and inequitable access to

safe and efficient mobility. On the other hand, there are substantial benefits that could be accentuated through effective governance and management of AVs including a reduction in number of traffic accidents, injuries, and fatalities on Delaware roads, less roadway congestion, greater roadway capacity, and a decrease in land used specifically for parking.

It is therefore imperative that the state's transportation planners and decision-makers engage in AV development if they are to accentuate the beneficial outcomes while minimizing the costly ones. Fortunately, DeIDOT has already anticipated the needed upgrades to its ITMS and is taking a proactive approach to preparing the state technologically. As a parallel effort, Delaware should develop an administrative and governance framework to enable AV integration into the state's transportation network, thus ensuring that AVs serve the needs of Delawareans, the state economy, and visitors alike. The state should begin that process without delay since the AV-dominated future will arrive shortly.





**Vehicle to Vehicle (V2V) Communication**  
*Source: DelDOT*



## 08 References

- Albright, J., Bell, A., Schneider, J., & Nyce, C. (2015). *Automobile insurance in the era of autonomous vehicles*. Boston, MA: KPMG. Retrieved from <https://home.kpmg.com/content/dam/kpmg/pdf/2016/05/marketplace-change.pdf>
- Alpert, D. (2012, March 5). Why driverless cars will increase tensions in cities and suburbs alike. Retrieved from <http://www.theatlanticcities.com/technology/2012/03/why-driverless-cars-would-be-bad-cities-and-suburbs-alike/1393/>
- Anderson, J., Kalra, N., Stanley, K., Sorensen, P., Samaras, S., & Oluwatola, O. (2014). *Autonomous vehicle technology: A guide for policymakers*. Santa Monica, CA: RAND Corporation. Retrieved from [http://www.rand.org/content/dam/rand/pubs/research\\_reports/RR400/RR443-1/RAND\\_RR443-1.pdf](http://www.rand.org/content/dam/rand/pubs/research_reports/RR400/RR443-1/RAND_RR443-1.pdf)
- Arieff, A. (2013, July 23). Driving sideways. Retrieved July 28, 2016, from <http://opinionator.blogs.nytimes.com/2013/07/23/driving-sideways/>
- Arseneau, B., Roy, S., Salazar, J., & Yang, J. (2015). *Autonomous and connected vehicles: Preparing for the future of surface transportation*. Minneapolis, MN: HRD Inc. Retrieved from <http://www.hdrinc.com/sites/all/files/content/white-papers/white-paper-images/7334-autonomous-and-connected-vehicles-preparing-for-the-future-of-surface-transportation.pdf>
- Badger, E. (2014, October 14). The many reasons millennials are shunning cars. Retrieved from <https://www.washingtonpost.com/news/wonk/wp/2014/10/14/the-many-reasons-millennials-are-shunning-cars/>
- Barnard, M. (2016, January 17). Autonomous cars likely to increase congestion. Retrieved from <http://cleantechnica.com/2016/01/17/autonomous-cars-likely-increase-congestion/>
- Barth, L. (2015, September 15). Electronic stability control 101. *Consumer Reports*. Retrieved from <http://www.consumerreports.org/cro/news/2010/04/electronic-stability-control-101/index.htm>
- Bergen, M. (2015, June 25). Google's self-driving "Koala" cars now out in the wild. Retrieved from <http://www.recode.net/2015/6/25/11563902/googles-self-driving-koala-cars-now-out-in-the-wild>
- Bloomberg New Energy Finance. (2016, February 25). Electric vehicles to be 35 percent of global new car sales by 2040. Retrieved from <http://about.bnef.com/press-releases/electric-vehicles-to-be-35-of-global-new-car-sales-by-2040/>
- Blumenauer, E. (2016, May 20). Let's use self-driving cars to fix America's busted infrastructure. Retrieved from <https://www.wired.com/2016/05/lets-use-self-driving-cars-fix-americas-busted-infrastructure/>
- Bose, U. (2015). The black box solution to autonomous liability. *Washington University Law Review*, 92(5), 1325–1351.
- Boudette, N. E. (2016, August 16). Ford promises fleets of driverless cars within five years. Retrieved from <http://www.nytimes.com/2016/08/17/business/ford-promises-fleets-of-driverless-cars-within-five-years.html>
- Bradbury, D. (2016, June 21). Which wireless technology will control the connected cars of the future? Retrieved from <http://www.forbes.com/sites/huawei/2016/06/21/why-5g-leads-format-war-over-which-tech-will-control-autonomous-cars/>
- Brown, A., Gonder, J., & Repac, B. (2014). An analysis of possible energy impacts of automated vehicle. In G. Meyer & S. Beiker (Eds.), *Road vehicle automation* (pp. 137–153). Dordrecht: Springer.



- Buhayar, N., & Robison, P. (2015, July 30). Can the insurance industry survive driverless cars? Retrieved from <http://www.bloomberg.com/news/articles/2015-07-30/can-the-insurance-industry-survive-driverless-cars>
- Bureau of Labor Statistics. (2015, May). Delaware - May 2015 OES state occupational employment and wage estimates. Retrieved from [http://www.bls.gov/oes/current/oes\\_de.htm#53-0000](http://www.bls.gov/oes/current/oes_de.htm#53-0000)
- Cambridge Systematics. (2004). *Traffic congestion and reliability: Linking solutions to problems*. Washington, DC: Federal Highway Administration. Retrieved from [http://www.ops.fhwa.dot.gov/congestion\\_report\\_04/congestion\\_report.pdf](http://www.ops.fhwa.dot.gov/congestion_report_04/congestion_report.pdf)
- Cambridge Systematics. (2011). *Crashes vs congestion: What's the cost to society?* Washington, DC: American Automobile Association. Retrieved from [https://newsroom.aaa.com/wp-content/uploads/2011/11/2011\\_AAA\\_CrashvCongUpd.pdf](https://newsroom.aaa.com/wp-content/uploads/2011/11/2011_AAA_CrashvCongUpd.pdf)
- Chafkin, M. (2016, August 18). Uber debuts its first fleet of driverless cars in Pittsburgh. Retrieved from <http://www.bloomberg.com/news/features/2016-08-18/uber-s-first-self-driving-fleet-arrives-in-pittsburgh-this-month-is06r7on>
- City of Wilmington. (2014). *City of Wilmington traffic light signal violation monitoring system program report for fiscal year 2014*. Wilmington, DE: Wilmington Policy Department. Retrieved from [https://www.wilmingtonde.gov/docs/2476/CoW\\_Red\\_Light\\_Annual\\_Report\\_FY2014.pdf](https://www.wilmingtonde.gov/docs/2476/CoW_Red_Light_Annual_Report_FY2014.pdf)
- City of Wilmington. (2015). *City of Wilmington traffic light signal violation monitoring system program report for fiscal year 2015*. Wilmington, DE: Wilmington Policy Department. Retrieved from <http://www.ci.wilmington.de.us/home/showdocument?id=488>
- Clark, L. (2016, September 20). Watch hackers take over a Tesla's brakes from 12 miles away. Retrieved from <http://www.wired.co.uk/article/tesla-remotely-hacked-by-chinese-collective-keen>
- Cohan, J. (2016). *Electronic red light safety program: Program report for CY 2015*. Dover, DE: Delaware Department of Transportation. Retrieved from [http://www.deldot.gov/information/red\\_light/pdfs/after\\_analyses\\_summary2015.pdf](http://www.deldot.gov/information/red_light/pdfs/after_analyses_summary2015.pdf)
- Davies, A. (2015, January 7). I rode 500 miles in a self-driving car and saw the future: It's delightfully dull. Retrieved from <https://www.wired.com/2015/01/rode-500-miles-self-driving-car-saw-future-boring/>
- Davies, A. (2015, April 3). This is big: A robo-car just drove across the country. Retrieved from <https://www.wired.com/2015/04/delphi-autonomous-car-cross-country/>
- Davies, A. (2015, November 10). Ford's plan for making self-driving cars sounds a whole lot like Google's. Retrieved from <https://www.wired.com/2015/11/ford-self-driving-car-plan-google/>
- Davis, B., Dutzik, T., & Baxandall, P. (2012). *Transportation and the new generation: Young people are driving less and what it means for transportation policy*. Santa Barbara, CA: Frontier Group. Retrieved from [http://www.uspirg.org/sites/pirg/files/reports/Transportation%20%26%20the%20New%20Generation%20vUS\\_0.pdf](http://www.uspirg.org/sites/pirg/files/reports/Transportation%20%26%20the%20New%20Generation%20vUS_0.pdf)
- Delaware Center for Transportation. (2013). *Delaware transportation infrastructure forum problem identification statements*. Newark, DE: Delaware Center for Transportation. Retrieved from <http://sites.udel.edu/dct/files/2014/03/Forum-Results-2lgylej.pdf>



- Delaware Department of Transportation. (2013). *Annual report and transportation facts*. Dover, DE: Delaware Department of Transportation. Retrieved from [https://www.deldot.gov/information/pubs\\_forms/fact\\_book/pdf/2013/2013\\_deldot\\_fact\\_book.pdf](https://www.deldot.gov/information/pubs_forms/fact_book/pdf/2013/2013_deldot_fact_book.pdf)
- Desouza, K., Swindell, D., Smith, K. L., Sutherland, A., Fedorschak, K., & Coronel. (2015). *Local government 2035: Strategic trends and implications of new technologies* (Issues in Technology Innovation). Washington, DC: Brookings. Retrieved from <http://www.brookings.edu/~media/research/files/papers/2015/05/29-local-government-strategic-trends-desouza/desouza.pdf>
- Ecarma, J. (2015, January 23). Feds Adding Automatic Braking Systems to Car Safety Guidelines. *Auto World News*. Retrieved from <http://www.autoworldnews.com/articles/12414/20150123/feds-adding-automatic-braking-systems-to-car-safety-guidelines.htm>
- Fagnant, D. J., & Kockelman, K. (2015). Preparing a nation for autonomous vehicles: Opportunities, barriers and policy recommendations. *Transportation Research Part A: Policy and Practice*, 77, 167–181.
- Fagnant, D. J., & Kockelman, K. M. (2014). The travel and environmental implications of shared autonomous vehicles, using agent-based model scenarios. *Transportation Research Part C: Emerging Technologies*, 40, 1–13. <https://doi.org/10.1016/j.trc.2013.12.001>
- Fox, S. (2016). Planning for density in a driverless world. *Northeastern University Law Journal*, Forthcoming. <https://doi.org/10.2139/ssrn.2735148>
- Freemark, Y. (2015, June 23). Will autonomous cars change the role and value of public transportation? Retrieved from <http://www.thetransportpolitic.com/2015/06/23/will-autonomous-cars-change-the-role-and-value-of-public-transportation/>
- Gelles, D., Tabuchi, H., & Dolan, M. (2015, September 26). Complex car software becomes the weak spot under the hood. Retrieved from <http://www.nytimes.com/2015/09/27/business/complex-car-software-becomes-the-weak-spot-under-the-hood.html>
- Gilbert, B. (2015, September 11). Uber's CEO gave us a lot of clues about what the future looks like. Retrieved from <http://www.techinsider.io/ubers-future-is-driverless-cars-2015-9>
- Gill, V., Kirk, B., Godsmark, P., & Flemming, B. (2015). *Automated vehicles: The coming of the next disruptive technology*. Ottawa, ON: Conference Board of Canada. Retrieved from [http://www.cavcoe.com/articles/AV\\_rpt\\_2015-01.pdf](http://www.cavcoe.com/articles/AV_rpt_2015-01.pdf)
- Glancy, D. J. (2015). Autonomous and automated and connected cars--oh my!: First generation autonomous cars in the legal ecosystem. *Minnesota Journal of Law, Science & Technology*, 16(2), 619–691.
- Golson, J. (2016, April 27). Volvo autonomous car engineer calls Tesla's Autopilot a "wannabe." Retrieved from <http://www.theverge.com/2016/4/27/11518826/volvo-tesla-autopilot-autonomous-self-driving-car>
- Government Accountability Office. (2015). *Intelligent transportation systems: Vehicle-to-infrastructure technologies expected to offer benefits but deployment challenges exist* (No. GAO-15-775). Washington, DC: Government Accountability Office. Retrieved from <http://gao.gov/assets/680/672548.pdf>
- Greenblatt, J. B., & Saxena, S. (2015). Autonomous taxis could greatly reduce greenhouse-gas emissions of US light-duty vehicles. *Nature Climate Change*, 5(9), 860–863.
- Greenblatt, J. B., & Shaheen, S. (2015). Automated vehicles, on-demand mobility, and environmental impacts. *Current Sustainable/Renewable Energy Reports*, 2(3), 74–81.



- Hampshire, R., & Gaites, C. (2011). Peer-to-peer carsharing market analysis and potential growth. *Transportation Research Record*, 2217, 119–126.
- Harding, J., Powell, G., Yoon, R., Fikentscher, J., Doyle, C., Sade, D., ... Wang, J. (2014). *Vehicle-to-vehicle communications: Readiness of V2V technology for application*. Washington, DC: National Highway Traffic Safety Administration. Retrieved from <http://www.nhtsa.gov/staticfiles/rulemaking/pdf/V2V/Readiness-of-V2V-Technology-for-Application-812014.pdf>
- Highway Loss Data Institute. (2015). Crash avoidance technologies. Retrieved from <http://www.iihs.org/iihs/topics/t/crash-avoidance-technologies/hldi-research>
- Hyland, T. (2016). *Delaware's annual traffic statistical report*. Dover, DE: Delaware State Police. Retrieved from <http://dsp.delaware.gov/pdfs/2015%20Traffic%20Annual.pdf>
- IHS. (2016, June 7). Autonomous vehicle sales forecast to reach 21 mil. globally in 2035, according to IHS Automotive. Retrieved from <https://www.ihs.com/country-industry-forecasting.html?ID=10659115737>
- IHS Automotive. (2014, January 2). Emerging technologies: Autonomous cars-- not if, but when. Retrieved from <http://press.ihs.com/press-release/automotive/self-driving-cars-moving-industrys-drivers-seat>
- International Transport Forum. (2015). *Urban mobility system upgrade: How shared self-driving cars could change city traffic*. Paris, France: International Transport Forum. Retrieved from [http://www.itf-oecd.org/sites/default/files/docs/15cpb\\_self-drivingcars.pdf](http://www.itf-oecd.org/sites/default/files/docs/15cpb_self-drivingcars.pdf)
- Kelley Blue Book. (2015, May 1). New-Car Transaction Prices Rise Steadily, Up 2.6 Percent in April 2015. Retrieved from <http://mediaroom.kbb.com/2015-05-01-New-Car-Transaction-Prices-Rise-Steadily-Up-2-6-Percent-in-April-2015-According-to-Kelley-Blue-Book>
- Kessler, A. M. (2015, October 15). Tesla adds high-speed autonomous driving to its bag of tricks. *The New York Times*. Retrieved from <http://www.nytimes.com/2015/10/16/automobiles/tesla-adds-high-speed-autonomous-driving-to-its-bag-of-tricks.html>
- Kirkham, E. (2016, March 21). Most (and least) expensive states to own a car. Retrieved from <https://www.gobankingrates.com/car-loans/most-least-expensive-states-own-car/>
- Knox, T. (2016, July 14). Columbus will “leap-frog” light rail as transportation option after Smart City Challenge win. Retrieved from <http://www.bizjournals.com/columbus/news/2016/07/14/columbus-will-leap-frog-lightrail-as.html>
- Korosec, K. (2015, October 7). Volvo will accept all liability when its cars are in autonomous mode. Retrieved from <http://fortune.com/2015/10/07/volvo-liability-self-driving-cars/>
- Kurczewski, N. (2014, January 29). Autonomous drive expert believes cars will be better drivers than humans. Retrieved from <http://www.nydailynews.com/autos/buyers-guide/cars-safer-drivers-self-driving-vehicles-eliminate-traffic-accidents-article-1.1595616>
- Kyriakidis, M., Happee, R., & de Winter, J. C. F. (2015). *Public opinion on automated driving: Results of an international questionnaire among 5000 respondents*. *Transportation Research Part F: Traffic Psychology and Behaviour*, 32, 127–140.





- Lambert, L. (2012, March 26). More Americans move to cities in past decade-Census. *Reuters*. Retrieved from <http://www.reuters.com/article/2012/03/26/usa-cities-population-idUSL2E8EQ5AJ20120326#Z1guwVCUuGPM7swK.97>
- Lavasani, M., Jin, X., & Du, Y. (2016). Market penetration model for autonomous vehicles based on previous technology adoption experiences. Presented at the Transportation Research Board 95th Annual Meeting, Washington, DC. Retrieved from <http://docs.trb.org/prp/16-2284.pdf>
- Le Vine, S., Zolfaghari, A., & Polak, J. (2015). Autonomous cars: The tension between occupant experience and intersection capacity. *Transportation Research Part C: Emerging Technologies*, 52, 1–14.
- Lee, J., & Park, B. (2012). Development and evaluation of a cooperative vehicle intersection control algorithm under the connected vehicles environment. *IEEE Transactions on Intelligent Transportation Systems*, 13(1), 81–90. <https://doi.org/10.1109/TITS.2011.2178836>
- Litman, T. (2015). *Autonomous vehicle implementation predictions: Implications for transport planning*. Victoria, BC: Victoria Transport Policy Institute. Retrieved from <http://www.vtpi.org/avip.pdf>
- Madrigal, A. C. (2014, May 15). The trick that makes Google's self-driving cars work. *The Atlantic*. Retrieved from <http://www.theatlantic.com/technology/archive/2014/05/all-the-world-a-track-the-trick-that-makes-googles-self-driving-cars-work/370871/>
- Marinik, A., Bishop, R., Fitchett, V., Morgan, J. F., Trimble, T. E., & Blanco, M. (2014). *Human factors evaluation of level 2 and level 3 automated driving concepts: Concepts of operation* (No. DOT HS 812 044). Washington, DC: National Highway Traffic Safety Administration.
- Markey, E. (2015). *Tracking & hacking: Security & privacy gaps put American drivers at risk*. Washington, DC: United States Senate. Retrieved from [http://www.markey.senate.gov/imo/media/doc/2015-02-06\\_MarkeyReport-Tracking\\_Hacking\\_CarSecurity%202.pdf](http://www.markey.senate.gov/imo/media/doc/2015-02-06_MarkeyReport-Tracking_Hacking_CarSecurity%202.pdf)
- Markoff, J. (2016, July 4). Tesla and Google take different roads to self-driving car. Retrieved from <http://www.nytimes.com/2016/07/05/business/tesla-and-google-take-different-roads-to-self-driving-car.html>
- Mattow, W. R., Greenblatt, J. B., Sturges, A., Saxena, S., Gopal, A., Milstein, D., ... Gilmore, E. A. (2014). Key factors influencing autonomous vehicles' energy and environmental outcome. In G. Meyer & S. Beiker (Eds.), *Road vehicle automation* (pp. 127–135). Dordrecht: Springer.
- McDonald, R. (2016, April 20). Why driverless cars may make cities sprawl even more. Retrieved from <http://blog.nature.org/science/2016/04/20/why-driverless-cars-cities-sprawl-urban-suburban-development/>
- McFarland, M. (2015, November 25). What happens when cities and states try to prepare for self-driving cars? Retrieved from <https://www.washingtonpost.com/news/innovations/wp/2015/11/25/what-happens-when-cities-and-states-try-to-prepare-for-self-driving-cars/>
- McKinsey & Company. (2016). *Automotive revolution – perspective towards 2030: How the convergence of disruptive technology-driven trends could transform the auto industry* (Advanced Industries). Stuttgart, Germany: McKinsey & Co. Retrieved from [https://www.mckinsey.de/files/automotive\\_revolution\\_perspective\\_towards\\_2030.pdf](https://www.mckinsey.de/files/automotive_revolution_perspective_towards_2030.pdf)
- Mirisch, J. (2015, June 1). Taking wheel on transit. Retrieved July 25, 2016, from <http://www.labusinessjournal.com/news/2015/jun/01/taking-wheel-transit/>



- Morris, D. Z. (2014, November 2). Trains and self-driving cars, headed for a (political) collision. Retrieved from <http://fortune.com/2014/11/02/trains-autonomous-vehicles-politics/>
- Mosquet, X., Dauner, T., Lang, N., Rüßmann, M., Meipochtler, A., Agrawal, R., & Schmieg, F. (2015, April 21). Revolution in the driver's seat: The road to autonomous vehicles. Retrieved from <https://www.bcgperspectives.com/content/articles/automotive-consumer-insight-revolution-drivers-seat-road-autonomous-vehicles/>
- National Highway Traffic Safety Administration. (2012, August 28). Obama administration finalizes historic 54.5 mpg fuel efficiency standards. Retrieved from <http://www.nhtsa.gov/About+NHTSA/Press+Releases/2012/Obama+Administration+Finalizes+Historic+54.5+mpg+Fuel+Efficiency+Standards>
- National Highway Traffic Safety Administration. (2013). *Preliminary statement of policy concerning automated vehicles*. Washington, DC: National Highway Traffic Safety Administration. Retrieved from [http://orfe.princeton.edu/~alaink/SmartDrivingCars/Automated\\_Vehicles\\_Policy.pdf](http://orfe.princeton.edu/~alaink/SmartDrivingCars/Automated_Vehicles_Policy.pdf)
- National Highway Traffic Safety Administration. (2016). *Federal automated vehicles policy: Accelerating the next revolution in roadway safety*. Washington, DC: National Highway Traffic Safety Administration. Retrieved from <https://www.transportation.gov/sites/dot.gov/files/docs/AV%20policy%20guidance%20PDF.pdf>
- Naughton, K. (2015, September 10). GM to Introduce Hands-Free Driving in Cadillac Model. *Bloomberg Business*. Retrieved from <http://www.bloomberg.com/news/articles/2014-09-07/gm-to-introduce-hands-free-driving-in-cadillac-model>
- O'Toole, R. (2010). *Gridlock: Why we're stuck in traffic and what to do about it*. Washington, DC: Cato Institute.
- Pianta, M., & Vivarelli, M. (Eds.). (2003). *The employment impact of innovation: Evidence and policy*. New York, NY: Routledge.
- PricewaterhouseCoopers. (2015). Potential impacts of automated driver assistance systems (ADAS) and autonomous car technologies on the insurance industry. *Top Issues: An Annual Report*, 7, 1–5.
- Rosenthal, E. (2013, June 29). The end of car culture. Retrieved from [http://www.nytimes.com/2013/06/30/sunday-review/the-end-of-car-culture.html?\\_r=1](http://www.nytimes.com/2013/06/30/sunday-review/the-end-of-car-culture.html?_r=1)
- Rulsi, E. M. (2014, June 6). Uber CEO Travis Kalanick: We're doubling revenue every six months. Retrieved from <http://blogs.wsj.com/digits/2014/06/06/uber-ceo-travis-kalanick-were-doubling-revenue-every-six-months/>
- Sakaria, N., & Stehfest, N. (2013). *Millennials & mobility: Understanding the millennial mindset and new opportunities for transit providers*. Washington, DC: Transportation Research Board. Retrieved from [http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp\\_w61.pdf](http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_w61.pdf)
- Shaheen, S., & Cohen, A. (2013). *Innovative mobility carsharing outlook: Carsharing market overview, analysis, and trends*. Berkeley, CA: Transportation Sustainability Research Center. Retrieved from [http://tsrc.berkeley.edu/sites/default/files/Innovative%20Mobility%20Industry%20Outlook\\_Carsharing\\_Spring%202013%20FINAL\\_0.pdf](http://tsrc.berkeley.edu/sites/default/files/Innovative%20Mobility%20Industry%20Outlook_Carsharing_Spring%202013%20FINAL_0.pdf)
- Shladover, S., Su, D., & Lu, X.-Y. (2012). Impacts of cooperative adaptive cruise control on freeway traffic flow. *Transportation Research Record*, 2324, 63–70.
- Silberg, G., & Wallace, R. (2012). *Self-driving cars: The next revolution*. Amstelveen, Netherlands: KPMG. Retrieved from <http://www.kpmg.com/Ca/en/IssuesAndInsights/ArticlesPublications/Documents/self-driving-cars-next-revolution.pdf>



- Sivak, M. (2013). *Has motorization in the U.S. peaked?* (No. UMTRI-2013-17) (p. 13). Ann Arbor, MI. Retrieved from <http://deepblue.lib.umich.edu/bitstream/handle/2027.42/98098/102947.pdf>
- Sivak, M. (2015). *Has motorization in the U.S. peaked? part 7: Update through 2013*. The University of Michigan, Transportation Research Institute. Retrieved from <http://deepblue.lib.umich.edu/bitstream/handle/2027.42/110979/103186.pdf?sequence=1&isAllowed=y>
- Sivak, M., & Schoettle, B. (2015). *Road safety with self-driving vehicles: General limitations and road sharing with conventional vehicles* (No. UMTRI-2015-2). Ann Arbor, MI: The University of Michigan, Transportation Research Institute. Retrieved from <http://deepblue.lib.umich.edu/bitstream/handle/2027.42/111735/103187.pdf?sequence=1&isAllowed=y>
- Skinner, R., & Bidwell, N. (2016). *Making better places: Autonomous vehicles and future opportunities*. London, UK: WSP | Parsons Brinckerhoff. Retrieved from <http://www.wsp-pb.com/Globaln/UK/WSPPB-Farrells-AV-whitepaper.pdf>
- Society of Automotive Engineers. (2014). *Automated driving: Levels of driving automation are defined in new SAE international standard J3016* (Press Release). Troy, MI: Society of Automotive Engineers.
- Solon, O. (2016, June 17). Self-driving trucks: what's the future for America's 3.5 million truckers? *The Guardian*. Retrieved from <https://www.theguardian.com/technology/2016/jun/17/self-driving-trucks-impact-on-drivers-jobs-us>
- Tachet, R., Santi, P., Sobolevsky, S., Reyes-Castro, L. I., Frazzoli, E., Helbing, D., & Ratti, C. (2016). Revisiting street intersections using slot-based systems. *PLoS ONE*, 11(3), 1–9.
- Tannert, C. (2014, January 31). Will you ever be able to afford a self-driving car? Retrieved from <http://www.fastcompany.com/3025722/will-you-ever-be-able-to-afford-a-self-driving-car>
- The Economist. (2015, July 1). If autonomous vehicles rule the world: From horseless to driverless. Retrieved from <http://worldif.economist.com/article/12123/horseless-driverless>
- Tientrakool, P., Ho, Y.-C., & Maxemchuk, N. M. (2011). Highway capacity benefits from using vehicle-to-vehicle communication and sensors for collision avoidance. Presented at the IEEE Vehicular Technology Conference, San Francisco, CA: IEEE. <https://doi.org/10.1109/VETECONF.2011.6093130>
- Transportation Research Board. (2016). Cybersecurity implications of CV/AV technologies on state and local transportation agencies. Retrieved from <http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4254>
- Transportation Trust Fund Task Force. (2011). *Report on conditions, planning and revenue options for Support of the Transportation Trust Fund*. Dover, DE: Delaware Department of Transportation. Retrieved from [https://www.deldot.gov/information/pubs\\_forms/ttf\\_task\\_force/pdf/Final\\_Transportation\\_Trust\\_Fund\\_Task\\_Force\\_Report\\_033111.pdf](https://www.deldot.gov/information/pubs_forms/ttf_task_force/pdf/Final_Transportation_Trust_Fund_Task_Force_Report_033111.pdf)
- Vincent, J. (2016, April 18). Beverly Hills wants to upgrade its public transportation with self-driving cars. Retrieved from <http://www.theverge.com/2016/4/18/11449750/self-driving-cars-public-transport-beverly-hills>
- Wadud, Z., MacKenzie, D., & Leiby, P. (2016). Help or hindrance? The travel, energy and carbon impacts of highly automated vehicles. *Transportation Research Part A: Policy and Practice*, 86, 1–18.





- Whitaker, B. (2015, October 4). Hands off the wheel. Retrieved from <http://www.cbsnews.com/news/self-driving-cars-google-mercedes-benz-60-minutes/>
- Winterhoff, M., Mishoulam, D., Shirokinskiy, K., Chivukula, V., & Freitas, N. (2015). *Automotive 4.0: A disruption and new reality in the US?* Bloomfield Hills, MI: Roland Berger. Retrieved from [https://www.rolandberger.com/media/pdf/Roland\\_Berger\\_TAB\\_Automotive\\_4\\_0\\_20150224.pdf](https://www.rolandberger.com/media/pdf/Roland_Berger_TAB_Automotive_4_0_20150224.pdf)
- Youngs, J. (2012, February 24). Adaptive Cruise Control. *JD Power & Associates*. Retrieved from <http://www.jdpower.com/cars/articles/tips-advice/adaptive-cruise-control>
- Ziegler, C. (2015, February 23). Volvo will run a public test of self-driving cars with 100 real people in 2017. *The Verge*. Retrieved from <http://www.theverge.com/2015/2/23/8091455/volvo-drive-me-self-driving-car-test-2017>



**Institute for  
Public Administration**

## **Institute for Public Administration**

School of Public Policy & Administration

College of Arts & Sciences

University of Delaware

180 Graham Hall University of Delaware Newark, DE 19716-7380

phone: 302-831-8971 e-mail: [ipa@udel.edu](mailto:ipa@udel.edu) fax: 302-831-3488

[www.ipa.udel.edu](http://www.ipa.udel.edu)

*The University of Delaware's Institute for Public Administration (IPA) addresses the policy, planning, and management needs of its partners through the integration of applied research, professional development, and the education of tomorrow's leaders.*