Are we there Yet, and Where is it we need to go?

Myths and Realities of Connected and Automated Vehicles

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Executive Summary

Following the 2007 DARPA Urban Grand Challenge many companies quietly pursued the commercialization of automated vehicle technology. Then in 2013 a media fueled race and subsequent hype cycle began and culminated in 2018 with the first pedestrian fatality plunging the industry into a trough of disillusionment. During this same time multiple connected vehicle technologies have evolved, driven by both the public and private sectors. Furthermore alternatively fueled and shared vehicle technologies quickly expanded in the marketplace.

This rapid deployment of multiple disruptive technologies in very short period of time has created confusion for the industry, policy makers and the public about the true state of technology. Now a period of more sober assessment has emerged moving toward industry standards, public policies and even public adoption of early levels of connected and automated technology. With this early public adoption there is evidence of impacts on safety and mobility as well as further deployment.

Purpose

The purpose of is paper is to provide a history and current assessment of connected and automated vehicle (CAV) technology. In this paper, we will survey the state of changes and anticipated impacts for connected and automated roadway vehicles, focusing upon deployment in the United States and provide some policy recommendations for the future.

I. Introduction

Evolution of Connected and Automated Vehicles

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2007 DARPA Urban Grand Challenge Demonstrated Technology Feasibility

While connected and automated technologies have evolved over many decades, the Defense Advanced Research Projects Agency's (DARPA) Urban Grand Challenge in 2007 marked a major turning point in the visibility and commercial interest for CAV (Defense Advanced Research Projects Agency, 2019). In this competition, six automated vehicles successfully completed a course requiring driving in traffic and performing complex maneuvers such as merging, passing, parking and negotiating intersections. Figure 1 shows the Carnegie Mellon University Boss entry, which won the challenge. It is notable that all teams that successfully completed the challenge were US based teams and all teams were led by universities. Since 2007, a variety of private firms, universities and government agencies throughout the developed world have been pursuing further development and implementation of these capabilities.

Figure 1: Carnegie Mellon University Automated Vehicle Boss won the 2007 DARPA Urban Grand Challenge and demonstrated the capability of automated vehicles to drive successfully in traffic. Source: Photo by Chris Hendrickson

2013 The Race Begins: The Second Significant Turning Point

From 2007 through 2013 the CAV research and development in both the traditional automotive industry such as General Motors and comparatively new technology companies such as Google, later Waymo, was being pursued aggressively, independently and secretly (Burns, l., Shulgan., 2018).

Then in September 2013 Carnegie Mellon University hosted Pennsylvania Department of Transportation Secretary Barry Schoch and US House Transportation and Infrastructure Committee Chairman Bill Shuster for a CAV demonstration (Carnegie Mellon University 2013).

This 33-mile ride in a highly automated (level 4) CAV was open to the media and performed on public roadways at speeds up to 65 miles per hour, navigating connected signalized intersections and interacting with traffic.

Later in September 2013 Google released news of its vehicle fleet operating 500,000 miles crash-free with its "Chauffer" system. (Popular Science, 2013). Google's automated efforts in California were supported by legislation signed into law September 25, 2012 by Governor Jerry Brown. This California law followed similar automated vehicle driving laws first enacted in Nevada in February 2012 then Florida in April of that year. (Wired 2012) This began and era of states aggressively enacting legislation and executive orders to support the automated vehicle industry and address safety concern of the public. As of March 2019, 35 states have enacted automated vehicle legislation and/or executive orders. (NCSL 2019)

In September of 2016, US DOT Secretary Foxx announced the National Highway Traffic Safety Administration (NHTSA) first guidance on automated vehicle standards for manufacturers and policy guidance for states. (Detroit Free Press 2016). In the following administration, US DOT Secretary Chao announce updates to the NHSTA automated vehicle guidance in 2017 with AV 2.0 and in 2018 further updates with AV 3.0. These updates continued with the framework of vehicle performance, model state regulation and regulatory tools (NHTSA ADS 2018). Congress has considered various pieces of legislation regarding autonomous vehicles but none has passed to date.

There has been some limited local government initiatives to regulate AV activity in cities such as San Francisco, Pittsburgh and New York City, which impose guidance or permits, in addition to their respective states, for companies to test and deploy automated vehicles on city roadways. Restrictions may limit locations for operations, speed of vehicles and requirements for vehicle operators.

In 2013, numerous companies beyond Google, including Audi, GM, Ford, Nissan, Toyota, Tesla and Volvo, announced their automated vehicle programs and ambitions for commercial deployment. (PCMAG 2013) Much of this automated vehicle research was being developed by these companies for many years but not publicly announced until this time.

Year 2014 began an era of industry collaboration, partnership and acquisitions among traditional auto manufacturers and both established and start-up technology companies. Some examples including GM and Cruise, Ford, Volkswagen and Argo AI, and Delphi acquiring Ottomatika and spinning off into Aptiv.

To further test automated vehicles in a real-world environment, Uber began the world's first automated taxi service open to the public in September of 2016 in Pittsburgh which later expanded to Arizona (Wired 2016).

Following the Hype: 2018 The Third Significant Turning Point

It can be argued that 2013 began the hype cycle of automated vehicles with overly optimistic predictions and timelines for full automation, which ended in March 2018 with the tragic fatality of a pedestrian in Tempe Arizona from a crash with an automated Uber test vehicle.

Following the fatality in Arizona the pubic, government officials and companies have taken a more sober assessment of the current state of automated vehicle technology and more realistic predictions for deployment.

Diverse companies and non-profit organizations are also beginning to collaborate around public educational initiatives such as Partner for Autonomous Vehicle Education (PAVE). "Volkswagen, GM, Daimler and Toyota are all members of PAVE. Other partners include tech companies Waymo, Intel, NVIDIA and groups like SAE International, the National Federation of the Blind and the National Council on Aging" (Autoblog 2019).

Focus on Standards

Often, existing standards omit or are inadequate for the new CAV technology and applications. In 2016, the Society of Automotive Engineers (SAE) developed the industry standard J3016 that defines the six levels of automation. (SAE 2019) In 2019, Underwriter Laboratory and Edge Case Research began developing AV standard UL4600 that covers autonomous product safety. (EE Times 2019). Considerable work on new standards and regulations for all aspects of CAV can be expected in the next few decades.

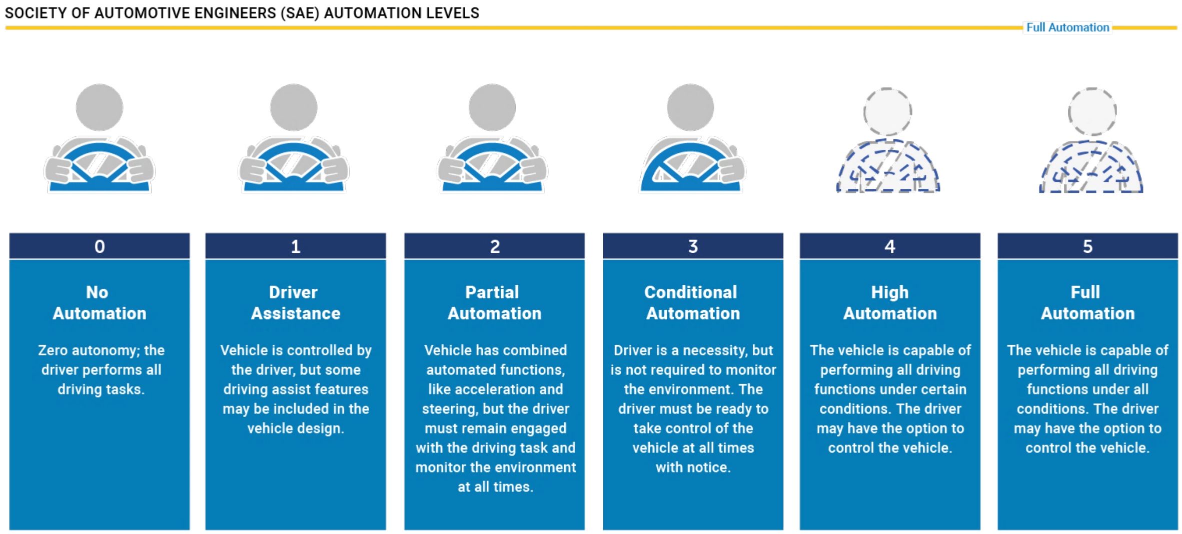
Do We Really Neel Level 5 Automation for Success?

Artificial intelligence is challenged in dealing with edge cases, for which cannot all be programed. We may face a reality that some human supervision of automated systems is required for the foreseeable future. Machines are very effective at completing repetitive tasks without distraction, and humans are superior to machines in applying common sense and past experience to and unforeseen situations. Moreover, Level 3 or 4 automation may be good enough for significant safety and efficiency gains. This is particularly so as the SAE definition of Level 5 is a vehicle that "can drive everywhere in all conditions" (SAE 2019), a standard which no machine or human may achieve independently but possibly together (see Figure 2). However, there will be continuing interest in Level 5 automation to reduce the cost of ride hailing services or freight movements.

Another concern about Level 5 automated vehicles is that they may create more congestion and emissions through vehicles miles travelled without any passengers on board.

In this short paper, the next section describes the current state and potential impacts of partial automation or 'co-pilot assistance.' Full automation, driverless vehicles are addressed next, followed by a discussion of connected vehicles. With regard to levels of automation (Figure 2), partial automation would be levels 1 to 3, while full automation would be levels 4 and 5 (NHTSA 2019).

There are examples of past disruptive technology that evolved with less human supervision over time. Our telecommunications systems began with a heavy reliance on human “operators” who played have played an evolving role for over a century and can still be accessed on our cell phones by dialing 611. Still today, any human passenger in automated elevator system can still hit a “call” button and connect with a human outside the system, but elevator operators were required in each unit for many years. Fully automated elevators were available in 1900 but it took 50 years for the public to become comfortable with phasing out operators. (NPR 2015)


SOCIETY OF AUTOMOTIVE ENGINEERS (SAE) AUTOMATION LEVELS

0	1	2	3	4	5
No Automation	**Driver Assistance**	**Partial Automation**	**Conditional Automation**	**High Automation**	**Full Automation**
Zero autonomy; the driver performs all driving tasks.	Vehicle is controlled by the driver, but some driving assist features may be included in the vehicle design.	Vehicle has combined automated functions, like acceleration and steering, but the driver must remain engaged with the driving task and monitor the environment at all times.	Driver is a necessity, but is not required to monitor the environment. The driver must be ready to take control of the vehicle at all times with notice.	The vehicle is capable of performing all driving functions under certain conditions. The driver may have the option to control the vehicle.	The vehicle is capable of performing all driving functions under all conditions. The driver may have the option to control the vehicle.

Figure 2: Levels of Vehicle Automation Originally Defined by the Society of Automotive Engineers (Source: NHTSA 2019).

## II.	Partially Automated Vehicles

Partially automated vehicles are now commercially available from virtually all vehicle manufacturers to assist drivers. These systems were first offered as options in high-end vehicles but are now appearing as standard features on all new vehicles.   In particular, the National Highway Traffic Safety Administration (NHTSA) requires all vehicles sold after 2018 to include rear view video displays (NHTSA 2014). Ten manufacturers have committed to make automatic emergency braking standard on all models (Consumer Reports 2019). However, these systems have varied names and come in different combinations from different manufacturers.

Partial automation systems include:

- forward collision prevention (such as adaptive cruise control, anti-lock braking, electronic stabilization, automatic emergency braking, adaptive headlights, obstacle detection, speed warnings)

- lane assisting (such as lane departure warning, lane keeping assist and blind spot monitoring)
- backing assistance (such as rear view cameras, backup warning, and rear cross traffic warning)
- driver monitoring and assistance systems (such as drowsiness alert, alcohol impairment detection, temperature and roadway condition warnings, safety exist assist, and parking assist)

Many of these systems only warn drivers of issues (which would be classified as level 1 automation in Figure 2). Other systems actively control some portion of driver responsibilities, such as adaptive cruise control controlling the gas pedal.

Driver monitoring can be accomplished with a variety of signals. Video of drivers can be used to assess attentiveness or drowsiness. Driving behavior such as lane keeping can also be used to monitor drivers. Driver impairment can be assessed with breathalyzer or video. Activities such as looking at external objects, reading, applying makeup or dialing or texting on a hand held device all increase the risk of vehicle crashes.

As an example of market penetration, Figure 3 shows the proportions of vehicle models with automatic emergency braking offered from 2006 to 2016. This partial automation feature was not offered commercially at all prior to model year 2008. By 2019, this feature was standard on roughly a quarter of all models and offered as an option on an additional third of all models.

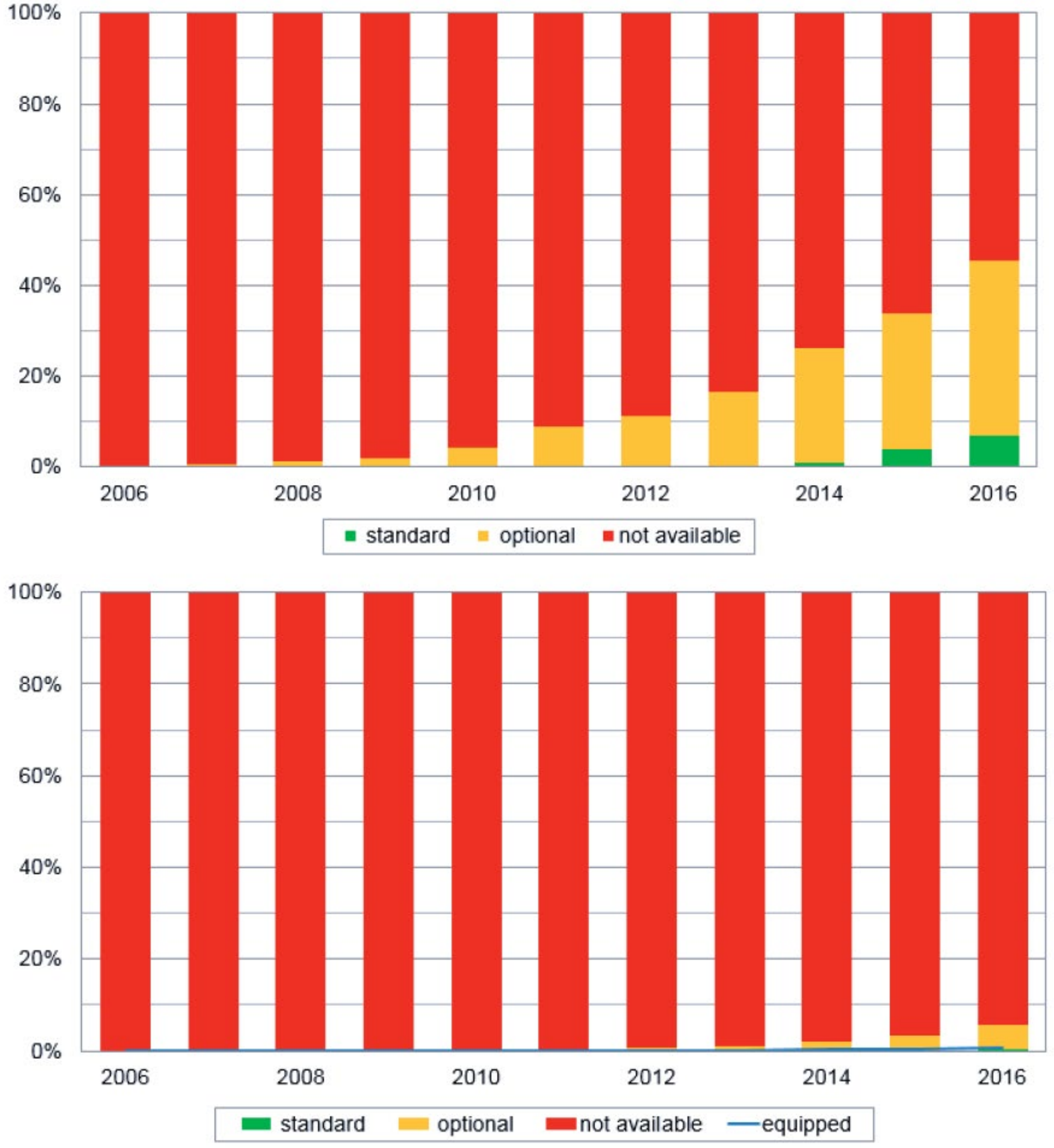


Figure 3 Share of new vehicles offering automatic emergency braking (top) and registered vehicles equipped with the feature (bottom). Source: NASEM 2018.

Newer partial automation systems are becoming available that are offered commercially as options on premium vehicles. Examples are enhanced night vision and obstacle identification systems. Enhanced night vision typically uses the infrared spectrum and can penetrate through fog. Obstacle identification is used to identify pedestrians or large animals. As with other driver assistance systems, these options should improve in capability and have cost reductions due to scale economies.

The cost of partial automation systems depends upon the amount of automation used, scale economies and manufacturing improvements. In 2015, Toyota offered blind spot, forward collision and lane departure warnings as a package of options for $ 600 (Harper 2016). Since then, these systems have become standard on Toyota vehicles. Partial automation systems can also increase the cost of vehicle repairs since the systems need re-calibration in case of damage.

While these partial automation systems can reduce the stress and fatigue of driving, their main impact will be on safety. Even with the first generation implementations, vehicles with driver warning systems had slightly less frequent and less severe crashes, even though the repairs for the warning systems tend to increase the cost of a crash (Harper, 2016, Khan 2019). Active collision avoidance braking and improved warning systems should be even more effective. The result will be fewer injuries and fatalities with partially automated vehicles. Khan et. al. (2019) estimated that the cost of equipping the entire US light duty fleet with three warning systems (forward collision warning, blind spot monitoring and lane departure warning) would cost roughly $ 16 billion annually, but result in social safety benefits of $ 37 billion annually and private safety benefits of $ 32 billion annually. The difference in social and private benefits consist of emergency responder and incident congestion costs. Thus, safety benefits are larger than the costs of the partial automation systems themselves even for simple warning systems.

Another benefit of partial automation systems is improved fuel efficiency. Based upon a large number of vehicle trips in Sweden, Volvo vehicles using adaptive cruise control (ACC) were found to have 5 to 7% lower fuel consumption than comparable trips without ACC (Zhu, 2019). Of course, ACC could be designed to be more or less fuel efficient depending upon the choice of acceleration rates, but fuel economy savings are possible relative to typical driver behaviors. A policy challenge is to encourage effective versions of such software.

While partial automation is available on new vehicles, the slow turnover of the vehicle fleet means that most vehicles will not have these technologies for a decade or more. The average age of vehicles in operation is 12 years (BTS 2019), so even the required rear view video would only be on roughly 50% of vehicles by 2028. Moreover, only rear view cameras are required, so many vehicles come with very limited driver assistance safety systems. Some systems can be retrofitted, but there is little evidence of such investment. Even though partial automation systems are commercially available, they will not be universal for many decades. As an example, Figure 4 shows the percentage of vehicles expected to have automatic emergency braking in the future. A 50% penetration of this feature is not expected until 2030.

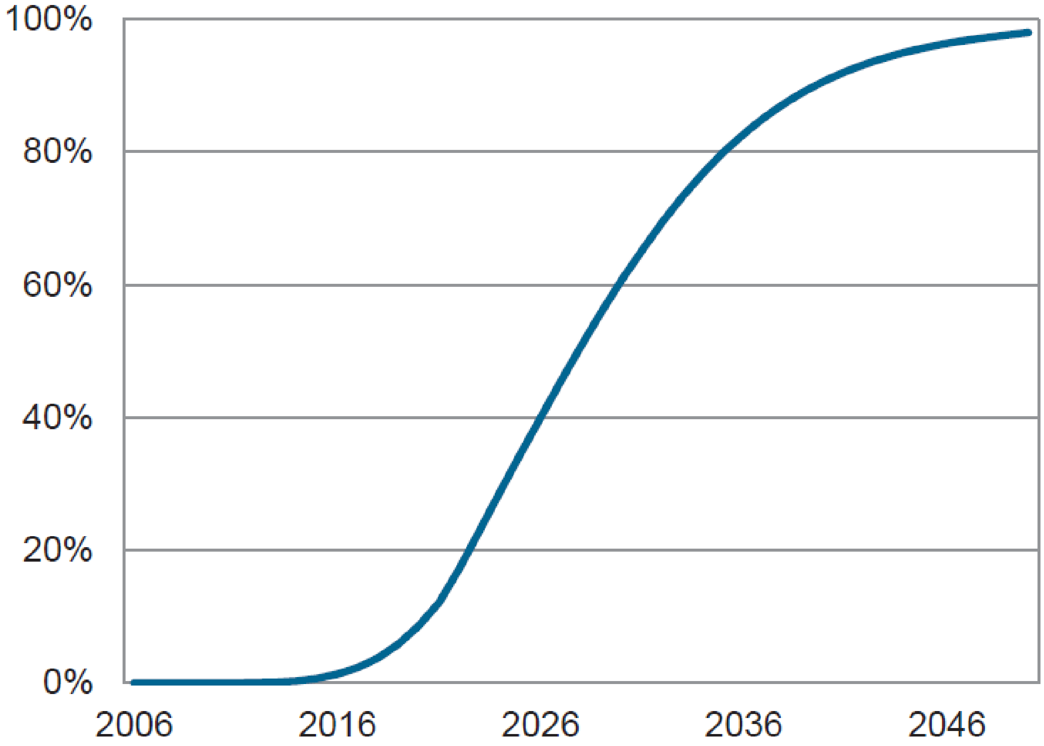


Figure 4 Estimated fraction of the registered vehicle fleet with automatic emergency braking (Source: NASEM 2018).

A likely scenario for partial automation is continued increasing penetration into the vehicle fleet. Required systems such as rear view video will increase the most rapidly. It is also possible that vehicles equipped with levels 4 and 5 of full automation may be manually driven with partial automation assistance. As a result, partial automation systems will be in use for many decades. It is also likely that vehicles without these driver assistance automation systems will be in use for many decades. For example, market acceptance of features such as drowsiness monitoring is unknown.

A number of policy and research issues still exist for partial automation systems. Some notable examples:

- How might widespread use of adaptive cruise control affect roadway traffic flow, energy use and air emissions?
- Should additional partial automation systems be required or result in lower insurance premiums?
- Will driver-warning systems increase problems of distracted driving?
- Will price reductions in partial automation systems continue as technology improves and more vehicles are equipped with the systems?

- How can the most effective versions of applications be identified and encouraged. Applications with variability include adaptive cruise control and lane following.

III. Highly Automated, Driverless Vehicles

Media and popular attention on CAV has tended to focus upon the prospects for widespread deployment of highly automated, driverless vehicles. The 2007 DARPA Urban Challenge described earlier demonstrated the feasibility of driverless vehicles in typical traffic. The commercial challenge is to make driverless vehicles robust and reliable under varied conditions and in mixed traffic.

Advances in computing and sensing technologies are crucial to achieving reliable driverless vehicle operations. Typical sensors would include:

- Radar to measure distance to obstacles mounted on the front, rear and sides of a vehicle.
- Video cameras for obstacle detection, lane marking and traffic sign identification mounted for 360-degree views.
- Lidar (‘light detection and ranging’) uses a pulsating laser to provide more detailed detection of obstacles and roadway paths.
- Environmental sensors to identify temperature and precipitation.

In addition, in-vehicle sensors provide data on vehicle performance and situation, such as speed and direction. All of these sensors provide a huge amount of data on the vehicle and its surroundings.

Global Navigation Satellite Systems (GNSS) and stored roadway maps are a common feature for highly automated vehicles. These maps provide fine detail on lane geometry and operational rules such as stop signs. Updates are needed regularly to insure accuracy. Real time data on construction, maintenance or incidents can also be used.

Multiple levels of software are required for perception, planning and control. At the perception level, sensor data must be integrated with map information and a model of the vehicle surroundings created including identification of obstacles. Planning for vehicle actions involves both strategic decisions about routes as well as tactical issues of lane choice. Control of vehicle actions converts plans into specific outputs for vehicle functions such as throttle or turning.

Currently, driverless on-road vehicles are in limited use. Many localities prohibit on-road highly automated vehicles unless a human driver is overseeing the vehicle operations. In addition, many highly automated vehicles are limited to special conditions such as interstate highways or low speed applications. For example, Tesla’s autopilot can be used hands free in many circumstances but drivers are directed to regularly engage. Low speed driverless shuttles are being used in demonstration trials at a variety of campuses, airports and urban areas. A few demonstration trials of ride hailing (or transportation network companies) services are also appearing. Level 5 delivery robots are also being deployed.

Remote human supervision of highly automated vehicles is another business strategy. Companies such as Phantom Auto, Starsky Robotics and even Waymo have developed systems for automated vehicle remote control. (Mashable 2019) This system demonstrates the convergence on the automated vehicle technology, connected vehicle technology and human supervision with all three systems playing a critical role.

Commercial competition is keen among highly automated software system developers. Participants include software companies (such as Aurora, Argo AI and Waymo), traditional vehicle manufacturers (in various partnerships), transportation network companies (such as Uber), and systems suppliers (such as Continental and Intel).

There are also competing business visions for the introduction of driverless vehicles. One approach would constrain driverless vehicles to fleet operations. These fleet vehicles would be available to the public as shared vehicles or used directly by the fleet operators for tasks such as deliveries. Alternatively, driverless vehicles could be sold to private individuals in the same way that conventional vehicles are sold. These privately owned vehicles might also be used to provide transportation network company ride hailing services. Market forces and regulation will determine which vision will prevail.

Driverless vehicles could have profound impacts on transportation systems. Since a high fraction of vehicle crashes are caused by driver errors, driverless vehicles have the potential for significantly improving roadway safety if they are effective. NHTSA estimated that the total costs of vehicle crashes in the United States was $ 277 billion annually in 2010 (Blinkoe, 2015), so safe and effective highly automated vehicles would be quite valuable.

Reliability in mixed traffic and with varying conditions is a considerable challenge. For example, at 9:58 pm on Sunday, March 18, 2018, a highly automated vehicle using a system developed by Uber Technologies struck and killed a pedestrian walking a bicycle across a street in Tempe Arizona (NTSA, 2018). Sensors detected the pedestrian, but did not identify the obstacle as a pedestrian until seconds before the crash (Figure 5). Factory installed emergency braking was disabled for the automation software. The driver was not actively engaged in controlling the vehicle until a second before collision. The overall effect from the crash and the resulting publicity has been a slowdown in highly automated vehicle deployments and continuing system testing and improvement.

Figure 5 Fatal crash of a Pedestrian and a Highly Automated Vehicle. Left: Path of pedestrian (orange) and vehicle (green). Right: post-crash view of vehicle. Source (NTSA 2018)

A second area of concern for highly automated vehicles is their ability to maneuver in mixed traffic. For example, drivers and cyclists occasionally use hand signals to communicate with other drivers. Similarly, police use hand signals to direct traffic when needed. Identifying and interpreting such hand gestures is a major challenge. Eye contact between drivers is often used to determine if it is safe to proceed through an uncontrolled intersection. Figure 6 is a hand painted sign posted in Pittsburgh in 2016 to highlight a concern for highly automated vehicles in mixed traffic.

As automated technology improves and more experience is obtained, the reliability of highly automated vehicles should also improve. As of 2019, Waymo has logged over a million miles of autonomous driving with a software disengagement and manual driving takeover occurring only once in 11,000 miles of driving (Ohnsman, 2019). This disengagement rate for Waymo has improved by at least 50% in recent years.

Figure 6 Hand Painted Sign Highlighting a Concern for Highly Automated Vehicles in Mixed Traffic (Source: Chris Hendrickson)

While safety is a primary motivation for developing highly automated vehicles, other significant impacts are likely. Elderly and mobility-impaired travelers would have new options for safe travel. With a lower burden of driving, travel demand may be enhanced, especially for ride hailing services. As noted earlier, driverless vehicles could be programmed to reduce energy use and emissions compared to manual drivers. Urban form may also be affected, especially for required parking spaced.

Vehicle operations could also be affected. Traffic flow stability could be improved with good programming and speed harmonization, eliminating shock waves of abrupt speed shifts. Vehicle following gaps could be altered, improving effective lane capacity. Increases in bottleneck capacity might also be possible with automated driving for enhanced lane and speed control.

The impact on driver employment is also problematic. Some truck drivers may find their jobs changing to more of a supervisory and customer relations role. New jobs will be created for supervision and maintenance of automated vehicles.

A number of policy and research challenges exist for highly automated vehicles, including:

- How can driverless vehicles be made to become highly reliable in varying conditions?
- What programs are needed to aid replaced drivers?
- Which business model will prevail in different markets for highly automated vehicles?
- How can public transportation be improved with the option of fully automated vehicles available?
- What policies can encourage shared passenger use and discourage single or zero passenger trips?
- How can municipalities manage reductions in revenue from parking fees, and fines from vehicle code violations?

IV. Connected Vehicles

Connected vehicles have electronic communication links on onboard. As with automation technology, there are a variety of levels and types of such communications that are possible. Applications of connected vehicle technology as described below do not require any vehicle automation. When these systems identify a safety issue, they provide a warning to the driver of a vehicle through a visual, audible or haptic signal. These connected vehicle systems can also provide non-safety information to a driver to such as routing or speed control to improve vehicle efficiency. In addition, some autonomous vehicle systems require no connectivity to other vehicles or the infrastructure as was demonstrated in the DARPA Urban Grand Challenge. However, connected vehicle systems can be augmented by automation, particularly when a driver may be distracted or slow to react and automated systems can be augmented by connectivity when sensors are limited in situations such as “seeing around corners”.

Most vehicles have cellular communications capabilities on board in the form of smart phones. A variety of applications are in regular use to aid travelers. Traveler information applications can suggest the best routes to use. Telephone communication with emergency services enhances security and response to incidents. Real-time bus arrival enhances service for riders. Ride hailing companies use cellular communications to match trip demands to travel suppliers.

Cellular communications can also be used for accessing a vehicle’s on board diagnostic systems. The On Star Corporation (a subsidiary of General Motors) provides a common system for this purpose. Other commercial vendors use the OBD-II standardized digital communications port to access the on board diagnostics system. Preventive maintenance and emergency services can be improved with this information.

Cellular communications can also distract drivers as illustrated in Figure 3, so not all connectivity is beneficial all the time. At the same time, travelers can benefit from having the capability of communicating with family, friends and associates.

Smartphones can provide cellular and data services to travelers not using private vehicles such as bikers, transit users and pedestrians. A variety of applications are available. For example, many transit systems provide real time information on vehicle locations to inform transit users when vehicles will be available. Route planners are useful for all these modes. Weather forecast applications are widespread.

Geographic coverage of cellular services is high but not comprehensive. Different carriers vary in their geographic coverage, and some areas are not served by the most recent 4G networks. Cellular communication can also be subject to significant congestion effects. As a result, some trucking communication systems rely on more comprehensive, dedicated satellite communications.

Connectivity with the satellite based global positioning system (GPS) is also common in US vehicles. This allows every vehicle's location to be known. Coupled with roadway maps, travelers can track their progress. Applications can also use this information to track roadway information on congestion and link speeds.

Trucking connectivity and GPS stems can monitor vehicle positions, vehicle conditions and driver behavior to improve operations. For example, shippers can track their shipment progress in real time.

In contrast to vehicle automation features, the cellular connectivity and GPS use has not required the long period of fleet turnover to be accomplished. While built in cellular services occur in many vehicles, most communication is accomplished through private smartphones. By 2019, 96% of Americans had a cellphone of some type, with 81% having smartphones (Pew 2019). Smartphone use has grown from only 31% in 2011.

Using connectivity to inform vehicle operations requires greater reliability and less latency than provided by existing cellular networks. An example is connectivity for truck platooning (Figure 7). In this example, acceleration and deceleration are coordinated for the three-truck platoon. Cost savings are available in the form of aerodynamic efficiencies to reduce fuel costs and possibly in the use of driverless trucks. While numerous demonstrations have shown that truck platoon is technically feasible, pairing trucks and insuring braking reactions are consistent provide practical challenges for widespread adoption.

Figure 7 Three-Truck Platoon with Cooperative Adaptive Cruise Control on I-66 (Source: FHWA 2017).

In 1999, the Federal Communications Commission allocated the 5.9 Ghz spectrum for use for intelligent transportation systems (NASEM 2019). This spectrum would permit use of Dedicated Short Range Communications with low latency and good capacity for connectivity. In 2014, the National Highway Transportation Safety Administration (NHTSA 2014a) proposed a regulation that would require DSRC in all new vehicles. NHTSA concluded that the safety benefits of intersection movement and left turn assist alone would justify the use of the 5.9 Ghz spectrum and the cost of connectivity technology. However, NHTSA has not announced a decision about proceeding with this regulation at the time of this writing.

Effective vehicle-to-vehicle (V2V) and vehicle to other (V2X) connectivity could enhance safety and transportation operations. Collision possibilities with obstacles could be communicated, as is currently done with airplanes and ships. Merging operations could be smoother with V2V communications. In the extreme, intersections could be controlled with V2V agreements rather than with traffic signals or signs.

The combination of connectivity and partial automation should provide additional safety benefits. For example, Yue et. al. (2018) estimated that the combination could reduce light duty crash rates by 33% and truck crash rates by 41%. Thus, for rather modest investments, significant numbers of fatalities and social costs could be saved.

Connected Vehicle Evolution

At the encouragement of the Intelligent Transportation Society of America (ITSA), The Federal Communications Commission (FCC) designated 75 MHz of the 5.9 GHz spectrum in 1999 for DSRC applications of Intelligent Transportation Systems (ITS) to improve safety and decrease congestion, air pollution and energy use. (FCC 1999)

In 2012 the US DOT Intelligent Transportation Systems Joint Program Office (ITS-JPO) Connected Vehicle Research Program awarded the University of Michigan Transportation Research Institute Safety Pilot Model Deployment. The "Safety Pilot" was a three-year program to test connected vehicle DSRC applications with thousands of vehicles along with roadside device on the streets of Ann Arbor, Michigan. Safety Pilot data was used to inform NHTSA's January 12, 2017 Notice of Proposed Rulemaking to mandate newly manufactured light duty vehicles to be equipped with DSRC radios for vehicle-to-vehicle (V2V) communications. (NHTSA NPRM 2017)

Following the Safety Pilot, the ITS-JPO awarded Connected Vehicle Pilot deployments in 2016 to Wyoming, New York City and Tampa to further test real-world applications of vehicle to vehicle and vehicle to infrastructure technology. (ITS-JPO CVPDP 2019)

The aforementioned NHTSA V2V rulemaking was stalled when 5G cellular technology was presented as an alternative to DSRC. Some automakers such as Ford who were originally supportive of DSRC switched support to 5G along with companies such as Qualcomm. (All About Circuits 2019)

Connected and automated vehicle impacts

A variety of benefits can be obtained from the integration of connectivity and automation technology (NASEM 2018b). Vehicle to vehicle connectivity can provide:

- Cooperative collision warnings and hazard alerts such as roadway debris.
- Cooperative collision mitigation or avoidance with turning maneuvers and automatic braking.
- Cooperative adaptive cruise control with smoother, more stable traffic flow and platooning.
- Automated maneuver coordination for smoother merging or conflict resolution at intersections.
- Transit bus connection protection.

Vehicle to infrastructure connectivity can extend these benefits to include benefits such as improved traffic signal coordination, identification of bicyclists and pedestrians, detailed traffic flow information for trip planning, and emergency services.

A number of policy and research challenges exist for vehicle connectivity, including:

- Which technology will used for advanced connectivity?
- How can connectivity best aid traffic movements through signalized intersections, merges, work zones and roadway bottlenecks?
- What standards will be developed for connectivity and associated applications?
- What is the time frame for implementation of advanced connectivity in the vehicle fleet?

V. What Do We Do Now?

There continues to be a reluctance from the federal government to regulate or legislate "winners and losers" in both the connected and automated vehicle industries and states continue patchwork of legislation, regulation and guidance. Industry has begun to collaborate on standards and outreach for public acceptance. Cities like Pittsburgh and the AV testing industry have developed innovative models of voluntary compliance to navigate balance of enabling innovation and ensuring public safety.

The Pittsburgh Principles include (Pittsburgh 2019):

- Instituting transparent lines of communication between the City and partners testing autonomous vehicles, and annual reports on the implementation of AV policies
- Promoting automated driving systems that encourage high vehicle occupancy with lower or no emissions, and lower cost and equitable transportation options
- Engaging industry leaders and community stakeholders to collaboratively facilitate the further development and deployment of self-driving technology

The State of Pennsylvania created an Autonomous Vehicle Policy Task Force with participation from representatives of academia, industry, and many state agencies and community stakeholder groups. This resulted in an innovative approach to voluntary standards for AV testing on public roadways.

Furthermore the states of Michigan, Ohio and Pennsylvania have developed the Smart Belt Coalition as a multi-state connected and automated vehicle test bed to explore CAV technology and policy challenges and to collaborate on solutions for wide scale deployment.

The authors of this report were actively engaged in the policy examples cited above but acknowledge that municipalities, states and countries are dealing with CAV technology through many different approaches. These various initiatives enable innovation while protecting public safety. They expose citizens to benefits of new technology and begin to address the community concerns of privacy, security and equity. What is important is that communities embrace this new technology, learn from success and mistakes of other communities and begin to coordinate response and investments. If we look at the example of the deployment of the US automobile roadways at the turn of the century, it was decades until the federally designated interstate highways and their subsequent standards were adopted.

To navigate the disruptive and rapid CAV evolution, government, industry, academia and community organizations should continue to collaborate on standards, policies for safe testing and deployment and transparency and forthright communications with public.

Acknowledgements

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Date	**Selected CAV Milestone**
October 21, 1999	FCC Allocated 75 Megahertz of Spectrum for Intelligent Transportation Services
November 3, 2007	DARPA Urban Grand Challenge
August 31, 2011	USDOT Awards Safety Pilot Model Deployment in Michigan
September 25, 2012	California Enacts First Law for Automated Vehicles
September 4, 2013	CMU Takes Public Officials on 33 Mile Level 4 CAV Tour on Public Roads
September 18, 2013	Google Released News of Vehicle Fleet Operating 500,000 Miles with Its "Chauffer" System
April 7, 2014	NHTSA Final Rule on Requiring Backup Cameras
September 11, 2015	Ten Automakers Commit to Make Automatic Emergency Braking Standard
May 7, 2016	First Automated Vehicle Fatality with Tesla's Autopilot in Florida
September 1, 2016	USDOT Announces NHTSA's First Guidance on Automated Vehicles
September 14, 2016	Uber's First Autonomous Public Ride Haling Service Debuts in Pittsburgh
January 12, 2017	NHTSA Notice of Proposed Rulemaking to Mandate Vehicle-to-Vehicle (V2V) Communications for New Light Vehicles
June 26, 2017	USDOT ITS-JPO Awards Connected Vehicle Pilots in Florida, New York, and Wyoming
March 1, 2018	First Automated Pedestrian Fatality from an Uber Vehicle in Arizona
October 4, 2018	USDOT Automated Vehicles 3.0: Preparing for the Future of Transportation
March 1, 2019	35 States Enacted Automated Vehicle Legislation, Regulation or Guidance

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