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16. Abstract

Automated vehicles are an emerging technology with the potential to greatly change and disrupt the American transportation system, but may also have significant benefits. This study sought to understand how automated vehicles will change the transportation system, identify implications on state and local transportation providers, determine future research needs, and understand emerging policy issues.

To accomplish these ends, the research team performed an in-depth literature review. Following this review, the research team interviewed expert personnel from automated vehicle manufacturers, suppliers, and developers; and state and local transportation agency representatives. These interviews informed the research process and provided insight into the future needs of transportation providers in the face of automated vehicles.

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AUTOMATED VEHICLES:
POLICY IMPLICATIONS SCOPING STUDY

by

Jason Wagner
Trey Baker
Ginger Goodin
and
John Maddox

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Project Title: Policy Implications of Automated Vehicles on Texas Highways

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EXECUTIVE SUMMARY

Automated vehicles have the potential to alter and disrupt the transportation system and society in numerous ways, but may also have significant benefits. This innovative technology could save lives by reducing crashes and managing traffic congestion, and could potentially have many other profound effects. This technology could also have significant implications for state and local transportation agencies, which operate and manage much of the nation's transportation systems. The research team sought to understand automated vehicles, determine how automation could affect transportation providers, and identify knowledge gaps and future research needs.

To understand automated vehicles and their effects, the research team performed an extensive review of various literature sources. These sources include industry reports and presentations, academic studies and papers, media articles, and government documents. The review explores:

- A taxonomy for automated vehicles;
- The status of automated vehicle development;
- The technologies enabling automated vehicles;
- Current and emerging automated functions and features;
- State and federal government responses to automated vehicles; and
- Economic and societal implications, including costs, benefits, and unintended consequences

The research team then performed two series of interviews: the first series with expert personnel from automated vehicle manufacturers, suppliers, and developers (hereafter referred to collectively as OEMs), and the second series with public agency officials. The first series sought to understand:

- OEM perspectives on automated vehicle development,
- Their impacts on society, and
- If and how state and local transportation agencies will need to adapt infrastructure and organizational operations in anticipation of automated vehicles.

The second series asked state and local transportation agency employees to react to the issues raised in the first series of interviews and discuss how their agencies could become better prepared to meet the needs of a road network with automated vehicles.

This research process yielded a variety of findings on how automated vehicles could affect the transportation system, a few of which are as follows:

- Automated vehicle capabilities, limitations, and developmental path are rife with uncertainty.
- Regulating automated vehicle operation for testing and development is a necessary but delicate process.
- Developing regulations and standards requires careful coordination between governmental and private-sector organizations.
- The societal benefits of automated vehicles could be many but are not yet well established, much less quantified and proven.

- The comparatively slow pace of infrastructure development presents a potential barrier for connected and automated vehicle systems integration.
- Limited funding, including for new technology, presents a significant issue for state and local transportation organizations.

ABBREVIATIONS

ACC	Adaptive Cruise Control
CACC	Cooperative Adaptive Cruise Control
DMV	Department of Motor Vehicles
DOT	Department of Transportation
DSRC	Dedicated Short-Range Communications
ESC	Electronic Stability Control
GPS	Global Positioning System
HOV	High-Occupancy Vehicle lane
I2V	Infrastructure to Vehicle
ITS	Intelligent Transportation Systems
NHTSA	National Highway Traffic Safety Administration
OEM	Original Equipment Manufacturer
USDOT	United States Department of Transportation
V2X	Vehicle to Other/All
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle

1.0 INTRODUCTION

Automated vehicles have the potential to alter and disrupt the transportation system and society in numerous ways, but may also have significant benefits. This innovative technology could save lives by reducing crashes and managing traffic congestion, and could potentially have many other profound effects. This technology could also have significant implications for state and local transportation agencies, which operate and manage much of the nation's transportation systems. The research team sought to understand automated vehicles, determine how automation could affect transportation providers, and identify knowledge gaps and future research needs.

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- OEM perspectives on automated vehicle development,
- Their impacts on society, and
- If and how state and local transportation agencies will need to adapt infrastructure and organizational operations in anticipation of automated vehicles.

The second series asked state and local transportation agency employees to react to the issues raised in the first series of interviews and discuss how their agencies could become better prepared to meet the needs of a road network with automated vehicles.

Finally, the report discusses areas that could benefit from additional research to improve understanding of this transformative technology and its implications.

2.0 CLASSIFYING AUTOMATED VEHICLES

The emerging automated vehicle industry has many different technologies and functions, and there is significant variation in the complexity and maturity of automated systems. Making sense of this complexity requires classifying the technologies in a unified taxonomic language. To accomplish this, the research team makes use of the current National Highway Traffic Safety Administration (NHTSA) automated level definitions (NHTSA, 2013 a). Below is a brief description of each level. The definitions consist of five levels, with each level progressively increasing the sophistication and automated abilities of the vehicle.

2.1 Level Zero—No Automation

Level zero is precisely as it sounds: the vehicle is not automated. NHTSA describes the driver as "in complete and sole control of the primary vehicle controls (brake, steering, throttle, and motive power) at all times, and is solely responsible for monitoring the roadway and for safe operation of all vehicle controls" (NHTSA, 2013 a, p. 4). The vehicle may have the ability to monitor the environment but only for driver support, information, or convenience systems. For example, the vehicle may provide warnings about roadway hazards but does not intervene in the act of driving in any way. This level includes connected vehicle and other sensor-based warning technologies such as forward collision warning, lane departure warning, etc.

2.2 Level One—Function-Specific Automation

NHTSA defines level-one automation as function-specific automation. In this category, "one or more specific control functions are automated," but the driver still has "overall control" of the vehicle and is responsible for its safe operation (NHTSA, 2013 a, p. 4). NHTSA specifies that if multiple control systems are engaged, they operate independently. The definition states that the vehicle may "assist or augment the driver in operating of one of the primary controls—either steering or braking/throttle controls (but not both)," and further specifies that the driver must actively engage with either the steering wheel or the brakes and accelerator while operating the vehicle. In other words, the vehicle cannot be automated in a manner that allows the driver to remove his or her hands from the wheel and take his or her foot off the pedals simultaneously. Examples of level-one automated functions include cruise control, automatic braking, and lane keeping.

2.3 Level Two—Combined Function Automation

Level two, or combined function automation, enables the driver to physically disengage from multiple aspects of the driving task simultaneously. Two or more of the "primary control functions" work in automated unison to monitor the road and control the vehicle (NHTSA, 2013 a, p. 5). The driver maintains primary responsibility for safe operation road monitoring and must be available to take over control at any time without advance warning. An example of this level of automation is adaptive cruise control working in coordination with lane centering.

2.4 Level Three—Limited Self-Driving Automation

Level-three automation entails the vehicle controlling all "safety-critical functions under certain traffic or environmental conditions" (NHTSA, 2013 a, p. 5). The driver need not constantly monitor the roadway and can rely on the vehicle to monitor the road at a sufficient level that if the situation changes and the vehicle cannot operate safely, it can notify and relinquish control to the driver. The driver must be available to take control in these occasional circumstances, and the vehicle can safely provide sufficient transition time. For example, the vehicle would recognize an upcoming work zone that it could not navigate and would inform the driver that he or she needs to retake control with adequate advance warning.

2.5 Level Four—Full Self-Driving Automation

Level four, the least detailed of the levels, states that the "vehicle is designed to perform all safety-critical driving functions and monitor roadway conditions for an entire trip" (NHTSA, 2013 a, p. 5). The driver may need to provide directions for navigation but does not need to control the vehicle at any point. The vehicle could be unoccupied or occupied, and is solely responsible for safe operation.

3.0 THE STATUS OF AUTOMATED VEHICLES

Automated vehicles are rapidly developing, and low-level automated features already exist on some vehicles. Higher-level automated vehicle development and proliferation seem a surety, with the most pressing question rapidly shifting from "if" to "when." Foreknowledge of the likely developmental timeline could provide public agencies with the tools to make better-informed decisions. However, it should be noted that all estimates, even expert estimates, are subject to assumptions of readiness of key sensing and decision technologies, as well as assumptions on operational and policy issues.

3.1 Deployment Timeline

Automated vehicles may seem like science fiction, but industry members indicate that they will soon be a reality. The research team asked automated vehicle OEMs their perspective on when they foresaw automated vehicles becoming commercially available. Table 1 displays the forecasted timeline for automated vehicle development based on aggregated responses.

Table 1: Automated Vehicle Development Timeline.

NHTSA Automation Level		**Forecasted Range**
One	Function-Specific	Now
Two	Combined Function	Now to 3 years away
Three	Limited Self-Driving	3 to 10+ years away
Four	Full Self-Driving	7 to 12+ years away

While there are disagreements about whether the highest level will ever be deployed, low- and mid-level automated vehicles will soon be available (and some already are). It is clear that in the coming years, vehicles will gradually assume greater control of driving functions.

3.2 Technologies

A wide variety of enabling technologies are required to make a vehicle automated, many of which include sensors dedicated to perceiving and understanding the roadway environment. The sensors detect other vehicles, pedestrians (under some conditions), traffic signals and lane markings (as available), and vehicle position. The vehicle integrates the information from these sensors to create a digital environment the vehicle can understand. The following subsections describe the most commonly used technologies.

3.2.1 Radar

Radar is a long-standing and relatively mature technology that vehicle manufacturers use in a similar fashion to its original military roots: a vehicle emits a radio wave, which bounces off objects in the area and then returns to the vehicle's receiver. Based on the information received, the vehicle calculates the distance to the object and other information. Manufacturers often use radar to support adaptive cruise control or other automated systems. Radar alone, however, has difficulty identifying and classifying stopped or non-moving objects (stopped cars), and may create false positives for metallic or bulky objects (e.g., construction plates, expansion joints, bridge abutments, etc.).

3.2.2 Lidar

Lidar (a portmanteau of the words *light* and *radar*) functions similarly to radar but can provide better, more detailed imaging. A lidar system emits a laser, which bounces off objects in the area and then returns to the vehicle's receiver. The vehicle uses the information to assess the distance to objects, as well as obtain other data.

Many OEMs are exploring the application of lidar for automated vehicles. A notable use of lidar is in the much-publicized "Google Car," which features a prominently placed spinning lidar system on top of various test vehicles (Guizzo, 2011). Google's lidar system spins at 900 RPM, which generates a 360-degree view around the car. Lidar, while powerful, is also quite expensive. According to Google, the cost for the lidar system in 2012 was $70,000, well beyond the reach of most consumers.

3.2.3 DSRC

Dedicated short-range communication (DSRC) is a technology that facilitates the wireless, low-latency transmission of information over a limited geographic area. While not an exclusively automated vehicle technology, DSRC enables vehicles to communicate information to other vehicles (V2V), the roadside infrastructure (V2I), and other receivers (V2X). When applied to automated vehicle purposes, DSRC could act as an additional sensor, enabling positive identification of other road users or objects, as well as function in non-line-of-sight scenarios to reduce crashes and relieve congestion by enabling vehicles to travel at reduced headways and higher speeds, while communicating about potential road hazards ahead (RITA, 2012; Guo, 2006).

3.2.4 Computer Imaging

In computer imaging, a camera captures images of the world and feeds the images into a computer program. The program analyzes the images for things it is programmed to understand, such as a traffic signal. Once the camera finds a traffic signal, the computer tells the vehicle how to respond to the signal (stopping at a traffic light when it is red, for example).

3.2.5 GPS

Global positioning systems (GPS) triangulate a vehicle's location by using satellites transmitting radio signals. At a very basic level, a GPS receiver on a vehicle receives radio signals from multiple satellites. The receiver triangulates vehicle position by assessing the amount of time it took to relay the signal between the satellites. Automated vehicles use GPS as a tool to aid in navigation. The vehicle knows roughly where it is (within about 3 meters) and combines this information with road maps to enable navigation.

3.2.6 Ultrasonic Sensors

Some vehicle systems make use of ultrasonic sensors as a means to perceive the world around them. The sensors function similarly to radar, in that they emit a high-frequency sound wave that bounces off objects and returns to the receiver. The vehicle uses these signals to determine the distance to an object (Brown Computer Science, n.d.; Ford Motor Company, 2012 a). These sensors operate at far shorter distances than radar.

3.3 Functions and Features

The technologies involved in automation enable vehicles to perceive and understand the external world, and act to control the vehicle. The vehicles use the perceptive capabilities to enable automated functions and features that can reduce crashes and ease the driving task. The following subsections describe selected automated functions and features, including those currently available and still under development.

3.3.1 Anti-lock Brakes

Anti-lock brakes are often referred to as the first automation feature. An electronic control unit monitors the speed of each wheel, and in the event of decreased wheel rotation, the unit reduces pressure on the associated brake pad. If one wheel is rotating faster than the other three, the control unit increases pressure on the wheel's brake pad or drum. The system increases and decreases pressure multiple times per second to prevent wheel lock.

3.3.2 Electronic Stability Control

Electronic stability control (ESC) aids the driver in controlling the stability of the vehicle during a skid. The vehicle detects a skid with a specialized sensor (often a form of accelerometer) and then applies braking power to one or more of the vehicle's brakes. ESC uses complex algorithms to make computer-controlled adjustments to the vehicle during an over-steer or under-steer event (NHTSA, 2006).

3.3.3 Adaptive Cruise Control

Adaptive cruise control (ACC) allows a vehicle to adjust its speed to vehicle(s) ahead, up to a pre-set speed while in a lane. The vehicle uses onboard sensors to monitor the vehicles ahead and automatically adjusts the closing distance through throttling and braking. Sensors could include radar, lidar, cameras, and others. ACC system functionality depends on the model; some systems only work at low speeds, while newer systems function at highway speeds (J.D. Power and Associates, 2012; Ford Motor Company, 2012 b).

3.3.4 Cooperative Adaptive Cruise Control

Similar to ACC, cooperative adaptive cruise control (CACC) improves ACC by enabling vehicles to communicate with each other and the infrastructure through onboard DSRC (or other) sensors. The inter-vehicle and infrastructure communication—known as V2V and V2I, respectively—allows the vehicles to cooperate and reduce the spacing between vehicles. This could increase highway capacity, decrease congestion, and provide environmental benefits (Park et al. 2011).

3.3.5 Park Assist

Park assist reduces the difficulty of parallel parking by enabling the vehicle to nearly park itself. While the specifics vary across manufacturers, the vehicles use onboard sensors (radar, ultrasonic, or computer imaging) to detect the size of a parking spot and the distance from the vehicles and roadside infrastructure. The vehicle uses this information to guide itself safely into the parking space while the driver monitors.

3.3.6 Advanced Park Assist

Some other automated parking systems function entirely differently. These systems use infrastructure-based laser sensors and Wi-Fi. This sort of system allows a car to navigate itself into a parking garage, locate a parking spot, park itself, and then later return to the individual—all upon command from a smartphone. The driver does not need to be physically present in the vehicle. According to the manufacturer, this feature is not yet publically available and will not become available for approximately 10 years (Lavric, 2013).

3.3.7 Collision Prevention Systems

Several automotive manufacturers offer collision prevention systems as an option on their vehicles. These systems use sensors (radar, computer imaging, etc.) to detect when a collision is imminent, and will initially warn a driver (level zero) and take corrective actions to prevent the collision, usually through braking or steering (level one) (Mercedes-Benz, 2013).

These systems can prevent collisions longitudinally—as in a rear-end collision—or laterally—such as when a vehicle drifts out of a lane. Longitudinal collision prevention primes brakes in anticipation of a collision, warns the driver, and applies the brakes if corrective actions are not taken. This sort of braking is referred to as crash-imminent braking or dynamic brake support (BMW, 2013; NHTSA, 2010).

Lateral collision prevention systems warn the driver when the vehicle begins to wander out of its lane and into an occupied lane. Lane-departure warnings use a front-facing camera to monitor road markings. An in-car processor tracks the vehicle path and alerts the driver if the vehicle begins to wander out of its current lane. Depending on the manufacturer, the cue for drifting into another lane can be either audible or tactile.

Currently, OEMs do not offer a level-two collision prevention system that both steers and brakes simultaneously to avoid a collision, though this is currently being developed.

4.0 GOVERNMENTAL RESPONSES

Automated vehicles are likely to have dramatic effects on both the transportation system and life in general in the United States. As a result, governmental agencies of various sizes have already responded to the perceived changes in various manners. This section describes those responses, from state legislatures passing laws regarding vehicle testing and liability, to federal regulatory agencies drafting recommendations.

4.1 State Government Actions

Several states have already drafted and passed legislation aimed at regulating or overseeing automated vehicles. Many more are considering legislation. As frequently occurs with state-level legislation, much of the language and many of the ideas are similar across the various states. This section briefly reviews the enacted laws and their most significant aspects (Stanford Center for Internet and Society, 2013).

4.1.1 California

The California Legislature passed Senate Bill 1298, establishing rules surrounding “autonomous vehicles” (California Legislature, 2012). The legislation permits the operation of autonomous vehicles for testing on public roads if the driver is sitting in the driver’s seat and would be able to take over the vehicle in the event of an emergency. The law requires an autonomous vehicle without a driver to meet certain rules that the Department of Motor Vehicles (DMV) will develop by 2015. Notably, the law specifically states that if NHTSA promulgates conflicting regulations, NHTSA regulations would supersede California law.

4.1.2 District of Columbia

Washington, D.C.’s Autonomous Vehicle Act of 2012 directed the Washington, D.C., DMV to create an autonomous vehicle designation and develop “safe operating protocols” (Council of the District of Columbia, 2013). The legislation created definitions for autonomous vehicles and established rules for their operation. The rules hold that the vehicle must:

- Have a manual override,
- Have a driver in the driver’s seat ready to take over at any time, and
- Operate in compliance with all of Washington, D.C.’s other normal traffic laws and regulations.

The law also sets rules for vehicle conversions and limits OEM vehicle liability for any vehicle converted to autonomous driving purposes.

4.1.3 Florida

Florida’s autonomous vehicle legislation—passed in 2012—says that a “person who possesses a valid driver license may operate an autonomous vehicle in autonomous mode” (Florida House of Representatives, 2012). Similar to other states’ legislation, the law establishes that autonomous vehicles must:

- Comply with federal motor vehicle standards,
- Have a function that enables and disables the autonomous functions,

- Have some sort of indicator inside the vehicle that indicates when the vehicle is in autonomous mode, and
- Have a feature that alerts the operator if the technology fails.

The law limits liability for OEMs of converted vehicles, requires testing companies to carry insurance, and directs the Florida Department of Highway Safety and Motor Vehicles to advise the legislature on recommended regulatory actions.

4.1.4 Nevada

The State of Nevada passed Assembly Bill 511 in 2011 and then amended the legislation in 2013 in SB 313 (Nevada Legislature, 2011; Stanford Center for Internet and Society, 2013). Similar to that of other states, this legislation:

- Establishes definitions for autonomous vehicles,
- Directs the DMV to develop regulations over autonomous vehicles,
- Limits liability of OEMs of autonomous test vehicles, and
- States that "a person is not required to actively drive an autonomous vehicle" (Nevada Legislature, 2011, p. 2).

4.1.5 Michigan

The State of Michigan passed two bills, SB 169 and SB 663, in 2013. This legislation:

- Establishes definitions for automated vehicles;
- Allows for testing by OEMs, suppliers, and others by operation on public roads;
- Requires a qualified operator to be present; and
- Directs the Michigan Department of Transportation to report in three years.

Both laws limit liability for OEMs and suppliers.

4.2 Federal Actions

In the summer of 2013, NHTSA published formal recommendations for states regarding the testing of automated vehicles on public roads (NHTSA, 2013 a). The document provides:

- A review of NHTSA's research activities in relation to automated driving;
- Definitions of the various levels of automation (discussed previously); and
- "Recommended principles" for state consideration about "driverless vehicle operation, especially with respect to testing and licensing" (NHTSA, 2013 a, p. 2).

Especially noteworthy is the tentative and cautious tone set out in the document. NHTSA states that the recommendations are "provisional and subject to reconsideration and revision as appropriate," and any future regulation "must appropriately balance the need to ensure motor vehicle safety with the flexibility to innovate" (NHTSA, 2013 a, p. 10)

Automated vehicles are still a nascent and developing technology. At this point, NHTSA does not currently have a rule-making action to formally regulate automated vehicles but provides guidance in response to state attempts at passing regulations. The guidance does not cover level-zero or -one automated vehicles or any operation by private individuals. Instead, it provides guidance to states considering regulating companies engaged in "the licensing, testing, and operation of [level-two, -three, and -four] self-driving vehicles on public roads” (NHTSA, 2013 a, p. 10).

NHTSA emphasizes that the automated vehicle industry is in the development stages and recommends that states avoid over-regulating several areas for fear of stifling innovation. First, they recommend that states do not regulate vehicles’ technical performance. Second, NHTSA does not recommend that “states attempt to establish safety standards” (NHTSA, 2013 a, p. 12). Finally, the agency recommends that states should not authorize self-driving vehicles for any purposes other than testing. Somewhat contradictorily, the agency lays out guidance if states wish to go against these recommendations and regulate nonetheless.

The recommendations are explained in complete detail in the original document. The recommendations cover four main areas, several of which contain sub-recommendations:

1. Licensing drivers to operate self-driving vehicles for testing
    a. Ensuring the driver understands how to operate a self-driving vehicle
2. Regulating the testing of self-driving vehicles
    a. Ensuring on-road testing minimizes risks to other road users
    b. Limiting testing operations to conditions suitable for the capabilities of tested self-driving vehicles
    c. Establishing reporting requirements to monitor testing
3. Establishing basic principles for testing self-driving vehicles
    a. The transition process from self-driving mode to driver control is safe, simple, and timely
    b. Self-driving test vehicles should have the capability of detecting, recording, and informing the driver that the system of automated technologies has malfunctioned
    c. The installation and operation of any self-driving vehicle technologies does not disable any federally required safety features or systems
    d. Self-driving test vehicles record information about the status of the automated control technologies in the event of a crash or loss of vehicle control
4. Regulating the operation of self-driving vehicles for purposes other than testing (NHTSA, 2013 a, pp. 11-14).

The relatively detailed recommendations provide a strong template for states considering regulating automated vehicles.

5.0 ECONOMIC AND SOCIETAL EFFECTS

Automated vehicles could potentially have a profound impact on the everyday lives of Americans, in both mundane and novel ways. This chapter discusses some potential implications to society and—when possible—provides quantitative illustrative estimates for the associated economic impacts. The first three areas are those OEMs most frequently cited as benefits of automation (as discussed below). The fourth subsection aggregates the quantitative implications into a range of possible impact and market penetration scenarios, assessing the implications of crash and congestion reductions. The final subsection discusses how automated vehicles could accelerate dispersed urban developments and the potential implications.

As a caveat, this technology is still developing, and there is no way to definitively know if these effects will occur or their exact magnitude. This is for illustrative purposes only. Further research and additional evidence could provide additional insights, enabling a better understanding of these complex issues.

5.1 Safety

When imagining an automated vehicle saving lives, one's mind likely jumps to a fully automated vehicle carefully navigating crowded roads and shepherding passengers safely to their destination. While this is quite possible in the long-term, automated features are already saving lives and preventing crashes today. Features like electronic stability control, lane-departure warnings, and brake assist already work in the background of vehicles, silently protecting motorists. The automated vehicles of tomorrow will integrate and build upon the same features that already work to make roads safer. The same basic technology that warns a driver not to switch into an occupied lane will enable an automated vehicle to have continuous knowledge of its surrounding environment.

While the technologies are impressive, perhaps the largest safety advantage to an automated vehicle is its inhumanity. While humans are normally very adept at monitoring, processing, deciding, and controlling to perform the driving task, humans are occasionally poor drivers, despite their persistent and prevalent beliefs to the contrary (Allstate Insurance, 2011). They speed, drive while intoxicated or tired, and commonly send text messages or otherwise distract themselves from the road. In fact, 95 percent of the crashes today are at least partially attributable to human error (NHTSA, 2008). Presumably, an automated vehicle will never fail to check a blind spot or divide its attention between driving and checking emails. There will be no blind spots on a car that constantly devotes its attention to simultaneously monitoring the complete vehicle surroundings and determining the most expedient and safest path forward.

However, one should not assume that automated vehicles will be completely crash free. It is doubtful that automated vehicles can be programmed for every feasible roadway or pre-crash scenario, and the efficacy of machine learning and decision making does not yet match the human capability to decide and react to unexpected, even unknowable, scenarios. Additionally, like all machines, automated vehicles will have shortcomings, flaws, and even defects, which will cause some small number of system failures, including potential crash outcomes.

5.1.1 Quantitative Example

The economic impact of improved safety could be remarkably large. Most people in the United States depend on the automobile for their personal transportation needs. Unfortunately, the automobile and the human driver are inherently unsafe, and as a matter of necessity, society accepts a large number of fatal and injurious crashes as the cost of mobility. Saving a life results in a huge economic savings, so if automated vehicles could save a significant number of the lives lost on the roads each year, the impact would be very large.

A true economic analysis of this topic would require accounting for much unknown and making many assumptions, all of which is beyond the scope of this project. Instead, this report provides a basic sensitivity analysis, illustrating the impact automated vehicles would have if they reduced fatalities by a given amount, assuming current fatality levels.

In 2011, there were 32,367 fatalities from automobile crashes (NHTSA, 2013 b). The associated economic cost is staggering. The current U.S. Department of Transportation (USDOT) guidance on the value of a life is $9.1 million, resulting in a total cost for 2011 fatalities at $294 billion (Trottenberg, 2012). These costs are calculated using an aggregation of a variety of factors commonly used to value a life, like lost earnings, willingness to pay to avoid a fatality, and other factors.[1] Table 2 shows the results of automated vehicles reducing the fatalities by a given percentage.

Table 2: Range of Annual Cost Savings from Reduced Fatalities Nationally.[2]

Percent Reduction	Fatalities Eliminated	Economic Impact (Billions)
99	32,043	$292
95	30,748	$280
90	29,130	$265
70	22,656	$206
50	16,183	$147
30	9,710	$88
10	3,236	$29
5	1,618	$15
1	324	$2.9

Similarly, if automated vehicles reduce or eliminate fatal crashes, the benefit to Texas would be substantial. In 2011, 3,016 Texans died from automobile crashes. Table 3 illustrates the hypothetical economic impact of automated vehicles reducing fatal crashes by a given percentage.

[1] The USDOT determines the value of a statistical life by synthesizing previous attempts to value life, drawing on empirical estimates, practical adaptations, and social policies. These measures can include lost earnings, willingness to avoid fatalities, and other aspects. Please see the USDOT memoranda, "Guidance on Treatment of the Economic Value of a Statistical Life in U.S. Department of Transportation Analyses" for more information.

[2] Total savings calculated by multiplying the economic savings from eliminating a fatality by the number of total fatalities, and then multiplying by the given percentage of total fatalities reduced.

Table 3: Range of Annual Cost Savings from Reduced Fatalities in Texas.

Percent Reduction	Fatalities Eliminated	Economic Impact (Billions)
99	2,986	$27
95	2,865	$26
90	2,714	$24
70	2,111	$19
50	1,508	$14
30	904	$8.2
10	302	$2.7
5	151	$1.3
1	30	$0.3

Obviously, automated vehicles are insufficiently sophisticated and proliferated to have such an impact today. It is worth noting that automation at some level is currently available on many vehicles. Technologies like ESC currently reduce fatalities without the futuristic packaging of a fully automated vehicle. Automated vehicle technologies will likewise continue to mature and proliferate throughout society, gradually reducing crashes and fatalities in often-unseen ways. Over time, it is plausible that society could accrue benefits consistent with the higher-end estimates.

5.2 Convenience, Comfort, and Productivity

Navigating congested traffic is a stressful and time-consuming chore millions of Americans endure daily. Automated vehicles could take this tedious task and alleviate its monotony, freeing drivers to concentrate on other things. OEMs anticipate this will be the first area motorists notice automation making their lives easier. At lower levels of automation, the vehicle will still require the driver's partial attention. At higher levels, the motorist would very rarely—or never—need to attend to the vehicle.

As automation matures and motorists can attend less to the vehicle and more to their lives, commutes will become more productive. Instead of watching traffic, motorists could check email, eat, or accomplish other tasks. Increased convenience, comfort, and productivity are important benefits but are not considered societal benefits because the individual vehicle owner privately reaps the benefits. As a result, these benefits are not included in the benefit calculation.

5.3 Mobility

Automated vehicles could have a substantial impact on the level of congestion in many American cities. Generally, congestion occurs when the demand for a road exceeds the supply. In other words, more vehicles want to be on the road than the road can allow with human-driven vehicles. The literature anticipates that automated vehicles will more efficiently use the roads through precisely controlled braking, acceleration, and vehicle platoons, reducing the distance between vehicles (Smith, 2012). If automated vehicles decrease crashes, this could lead to a reduction in non-recurring congestion—the congestion caused by infrequent events like crashes. Automated vehicles may even be able to drive in narrower lanes, enabling departments of transportation (DOTs) to add lanes without building additional infrastructure. Currently, many of the design standards on roads are in place for motorists' safety. Automated vehicles could render shoulders obsolete, result in much narrower lanes, and affect other safety-related design standards.

These effects may largely depend on the availability of V2V and V2I communications, which are not yet a given. Automation could also improve mobility for handicapped or otherwise driving-impaired individuals, although this outcome is much less certain. Automated vehicles at all but the highest levels require a driver at the wheel who is capable of taking over in the event of system failure.

5.3.1 Quantitative Example

Many Americans sit in traffic every day, and there are tremendous associated costs. These costs occur when motorists spend more time, burn more fuel, and put more wear on their vehicles than they would in uncongested conditions. TTI's *Urban Mobility Report* estimates the annual amount and impact of U.S. congestion. For 2011, TTI estimated that the total cost of congestion was $121 billion (Schrank et al. 2012).

It is unclear how much automated vehicles would decrease congestion or how soon that relief would occur, especially since there will be a mix of automated and non-automated vehicles for many decades to come. While Table 4 and Table 5 display the potential economic impacts of reducing congestion up to 99 percent, the highest ranges of congestion reduction seem unlikely and even implausible. Additional research into the causes of congestion and automated vehicles' abilities to reduce these causes could provide more accurate estimates. Similar to the method used previously, Table 4 and Table 5 show the potential annual cost saving ranges from automation decreasing congestion nationwide and in Texas, respectively. These values represent the costs imposed on Americans from extra travel time and fuel costs by vehicles traveling at lower speeds.

Table 4: Range of Annual Cost Savings from Decreased Congestion Nationally.

Percent Reduction	Economic Impact (Billions)
99	$120
95	$115
90	$109
70	$85
50	$61
30	$36
10	$12
5	$6.1
1	$1.2

Concerning the data in Table 5, the total cost is the result of aggregating the cost of all 10 Texas cities covered in TTI's *Urban Mobility Report*. This includes 10 large and medium cities (nine of which are among the state's largest), approximately 8.5 million people, and 32 percent of Texas' total population.

Table 5: Range of Annual Cost Savings from Decreased Congestion in 10 Texas Cities.

Percent Reduction	Economic Impact (Billions)
99	$9.9
95	$9.6
90	$9.1
70	$7.7
50	$5.1
30	$3.0
10	$1.0
5	$0.5
1	$0.1

Just as automation could decrease congestion, there is also the possibility that it could *increase* congestion, especially in the short term and in the absence of V2X communication (Smith, 2012). This could occur under a few circumstances. The first would occur if automated vehicles maintain a recommended following distance of the "three-second rule" under all circumstances. Human drivers do not always maintain this recommended distance, and if automated vehicles do so, they could potentially increase congestion (Smith, 2012). It is plausible that automated vehicle manufacturers could require vehicles to maintain this distance as a precautionary or liability-decreasing measure, and a method to reassure early adopters of the vehicle's safety.

Another situation where automated vehicles could increase congestion is if they do not make use of communication technologies like DSRC, eliminating vehicles' ability to communicate with each other and the infrastructure about traffic conditions. This sort of communication technology could potentially allow vehicles to travel much closer and form platoons. Without such technology, automated vehicles would lack the requisite information.

A final condition where automated vehicles could increase congestion is if the cost of transportation drastically decreases and automated vehicles become inexpensive and widely distributed throughout society (Smith, 2012). Under this scenario, the cost of sending an autonomous vehicle onto the road by itself would be very low, and the road could plausibly fill with these vehicles. The severity of this scenario would be compounded if the vehicles were not equipped with V2X communication technology.

These scenarios seem less likely, although certainly plausible. Table 6 and Table 7 display a range of annual cost increases from automation increasing congestion nationwide and in Texas, respectively. The basis for these estimates comes from TTI's *Urban Mobility Report*, as discussed previously (Schrank et al. 2012). These tables have a lower overall range than the previous tables because it seems implausible that congestion would increase beyond 50 percent the base rate. The justification for this limit is based on rational economic choice: individual members of society would likely rearrange themselves or make different choices to reduce their costs from congestion (e.g., living closer to work, traveling on alternative modes or at alternative times, telecommuting, etc.) (So et al. 2001). Society would also likely take steps to aggressively manage congestion through road pricing or other methods, especially if social costs became overwhelming.

Table 6: Range of Annual Cost from Increased Congestion Nationally.

Percent Increase	Economic Impact (Billions)
50	$61
30	$36
10	$12
5	$6.1
1	$1.2

Table 7: Range of Annual Cost from Increased Congestion in 10 Texas Cities.

Percent Increase	Economic Impact (Billions)
50	$5.1
30	$3.0
10	$1.0
5	$0.5
1	$0.1

The juxtaposition of these and the preceding tables illustrates the importance of ensuring that automated vehicles do not worsen current congestion levels, but instead contribute to its alleviation. Figure 1 graphically illustrates the aggregated cost ranges for potential automated vehicle effects from changes in congestion and fatal crashes at the national level.

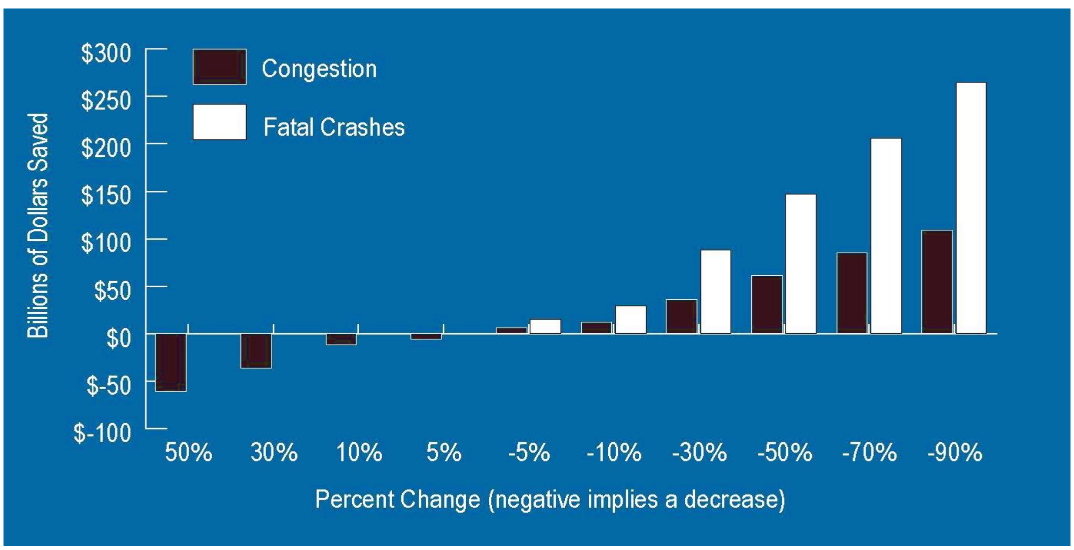

Figure 1: Range of National Economic Impacts from Changes in Congestion and Fatal Crashes.

5.4 Estimating the Economic Impact

If the early expectations are at all accurate, automated vehicles will have a very profound impact on society. However, accurately quantifying the economic effects presents serious challenges.

5.4.1 Methodological Challenges

A first difficulty is determining the automated vehicle's exact effects and their associated magnitudes. The popular media is rife with conjecture and speculation about the technology's abilities and impacts, but scant empirical and verifiable evidence is available. Will automated vehicles decrease fatal crashes and congestion as anticipated? Will automated vehicles have other unanticipated effects on society? If so, how large will the effects be? A projection must have some knowledge about the magnitude of the impact. Will automated vehicles decrease congestion and crashes by 10 percent, 50 percent, or even 100 percent?

Another question to answer is when the effects will occur. Will the automated vehicles available in 10 years decrease congestion and fatalities? Will society feel the effects gradually or suddenly? What level of market penetration is required before lives are saved and congestion reduced?

To quantify the economic impacts accurately, one must know (or be able to accurately estimate) the number of fatalities that would occur without any intervention. In other words, how many fatalities would have occurred without automated vehicles? Predicting the number of fatalities occurring next year is very difficult, without adding the complexity of estimating fatalities 10 or 20 years hence. Additionally, as discussed previously, automation is already reducing crashes in unseen ways. Any projection would have to take into account the effect of existing automation, resulting in confounding feedback loops when extrapolating the results into future cases.

Another vital component required to predict automated vehicle effects is the likelihood of a given outcome occurring, or *risk*. Is it 90 percent certain that automated vehicles will reduce congestion, or 50 percent? At this point, it is not possible to estimate the likelihood of these uncertain events occurring, making an accurate projection impossible.

One final layer of complexity is the likely existence of *unknown unknowns*. An unknown unknown is the existence of some factor that is so far removed from expectations that it cannot be accounted for in projections and calculations. For example, the most pressing issue at the first international conference of urban planners in 1898 in New York City was horse manure (Morris, 2007). Horses created so much manure in cities that one individual predicted that by 1930 the manure piles on Manhattan streets would be three floors deep. Obviously, these planners failed to account for the automobile, which eliminated manure issues. In the same way, it is a virtual certainty that a technology as transformative as automated vehicles will have effects that cannot be anticipated or accounted for in advance.

5.4.2 Economic Impact Model

Developing a model that accounts for these uncertainties and unknowns is far beyond the scope of this project. Instead, researchers developed illustrative models that look at a range of plausible automated vehicle impacts on congestion and fatality reduction, based on today's fatal crashes and congestion levels. The models assess impacts at both the national level and in Texas. The model aggregates the results from Table 2 through Table 7 for the appropriate categories, and weights them to simulate the market penetration throughout society. The high-, medium-, and low-impact categories pull from the 90 percent, 50 percent, and 10 percent figures from the crash and congestion impact tables. The market penetration factor weights these estimates by 90 percent, 50 percent, and 10 percent to simulate the level of penetration throughout society.

For example, the top left quadrant in **Error! Reference source not found.** (high market penetration and high impact) multiplies the economic impact of a 90 percent reduction in today's fatalities by 90 percent to simulate a high impact on 90 percent of society. It also includes the effect of a 90 percent congestion reduction for 90 percent of society. Figure 2 illustrates this process more concisely.

Table 8: Estimation of Automated Vehicle Economic Impacts on Congestion and Fatal Crash Reductions Nationally, by Impact and Market Penetration.

	High Penetration (Billions)	Medium Penetration (Billions)	Low Penetration (Billions)
High Impact	$337	$187	$37.4
Medium Impact	$293	$104	$20.7
Low Impact	$37.3	$21	$4.15

(Crash Reduction Impact × Market Penetration) + (Congestion Reduction Impact × Market Penetration)

Figure 2: Formula to Calculate Crash Reduction Impact and Congestion Reduction Impact by Market Penetration.

The same process is repeated for each quadrant to provide a range of outcomes, illustrating the effect of automated vehicles reducing fatal crashes and congestion by various levels for various percentages of society.

There is a large range in these estimates, from $337 billion if automated vehicles reduce congestion and fatalities by 90 percent for 90 percent of society, to a low of $4 billion if they reduce congestion and fatalities by 10 percent for 10 percent of society. The large benefit illustrates both the potential of automated vehicles and the magnitude of the deleterious effects that fatal crashes and congestion collectively levy on society. If automated vehicles reduced the impact of these societal maladies, the results could be very large.

Table 9 uses the same methodology but applies it to Texas' crash and congestion levels. The table illustrates that, similarly, the effects in Texas could be quite large. At the high end, Texas could save nearly $30 billion per year. At the low end, Texans could save $367 million—small in comparison but still certainly significant.

Table 9: Estimation of Automated Vehicle Economic Impacts on Congestion and Fatal Crash Reductions in Texas, by Impact and Market Penetration.

	High Penetration (Billions)	Medium Penetration (Billions)	Low Penetration (Billions)
High Impact	$29.72	$16.51	$3.30
Medium Impact	$16.51	$9.17	$1.83
Low Impact	$3.30	$1.83	$0.36

5.5 Urban Development Patterns

Finally, automated vehicles could also have unintended consequences that are neither a clear benefit nor cost; one such example is the facilitation of dispersed urban development. Automated vehicles could facilitate greater dispersed development by decreasing commute times, enabling more commuters to live further from the urban core. This could have large implications for the transportation system and transportation agencies.

5.5.1 Decreased Commute Times

Choosing where to live and work is a large decision. It is common to spend much of one's time at either work or home, so these decisions will inevitably have a large effect on quality of life. The economic literature says that when selecting housing and working locations, consumers make "trade-offs between wages, commuting time, and living costs" (So et al. 2001, p. 1036). In other words, a consumer can get more property far outside the city, but then must either accept lower wages in the rural area or make a lengthy commute to the city in exchange for higher wages. Consumers evaluate their options and select their preferred mix of housing, wages, and commuting time (Alonso, 1964; Mills, 1972; Muth, 1969).

Changes in these variables—through decreases in commute times, for example—will alter a consumer's choices and lead them to make different decisions. Empirical economic research finds that among these variables, commute times have the largest effect (So et al. 2001). In fact, a 10 percent reduction in commute times will increase the proportion of commuters by 17 percent.

Decreased commute times not only make consumers more willing to commute but also lead them to relocate outside the urban core. The economic literature finds that this result is substantial: every "10 percent reduction in commuting time raises nonmetropolitan population by 1.1 percent, while it reduces the metropolitan population by 1.9 percent" (So et al. 2001, p. 1045). These findings are consistent with the historical evidence from the U.S. highway system. Connecting rural and urban areas with highways decreased commute times, enabling individuals to earn large salaries in urban areas while commuting to rural areas where they live in larger and lower-cost homes.

Similarly, if automated vehicles decrease commute times, society may gradually rearrange itself, with more individuals choosing to take advantage of the amenities offered from living in nonmetropolitan areas. If accurate, the economic models can provide a glimpse at what might occur in the future. Using the current Houston metropolitan area as an example, if automated vehicles decrease commute times by 10 percent, 40,755 people would leave the city (U.S. Census Bureau, 2013).[3]

5.5.2 Potential Implications

The implications of increased dispersed development on state and local governments are extensive. The current amount of dispersed urban development would extend even further from the city center if automated vehicles make travel more efficient and motorists willingly increase their commute times. Vehicle miles traveled would increase, as would fuel consumption and emissions. DOTs and local transportation providers would need to build and maintain more roadway infrastructure in and around cities. Depending on how automated vehicles affect congestion, state and local governments might need to implement demand-based pricing to minimize the impact of decreased driving costs.

[3] The Houston population was 2.15 million as of July 2011.

It is important to emphasize that this is a possibility, although by no means a certainty. Further research into the topic could aid in better understanding the economic and psychological factors driving commuter preferences and decision making. Further research could also explore the impacts to urban planning, land use, economic impacts, and environmental impacts. This knowledge could aid in making decisions about long-term infrastructure investments and assigning priorities.

6.0 INTERVIEWS

The previous chapters describe the context of current developments in the automated vehicle industry. This material frames the discussion, and served as a starting point for the research team when performing interviews with public- and private-sector representatives. The material also provided the foundational information to develop interview questions and prepared the research team with the language to engage with the industry.

The interviews provided the opportunity to both identify research needs and facilitate knowledge transfer from the industry to the public sector. The research team gained the automated vehicle industry perspective and then took that information to the public sector to discuss implications and impacts. This entire process enabled TTI researchers to identify future needs and research areas.

6.1 Methodology

The research team conducted two sets of interviews. The first round consisted of members of the automated vehicle industry, including OEMs. The second round of interviews consisted of public-sector representatives, including members of state DOTs and DMVs, legislators, and local government representatives.

The research team developed the first-round interview questions after reviewing the results of the literature review. To formulate the second-round interview questions, the research team drew upon materials developed during the literature review and first-round interviews. This principally consisted of the research team identifying pertinent findings and determining which of these might have implications for the public sector, primarily in the transportation realm. For example, most industry representatives responded consistently that they felt a patchwork of state legislation would likely impede automated vehicle development. The research team used this information to formulate questions for transportation officials.

Interviews lasted approximately one hour. The research team did not disclose the interviewees' names or organizations. This was done for two reasons: first, to protect the interviewees and, second, to ensure they could freely provide their perspective. The private-sector interviews consisted of 11 questions, with associated follow-up questions. The research team interviewed 10 individuals from the automated vehicle industry.

6.2 OEM Interview Results

The appendix provides a complete list of the questions asked of the automated vehicle OEMs. The research team provided the questions to interviewees ahead of time, and included a list and description of the NHTSA automation levels (as discussed previously). The following subsections describe the results by question.

6.2.1 Timeline

The research team asked interviewees over what time frame they saw automated vehicles developing capabilities consistent with NHTSA automation levels two and three (see Table 1). Responses were relatively consistent for level two, but the variation increased dramatically for the higher levels of automation. As a note, the researchers specifically asked about levels two and three only, but some respondents spoke about level four as well.

Respondents often provided a rationale supporting their projections. Several said that when developing an automated vehicle, there is a tremendous technical distance between a 99.9 percent reliable vehicle and a 100 percent reliable vehicle. According to these respondents, bridging that gap will result in a significant increase in development time for the level-three to level-four vehicles.

Several other respondents felt that the technical issues were less of a barrier than the unresolved institutional issues. Liability, licensing, regulations, and inconsistent legislation all would play a role in slowing automated vehicle development and proliferation.

Two respondents took a more optimistic position about the development path. These respondents felt that they could develop and begin selling level-three vehicles within the next three years and level-four vehicles in 10 years or less. Both of these respondents moderated their answers somewhat: one said that cost would be a barrier for most consumers, and the other stated that while the high levels of automation would exist in this time frame, they might not function in all environments or road conditions.

6.2.2 Standardized Technologies

The research team asked respondents if they anticipated that all automated vehicles would eventually use a standard technology or technology set and, if so, which set would become dominant. This question received a range of responses, but most respondents fell somewhere between a clear yes and no.

Generally, respondents felt that the industry is in the early stages of developing the enabling sensory technologies. In the beginning of the process, there are many different technologies. As they progressively become more mature, OEMs will slowly converge to using some combination of the same technologies. One respondent emphasized that setting standards on the industry too early would stifle innovation and that it is impossible to standardize a technology that does not yet exist.

6.2.3 Role of V2X Communications in Automated Vehicle Deployment

The third question asked respondents what role they foresaw V2X playing in automated vehicle deployment. The majority of interviewees felt that V2X would play some role in automated vehicle development, but there were many different opinions about the exact nature of that role. A few respondents mentioned that V2X enables vehicles to “see around corners” and is especially beneficial in high-speed environments. Several respondents also mentioned the benefits of connectedness in relation to traffic management and especially vehicle platooning.

Those opposed cited a variety of barriers that limit DSRC (the V2X-enabling technology). Interviewees often mentioned privacy, security, and funding issues. The most frequently cited issue was the lack of availability. DSRC sensors are not currently mandated in vehicles and are not installed on the roadside infrastructure. One respondent also felt that DSRC was an obsolete technology and that better options exist for communications.

6.2.4 Roadway and Infrastructure Changes
The fourth question asked if the roadway infrastructure, digital infrastructure, maps, or other associated data would need to change to accommodate automated vehicles and, if so, how. The question also asked what changes to roadway infrastructure or DOT operations would facilitate automated vehicle development.

This question received a range of responses, with individuals often focusing on different aspects of the question. One of the most frequently raised sentiments was that additional services from the public sector might aid automated vehicle deployment, but respondents did not think the infrastructure could adapt rapidly enough to keep pace with automated vehicle developments.

Several respondents felt that well-maintained infrastructure is very important for the safe operation of automated vehicles, noting specific issues like pavement striping and roadside vegetation control. One respondent stated that dedicated lanes would make some aspects of automation easier.

Several respondents focused on the need for high-quality digital maps to aid automated vehicle navigation. One respondent mentioned that a sensory system that detected animals in the roadway would potentially be helpful to automated vehicles.

6.2.5 Managed Lanes
The fifth question asked about the plausibility of using managed lanes as an early implementation opportunity for automated vehicles. Interviewees were essentially split on the issue, with roughly half responding positively to the idea and half responding negatively. Some of those in favor of the idea raised the following points:

- It would encourage automated vehicle adoption by providing access to expedited lanes.
- It would encourage consumer acceptance of the technology.
- It would accelerate the availability of high-functioning automated systems.
- It would increase efficiency through vehicle platooning.

Those opposed mentioned the following points:

- Infrastructure changes are too slow to keep pace with automated vehicle developments, and waiting for dedicated lanes would mean society would not be making adequate use of the technology.
- There is a chicken and egg problem: companies will not build vehicles with the necessary V2X sensors unless there is existing demand, consumers will not buy them unless the infrastructure already existed, and governments will not build the infrastructure without equipped vehicles and sufficient funding.
- Using managed lanes for this purpose is, according to one respondent, “a waste of infrastructure.”

6.2.6 State Legislation and Regulations
The sixth question asked respondents what effect state legislation has on an OEM’s ability to test its vehicles. Generally, respondents felt that the state legislation passed thus far had little impact on OEMs’ actual operations. One OEM specifically discussed the laws in the three states with existing legislation and concluded that its organization does not “see any barriers in the

legislation that has been passed." Another respondent put it slightly differently, stating that as long as manufacturers keep a driver in the seat, "these laws pose minimal concerns to OEMs."

One issue OEMs raised was that they do not wish to see unqualified individuals or organizations testing unsafe vehicles, out of fear of the potential implications to the larger industry in the event of a crash. The fear was that a crash in an automated vehicle would grab headlines and create unwarranted safety concerns. The OEM felt that states licensing companies wishing to test automated vehicles would reduce the likelihood of this occurring.

One respondent had completely different views than the others. This interviewee felt that state laws and regulations are much too loose and that there is very little control over testing. This individual felt that states should tighten and clarify existing regulations. The individual pointed specifically to one state's legislation as being particularly problematic; the state had not sought adequate input from the automated vehicle industry or technically proficient, neutral third parties.

6.2.7 Role of Federal, State, and Local Governments

The seventh question asked respondents what role, if any, they felt federal, state, and local governments play in the automated vehicle development and deployment process. This question also received a wide variety of responses. The most frequently raised issues revolved around developing consistent standards, regulations, and definitions. Respondents generally felt that innovation would best flourish when the states do not pass "a tapestry of regulations" with substantial variations between states. Interviewees felt that standards and definitions should be set at a national or international level, and that the development of these should be done in close concert with relevant industry stakeholders. Some individuals expressed displeasure with the NHTSA definitions, saying they were too hastily released and received insufficient industry feedback.

Several interviewees mentioned that they would like to see federal regulations on testing and certification of automated vehicles. Another individual raised a conflicting point, stating that it might be technically impossible to develop a robust testing method for automated vehicles. Still another felt that states should license users but that the federal government should set regulations. Finally, one individual felt that there needed to be much better direct communication between the federal government and the industry, and that better information exchange would result in better policies.

6.2.8 Economic Benefits

The eighth question asked respondents how they would characterize the economic benefits of automated vehicles, with a specific focus on automation levels two and three. This question generated relatively consistent responses from interviewees. Three benefits arose most frequently:

- *Safety*—Many crashes are the result of human error, and shifting the driving burden from humans to vehicles will likely reduce crashes. At the lower automation levels, sensors will reduce low-speed, property damage crashes.
- *Convenience, comfort, and productivity*—Commuters sit in traffic for many hours every year. The earliest benefits of automated vehicles will be easing the stress associated with navigating traffic by allowing motorists to reduce the amount of attention paid to the road

and the traffic around them. As automation matures, motorists will have the option of freeing themselves of the mundane and stressful task of navigating traffic by allowing an automated vehicle to drive for them. More advanced systems will enable drivers to use this time more productively because they will no longer need to constantly monitor traffic.

- *Congestion reduction*—Automated vehicles may reduce congestion, especially at higher levels or in conjunction with connected technologies that enable platooning.

Interviewees also mentioned a few other noteworthy benefits. Automated vehicles may grant greater mobility to handicapped or other traditionally driving-impaired individuals. They may also reduce crashes from impaired driving (e.g., drugged or drunken).

6.2.9 Cybersecurity

The ninth question asked respondents what role they foresaw for federal, state, or local governments in addressing cybersecurity. The question also asked if respondents felt cybersecurity was a risk for automated vehicles. Respondents were evenly split on this issue, with half believing the federal government should take a lead role, and half feeling that cybersecurity is either not a concern or their organization was adequately prepared to effectively address it.

The respondents supporting federal government involvement frequently mentioned that the government should set cybersecurity standards and minimum requirements. Interviewees also mentioned connected vehicles, stating data transmissions will require authentication. Vehicles will also need firewalls and the assurance that unauthorized entities can never control the vehicle.

6.2.10 Vehicular Data Usage

The 10th question asked respondents what issues they saw arising with the use and ownership of vehicular and driver data generated by automated vehicles. This question garnered a wide variety of responses. Many of the respondents indicated that this issue is essentially a choice between two competing goals: safety and privacy. The most frequently given response said that companies would use data to:

- Improve automated vehicle system safety,
- Fine-tune technical aspects, and
- Determine liability in the event of a crash.

One respondent felt that OEMs need sensors monitoring drivers to ensure they are not impaired or asleep, and can take control of the vehicle.

On the opposite end of the safety/privacy spectrum, several respondents expressed concerns about the need to ensure an operator's privacy. One respondent emphasized that a potential user needs strong assurances that using an automated vehicle does not forfeit personal privacy. One individual felt strongly that the United States needs stronger federal regulations to safeguard privacy. One respondent stated that society needs to find "an appropriate balance of vehicular data and safety." The individual felt that the balance should come "through a national discussion and appropriate regulation," and that those rules must be both "robust and clear."

6.2.11 Product Liability

The 11th and final question asked respondents how liability affected their organization's approach to automated vehicles. This question received very consistent results: almost all respondents felt that liability was one of the largest issues facing the industry, and one felt that liability would likely "dictate how automated vehicle development proceeds."

Consumers are not very accepting of machine error, especially when that error leads to harm. As a result, automated vehicles must be perfect or very near perfect. The OEMs felt that producing a 99.9 percent reliable vehicle would be much easier than developing a 100 percent reliable vehicle. Due to the current liability, even if automated vehicles are much safer and reduce crashes compared to current levels, OEMs would be responsible for any crashes in their vehicles. This liability will slow the pace at which OEMs develop and sell their vehicles. One respondent even went so far as to say that the liability could keep high-level automated vehicles from ever reaching the market.

Several respondents would like to see the federal government pass legislation reforming or clarifying the current liability structure. One respondent suggested the idea of shifting liability off the industry, as occurred with the small aircraft industry in the 1990s. One respondent raised concerns about the liability associated with amateur individuals equipping vehicles with low-quality automated sensors and causing a crash as a result.

One individual did not feel that liability was a large issue and believed that the existing liability structures are sufficient. From this person's perspective, vehicles will gather data when or if a crash occurs. Those data would help to assign liability; if the crash were the company's fault, it would take responsibility.

6.3 Public-Sector Interview Results

The research team also interviewed public-sector representatives, including members of state DOTs and DMVs, legislators, and local government representatives. As with the private-sector interviews, the research team provided the questions to interviewees ahead of time, and included a list and description of the NHTSA automation levels. A complete listing of the questions asked of the public-sector representatives is included in the appendix. The following subsections describe the results of the interviews by discussion topic.

6.3.1 Concerns with Automated Vehicle Development

One of the first topics of discussion in the public-sector interviews was concerns the interviewees had with the way that automated vehicles have been developed and how they will eventually be incorporated onto the roadway.

The biggest and most frequently cited concern of interviewees was that of safety. The public-sector interviewees—and specifically representatives from state DOTs—felt that one of their principal charges was ensuring that roadways are safe. Consequently, their primary concern was making sure that automated vehicles are tested and introduced to the roadway in a safe manner.

One option an interviewee cited for addressing safety is the use of secure manufacturer's plates. A state with a strong automotive manufacturing presence places requirements on manufacturers to ensure the roadways are safe. These require automated vehicle developers and manufacturers to use sound engineering practices, meet certain guidelines, and have liability measures in place.

Entities applying for the plate have to accept liability for technology issues and show that the technology will operate. Other states could follow suit by authorizing the DMV, or similar entities, to license and regulate automated vehicle manufacturers and developers to ensure their vehicles being tested on public roads are sufficiently safe.

A second concern that interviewees cited was insufficient coordination between government entities and the automated vehicle industry they seek to license or regulate. One interviewee noted that much of the regulatory work occurs at the state level, but states are generally only responsible for the maintenance and operation of a portion of the total roadway network. This interviewee stated that local and regional entities lack detailed knowledge about automated vehicles and the issues surrounding their deployment. It was recommended that a greater level of coordination and information sharing between states that are undertaking automated-vehicle-related efforts and regional and local officials needs to occur.

Governmental interviewees also stated that they had concerns that inconsistency in state licensing and other regulatory efforts could potentially stifle innovation on the part of automated vehicle developers. Interviewees noted that states have the potential to significantly affect the industry itself and that any regulations passed should be focused on ensuring that automated vehicle technologies are tested in a safe manner. These respondents believe states should avoid any regulation of the technologies themselves or in any way prescribing preferred technology configurations.

A final concern expressed among interviewees that was particular to the governmental role in automated vehicle development was the lack of a business case for investment by the public sector in automated vehicle infrastructure. For example, many interviewees recognized that there may be a need for the placement of V2I communication technologies such as DSRC in order to maximize the potential benefits of automated vehicle technologies. However, outside of the potential safety benefits, a strong case has not been made for investing in V2I infrastructure. Interviewees noted that more research on the effect of automated vehicle applications on local and regional planning, commuting patterns, and congestion could help make this business case.

6.3.2 Benefits of Automated Vehicles

Interviewees were asked about what they saw as the most significant benefits to be gained from the development of automated vehicle technologies. The two most commonly cited were safety and efficiency. Interviewees recognized that there is a strong potential for automated vehicle applications to reduce the incidence of certain types of crashes and improve the overall safety of the highway network.

Interviewees also recognized that there is a strong potential for automated vehicles and the ITS that might support them to improve the efficiency of the highway system. One example of an efficiency-improving application stemming from automated vehicle development cited by interviewees was enhanced throughput through platooning. Interviewees also stated that automated vehicle applications could improve the management of intersections.

6.3.3 Steps Taken in Preparation for Automated Vehicles

Interviewees were asked if the entities they represent have taken any steps to prepare for the possible introduction of automated vehicle technologies in the coming years. Most of the actions that have been recently undertaken at the state level are in the realm of licensing and the development of regulations. Specifically, these actions have been oriented around the testing of vehicles on public roadways as opposed to actually regulating their introduction to the general vehicle fleet. One state entity that has been active in the licensing of OEMs for testing on public roadways noted that it has issued a safety packet that OEMs must complete and submit in order to be certified to test automated vehicles in that state. Companies completing that packet have to provide the state DMV with the specifications of the vehicles being tested and also must demonstrate to the state that the technologies work.

Some states are actually involved or considering whether to be involved in the incubation of automated technologies or the direct testing of automated vehicle systems. One interviewee noted that there are efforts in his state to reactivate a test bed for the evaluation of roadside equipment at intersections that might be beneficial to automated vehicle applications. Another is looking at using V2V communications for automation applications in commercial vehicle operations.

States that have not initiated any type of licensing or regulatory measures for the testing of automated vehicle applications are generally interested in examining what sort of institutional changes will eventually be required to facilitate testing and eventual deployment of automated vehicle applications. For example, it was noted that the definition of "operator," a term common to most state-level vehicular codes, would likely require significant alteration with the advent of automated vehicles. Another interviewee noted that his state's vehicular code has restrictions on what drivers can and cannot do while operating the vehicle. These restrictions would likely need to be reevaluated in order to maximize the benefit of automated driving capabilities for the driver, such as allowing cell phone use while the vehicle is operating in automated mode. Consequently, some states are looking at what aspects of their vehicle codes will eventually need to be changed.

States are also interested in research on how their operational practices may need to adapt to automated vehicle development. A consistent theme that several interviewees cited was lane markings and, specifically, to what extent automated technologies will need consistency in lane markings in order to operate. Some state entities are concerned that they will have to change the way they do striping to ensure that automated vehicles operate in a safe and reliable manner. Restriping roadways to accommodate automated vehicles could therefore be a significant undertaking from a funding standpoint, and states are interested in seeing more from private-sector automated vehicle component developers in terms of what their systems will require from an infrastructure standpoint. Several interviewees noted that their state would not be able to proceed with these sorts of evaluations until the state has a better idea of the technology components that automated vehicle systems will use. For example, one interviewee observed that a reliance on internal maps and onboard sensors for operation implies a different role for the public sector than systems that would rely on data feeds from roadside infrastructure.

Other areas of research that were of interest to interviewees that would help their state prepare for automated vehicle deployment include:

- Scenario planning and testing to better quantify the potential penetration of automated vehicle applications in the vehicle fleet,
- Examination of potential automated vehicle applications for commercial vehicle operations,

- Human factors research and specifically how the transition from human to automated control of the vehicle is to occur, and
- Assessment of the potential impact of automated vehicle technologies on car ownership patterns.

6.3.4 Safety Incentives

Interviewees were asked if their state has looked into implementing policies to encourage the use of automated vehicle technology for safety-related purposes. While most interviewees acknowledged that there are potential safety benefits from the development and deployment of automated vehicle systems, none had undertaken any actions to encourage the accelerated development of these systems. Many state entities already have safety-related programs, and automated vehicle technology should certainly be looked into as part of those programs. Most activities have been confined to simply talking to or otherwise meeting with other transportation entities or automated vehicle system developers in order to discuss how safety issues might be addressed. One state entity indicated that it is currently awaiting movement on the national front before considering such incentivizing policies. A representative from a regional entity stated that the agency would most likely advocate the use of these technologies due to their potential safety applications, but was unsure of whether the agency would enact any policies aimed at encouraging the technologies' adoption.

6.3.5 NHTSA Regulations

A brief description of the current NHTSA automated vehicle definition and regulations was forwarded as part of the interview packet. Interviewees were asked to provide their thoughts on the NHTSA regulations and to discuss their opinions on the need for consistency in such policies.

Interviewees acknowledged that there is disagreement on the adequacy of the current NHTSA standards with regard to vehicle automation. One noted that his or her state has a strong OEM presence and that these companies have been testing vehicle automation technologies for decades. This person feared that the current NHTSA standards might impede further progress in this field. Another interviewee echoed this sentiment, stating that he or she did not know if the current standards and definitions encourage innovation, but that they could be read as discouraging innovation. Another interviewee noted that these definitions should have been issued 10 years ago and that the federal government is already far behind the industry.

Most interviewees agreed that at the state level, the entities that need to be the most engaged in rule making are those that deal with the licensing of drivers. The entities responsible for these functions vary state to state. In some states, the DOT handles licensing, while in others a dedicated DMV or DPS handles the job.

6.3.6 Infrastructure Connectivity

A lingering question in the development of automated vehicle systems is the extent to which these technologies will rely on the use of V2I and infrastructure-to-vehicle (I2V) communications. Consequently, interviewees were asked about the opportunities and challenges for their respective entities in supporting such infrastructure.

The biggest issue raised regarding the potential need for connectivity infrastructure was cost. States are already having difficulty maintaining their existing ITS infrastructure. Even those that have mature and robust ITS infrastructure noted that the level of ITS development required to facilitate vehicle automation would be significant and that they were unsure of how to pay for it.

Many noted that the case for increased connectivity has not been adequately made to policy makers. The transportation community agrees that ITS infrastructure in and of itself, outside of any potential vehicle automation applications, is valuable from a safety and congestion management standpoint. However, this is not necessarily the opinion of policy makers, who need to be shown the benefits of these technologies. Related to this is the question of the business model for vehicle automation, which also has yet to be fully developed. It is difficult from a governmental standpoint to establish the business model for ITS investment with regard to vehicle automation when it is unclear what sort of data these vehicles will require.

An additional concern with regard to the placement of connectivity infrastructure was a lack of institutional knowledge, particularly among DOTs. Existing institutional knowledge in many DOTs on ITS and related activities is minimal, and one participant noted that the people already experienced in this field are getting older and leaving the industry. New ITS infrastructure for the facilitation of automated vehicle deployment would require new knowledge and experience in a field that is already, according to some interviewees, in decline. However, this was not necessarily a universal sentiment. State and regional entities with a strong tolling presence noted that they were positioned to be early adopters of the required technology components, given their experience with ITS systems and existing relationships with drivers. However, these interviewees also stated that securing the necessary funding in order to develop this infrastructure would likely be a significant barrier.

6.3.7 Cybersecurity

Cybersecurity is significant concern with most new technologies, even outside of the transportation sector. Consequently, interviewees were asked about their organizations' specific cybersecurity concerns and what they viewed is their role with regard to cybersecurity. Most interviewees stated that cybersecurity was a significant concern for their organization, particularly from a safety standpoint. These individuals stated that it would be paramount to ensure that signals transmitted between vehicles, or between vehicles and the infrastructure, could be trusted and that the system could not be hacked by outsiders.

Cybersecurity concerns were also expressed with regard to the aforementioned lack of institutional knowledge among local, regional, and state transportation officials. The certification and regulation of data transmitted between vehicles are areas where many transportation entities lack experience and expertise. Tolling authorities do have some experience with this, but the type of information that would be transmitted as part of automated vehicle operations is significantly different than that transmitted for tolling transactions. The allowable error is much lower for safety-related applications, which appear to be among the most attractive of automated vehicle applications from a governmental perspective.

6.3.8 Commuting

Interviewees were generally unsure, or even skeptical, of claims that vehicle automation technologies would affect commuting patterns. Many noted that the industry has not developed to a point where anyone can predict what automated vehicle operation would entail from the perspective of the driver, and that this would be a critical factor in determining how commuting patterns would change. Many stated other technology developments outside of vehicle automation, like maturing telecommuting technologies, could have a greater impact on travel and urban development patterns.

6.3.9 Managing the Transition

Interviewees were asked about how the transition to automated vehicle operation should be managed or regulated. Vehicle platooning was seen as one potential operational application that could eventually lead to greater adoption of automated vehicle technologies in the future. One interviewee noted that platooning had the potential to double the throughput of a single lane. However, another interviewee noted that the potential success of platooning applications would depend to a great extent on the determination of what constitutes a safe driving distance between vehicles operating in automated mode.

Most entities interviewed for this effort have not yet begun internal discussion about how they might manage the transition to automated vehicle operation. Much of this has to do with the fact that what will be required of drivers as part of automated vehicle operation is still unclear. There are already driver assistance applications in newer vehicles, but these applications still require the driver to be engaged in the task of driving.

Many interviewees were open to the idea of having dedicated lanes for automated vehicles or allowing such vehicles into limited-access facilities such as managed lanes. However, these individuals felt that the benefits of this segregation would be greatest in terms of testing the technologies and showing that they can operate safely. Most felt that it would be necessary, in the long term, for automated vehicles to be treated just like every other vehicle on the roadway.

6.3.10 Operations and Maintenance

Interviewees were asked to discuss how automated vehicle deployment might affect their agencies’ approach to asset management and the potential funding implications. Non-DOT entities (such as DMVs) deferred this question to their respective DOT, noting that asset management was outside of their purview.

Most of the DOT representatives interviewed for this effort noted that their state is already having difficulty maintaining and, in some cases, operating their state infrastructure due to funding shortfalls. The representatives noted that if vehicle automation technologies were to require a heightened level of maintenance, new funding sources would have to be mobilized or existing revenue sources would have to be increased. The question of who would bear these costs—the federal government or the states and local authorities—was raised repeatedly. Many state-level interviewees noted that they are already tapping into non-transportation-related revenue sources, such as general funds, in order to maintain and operate their existing infrastructure. They noted that it was unlikely they would be able to shoulder the cost of maintaining infrastructure at a higher level in order to facilitate automated vehicle development, particularly if these vehicles required additional technology infrastructure such as maintaining and operating V2I roadside equipment.

One interviewee recommended that cost-benefit analyses and comprehensive asset inventories would help states and local entities determine what sort of costs they could sustain for automated vehicle development. Some DOTs noted that they are already evaluating new methods of asset management that, while not directly related to encouraging automated vehicle development, would likely benefit the industry.

Similar to the industry experts interviewed, many of the public agency respondents expressed the same concerns about the slow pace of infrastructure development. One interviewee noted that while the Model T was originally developed in the 1910s, it was not until the 1950s that the highway system enabled motorists to take full advantage of the benefits that mass production of the automobile offered. This interviewee noted that the slow pace of infrastructure development implies a greater need for private-sector involvement because the private sector will be able to better adapt their in-vehicle components to the needs and expectations of drivers.

One interviewee recommended that a *Manual on Uniform Traffic Control Devices* specifically for automated vehicle systems would be beneficial in evaluating potential changes to asset management, in addition to ensuring consistency in automated vehicle development and state-to-state regulations.

Another interviewee stated that his or her office is trying to make its organization more flexible by allowing employees to use their professional judgment. Previously, the process for making decisions was entirely dictated by a lengthy manual, using decision trees to prescribe the exact action employees should take under nearly every situation. This manual eliminated the ability of employees to use their professional judgment. The agency is literally throwing out the manual and replacing it with guidelines for specifications that allow employees flexibility in decision making. The anecdote the individual cited was that it was very difficult for employees to shift the agency to using a better pavement product because of the previous decision process, despite the fact that the new product was a clear improvement. The new process granted employees the flexibility to discern what the agency values in the pavement product, and select a new product based on the agency's values, rather than forcing employees to simply follow a decision tree. This greater flexibility will allow the agency to become more nimble and respond to changing situations more readily than it had before.

7.0 FINDINGS

The interviews that the research team conducted for this research effort yielded several overall findings that could be useful to policy makers as they consider the development of automated vehicle systems and the implementation of connected vehicle infrastructure.

7.1 The Automated Vehicle Capabilities, Limitations, and Developmental Path Are Rife with Uncertainty

Uncertainty was a general and recurring theme in discussions with OEMs about the automated vehicle system development, deployment timeline, and operational capabilities and limitations. OEMs were not in agreement about when automated vehicles would become readily available and technologically mature, and none of the representatives interviewed for this effort were certain about what sort of standardized components (if any) will eventually attain dominance. Because the automated vehicle capabilities, limitations, and development path are uncertain, a large amount of uncertainty surrounds how automation will affect the transportation system, transportation agencies, and consumers generally.

Strategies for incorporating automated vehicle technologies into general-purpose traffic environments are being explored, but there is no unified or clear strategy. It is not clear whether automated vehicles will be incorporated into general traffic on a slow, gradual basis, or whether they will be deployed on a wide scale and immediately incorporated into general traffic. Low-level automated vehicles already operate on public roadways, and it seems possible that automation will slowly increase in maturity and sophistication, and will gradually continue to integrate with traffic on the roadways.

The question of how drivers will ultimately interact with the technology is also unclear. For example, it is not known how a driver's responsibility will evolve as a result of automation. Will certain activities, such as texting or driving while intoxicated, be allowed? If not, how can society enforce such laws when automation masks evidence of impairment or distraction? Such questions have significant implications for public policy because all states ban certain activities while driving.

Another uncertain interaction issue is how the transition between human and machine control occurs. There is not yet a consensus on how a vehicle hands off control to a human driver, or how a human driver cedes control to an automated vehicle. It is also unclear if there should be a minimum timing threshold and, if so, what that threshold should be.

A consequence of the uncertainty surrounding the future of automated vehicle system development is that it is unclear what sort of public investments in infrastructure will be required to accommodate automated vehicles. Will transportation agencies need to invest heavily in implementing, operating, and maintaining roadside communications technologies like DSRC for V2I communications? Are current pavement marking design and maintenance practices sufficient for the sensing equipment that automated vehicle systems may use? Public entities will need a much clearer idea of how automated technologies will function before making additional investments.

7.2 Societal Benefits of Automated Vehicle Deployment and Adoption Could Be Large but Are Not Well Established

Both the literature and interviewees felt that automated vehicles could provide substantial benefits to society. Improved highway safety from crash avoidance, enhanced system efficiency through increased vehicular throughput, and increased mobility for vulnerable populations are just some of the potential benefits.

It is clear there will be societal implications from automation, but more research is needed to understand and quantify these benefits. Once they are better understood, it would be possible to determine some potential effects on planning, congestion, commuting patterns, mobility, and the economy. In an era of fiscally constrained public institutions, there are increasing pressures to justify the expenditure of public dollars. Advanced technologies may easily generate a wow factor, but without a value proposition that quantitatively displays the societal benefit, public agencies will be unlikely to invest.

As an illustrative example, there is a significant amount of discussion regarding the automated vehicle's potential to reduce congestion, but it is unclear if that will occur. OEMs and governmental agencies have conflicting opinions, and early models are inconsistent. Both the literature and some interviewees fear that automated vehicles will operate with conservative vehicle headways, resulting in worsened congestion. Early indicators show that investments in connected vehicle applications could facilitate congestion reduction and improve safety, but the empirical evidence is scant, and the costs and benefits are not yet firmly established. Additional research will improve strategic decision making and facilitate better-informed investments.

The potential economic benefits of automated vehicle development, particularly with regard to crash reduction, are also not well established. It is difficult to make a case against the federal government mandating technologies in newer-model vehicles that could potentially save tens of thousands of lives annually. Such mandates would likely increase vehicle costs in the short term and represent a significant undertaking by the private sector. Any such decision requires a robust and comprehensive benefit-cost analysis.

Automated vehicle systems are also touted for their potential to improve mobility for populations that cannot operate a motor vehicle, such as the blind or the elderly. However, in order for these benefits to be realized, the technology must be extremely robust and reliable in a dynamic travel environment, which has not yet been demonstrated. If feasible, this would require highly automated, level-four vehicles—something that is not anticipated in the near or medium term.

7.3 Developing Regulations and Standards Requires Coordination between Governmental and Private-Sector Entities

Regulating an emerging technology is a tricky endeavor; getting it right will require coordination between the automated vehicle industry and governmental agencies. There are several key areas in which the industry and governmental actors have concerns.

The first is the basic concern surrounding what should be regulated and who should do it. According to industry interviewees and NHTSA, states seeking to regulate automated vehicles should limit their regulations to licensing and certifying OEMs in a testing environment, and should avoid regulations related to specific technologies. The industry does not wish to see governments bias or constrain innovation toward any particular technology configuration, particularly since automated systems are still far from mature. The industry wishes the optimal configuration to emerge from the market and not be directed by governmental regulations.

The private sector is also concerned that many different states will implement conflicting regulations, in effect creating a patchwork of state regulations. The industry worries that such a patchwork of regulations would make compliance difficult, severely limiting the manufacturer's ability to operate in multiple states.

Conversely, the public sector has its own motivations for developing these rules. Its primary concern is ensuring automated systems are tested in a safe and reliable manner and that, once deployed, these technologies continue to operate safely. States have an obligation to ensure the safety of their roads but perceive the automated vehicle technologies being tested on their roads without oversight as unsafe. Some states wish to regulate automated vehicle testing to ensure that OEMs practice good engineering, have sufficient insurance to cover the loss, provide reports on crashes or near crashes, and meet other safety-related requirements.

The private sector feels that it is already focused on developing a safe and reliable product, but the public sector believes that one of its primary mandates is highway safety. It is therefore impossible for the public sector to remove itself entirely from the issue of product safety. When regulations and certification requirements for automated vehicles are being developed, coordination between the government and the private sector will ensure that systems are developed with the maximum amount of flexibility by OEMs, while still assuaging the safety concerns of the public sector.

7.4 Regulating Automated Vehicle Testing and Development Is a Necessary but Delicate Process

OEMs are also concerned about smaller, unqualified developers testing automated vehicle systems on public roads. They fear that a highly publicized traffic collision by an unqualified developer, particularly a crash that results in harm to uninvolved motorists, would result in a strong negative reaction from the public and unjustifiably reduce public trust in automated vehicles. OEMs would like states to address this issue by licensing and certifying companies as qualified to safely test automated vehicle systems on public roadways.

While some regulations may be worth considering, states also must be careful to create an environment that does not unfairly bar small developers and manufacturers from entering the market. If the state, in seeking to ensure public safety, implements regulations that are too stringent, the effect could be codifying and institutionalizing a competitive advantage for established manufacturers. States must carefully balance the need for roadway safety with the need to ensure a competitive marketplace that allows automated vehicle innovation.

7.5 Limited Funding Is an Issue for Public Entities

A recurring theme among the governmental interviewees is that they currently lack the funding to make additional investments in infrastructure in preparation for automated vehicle deployment. State, regional, and local transportation budgets are already straining to meet maintenance needs, and agencies often cannot afford to expand their road network or invest in new technologies. Public-sector interviewees also noted that the business case for investments in automated vehicle-related infrastructure is not well established.

Transportation entities acknowledge that there are potentially large benefits from automated vehicle development, but without a stronger business case backed by empirical evidence of benefits, justifying additional investments is difficult while under stringent budgetary constraints. The public sector needs better, empirically derived information demonstrating how automation will affect highway safety, congestion, commuting, and development patterns in order to conduct robust benefit-cost analyses and justify additional investments.

7.6 The Slow Pace of Infrastructure Development Presents a Potential Barrier for Connected and Automated Vehicle Systems Integration

Several representatives from state and local transportation agencies were eager to determine how the transportation system needs to adapt for automated vehicles. They were interested in learning what the transportation system needs to do to facilitate automation. When considering the industry perspective, however, these feelings may be premature or even misplaced.

OEMs are currently designing their vehicles to function under the constraints of the existing roadway system. Several felt strongly that if they were to design vehicles that relied on infrastructure changes or specific actions by the public sector, their vehicles would never function. They noted that the infrastructure system is often very slow to change. Large infrastructure projects are, by necessity, a slow process. If automated vehicles depended on the infrastructure or public sector making significant changes to accommodate them, their vehicles would take many years before they could function.

The same principle applied for connected vehicle applications. Some OEMs were interested in the improved functionality that V2X applications and hardware could provide, but they were certain their vehicles would function independent of the connectivity. They feared that waiting for V2X would mean their vehicles would not reach the hands of consumers in the near future.

7.7 Ensuring Cybersecurity Is Crucial

Vehicles are rapidly becoming increasingly connected. Vehicles are progressively becoming more reliant on the information they send and receive; automated and connected vehicles will only further this trend. As the vehicular reliance on connectedness increases, the need for a reliably secure and trustworthy information transmission system also increases.

If someone hacks into an individual's computer and gains access to personal financial information, the impacts can be substantial and extremely disruptive. If someone hacks into the information transmission system on which automated and connected vehicles rely, the effects could be fatal. For this reason, it is extremely important that connected and automated vehicles be highly secure, and all information transmissions be reliable and accurate. Many public and private-sector interviewees acknowledged this need. Opinions were divided on who should be responsible for the operation of these vehicles, but many interviewees felt the federal government should play a leading role in the development and management of a security certificate system that ensured all messages sent and received were genuine and secure.

7.9 Liability Is a Concern for OEMs

If automated vehicles improve safety and decrease vehicular crashes, society will benefit. Fewer lives will be lost, fewer injuries will occur, and insurance premiums will decrease. Even if society is unequivocally better off with automation, OEMs worry that a comparatively small number of motorists and passengers harmed in an automated vehicle will hold the vehicle manufacturers responsible. When they do, they will sue the manufacturers, which will increase OEMs' costs and could result in significant damage payouts.

This liability serves as a deterrent for automated vehicle manufacturers: they are less likely to bring innovative and new technologies to market, even if by most measures society would be safer. If the liability concerns are significant enough, OEMs may decide against bringing automated vehicles to market, denying society the clear improvement in safety and resulting economic benefits.

Society should carefully consider the costs of this liability. One OEM stated in an interview that liability concerns could "dictate the automated vehicle development path." In the past, society has passed laws that shift liability off manufacturers of a good that provides a substantial public benefit—two apt examples include vaccines in the 1990s and small aircraft manufacturers in the 1980s (Viscuci, n.d.; U.S. Department of Health and Human Services, n.d.). These cases are rare, and society must eventually decide if such legislation is justified in the case of automated vehicles.

7.9 Perspectives on Current NHTSA Recommendations and Definitions Vary

There does not appear to be agreement, in the automated vehicle industry or public sector, about the adequacy of the current NHTSA definitions and guidelines on automated systems. OEMs seem split in their support: some felt the definitions lacked sufficient industry input, while others either had no opinion or felt they were adequate. States are unclear about whether they should follow the NHTSA guidelines for the sake of consistency or work to issue their own. Some states object due to their own legacy regulatory systems, which they feel are adequate.

8.0 RESEARCH NEEDS

As seen throughout this document, automated vehicles could have very significant implications for society. However, the impact of automated vehicle technologies will depend very much on how these systems are ultimately designed—a significant unknown at this relatively early stage of the industry. Broad speculations about potential impacts absent a particular system design do not provide the detail required to adequately plan for how automated vehicles will change society.

In addition to a better understanding of how automated vehicle systems will be designed and incorporated into vehicles, the research team has identified the following research needs:

- It is not clear how automated vehicles will affect traveling patterns and congestion. Additional research and better information are needed to aid in planning future infrastructure investments.
- Better information is needed to develop economic models, such as adoption rates, technology development timelines, and cost.
- Better models are needed to improve understanding of potential unintended consequences like increased dispersed urban development, effects on commuting patterns, and associated implications for urban planning models and forecasts.
- Automated vehicle liability is a concern for manufacturers, and could slow development and implementation.
- As vehicles become increasingly connected, data security and privacy are pressing concerns for public transportation agencies, especially if they have some level of responsibility for ensuring data security or must handle data transmissions that might occur under connected vehicle applications.
- Future research could develop strategies to help DOTs understand the issues surrounding managing and operating a mixed vehicle environment of connected, automated, and non-connected or automated vehicles.
- There are questions about the value of using managed or otherwise controlled lanes as an early deployment option for automated and connected vehicles. Additional research could explore the efficacy and operational challenges of such a system.
- Certifying automated test vehicles as safe to operate on public roadways is a challenge several states are currently undertaking. Developing robust certification techniques may be a challenge requiring future research.

There are many potential research needs, and this list only captures some of the most salient needs.

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10.0 APPENDIX

10.1 Private-Sector Interview Questions

1. Over what time frame do you see automated vehicles developing capabilities consistent with automation levels two and three? When will the enabling technologies like lidar, radar, or computer-based image recognition be sufficiently developed to enable these levels of functionality?

2. Do you anticipate that all automated vehicles will eventually use a standard technology (or combination of technologies), or do you anticipate that different OEMs will all have unique automated vehicle technological configurations? Which technology or technologies do you see as most likely to succeed or become dominant?
    a. Within what time frame would you expect these changes to occur?
    b. Do you expect that different OEMs will use different technologies for implementation?

3. What sort of role, if any, do you envision for vehicle-to-vehicle and vehicle-to-infrastructure communications and connectedness in automated vehicle deployment (for example, using DSRC to connect personal vehicles and roadside infrastructure in specialized and/or general applications)?
    a. If there is a role, what sort of role do you envision?
    b. If not, why not? Can vehicle platooning be accomplished without V2V communications?
    c. If the necessary communications infrastructure were already in place, would automated vehicles use it?

4. Do you anticipate the roadway infrastructure, digital infrastructure, maps, or other associated data will need to change to accommodate automated vehicles? In what way(s)? Even if not required, are there any changes to roadway infrastructure or DOT operations that would facilitate automated vehicle development?
    a. How could infrastructure help?

5. Even the earliest stages of automated vehicle implementation could provide an opportunity for decreasing congestion and increasing safety if an infrastructure environment existed to serve equipped vehicles. One possible way to enable this is to allow vehicles with platooning or CACC-type functionality to operate in dedicated lanes, potentially in existing high-occupancy vehicle (HOV) or managed lanes.
    a. Could the automated vehicle industry potentially support this idea as an early implementation opportunity?
    b. Does it seem necessary (or beneficial) to equip vehicles with DSRC sensors to enable interoperable vehicle and infrastructure communications and cooperation in such an environment?

6. How does state legislation on automated vehicles affect the ability of OEMs to test or implement automated vehicles?
    a. Have any state's legislation had an especially profound effect (positive, negative, or neutral)?
    b. What aspects of legislation or regulation have the most pronounced effect?

7. What role, if any, do you see for federal, state, or local governments in the automated vehicle development and implementation process?
    a. What do you see as the state role versus federal role with regard to licensing and regulating automated vehicles?

8. How would you characterize the societal and economic benefits of automated vehicles? What do you see as the benefits of function-specific or combined function automated vehicles (levels two and three)?

9. Cybersecurity is an increasingly important issue in the public consciousness. What role, if any, do you see for the federal, state, and local governments in cybersecurity with regard to automated vehicles?
    a. Do you see cybersecurity as a risk to automated vehicles?

10. What sorts of issues do you see arising with regard to the use and ownership of the vehicular and driver-related data that might be generated by an automated vehicle? For example, what sorts of issues (if any) might arise with impaired driving, distracted driving, insurance, or licensing?

11. In what concrete ways do product liability considerations alter your organization's approach to vehicle automation? Can you provide any specific examples?
    a. Does it delay or prevent implementation or development?
    b. How can legislation or regulation mitigate your liability concerns?
    c. Is this an issue for federal or state governments to address?

10.2 Public-Sector Interview Questions

1. What are your biggest concerns and issues with the way that automated vehicle technology has developed and been tested? What are your biggest concerns with regard to having automated vehicles on the roadway? What benefits do you anticipate from automated vehicles?

2. Low-level automated vehicles are already on the market, with high-level automated vehicles expected to be on the market as soon as 7–12 years from now. Do you feel your organization needs to prepare or take any actions in advance?
    a. What actions, if any, has your organization/state taken in preparation?
    b. What was the intent of the action(s), legislation, or regulation?
    c. How were the actions determined? Did you involve the automated vehicle industry or other technically proficient groups? In what capacity?
    d. Have you received any feedback (industry or otherwise) after taking the actions, passing legislation, or implementing regulations?

3. Automated vehicles will likely provide a significant safety benefit to society. Has your organization/state given any thought to implementing policies to encourage the use of automated vehicle technology for safety-related purposes?

4. The automated vehicle industry and NHTSA (which recently released recommendations for state regulations) share the opinion that disparate rules governing automated vehicles will impede innovation and slow implementation. Would your organization/state consider implementing some version of NHTSA's recommended regulations to maintain consistency and encourage innovation?
    a. Why or why not?
    b. Has your organization/state considered implementing specialized training requirements for drivers of privately owned automated vehicles?

5. The visibility of lane markings and other traffic control devices and the state-of-good-repair of pavement surfaces are among the important features supporting the safe operation of automated vehicles. In your assessment, what are the implications of maintaining roadway assets to a high level of service to support automated vehicles?
    a. How might this change your agency's approach to asset management?
    b. What are the potential funding implications?

6. Connectivity to the infrastructure may help support safe and reliable operation of automated vehicles. What are the opportunities and challenges for your agency in supporting V2I and I2V applications, including installation, operation, and maintenance of roadside readers, communications backhaul, and data processing?
    a. Does your organization have the funding and institutional knowledge to install, operate, and maintain a new ITS to support connected and automated vehicles?
    b. Does your organization/state have the funding and institutional knowledge to gather, analyze, and use large amounts of data with the intent of optimizing road operations in coordination with automated and connected vehicles?

7. Cybersecurity is an increasingly important issue in the public consciousness. Do you and your organization have such security concerns for automated vehicles? What role, if any, do you see for your organization/state in cybersecurity with regard to automated vehicles?

8. Automated vehicles will likely lessen the burden of commutes and shorten trip times through improved throughput efficiency. Decreasing commuting costs may increase demand for commuting (i.e., more people may wish to live further away).
    a. What are the implications on the transportation planning process?
    b. Will this change transit and general transportation demand?
    c. Will it affect long-term land use?
    d. How will this affect transportation organizations at an institutional or administrative level?

9. Should governments attempt to manage or regulate the introduction and transitional phase for automated vehicle operations? Should governments regulate their operation within general traffic, or should they be treated like any other vehicle?
    a. Should states require automated vehicles operating in automated mode be easily identifiable from the vehicle exterior through some visual signal (light, etc.)?
    b. Do you see the following idea as a feasible transitional approach to automated vehicles: dedicating roadway facilities (such as managed, high-occupancy toll, or HOV lanes) solely or partially for automated vehicles operating in cooperative platoons to maximize throughput and increase revenues?

10. After this discussion on automated vehicles, how would you recommend states/public transportation agencies begin preparing for automated vehicles?
    a. What new skill sets are needed?
    b. What regulation or legislation is needed?
    c. How should infrastructure and operations change in anticipation of automated vehicles?
    d. In what other ways should state and local transportation agencies begin preparing for automated and connected vehicles?