Transportation Policy Brief #2

Autonomous Vehicles in Texas

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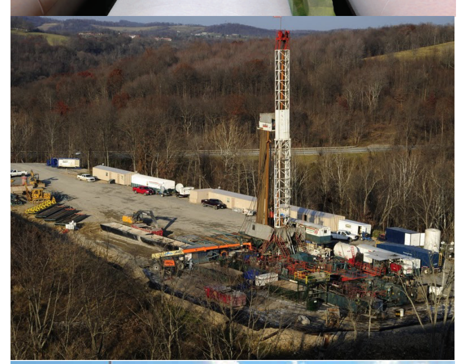

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Project Directors:

Leigh B. Boske, Ph.D., Professor,
Lyndon B. Johnson School of Public Affairs,
The University of Texas at Austin

Robert Harrison, Deputy Director,
Center for Transportation Research,
The University of Texas at Austin

LBJ Lyndon B. Johnson School of Public Affairs
The University of Texas at Austin

CTR The University of Texas at Austin
Center for Transportation Research

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Autonomous Vehicles in Texas

POLICY RESEARCH PROJECT PARTICIPANTS

Students:

- Gregory Conte, B.S. (Hospitality Administration), Boston University; M.S. (Intelligence and National Security Studies), The University of Texas at El Paso
- Jane Santa Cruz, B.A. (History), B.A. (Spanish), Hendrix College
- Paul Gainey, B.S., (American Politics and Law), United States Naval Academy
- Miranda Hoff, B.A. (Government and Latin), The University of Texas at Austin
- Corey Howell, B.A. (Government), The University of Texas at Austin
- Salima Hakim Khan, B.A. (Business Administration), Institute of Business Administration, Karachi, Pakistan
- Kyle McNew, B.A. (English Literature), Penn State University
- Kevin Merrill, B.S. (Political Science), Texas A&M University
- John Montgomery, B.A. (Government and History), The University of Texas at Austin
- Benjamin Moriarty, B.A. (Journalism and Psychology), University of Massachusetts Amherst
- Vivek Nath, B.S. (Electrical Engineering), Georgia Institute of Technology
- Hector Rojas, B.A. (Anthropology), The University of Nevada Las Vegas
- Vance Roper, B.A. (Political Science), Saint Edwards University
- Jacob Thayer, B. A. (Political Science), The George Washington University
- Tiffany Wu, B.S. (Chemical Engineering), The University of Texas at Austin
- Wu Zheng, B.S. (Computer Science), B.A. (Physics), The University of Texas at Austin; M.S. (Computer Science), The University of Texas at Austin

Project Directors:

- Leigh B. Boske, Ph.D., Professor, Lyndon B. Johnson School of Public Affairs, The University of Texas at Austin
- Robert Harrison, Deputy Director, Center for Transportation Research, The University of Texas at Austin

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FOREWORD

The Lyndon B. Johnson School of Public Affairs, University of Texas at Austin, has established interdisciplinary research on policy problems as the core of its education program. A major part of this program is the nine-month policy research project (PRP), in the course of which two or more faculty members from different disciplines direct the research of 10 to 20 graduate students of diverse backgrounds on public policy issues of concern to a government or nonprofit agency.

During the 2013–2014 academic year, the Texas Department of Transportation (TxDOT) funded, through the Center for Transportation Research (CTR), a policy research project addressing seven key policy issues.

The research team interacted with TxDOT officials throughout the course of the academic year. Overall direction and guidance was provided by Mr. Phil Wilson, former Executive Director of TxDOT. Mr. Wilson participated in an October 10, 2013 workshop to determine the scope of study. As a consequence, the following policy issues were selected for study:

- Air Transportation in Texas
- Autonomous Vehicles in Texas
- North Carolina's Strategic Mobility Formula
- Oregon's Voluntary Road User Charge Program
- Potential Use of Highway Rights-of-Way for Oil and Natural Gas Pipelines
- State Energy Severance Taxes and Comparative Tax Revenues
- U.S.–Mexico Transportation and Logistics

The findings of each policy issue are presented within the context of separate transportation policy briefs. This particular policy brief, "Autonomous Vehicles in Texas," was researched and written by John Montgomery and Vivek Nath.

The following template was also adopted for each of the above-mentioned policy briefs:

- Executive Summary
- Background
- Key Policy Issues
- Lessons Learned
- Relevance to Texas
- Appendices

ACKNOWLEDGMENTS

This policy research project would not have been possible without the generous contributions of assistance of a great number of individuals and organizations. Useful contacts are provided in Appendix 1 of each of the respective transportation policy briefs. As previously mentioned, overall direction and guidance was provided by Mr. Phil Wilson, former Executive Director of TxDOT. We are also indebted to the following TxDOT officials for participating in weekly class presentations or scheduled interviews, sharing information and data, and suggesting useful contacts:

- John Barton, P.E., Deputy Executive Director/Chief Engineer
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- Jessica Butler, Unified Transportation Program Coordinator
- Shannon Crum, Ph.D., Director, Research and Technology Implementation Office
- Will Etheredge, Financial Analyst, Finance Division
- David Fulton, Director, Aviation Division
- Jerry Haddican, J.D., Director, State Legislative Affairs Office
- Caroline Mays, Freight Planning Branch Manager
- Peggy Thurin, Systems Planning Branch Manager
- Lanny Wadle, Deputy Director, Finance Division
- Marc Williams, P.E., Director of Planning

EXECUTIVE SUMMARY

The Texas highway and road systems have reached a turning point. Capacity limitations, pervasive safety concerns, and limited public capital are creating strain. Technological breakthroughs in sensors and autonomy seek to solve these problems by reinventing the automobile itself. This paper examines autonomous vehicle (AV) technology, and the potential it offers to TxDOT.

The examination of AV's usefulness for TxDOT begins with brief background section. Great advances in wireless communications, as well as ongoing deployment research, demonstrate the usefulness of AV systems. The scope of this analysis is also presented in the report which envisions an Intelligent Transportation System (ITS) which is fully executing AV operations.

While offering significant safety improvements over traditional drivers, AVs also present a wide range of challenges. The economic and capacity benefits associated with autonomous driving are not readily known due to the currently limited deployment of these vehicles. In addition to these uncertainties, the technological complication of deploying AVs will require TxDOT to develop new capabilities. However, as with all new technologies, the up-front risks can be mitigated with measured and thoughtful action.

Important lessons have been gleaned from other states to establish some best practices in deploying AV technologies. Other states have been too specific in establishing technology requirements for testing AVs on their roads. TxDOT would be wise to avoid such prescriptive policies, and use the information in this brief to better educate the lawmakers ahead of the 2015 session. In addition, international transportation agencies in countries such as the United Kingdom and Canada offer examples of how ITS can be utilized to create a more efficient highway driving experience. These ITS lessons are invaluable in the deployment of AV technology.

While the previous lessons learned will be compared for best practices, in certain areas Texas can take the lead in establishing AV technology. Specifically, autonomous freight vehicles (AFVs) are at a stage in development where the technology is well tested, but still requires wider deployment to be commercially validated. Situated on the largest freight corridor in North America, Texas has a unique position in America's freight system, which can be a huge advantage when deploying AFV technologies. In addition, the federal government is deploying AFV technology for testing on Texas military bases. This report will examine the sorts of services Texas can offer freight companies using AFVs, and the particular requirements of introducing autonomous freight services.

Taking all of the aforementioned into consideration, this paper then demonstrates the steps needed to establish a full autonomous AV system, where drivers, vehicles, and the transportation network all interrelate through a dedicated short-range communications (DSRC) network administered by TxDOT. In such a set-up, drivers can enter vehicles which will automatically ferry them to a destination of their choice by using ITS. The technological, regulatory, and administrative requirements of such a Vehicle-to-Infrastructure (V2I) system will be detailed. Finally, a timetable based on industry-wide assumptions will be presented that offers a basic path toward full implementation.

BACKGROUND

This section provides context for why AVs are needed on Texas roads. Automobile travel in Texas is becoming more time consuming, expensive, and dangerous. Commuters spend more time in traffic each year, with increasingly erratic travel times.[1]According to the Annual Urban Mobility Report 2012, an average commuter in Austin spends 44 hours a year to travel to work. The increase in commute time results in associated economic impacts that affect the economy (e.g., 44 hours per year in Austin traffic costs society approximately $930 for each commuter).[2] Limited capacity and societal reliance on automobiles exacerbate these outcomes.

Increasing travel time is one of the major consequences of higher automobile use. Automobile accidents and fatalities represent a major ongoing problem not only for Texas but also for American society at large. In 2012 alone, there were almost 3,400 traffic deaths on Texas roads, which represented a 10% increase over the previous year.[3] This unfortunate loss of life also impacted the state's economy to the tune of $26 billion.[3] What can be done about these negative impacts on Texans' lives and economic prosperity?

Failure to control speed, driver inattention, and tailgating are the most common causes for automobile accidents in Texas.[4] These problems are inherent to human drivers, and represent major behavioral issues that can only partially be overcome through training and licensing. Technological solutions offer new and effective methods for addressing much of the unsafe driving on Texas roads, along with the associated negative economic impacts.

AUTOMATING THE DRIVING EXPERIENCE

AVs and Autonomous Freight Vehicles (AFVs) utilize technology to improve the driving experience along with safety. These technologies seek to automate many of the functions controlled by drivers, such as speed maintenance, following distance, and device control (headlights, radios, phones, etc.). A majority of automobiles made today include some level of automation, and car manufacturers are seeking to increase these services in new production vehicles.[5]

AV technology is always evolving as new discoveries are being tested and deployed. Because of this fluid process, AV technology can be broadly categorized into five main categories, or levels of sophistication.[6] This report assumes that TxDOT's deployment of AV infrastructure will be focused on supporting a fully autonomous Level 4 vehicle throughout its travel on Texas roads. A Level 4 system "anticipates that the driver will provide destination of navigation input, but is not expected to be available for control at any time during the trip".[7] By operating under this expectation, TxDOT would be able to roll out its AV support in a timely manner based on clear technical goals.

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[1]Schrank, 2012.
[2]Ibid.
[3]Texas Department of Transportation, 2013b.
[4]Texas Department of Transportation, 2013a.
[5]Eno Center for Transportation, 2013.
[6]National Highway Transportation Safety Administration, 2013.
[7]Ibid.

AFV technology is less developed than its AV counterpart, but is evolving in new ways that will change the commercial freight industry around the world. These developments include electronic platooning of driverless trucks[8], and the deployment of modular sensor packages for retrofitting on any existing freight vehicle.[9] AFVs operate along similar lines to standard passenger AVs, but additional safety requirements limit the extent of automation for these vehicles. Therefore, any system that seeks to integrate AFV operations must make several additional considerations.

The most vital infrastructure required to support AV and AFV operations is a robust wireless communications system.[10] AV communication can occur through Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) means, and is based on the concept of a mesh wireless network.[11] This report will focus primarily on V2I networking capabilities since these are the most applicable to TxDOT.

The overall implication of connected AVs in a V2I system is an Intelligent Transportation System (ITS) that integrates system information and vehicular information into a synchronized command and control structure. An ITS facilitates interaction between drivers, their vehicles, and infrastructure. ITS capabilities already exist in Texas' major metropolitan areas, but this report will examine how other transportation authorities implement larger-scale ITS deployments.

KEY POLICY ADVANTAGES

SAFETY

The primary advantage of an AV use is the prevention of road accidents. Over 30,000 people die each year in the U.S. in automobile collisions, with 2.2 million crashes resulting in injury.[12] The annual economic cost to the United States of these crashes is estimated to be $300 billion.[12] Traffic accidents remain the primary reason for the death of Americans between 15 and 24 years of age. Several safety pilot tests of AVs indicate a high degree of success in preventing road accidents.[12]

CONGESTION

The annual economic cost associated with road congestion in the U.S. is estimated at $100 billion, based on a 2009 estimate. AVs can sense and possibly anticipate lead vehicles' braking and acceleration decisions, leading to reductions in traffic-destabilizing shockwave propagation. AVs can use existing lanes and intersections more efficiently, which could increase congested traffic speeds by 8 to 13%.[13] However, because of lack of large-scale deployments,

[8] Davila and Nombela, 2010.
[9] Lockheed Martin, 2014
[10] National Highway Transportation Safety Administration, 2013.
[11] Naranjo, 2012.
[12] Eno Center for Transportation, 2013.
[13] Ibid.

field testing of these theories have not been conducted. The most urgent AV research moving forward will test theories of congestion mitigation.

INCREASED MOBILITY

Theoretically, the elderly, visually impaired and other disabled individuals could take advantage of autonomous vehicle technology to navigate roads safely.

KEY POLICY DISADVANTAGES

TECHNOLOGICAL INVESTMENT

The adoption of a full Level 4 automated system will require significant technological investments that go beyond traditional transportation systems. The technologies needed for AVs include the addition of new sensors, communication and guidance technology as well as software for each automobile. KPMG and the Center for Automotive Research note that the Light Detection and Ranging (LIDAR) systems on top of Google's AVs cost $70,000. Author Dellenback estimates that majority of the current civilian and military AV applications cost over $100,000, and at least for ten years, these costs will most likely not fall to $10,000 with mass production. Additional investment would be needed to upgrade the ITS to facilitate communication between vehicles and transportation infrastructure.[14]

UNCERTAIN ECONOMIC BENEFITS

The lack of deployed Level 4 automated systems and the imprecise business model of selling AV technology in the current market reveal an uncertain picture of the associated economic benefits. Despite the current enthusiasm for AV technology and the amount of research among automakers and other institutions, this technology might not be widely adopted due to high expense and/or consumer uncertainty in the safety benefits of the technology. Some of the expected economic benefits associated with congestion may not materialize. When drivers can use the time in the vehicle for other tasks, such as checking email and videoconferencing, the cost of congestion is effectively reduced for vehicle operations. This cost reduction may lead to additional vehicle miles travelled resulting in a negative externality and higher economic costs.[15]

LAG TIME

As with any new paradigm, the deployment of AVs will take time. TxDOT may therefore experience higher short-term costs (in terms of technological and infrastructure upgrades) than short-term benefits to safety and congestion. A phased approach may need to be laid out for a

[14] Eno Center for Transportation, 2013.
[15] Anderson et al., 2014.

smooth transition to the regular use of AVs on the road. The infrastructure requirements for a phased rollout are discussed in the "Relevance to Texas" section of this report.

LIABILITY COMPLEXITY

As AVs take on more of the driving functions that were historically the responsibility of the driver, new questions arise regarding accident responsibility. Risk is introduced for manufacturers as they may be held liable for AV-involved road accidents. This, in turn, may introduce a reluctance to adopt new AV technology despite the associated safety improvements. AV technology may lead to lower car insurance costs for consumers, but the new complexities for processing insurance claims after accidents, and the possible shift of liability costs to manufacturers, are notable disadvantages of AV technology.[16]

LESSONS LEARNED

This section evaluates lessons from AV deployments in other states and countries. These initiatives provide examples of the policy and technological challenges associated with AV technology.

TECHNOLOGY: UNITED KINGDOM

The ITS plan in the United Kingdom highlight the advantages associated with a well-functioning information system working in tandem with V2Iand V2V communication.[17] Apart from the safety benefits of AVs, the associated ITS system may also serve several other functions. Road-side vehicle detectors add reliability and accuracy to traffic management. Real-time analysis of traffic flow can be used to vary electronic speed limit signs to maximize traffic throughput. Cameras and sensors on motorways can help detect accidents and accordingly relay routing and traffic information to the central ITS server as well as to drivers. The system also has the ability to charge tolling fees of varying amounts based on vehicle identity.

TECHNOLOGY: CANADA

The ITS plan for Alberta, Canada suggests several of the advantages mentioned in the 'United Kingdom' section. In addition, the Alberta plan also suggests using ITS applications that include changeable message signs to display real-time information collected by sensors and warn motorists of collisions and road-weather conditions. It provides a thorough template for how ITS systems may be managed and seamlessly integrated into a knowledge-based economy.[18]This flexibility will allow for easier integration of AVs in future road operations.

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[16] Anderson et al., 2014.
[17]Walsh, 2011.
[18] Alberta Infrastructure, 2000.

TECHNOLOGY: GERMANY

A project called KONVOI, which stands for the "Development and Examination of the Application of Electronically Coupled Truck Convoys on Highways" in German, was conducted in Germany to evaluate the performance of automated truck platoons. During test runs of these experimental vehicles on motorways, data were collected to analyze the traffic flow, road safety, economic efficiency and environmental effects as well as the acceptance and stress levels of the truck drivers. The KONVOI test concluded that traffic flow and road safety could be increased through autonomous truck platoons which would lead to a more effective use of existing resources. The study also concluded that further advancement in V2V and V2I communication would be required to incorporate truck platoons in road traffic.[19]

TECHNOLOGY: UNITED STATES

To understand the effectiveness of AV technology in addressing road safety issues, the U.S. Department of Transportation (USDOT) ITS Joint Program Office created a test and evaluation effort called the Connected Vehicle Safety Pilot.[20] Close to 3,000 vehicles were deployed in the largest-ever road test of V2V technology. The National Highway Traffic Safety Administration (NHTSA) issued a statement in February 2014 stating that the DOT testing indicated interoperability of V2V technology among products from different vehicle manufacturers and suppliers and that they work in real-world environments.[21]

In the private-sector, as of March 2013, Google AV fleet had logged more than 500,000 miles of autonomous driving on public roads without incurring a crash attributable to AV technology.[22]

POLICY: FEDERAL

Since 2001, the Federal Government has pursued standards to facilitate nationwide ITS projects. In 1999, the Federal Communications Commission (FCC) allocated a frequency spectrum known as Dedicated Short Range Communications (DSRC) in the 5.9 GHz band for communication between vehicles. In 2003, the FCC issued corresponding licensing and service rules. The Moving Ahead for Progress in the 21st Century Act of 2012 called for an assessment and evaluation of V2V and V2I communication, including DSRC.[23]

POLICY: CALIFORNIA

California has enacted prescriptive laws that specify the ideal technologies that an AV should have. For instance, AVs need a manufacturer certification of a mechanism to engage and

[19] Ramakers et al., 2009.
[20] Research and Innovative Technology Administration, 2014.
[21] National Highway Traffic Safety Administration, 2014.
[22] Anderson et al., 2014.
[23] US Congressional Report, 2012.

disengage the autonomous technology. Manufacturers must provide privacy notifications to purchasers of autonomous vehicles, and obtain a form of insurance in the amount of $5 million before starting the testing of AVs in the state.[24] California has come under criticism for enacting legislation that is too prescriptive of technology safety requirements, and therefore stifles the development of AV technology.

POLICY: NEVADA

Nevada has promulgated regulation requiring AVs to possess a certificate of compliance stating that the AV is capable of being operated in autonomous mode without the physical presence of the operator in the vehicle. Licensed dealers may only sell AVs with certifications issued by the manufacturer or an authorized certification facility. The regulation requires an endorsement on the driver's license to operate it. In addition, Nevada has regulation that creates a privately operated technology certification facility market.

POLICY: FLORIDA

Florida does not have as many prescriptive laws as California and Nevada. Florida's laws provide liability protection for original equipment manufacturers whose vehicles are converted to AVs.

COMMONALITIES OF STATE LEGISLATION

Florida, Nevada and Washington D.C provide liability protection for original equipment manufacturers whose vehicles are converted to AVs. California, however, has no explicit mention of such liability protection. Apart from California, Florida, Nevada and Washington, D.C., there are ongoing legislations regarding AVs in Arizona, Colorado, Hawaii, Massachusetts, Michigan, New Hampshire, New Jersey, New York, Oklahoma, Oregon, South Carolina, Washington and Wisconsin. Most states, including Texas, have passed laws that define 'Autonomous Vehicle', 'Autonomous Technology' and 'Operator'. They also engage in setting up a bonding system to test upcoming vehicle technology. The states also provide protections for manufacturers against claims due to third party AV conversions, and most of these states establish clear lines of accountability for the testing and certification of prototypes.

RELEVANCE TO TEXAS

This section explores how AV technology can be facilitated on Texas roads by exploring the technology and timing issues for an effective TxDOT AV rollout. TxDOT will need to address the AV issue comprehensively for a successful implementation. This section proposes a timeline formed around benchmarks to guide AV rollout in Texas. The rollout efforts should aim on

[24] State of California, 2012.

having an ITS that can support V2I communications between Level 4 AVs, which will give Texas the technological flexibility to facilitate a variety of AV systems well into the future.

COMMUNICATIONS INFRASTRUCTURE

As previously mentioned, communications technology will be the largest component of any state-wide AV rollout. International case studies have shown that effective wireless communications is critical for traffic management and information dissemination.[25] This is also true for the operation of AVs, which will rely on wireless communications for safe operations. Since AV technologies rely so heavily on wireless communications, it is important to understand the standards that will be in place during TxDOT's AV rollout. These standards for wireless communication will control how wireless information is exchanged between AVs over V2I networks.

Since 2003, the federal government has DSRC standards for automobile use in place. This system envisions a microwave communications network operating at 5.9 GHz, and automobile manufacturers are seeking to conform to these requirements with their AV deployments. Therefore these DSRC standards in turn set the industry-wide standard, and represent the mode of compatibility that TxDOT's wireless communications system must meet.

Note that this wireless communications format is not intended to cover all the possible communications with AVs, but only those strictly related to safety. However, despite this limited use, DSRC represents the most likely medium for wireless communication between AVs and infrastructure.[26] There is no uniform agreement on the usefulness of DSRC, and many are examining how this wireless standard can be improved to allow for cross compatibility with wireless and cell phone services.[27] Many complaints about DSRC, however, are based on this lack of flexibility, which can be justified via its role in protecting motorists' lives. There are developments to utilize hybrid systems to operate on multiple frequencies, which would separate out safety critical functions from other wireless operations.[28] Therefore, even in the face of industry scrutiny, DSRC offers the best path forward for vehicular wireless safety communications.

In conjunction with the USDOT, AASHTO released a field guide in 2011 outlining some major obstacles to and recommendations for AV implementation.[29] Most notable is the deployment flexibility that many DSRC technologies permit. Existing camera masts, traffic control boxes, and road sign installations can be adapted to use the wireless communications technology prescribed by the FCC. Thus, TxDOT's existing networking infrastructure can be modified to facilitate greater V2I coverage for AVs.

[25] Walsh, 2011.
[26] KPMG, 2012.
[27] Li, 2012.
[28] Samuel, 2013.
[29] Intelligent Transportation Systems Joint Program Office, 2011.

V2I SERVICES INFRASTRUCTURE

TxDOT can build upon its robust ITS system to create more unified statewide services for AV drivers. The advancement of AV technology will change a driver's relationship with the roads they travel on, and TxDOT will need to determine how much they want to provide to users of Texas' ITS. V2V and V2I technologies mean that a continuous two-way exchange of information between driver, car, and road will occur. The ability to interface directly with infrastructure users, either through information dissemination or traffic control, will have major impacts on AV deployment.

Some V2I applications in other countries provide a wide range of information and safety services to customers as a part of their national transportation plans.[30] These applications can include (but are not limited to) traffic information, routing options, hazard warning, platooning services, and user feedback. TxDOT can provide these services either in-house, or by hiring outside contractors. Failing to provide these services, however, would be missing a unique opportunity to advance road infrastructure into a useful information age. TxDOT, AVs, and drivers would be able to interact in real-time, which will revolutionize TxDOT's customer service capacity. TxDOT must decide how far to take this new relationship:

- Should TxDOT supply AV motorists with traffic information?
- Can there be automatic rerouting of vehicles around congestion areas?
- Should TxDOT help facilitate platooning for AV and AFV motorists?
- Should AV motorists be able to interact with TxDOT to submit complaints?

An important starting point for building these capabilities within TxDOT would be the enhancement of the state's ITS. Establishing a statewide ITS center can facilitate the dissemination of real-time traffic data along major interregional transport routes, which would improve Texas' traffic management capabilities.[31] Not only this, but interregional traffic could be automatically rerouted around major congestion areas.[32] TxDOT could establish alternative routes for interregional traffic, and provide variable tolling to motorists who are willing to circumvent congested areas at a discount. Alternatively, the state could offer to "do the driving" for AV users and facilitate platoons of vehicles for interregional travel.

Establishing the parameters of TxDOT's V2I program is beyond the scope of this report, but one thing is clear: the massive amount of information and connectivity between the cars and the road will change TxDOT's interaction with its users. A more unified statewide ITS would place TxDOT in a better position to capitalize on this evolution.

TRADITIONAL INFRASTRUCTURE

TxDOT will not only need to address the communications infrastructure requirements, but also several traditional infrastructure requirements that AVs present. Only a handful of

[30] Walsh, 2011.
[31] Ibid.
[32] Alberta Infrastructure, 2000.

large-scale AV deployments have occurred, and hence this area of research lacks examples and data. Traditional infrastructure recommendations fall into two major categories: signage and pavement.

As mentioned previously, the dissemination of information to AV users will be one of the most important developments in AV rollouts. TxDOT's ITS will be able to send information directly to the dashboard of participating AV users, increasing the visibility of this information to drivers. Other countries have incorporated electronic signage to inform motorists about impending changes to road conditions.[33] Therefore one of the primary tasks in maintaining modern signage is to establish how TxDOT wants to disseminate information directly to AV motorists.

Due to the lack of AV deployments, the benefits of reduced congestion can only be modeled at this point. While many advocates of AVs propose that these vehicles will reduce congestion, some have noticed that there is a chance for increased traffic when AVs and traditional vehicles are mixed due to the uncertain nature of their interaction.[34] TxDOT may consider allowing AV motorists to utilize high-occupancy-vehicle (HOV) lanes or other designated rights-of-way.[35] This approach could have two important impacts: limiting the interaction of AVs with traditional vehicles, and establishing an additional incentive for the adoption of this technology. These designated rights-of-way for AVs would need to have additional pavement reinforcement due to increased wear caused by shorter following distances. A policy of allowing AV users into HOV lanes would ease the transition into AV use, and help increase utilization of those special lanes.

AUTONOMOUS FREIGHT VEHICLES

While a great deal of research has been conducted on passenger AV deployment, AFVs remain fertile ground for progress. The main focus for AFV use is through road trains, which are extended convoys of platooning freight vehicles led by a single human driver. TxDOT has the opportunity to not only offer resources for the testing of AFV equipment on public roads, but also to partner with the freight industry to collaborate on future freight routing services.

Most testing on AFVs has been done in Europe, where a consortium of universities led by automaker Volvo is seeking to better understand the safety requirements of this technology.[36] This research is ongoing, and will produce data on the extent to which road surfaces are worn, the economic savings produced, and the safety considerations that arise from the deployment of road trains that involve not only AFV but also traditional passenger vehicles. Another project, headed by Daimler Chrysler, focused on "electronic tow bars" which link AFVs to follow a lead driver. Simulations of road conditions from this project indicate many unique safety requirements for the eventual deployment of AFVs in platoons.[37] In addition to these deployment studies, Lockheed Martin and the US Department of Defense have

[33] Walsh, 2011.
[34] House Transportation and Infrastructure Committee, 2013.
[35] Kurman and Lipson, 2013.
[36] Davila and Nombela, 2010.
[37] Liang et al., 2003.

collaborated to test AFV technologies on military vehicles at Fort Hood.[38] The unique nature of this project is that the sensor and control equipment was an aftermarket kit that could be deployed on any freight vehicle.

Taken together, these efforts show that AFV technology is on the cusp of widespread deployment. TxDOT will need to actively partner with research organizations to permit the testing of AFVs on Texas roads. Moving beyond testing, TxDOT can employ an improved state-wide ITS system to motivate companies to adopt AFV technologies. One recommendation from international ITS applications is the classification of vehicle traffic into different categories, and TxDOT could do the same with interregional AFV traffic. This would allow TxDOT's state-wide ITS to route commercial freight around congestion areas. In addition to these routing services, TxDOT could facilitate platooning services for AFVs which would permit commercial freight operators to reduce the number of drivers they require. A wide variety of services can be offered to freight operators,[39] and as with the standard AV operations, TxDOT will need to establish the scope of its operations.

Whether or not TxDOT decides to go into AFV services, important infrastructure and safety considerations must be taken into account to accommodate AFVs on the road. First, road trains will make a considerable impact on road surfaces because of the concentration of wheels into a smaller space.[40] This means that any designated AFV routes will need to have reinforced road surfaces to increase operating life. In addition, grave safety concerns arise when operating mile-long road trains around traditional motorists.[41] Therefore, TxDOT should seek designated AFV routes away from major thoroughfares to prevent accidents. A good example of such a route would be State Highway 130 around Austin. Separating motorists from AFVs can ensure safe and economic operations.

ROADMAP FOR IMPLEMENTATION

This section provides one potential timetable for the upgrade of infrastructure and other deployment and development activities over the next ten years. The goal is to enable Level 4 AV/AFV use on Texas roads, based on deployment scenarios anticipated by the AASHTO. The ten-year deployment schedule is set up in two-year time frames to coincide with the state biennial budgeting cycle.

2013–2014

This phase is mainly devoted to research, evaluation and planning. A study of the technology implementation requirements should be conducted, with special attention to any updates on using DSRC as a communication standard and possible technological requirements for ITS. This is also the phase where state legislation on AVs may be planned with the help of the lessons learned from other states such as California and Nevada. Some of the initial steps,

[38] Lockheed Martin, 2014.
[39] Intelligent Transportation Systems Joint Program Office, 2011.
[40] Liang et al., 2003.
[41] Davila and Nombela, 2010.

such as legally defining an AV, have already taken place in Texas. There are still details on liability and licensing that will need clarification, especially establishing clear responsibility for the Department of Motor Vehicles (DMV) and Department of Public Safety (DPS).

TxDOT would benefit from outreach to the trucking and auto manufacturing industries, which can enable a smoother transition to AFV and consumer AV use. During this period, it should also conduct an internal organization evaluation to comprehend how to deal with the current silos within metro area traffic management systems. An important area of planning and budgeting would be to estimate the extent of V2I services that would be offered. Budgeting may be conducted for a full-scale AV technology rollout with a 2023 time frame.[42]

2015–2017

The year 2015 may mark the beginning of the establishment of wireless communication networks in Texas for AVs rollout which can be done in four stages:

- Stage 1: Major Metro Areas (2015–2017)
- Stage 2: All Interregional/ Interstate traffic routes (2017–2019)
- Stage 3: Secondary roads/ State Highways (2019–2021)
- Stage 4: All TxDOT rights-of-way (2021-2023)

TxDOT may consider upgrading its existing infrastructure of traffic signal controllers to facilitate V2I communication with AVs. Controller cabinets, for instance, may be used for deploying DSRC roadside equipment, as the cabinets provide secure environmentally-protected enclosures with electric power and backhaul communications. In many cases, integration of DSRC capabilities for AVs with signal controllers may require an upgrade or replacement of the existing controllers. The benefit of using existing controller cabinets would have to, therefore, be weighed against the use of new stand-alone cabinets that are equipped with the required controller.

This phase may also involve the development of a unified protocol for traffic management between metro areas. Traffic management issues include those to do with information dissemination, traffic routing and incident management (e.g., weather or accidents). TxDOT may conduct a study to plot acceptable AFV routes in Texas. The outreach to trucking companies and AV manufacturers would help TxDOT to determine the V2I services and infrastructure that would be useful.[43]

2017–2019

Stage 2 of the communications network rollout may start in 2017. TxDOT might consider expanding electronic road signage along major corridors as well as identifying less populated areas to receive communication networks in Stage 3.[44]

[42] Intelligent Transportation Systems Joint Program Office, 2011.
[43] Intelligent Transportation Systems Joint Program Office, 2011.
[44] Ibid.

2019–2021

The year 2019 would set forth Stage 3 of the communications network rollout. This year may be designated as “year zero” for estimating the number of equipped vehicles in the fleet for subsequent years. Widespread 4G and possibly 5G commercial services as well as increasingly available DSRC installations would make it easier to gather and share data with AFV and AV users. Thus, 2019 would mark the beginning of the provision of TxDOT V2I data services to these users. Data exchange may include routing and weather information.[45]

2021–2023

2021 would mark the beginning of Stage 4 of the communications network rollout.

[45] Ibid.

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APPENDIX 1: CONTACTS

Duncan F. Stewart, Ph.D
Volunteer Researcher
Center for Transportation Research
University of Texas at Austin
512-300-3571
stewart.duncan@austin.utexas.edu

Scott Haywood
Former Chief of Staff to the Executive Director
Texas Department of Transportation
scott.haywood@txdot.gov

APPENDIX 2: LEVELS OF AUTOMATION

The following text was taken from a National Highway Traffic Safety Administration statement entitled "Preliminary Statement of Policy Concerning Automated Vehicles."

Definitions – Levels of Vehicle Automation

The definitions below cover the complete range of vehicle automation, ranging from vehicles that do not have any of their control systems automated (level 0) through fully automated vehicles (Level 4). The agency has segmented vehicle automation into these five levels to allow for clarity in discussing this topic with other stakeholders and to clarify the level(s) of automation on which the agency is currently focusing its efforts.

• Level 0 – No-Automation. The driver is 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. Vehicles that have certain driver support/convenience systems but do not have control authority over steering, braking, or throttle would still be considered "level 0" vehicles. Examples include systems that provide only warnings (e.g., forward collision warning, lane departure warning, blind spot monitoring) as well as systems providing automated secondary controls such as wipers, headlights, turn signals, hazard lights, etc. Although a vehicle with V2V warning technology alone would be at this level, that technology could significantly augment, and could be necessary to fully implement, many of the technologies described below, and is capable of providing warnings in several scenarios where sensors and cameras cannot (e.g., vehicles approaching each other at intersections).

• Level 1 – Function-specific Automation: Automation at this level involves one or more specific control functions; if multiple functions are automated, they operate independently from each other. The driver has overall control, and is solely responsible for safe operation, but can choose to cede limited authority over a primary control (as in adaptive cruise control), the vehicle can automatically assume limited authority over a primary control (as in electronic stability control), or the automated system can provide added control to aid the driver in certain normal driving or crash-imminent situations (e.g., dynamic brake support in emergencies). The vehicle may have multiple capabilities combining individual driver support and crash avoidance technologies, but does not replace driver vigilance and does not assume driving responsibility from the driver. The vehicle's automated system may assist or augment the driver in operating one of the primary controls – either steering or braking/throttle controls (but not both). As a result, there is no combination of vehicle control systems working in unison that enables the driver to be disengaged from physically operating the vehicle by having his or her hands off the steering wheel AND feet off the pedals at the same time. Examples of function-specific automation systems include: cruise control, automatic braking, and lane keeping.

•Level 2 - Combined Function Automation: This level involves automation of at least two primary control functions designed to work in unison to relieve the driver of control of those functions. Vehicles at this level of automation can utilize shared authority when the driver cedes active primary control in certain limited driving situations. The driver is still responsible for monitoring the roadway and safe operation and is expected to be available for control at all times and on short notice. The system can relinquish control with no advance warning and the driver must be ready to control the vehicle safely. An example of combined functions enabling a Level 2 system is adaptive cruise control in combination with lane centering. The major distinction between level 1 and level 2 is that, at level 2 in the specific operating conditions for which the system is designed, an automated operating mode is enabled such that the driver is disengaged from physically operating the vehicle by having his or her hands off the steering wheel and foot off pedal at the same time.

• Level 3 - Limited Self-Driving Automation: Vehicles at this level of automation enable the driver to cede full control of all safety-critical functions under certain traffic or environmental conditions and in those conditions to rely heavily on the vehicle to monitor for changes in those conditions requiring transition back to driver control. The driver is expected to be available for occasional control, but with sufficiently comfortable transition time. The vehicle is designed to ensure safe operation during the automated driving mode. An example would be an automated or self-driving car that can determine when the system is no longer able to support automation, such as from an oncoming construction area, and then signals to the driver to reengage in the driving task, providing the driver with an appropriate amount of transition time to safely regain manual control. The major distinction between level 2 and level 3 is that at level 3, the vehicle is designed so that the driver is not expected to constantly monitor the roadway while driving.

• Level 4 - Full Self-Driving Automation (Level 4): The vehicle is designed to perform all safety-critical driving functions and monitor roadway conditions for an entire trip. Such a design anticipates that the driver will provide destination or navigation input, but is not expected to be available for control at any time during the trip. This includes both occupied and unoccupied vehicles. By design, safe operation rests solely on the automated vehicle system.

APPENDIX 3: ECONOMIC BENEFITS FROM AVS

The following table is from the October 2013 report of the Eno Center for Transportation entitled "Preparing a Nation for Autonomous Vehicles: Opportunities, Barriers and Policy Recommendations."

Table 2: Estimates of Annual Economic Benefits from AVs in the United States

	10%	**50%**	**90%**
Crash Cost Savings from AVs			
Lives Saved (per year)	1,100	9,600	21,700
Fewer Crashes	211,000	1,880,000	4,220,000
Economic Cost Savings	$5.5 B	$48.8 B	$109.7 B
Comprehensive Cost Savings	$17.7 B	$158.1 B	$355.4 B
Economic Cost Savings per AV	$430	$770	$960
Comprehensive Cost Savings per AV	$1,390	$2,480	$3,100
Congestion Benefits			
Travel Time Savings (M Hours)	756	1680	2772
Fuel Savings (M Gallons)	102	224	724
Total Savings	$16.8 B	$37.4 B	$63.0 B
Savings per AV	$1,320	$590	$550
Other AV Impacts			
Parking Savings	$3.2	$15.9	$28.7
Savings per AV	$250	$250	$250
VMT Increase	2.0%	7.5%	9.0%
Change in Total # Vehicles	-4.7%	-23.7%	-42.6%
Annual Savings: Economic Costs Only	$25.5 B	$102.2 B	$201.4 B
Annual Savings: Comprehensive Costs	$37.7 B	$211.5 B	$447.1 B
Annual Savings Per AV: Economic Costs Only	$2,000	$1,610	$1,670
Annual Savings Per AV: Comprehensive Costs	$2,960	$3,320	$3,900
Net Present Value of AV Benefits minus Added Purchase Price: Economic Costs Only	$5,210	$7,250	$10,390
Net Present Value of AV Benefits minus Added Purchase Price: Comprehensive Costs	$12,510	$20,250	$26,660
Assumptions			
Number of AVs Operating in U.S.	12.7 M	63.7 M	114.7 M
Crash Reduction Fraction per AV	0.5	0.75	0.9
Freeway Congestion Benefit (delay reduction)	15%	35%	60%
Arterial Congestion Benefit	5%	10%	15%
Fuel Savings	13%	18%	25%
Non-AV Following-Vehicle Fuel Efficiency Benefit (Freeway)	8%	13%	13%
VMT Increase per AV	20%	15%	10%
% of AVs Shared across Users	10%	10%	10%
Added Purchase Price for AV Capabilities	$10,000	$5,000	$3,000
Discount Rate	10%	10%	10%
Vehicle Lifetime (years)	15	15	15