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16. Abstract

This report considers a broad range of emerging transportation technologies that have potential for enhancing travel on and operations of the Texas transportation system. It provides an overview of technology classifications and assesses the policy implications of emerging vehicle and infrastructure technology classifications—namely, connected, autonomous, and electric vehicle technologies—as well as cloud computing and crowdsourcing in the context of transportation systems and services. The researchers assessed these technologies in terms of their ability to further state and national transportation goals. Also assessed were barriers to adoption and promotion at various development stages. Research is presented on new policies and institutional changes that are being implemented outside of Texas. Finally, policy implications for Texas are discussed.

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POLICY IMPLICATIONS OF EMERGING VEHICLE AND INFRASTRUCTURE TECHNOLOGY

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DISCLAIMER

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EXECUTIVE SUMMARY

POLICY IMPLICATIONS OF EMERGING VEHICLE AND INFRASTRUCTURE TECHNOLOGY

Content in this report has greatly been supported and developed by a special task force created by the State of Texas with the sole mission of identifying new and emerging technologies, prioritizing the promotion of such technologies, and developing a plan for their implementation.

The Texas Department of Transportation's (TxDOT) mission is to provide a safe and reliable transportation system for Texas, while addressing congestion, connecting Texas communities, and becoming a best-in-class state agency. In an effort to help TxDOT achieve its mission, researchers worked with the specially established Texas Technology Task Force (TTTF). The TTTF was formally created in February 2013, and after General Appropriations Bill, S.B. No. 1, Eighty-third Legislature, item 44, VII-31 (2013) was passed, TxDOT and the TTTF were directed to oversee a study on transportation technology. Through guidance from a technology industry expert panel, the TTTF has developed a vision for the future Texas transportation system that furthers these goals via technology-based solutions. The TTTF met from March to August of 2013 (Phase I) to develop a set of recommendations for continuing work in a second phase of a technology study.

The TTTF completed work in two phases. Those phases are described below.

Phase I of the Texas Technology Task Force

Three objectives were established for Phase I:

1. Assemble a panel of subject matter experts drawn from industry and the public sector to identify key emerging technologies likely to impact transportation over the next five to twenty years.
2. Convene the TTTF to identify key emerging technologies and outline a path to implementation by analyzing policy, economic, and institutional barriers.
3. Develop recommendations for an initial program of work for a public-private consortium and next steps.

Phase II of the Texas Technology Task Force

Phase II of the TTTF project focused on the initial work toward a strategic technology business plan for the state. Phase II saw the completion of initial background work for the establishment of the strategic business plan following recommendations from Phase I.

TRANSPORTATION TECHNOLOGY IN TEXAS

Social, economic, and travel trends demonstrate why Texas should invest in the adoption and diffusion of the new technologies discussed. Several national and state efforts are underway to encourage research, development, and implementation of emerging transportation technologies in Texas. Travel statistics show increased travel on the Texas system, and long commutes and congestion in the state's metro areas. Texas ranks second among all U.S. states in total fuel consumption and carbon emissions. The new emerging technologies offer capabilities that show potential for improving these trends.

Identification of Emerging Transportation Technologies

The research team, under the direction of the experts on the TTTF, classified emerging transportation technologies into the following four broad classes.

Connected Vehicles

Connected vehicle (CV) technologies allow secure, interoperable, networked wireless communications among, vehicles, infrastructure, and personal communication devices. Devices collect and share data over global or local communication networks related to important safety and mobility information such as vehicle position, speed, vehicle size, traffic signal information, and pavement and weather conditions. CV technologies could enable a safer transportation system, support better connected communities, enhance mobility, enable environmental-sensing solutions to help save lives, prevent injuries, ease traffic congestion, and improve the environment.

Autonomous Vehicles

Autonomous vehicles (AV) are capable of accomplishing navigation and driving tasks with limited-to-no human input, based on sensing of their environment through technologies such as

radar, lidar, GPS, and image recognition (computer vision). Benefits may include, but are not limited to, reduced traffic collisions due to elimination of human driver errors (including distraction, inattention, and aggressive driving); greater system reliability and faster reaction times; smarter, greener driving and navigation; reduced need for urban land for parking due to autonomous parking capabilities; and increased access to travel by individuals who face obstacles due to age, physical impairment, or low income.

Electric Systems

Vehicle electric systems include DC fast-charging stations along highways and wireless electricity transfer technologies that may be embedded within a roadway to provide ongoing power supply to electric vehicles. Fast chargers and in-road, wireless charging can help connect Texas communities by removing distance constraints imposed by vehicle battery capacity, opening up long-distance travel in electric vehicles. Other advances in technology may allow for smart-metering and more efficient use of electric infrastructure (e.g., smart grid) for vehicle charging.

Crowdsourcing and Cloud Computing

Two emerging technologies are coming together to enhance data services for transportation: cloud computing and crowdsourcing. Cloud computing makes information technology (IT) infrastructure, platforms, and software available on the Internet, and allows end-users to remotely access high-powered computing and data archiving resources through broadband connections. Crowdsourcing allows for fast collection and synthesis of information from system users through telematics and applications. Combined with advanced big data analytics, these tools could enable better system management, organization efficiency, and public communication.

ASSESSMENT OF GOALS AND BARRIERS TO ADOPTION

Once technologies were categorized and described, the next task was to analyze the ability of technologies to further state and national transportation goals and identify existing barriers to adoption and promotion. The TTTF took a unique approach to this task, viewing the technologies in three stages that corresponded to development and activities at each development stage. These were defined as

1.1) initial idea and prototype testing stage on closed systems,

1.2) large-scale field validation stage on public roadways, and

2.1) initial deployment stage and commercialization stage.

ASSESSMENT OF TRANSPORTATION TECHNOLOGY GOALS, ISSUES, AND CONCERNS

Next, the TTTF developed a series of matrices designed to expose potential barriers to technology adoption and to reveal benefits that could be realized through their use. First, the degree to which different technologies and applications generate benefits to serve the Texas' overarching goals was assessed. These benefits include the following:

- **State of Texas Goal**: Economic Development
- **TxDOT Goals**: Safety Enhancement, Congestion Mitigation, Connecting Texas Communities, and Becoming a Best-in-Class Agency
- **USDOT Goals**: Infrastructure Condition, System Reliability, Environmental Sustainability, and Reduced Project Delivery

Next, issues and concerns related to individual transportation technologies or combined technology applications were analyzed in terms of each of the three development phases. As with the proposal goals, issues and concerns were separated into three categories:

- **Public Agency Concerns**: Institutional, Infrastructure, Regulatory, Policy, and Public Cost Concerns
- **Societal Concerns**: Safety, Energy, and Other Public Concerns (e.g., privacy, disparate income impact, neighborhood concerns, etc.)
- **Technology to Market Concerns**: Private Cost, Time Required for Development and Deployment, and Technology Concerns

Factors that were considered in the evaluation of these matrices are shown in Tables ES1 and ES2.

Table ES1: Factors Considered in Goal Rankings

Proposal Goal	Factor Consideration
Economic development	• Quantity and quality of jobs directly created in Texas
Safety	• Crash frequency reduction • Crash severity reduction
Congestion	• Decreased hours of congested travel • Improved traffic flows during congestion • Improved travel time reliability
Connect Texas communities	• Enhanced access to goods and services • Increased Texas gross state product • Public relations and dissemination of information to Texas communities
Best-in-class agency	• Agency able to deploy resources more efficiently
Infrastructure condition	• Direct improvement to infrastructure condition • Indirect improvement to infrastructure condition
System reliability	• Improved system efficiency
Environmental sustainability	• Reduced fuel and energy consumption • Reduced air pollutant emissions, to meet EPA standards
Reduce project delivery	• Reduced project delivery delays due to shortened time during construction

Table ES2: Factors Considered in Issues and Concerns Rankings

Proposal Issues & Concern	Factor Consideration
Institutional	• Internal public transportation agencies changes • Potential new agency positions and duties • Technology standardization and coordination • Cross-agency and private institution collaboration
Infrastructure	• Extent of new infrastructure required • Existing infrastructure repurposed
Regulatory	• Legislative regulatory changes (may be helpful or necessary) • Administrative regulatory changes (may be helpful or necessary)
Policy	• Public agency direction and support
Cost, public	• Direct public agency costs
Safety	• New crashes or incidents otherwise avoidable • Increased crash or incident severity • Electronic security vulnerabilities
Energy	• Energy consumption of new technology greater than potential savings
Public concerns	• Disparate impacts across income groups • Privacy concerns • Neighborhood concerns • Other non-safety or energy concerns
Cost, private	• Consumer technology purchase costs • Corporate technology development costs
Time (develop & deploy)	• Timeframe required to complete phase after entering
Technology	• Technical barriers technology development

The research team's most notable observation was that higher levels of automation provide the capability to greatly further state transportation goals, especially in safety- and mobility-related areas. Also, the combined capabilities of AV and CV technologies offered substantial benefits that may not be realized through stand-alone technologies. Substantial issues and concerns appear to present barriers to new technology development and promotion, especially as the technologies progress through development phases. Interestingly, the technologies and applications that show the greatest promise also largely warrant the greatest concern. During the initial deployment and commercialization phase, infrastructure and public costs represent substantial challenges for CV technology. Infrastructure-focused safety and mobility systems are significant concerns during both public road testing and initial deployment phases. Once initial deployment and commercialization begins, additional concerns become more prominent, including public worries about privacy and increasing government control.

IMPLICATIONS FOR TEXAS

A review of the current state of the practice in emerging transportation technologies revealed several critical insights for the state of Texas and, ultimately, the following final observations for institutional and policy development for the State were developed.

- **Policies and legislation**: Regulatory and legislative barriers that may need to be addressed to encourage and enable new technologies may include (but are not limited to) vehicle permitting and testing, insurance and liability, equipment certification, operation certification, requirements on accident reporting, licensing, driver requirements, performance standards and monitoring, data ownership, data security, data ownership, etc.
- **Standards and licensing**: For the state of Texas, it might not be necessary to initiate the development of a new set of standards and licensing procedures; instead, the State could track and monitor existing efforts and adopt "well-accepted" standards and procedures.
- **Technology development**: For Texas to stand out among other states in promoting emerging transportation technologies, the real opportunity is to provide an open and supportive environment for technology developers or industry research and development. Such an environment should address some of the key barriers found in other states, such

as lack of financial support and economic stability; legislative barriers to testing technologies; and the lack of data, infrastructure, and facility support.

- **Market and economic development**: The State should continue to support economic and market development, taking advantage of the vibrant economy, technology foundation, investment opportunities, and the consumer market. Market development will place Texas in a prime position, promoting and leading the effort in technology development. Doing so requires that TxDOT and state government facilitate and collaborate with private sectors in creating a healthy, sustainable, and economically viable environment.

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Chapter 1. Emerging Transportation Technology: Introduction and Background

This chapter provides the context of and motivation for the need to promote new and emerging technologies for transportation system solutions in the State of Texas. Content in this report has greatly been supported and developed by a special task force created by the State of Texas; this task force has the sole mission of identifying new and emerging technologies, prioritizing the promotion of such technologies, and developing a plan for their implementation. Background on this special task force is provided in this chapter as well as background and context of the current transportation system within Texas. A vision for the future transportation system is provided, and related national and state actions that motivate technology investigation and promotion in Texas are described.

1.1. Background Information

The Texas Department of Transportation's (TxDOT) mission is to provide a safe and reliable transportation system for Texas, while addressing congestion, connecting Texas communities, and becoming a best-in-class state agency. In an effort to help TxDOT achieve its mission, researchers worked with the specially established Texas Technology Task Force (TTTF). The TTTF was formally created in February 2013, and after General Appropriations Bill, S.B. No. 1, Eighty-third Legislature, item 44, VII-31 (2013) was passed, TxDOT and the TTTF were directed to oversee a study on transportation technology. Through guidance from a technology industry expert panel, the TTTF has developed a vision for the future Texas transportation system that furthers these goals via technology-based solutions. The TTTF met from March to August of 2013 (Phase I) to develop a set of recommendations for continuing work in a second phase of a technology study. The recommendations from Phase I are provided below; the subsequent section of this chapter provides an overview of additional work completed in Phase II.

1.1.1 Phase I of the Texas Technology Task Force

Three objectives were established for Phase I:

1. Assemble a panel of subject matter experts drawn from industry and the public sector. This panel became the TTTF, which ultimately identified key emerging technologies likely to impact transportation over the next five to twenty years. Three in-state meetings were held with members between April and July 2013, at which members worked to develop a vision and recommendations for furthering emerging technologies.
2. Convene the task force to identify key emerging technologies and outline a path to implementation, addressing policy, economic, and institutional barriers. Results from the completion of the second objective included a list of the key emerging technologies the state should immediately address; preparation of a preliminary analysis of policy; identification of economic and institutional barriers to be addressed in order to enable and encourage development and adoption of the emerging technologies while minimizing potential negative impacts; and an assessment of the steps necessary to position TxDOT to develop strategies that utilize technology to make transportation safer and more efficient. Based on guidance from the TTTF, three white papers were developed on identified emerging technologies. These papers included details on the state of identified technologies, their applications in Texas, and critical areas for further investigation.
3. Make recommendations for an initial program of work for a public-private consortium and next steps. The result of this objective included recommendations for an initial program of work for a public-private consortium that would be supportive of emerging technologies based on findings from the first two tasks. It also included recommendations for next steps, continuing research, and further potential legislative and/or policy recommendations.

The following implementation strategies were the final TTTF recommendations from Phase I's third objective and are intended to lay a framework for moving toward the vision for emerging technologies in Texas.

- Incubator – Create an organization to act as a technology incubator focused on disruptive transportation technologies. The key differentiator for this incubator is the public partnership with TxDOT where ideas and innovations can be tested and proven in a real-world environment. Technology support services and resources may be offered to emerging technology partners.

- Public-Private Partnership – Use a range of approaches to create an organizational structure that facilitates economic development in emerging industries via collaboration and coordination among the public, private, and not-for-profit/academic sectors. Such partnerships will create intellectual capital and technology that can be shared to the common benefit or focus on bringing new and evolving technologies to market.
- Pilot Program – Conduct a pilot program within Texas to encourage and enable the development of new transportation technologies. The pilot program would collect specific data through testing for evaluating alternatives to the existing transportation regulations, or create innovative approaches to safety and ensure that the safety performance goals of the regulations are satisfied for a preselected technology.
- Legislative and Regulatory Changes – Identify regulatory and legislative barriers to emerging transportation technologies, and provide support on addressing them.

1.1.2. Phase II of the Texas Technology Task Force

Recommendations from Phase I supported the establishment of partnerships and other efforts that would provide continued support in the pursuit of emerging technology goals. A first step toward partnership and goals is a strategic business plan. Phase II's sole task was to start initial work to support the creation of a business plan that would ultimately serve to facilitate partnerships between public and private participants in technology. Such partnerships will be integral to enabling TxDOT's vision of providing a safe and reliable transportation system for Texas, while addressing congestion, connecting Texas communities, and becoming a best-in-class state agency. Phase II of the TTTF project focused on the initial work toward a strategic technology business plan for the state. Phase II saw the completion of initial background work for the establishment of the strategic business plan following recommendations from Phase I. The intention is that in later phases of the technology study, the strategic business plan will be completed to fully demonstrate how public and private partners can collaborate in the creation of an economic roadmap to diversify and strengthen the state economy and transportation system though transformative emerging technology adoption. Final contents of the plan will provide an analysis of the State's transportation, information, and communication technology industries, establish state goals and objectives, develop an action plan for implementation, and articulate investment priorities and funding sources.

Preliminary work was completed in Phase II on the following topics:

- Review of technology development plans in other states, at the national level, and abroad
- Development of the work plan for a Strategic Business Plan for the State
- Environmental scan identifying useful resources for transportation technology initiatives in Texas
- SWOT (strengths/weaknesses/opportunities/threats) analysis of various technologies
- Vision and strategy development

1.2 Transportation Technology in Texas

This section provides a background on the current state of the Texas transportation system and illustrates how emerging automotive, information, and communication technologies could benefit the Texas transportation system in terms of safety, operational efficiency, reliability, and air quality. Social and economic trends that demonstrate why Texas should invest in the adoption and diffusion of new technologies are discussed, and finally an overview is given on national and state efforts to research, develop, implement, and encourage emerging transportation technologies.

1.2.1 The Texas Transportation System of Today

In 2012 3,399 traffic fatalities occurred on Texas roads—an 11% increase in fatalities from 2011. Total vehicle miles traveled in Texas increased by 1.34% from 2011 to 2012 (to roughly 240 billion miles), and the estimated economic loss of all motor vehicle crashes in Texas jumped from $23.4 billion in 2011 to $26 billion in 2012 (a historical high) [1]. A report by the Texas Transportation Institute compared urban congestion and delay in U.S. cities, ranking five Texas cities among the 56 worst in terms of delay (Dallas was 6th, Houston 9th, Austin 32nd, San Antonio 38th, and El Paso 56th). Annual delay per peak hour in these Texas cities ranged from 32 to 52 hours [2]. Texas consumed more than 15.6 billion gallons of gasoline and diesel fuels in 2009 and was ranked second in the U.S. in total fuel consumption [3]. In 2010, the U.S. Energy Information Administration reported that Texas ranked first in energy-related carbon dioxide emissions by state, with 650 million metric tons carbon dioxide emitted in that year (a 300

million metric ton difference between Texas and the second-ranked state). When considering transportation-related carbon emissions only, Texas ranked second only to California, with 195 million metric tons [4].

1.2.2. The Texas Transportation System of the Future

With the adoption and diffusion of emerging automotive, information, and communication technologies that interface with the transportation system, major issues such as those highlighted above may be mitigated. Texas drivers could experience safer roads and vehicles, less congestion, greater mobility, and better air quality, and TxDOT may be able to more efficiently allocate and utilize limited resources. Emerging state-of-the-art transportation technologies could decrease automobile crashes and fatalities through partially or even fully automated vehicles, connected vehicles, and in-vehicle safety applications [5]. Real-time information, crowdsourcing, and data analytics could instantly provide updates on roadway conditions and hazards to state maintenance crews and drivers, resulting in quicker emergency response as well as crash prevention. Texans may experience greater energy efficiency and better air quality by shifting away from petroleum-based fuels and toward alternative fuels (such as in the form of electric vehicles). Cloud computing and crowdsourcing may provide increased efficiency in DOT operations and public outreach.

1.2.3 National and State Actions that Motivate Efforts in Texas

At the national and state level, multiple efforts have begun that indicate interest in emerging technology adoption. Such efforts are described below.

Subtitle C—Intelligent Transportation System Research of Public Law 109-59, Safe Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users, enacted August 10, 2005, directed the Intelligent Transportation Systems' Joint Program Office (ITS JPO), within the Research and Innovative Technology Administration (RITA), to organize and oversee ongoing intelligent transportation system (ITS) program research to accomplish the following:

- Work toward development of an ITS
- Operationally test ITS

- Provide technical assistance in the nationwide application of ITS

The current research portfolio of the ITS JPO includes research on specific connected vehicle technologies and their performance, international ITS standards, human factors, systems engineering, pilot programs, real-time data capture, dynamic mobility applications, and other topics. The ITS JPO updated its latest version of the National ITS Strategic Research Plan for 2010–2014 in October 2012. The plan describes the status of national research programs that were established by the U.S. Department of Transportation (USDOT) in 2010 and relate primarily to connected vehicles.

The report highlights critical ITS areas that have seen advances in research, such as the following:

- Safety enhancement capabilities of connected vehicles, dedicated short-range communication (DSRC), and other communication technologies
- Policy research on institutional barriers and security
- Mobility, environment, and road weather management applications, including data capture and management
- Connected vehicle applications and technologies based on the existing cellular network and smart in-vehicle and personal devices
- Other connected-vehicle topics

Another national entity that is a key player in transportation technology research and implementation is the National Highway Traffic Safety Administration (NHTSA). This agency has a number of research focuses and is responsible for carrying out safety programs aimed at reducing fatalities, injuries, and economic losses that result from vehicle crashes. The NHTSA does this by determining and enforcing safety performance standards for motor vehicles and motor vehicle equipment. The NHTSA is federally funded and awards grants to local and state government agencies to enable them to carry out effective local highway safety programs.

On occasion, the NHTSA issues policy statements for emerging transportation technologies that have not been fully developed, tested, or commercialized. For example, the NHTSA released a policy statement regarding autonomous vehicles (AVs) on May 14, 2013, providing

recommendations to states regarding testing and licensing AVs on public roadways. The NHTSA has not yet released any official restrictions or safety performance standards for AVs, but it has proposed an extensive research program to gain insight into AV operations, performance, and licensing. The full research program has begun for partial AVs and will turn to full AVs in future years. The NHTSA has been involved in researching a number of connected vehicle testbeds across the U.S. in collaboration with the USDOT, the ITS JPO, and university research centers [6].

At the state level, California, Florida, Michigan, and Nevada have passed legislation regarding AVs with the purpose of allowing licensing of fully AVs on public roads for the sole purpose of testing. Testing first began in 2011 in Nevada and expanded to California and Florida in 2012 and Michigan in 2013 [7]. Other states have passed or proposed state legislation directing committees or task forces to research AVs and make recommendations for their licensing, performance standards, and regulation in the next two to three years. In states where vehicle performance standards, regulations, and licensing are being developed, the state Departments of Motor Vehicles have been directed to work with the state Departments of Transportation to develop and enforce standards and regulations.

Chapter 2. Identification of Emerging Transportation Technologies

Researchers completed a thorough scan of literature and media in order to establish a list of new, emerging technologies for the purposes of further investigation, research, and analysis. Initially, a list of 142 relevant resources covering a wide variety of related topics was developed and distributed to the TTTF members. The comprehensive list was used to gain an understanding of all possible technologies for consideration, the primary way in which a particular technology could be used to enhance the transportation system or operations, and the broader technology classification in which it belongs. The researchers used the broad classifications from the USDOT's RITA National Intelligent Transportation Systems Architecture [8] as a starting point. Technologies were then categorized into distinct technology types for the next stage of discussion. Finally, emerging technologies from the comprehensive scan were grouped into four larger categories under direction of the task force.

The following section provides an overview of the three stages of technology classification that was used, including the RITA ITS architecture, broad categorizations of technology, and the final four technology classifications that were adopted by the TTTF.

2.1 Existing Technology Classification: National ITS Architecture

The National ITS Architecture developed and maintained by RITA provides definitions and standard relationships for technology elements used in intelligent transportation systems. In addition, the Architecture classifies technological components by use (called User Services Bundles) and sub-uses (called User Services). The following ITS Architecture User Service Bundle categories served as a guide in the literature scan, ensuring that technological components under each use were sought out for consideration.

- Archived Data Management
- Commercial Vehicle Operations
- Emergency Management
- Maintenance and Construction Management
- Public Transportation
- Traffic Management

- Traveler Information
- Vehicle Safety

2.2 Broad Technology Groups

Next, researchers grouped technologies identified in the literature and media scan into groups by technology type. The following emerging technology types were identified.

- Connected Vehicles
- Connected Cities
- Probe Data
- Cloud Computing
- Mobile Applications
- Autonomous Vehicles
- Vehicle-to-vehicle (V2V)
- Vehicle-to-infrastructure (V2I)
- Big Data
- Energy Systems
- Finance-related technology

Next, the task force and researchers categorized all found emerging technologies into the final four broad technology classifications.

2.3 Technology Classification and Technology Evaluation and Assessment by the Task Force

The following section describes broad technology classifications and their subcomponents, which were used for various assessment and evaluation methods that the TTTF used to gain better understanding of various emerging technologies. Evaluation methods are described in the next chapter.

2.3.1 Technology Classification

The emerging transportation, information, and communication technologies identified from review of the literature and the TTTF-grouped media fall into four broad categories:

- Connected vehicles, which can be further divided into the following:
    - cellular-based technologies
    - DSRC-based technologies
- Autonomous vehicles
- Electric systems
- Cloud computing and crowdsourcing

Each technology class is described below, including a discussion of the state of the technology.

2.3.1.1 Connected Vehicles

Connected vehicle (CV) technologies allow secure, interoperable, networked wireless communications among vehicles, infrastructure, and personal communication devices. Devices collect and share data over global or local communication networks related to important safety and mobility information such as vehicle position, speed, vehicle size, traffic signal information, and pavement and weather conditions. CV technologies could enable a safer transportation system, support better connected communities and enhance mobility, enable environmental-sensing solutions to help save lives, prevent injuries, ease traffic congestion, and improve the environment.

To date, there has been much research and development (R&D) of CV technologies. The NHTSA and RITA have been working with state and other federal agencies and auto industry partners to research CV technologies through a handful of pilot programs since August 2011 [9]. The most notable of these, in Ann Arbor, Michigan, has deployed nearly 3,000 CVs in the largest road test of V2V technology to date [10]. Experiments in these programs have examined how drivers interact with CV technologies and how the technology performs in simulated and real-world situations. Specifically, testing has been conducted to understand how drivers and vehicles respond to warnings about approaching blind intersections, changing lanes, approaching another vehicle's blind spot, and avoiding a rear collision with a vehicle stopped ahead [9]. These pilot programs have led to the NHTSA's ambitious mandate of CV technologies onboard all light-

duty vehicles in future years. After analysis its findings and reporting its pilot program results, the agency will move forward with drafting a regulatory proposal requiring V2V communication technology on new vehicles, to be consistent with relevant legal requirements, executive orders, and guidance. Such an announcement sends a strong message to automotive, communications, and other relevant industries to pursue R&D for CV applications [10].

2.3.1.2 Autonomous Vehicles

Autonomous vehicles (AV) are capable of accomplishing navigation and driving tasks with limited-to-no human input, based on sensing their environment through technologies such as radar, lidar, GPS, and image recognition (computer vision). Benefits may include, but are not limited to, reduced traffic collisions due to elimination of human driver errors (including distraction, inattention, and aggressive driving); greater system reliability; faster reaction times; smarter, greener driving and navigation; reduced need for urban land for parking due to autonomous parking capabilities; and increased access to travel for individuals who face obstacles due to age, physical impairment, or low income.

R&D of AVs was heavily spurred by the Defense Advanced Research Projects Agency (DARPA) Grand and Urban Challenges in 2004, 2005, and 2007, in events that allowed early AVs to interact with other autonomous and non-autonomous vehicles for the first time in an urban environment [11]. Since then, private companies such as Google and a number of automobile manufacturers have been continuously developing their AV systems. Google's full AV has tested 500,000 crash-free hours using technology that Google says will be available to drivers by 2018 [12]. In addition, Google has announced plans for a low-speed, electric, full AV specifically for urban and suburban environments [13]. Manufacturers have developed technologies of varying automation levels; General Motors, Volkswagen, Toyota, Nissan, Volvo, and BMW, among others, have released plans for increased automated technologies in future-year vehicles. Policy makers have demonstrated interest in supporting AV developments and adoption. At the national level, the NHTSA has released a statement standardizing definitions of the levels of autonomy and laying out a comprehensive AV research plan to inform and develop broad safety regulations [14]. Automation levels were defined by the NHTSA on a graduated scale from level 0 (have no automated features) to level 4 (fully automated). A distinction of lower levels of automation (levels 1 and 2) from higher levels of automation (levels 3 and 4) was

made by the TTTF for evaluation and assessment purposes. Finally, across the U.S., notable policies are increasingly being developed and adopted to allow AV testing on public roads and to allow for licensing of such vehicles [15].

2.3.1.3 Electric Systems

Vehicle electric systems include DC fast-charging stations along highways and wireless electricity transfer technologies that may be embedded within a roadway to provide ongoing power supply to electric vehicles. Fast chargers and in-road, wireless charging can help connect Texas communities by removing distance constraints imposed by vehicle battery capacity, opening up long distance travel in electric vehicles. Other advances in technology may allow for smart-metering and more efficient use of electric infrastructure (e.g., smart grid) for vehicle charging. Already, research labs and universities have been experimenting with and developing such systems: Utah State University and Stanford University have demonstrated successful small-scale, wireless, in-road vehicle charging capabilities [16][17]. In Victoria, Australia, demonstrations have been completed that use smart (electric) grids to optimally manage electric vehicle charging, thus improving charging efficiency, access, and demand management [18].

2.3.1.4 Crowdsourcing and Cloud Computing

Two emerging technologies are coming together to enhance data services for transportation: cloud computing and crowdsourcing. Cloud computing makes information technology (IT) infrastructure, platforms, and software available on the Internet, and allows end-users to remotely access high-powered computing and data archiving resources through broadband connections. Crowdsourcing allows for fast collection and synthesis of information from system users through telematics and applications. Combined with advanced big data analytics, these tools could enable better system management, organization efficiency, and public communication. Vehicle and environmental data can be gathered via computer vision, GPS, and onboard sensors and then shared through a number of complementary technologies such as 3G, LTE, WLAN, Wi-Fi, and DSRC. Once aggregated, large volumes of data can be processed and analyzed via cloud computing and provide the foundation for crowdsource applications such as car-sharing apps.

Chapter 3. Assessment of Goals and Barriers to Adoption

Once technologies were categorized and described, the next task was to assess existing barriers to adoption and promotion. The task force took a unique approach to this task: technologies were viewed in three stages that corresponded to development and activities at each development stage in an early development-to-adoption trajectory. These three stages are described below. The identified barriers to adoption are presented for each stage, as these barriers will likely change as the technologies mature.

3.1 Technology Development Stages

The defined technology stages and their associated activities attempt to provide a full picture of the characteristics and needs of different technologies at different development phases. The technology development process can be generally divided into two major phases: R&D and deployment. Each phase can also be further divided. For identification of barriers, the R&D phase included these two development stages: *1.1) initial idea and prototype testing stage on closed systems*, and *1.2) large-scale field validation stage on public roadways*. The deployment phases can generally be classified into these development stages: *2.1) initial deployment stage and commercialization stage*, *2.2) transitional stage from legacy technologies to new technologies*, and *2.3) the fully converted system under new technologies*. For purposes of barrier identification, only the first three stages were evaluated (1.2–2.1), as it was believed that adoption would be largely successful during the last two phases (2.2–2.3).

3.2 Assessment of Transportation Technology Goals, Issues, and Concerns

Next, the TTTF developed a series of matrices designed to expose potential barriers to technology adoption and to reveal benefits that could be realized through their use. The first matrix notes the anticipated degree to which different technologies and applications generate benefits to serve the Texas' overarching goals. These benefits include the following:

- **State of Texas Goal**: Economic Development
- **TxDOT Goals**: Safety Enhancement, Congestion Mitigation, Connecting Texas Communities, and Becoming a Best-in-Class Agency

- **USDOT Goals**: Infrastructure Condition, System Reliability, Environmental Sustainability, and Reduced Project Delivery

For the purposes of this assessment, the State of Texas' goal of economic development is considered the highest priority, followed by TxDOT's goals, and lastly the USDOT's goals (those specified in MAP-21, but not directly covered by other State of Texas or TxDOT goals).

The second set of three matrices notes issues and concerns that may be encountered by individual transportation technologies or combined technology applications. These are broken into three distinct phases outlined earlier: prototyping and closed testing, testing on public roadways, and initial deployment and commercialization. As with the proposal goals, issues and concerns are separated into these three categories:

- **Public Agency Concerns**: Institutional, Infrastructure, Regulatory, Policy, and Public Cost Concerns
- **Societal Concerns**: Safety, Energy, and Other Public Concerns (e.g., privacy, disparate income impact, neighborhood concerns, etc.)
- **Technology to Market Concerns**: Private Cost, Time Required for Development and Deployment, and Technology Concerns

Ratings in these matrices represent the degree of concern required to progress from one phase to the next, rather than from the present day to that phase or beyond. Factors that were considered in the evaluation of these matrices (presented as Table 3) are shown in Tables 1 and 2.

Table 1: Factors Considered in Goal Rankings

Proposal Goal	Factor Consideration
Economic development	• Quantity and quality of jobs directly created in Texas
Safety	• Crash frequency reduction • Crash severity reduction
Congestion	• Decreased hours of congested travel • Improved traffic flows during congestion • Improved travel time reliability
Connect Texas communities	• Enhanced access to goods and services • Increased Texas gross state product • Public relations and dissemination of information to Texas communities
Best-in-class agency	• Agency able to deploy resources more efficiently
Infrastructure condition	• Direct improvement to infrastructure condition • Indirect improvement to infrastructure condition
System reliability	• Improved system efficiency
Environmental sustainability	• Reduced fuel and energy consumption • Reduced air pollutant emissions, to meet EPA standards
Reduce project delivery	• Reduced project delivery delays due to shortened time during construction

Table 2: Factors Considered in Issues and Concerns Rankings

Proposal Issues & Concern	Factor Consideration
Institutional	• Internal public transportation agencies changes • Potential new agency positions and duties • Technology standardization and coordination • Cross-agency and private institution collaboration
Infrastructure	• Extent of new infrastructure required • Existing infrastructure repurposed
Regulatory	• Legislative regulatory changes (may be helpful or necessary) • Administrative regulatory changes (may be helpful or necessary)
Policy	• Public agency direction and support
Cost, public	• Direct public agency costs
Safety	• New crashes or incidents otherwise avoidable • Increased crash or incident severity • Electronic security vulnerabilities
Energy	• Energy consumption of new technology greater than potential savings
Public concerns	• Disparate impacts across income groups • Privacy concerns • Neighborhood concerns • Other non-safety or energy concerns
Cost, private	• Consumer technology purchase costs • Corporate technology development costs
Time (develop & deploy)	• Timeframe required to complete phase after entering
Technology	• Technical barriers technology development

Table 3: Goals, Issues, and Concerns Relating to Emerging Transportation Technologies and Applications

Proposal Goals		V2V	V2I	Electr	CI + CS	A1 & A2	A3 & A4	Joint Technology Systems				
								V-F Safety	I-F Safety	V-F Mobility	S-F Mobility	Energy
Texas Goals	Economic development	3	3	3	3	3	4	4	4	4	4	3
TxDOT Goals	Safety	4	3	1	2	3	5	5	5	2	2	1
	Congestion	4	3	1	2	2	4	3	3	5	5	2
	Connect TX communities	2	3	1	3	1	4	1	2	4	4	1
	Best in class agency	2	3	2	3	1	3	4	4	3	3	3
Other USDOT Goals (MAP-21)	Infrastructure condition	2	3	1	2	1	2	2	3	2	3	1
	System reliability	3	3	2	3	2	3	3	3	3	4	2
	Environmental sustain.	2	2	4	2	1	2	1	1	3	3	4
	Reduce proj. delivery	2	2	1	2	1	1	2	2	2	2	1

Stage 1.1: Prototyping & Closed Testing

Issues & Concerns		V2V (DSRC/Cell)		V2I (DSRC/Cell)		Electr	CI + CS	A1 & A2	A3 & A4	Joint Technology Systems				
										V-F Safety	I-F Safety	V-F Mobility	S-F Mobility	Energy
Public Agency	Institutional	3	1	3	2	2	3	3	3	2	3	2	3	2
	Policy	3	2	3	2	3	2	2	3	2	2	2	2	2
	Regulatory	1		2		3	3	2	3	2	2	2	2	2
	Infrastructure	1		3	2	3	2	1	1	1	2	2	2	2
	Cost - Public	2		2		2	1	1	2	2	2	2	2	2
Societal	Safety	1		1		2	1	2	2	1	1	1	1	2
	Energy	1		1		2	1	1	2	1	1	1	1	1
	Public Concerns	1		1		2	1	1	2	1	1	1	1	1
Technology to Market	Time (Develop & Deploy)	2		2		2	1	2	3	3	3	3	3	2
	Technology	2		2		2	1	2	3	3	3	3	3	3
	Cost - Private	2		2		3	2	3	3	3	3	3	3	2

Stage 1.2: Testing on Public Roadways

Issues & Concerns		V2V (DSRC/Cell)		V2I (DSRC/Cell)		Electr	CI + CS	A1 & A2	A3 & A4	Joint Technology Systems				
										V-F Safety	I-F Safety	V-F Mobility	S-F Mobility	Energy
Public Agency	Institutional	3	2	3	2	3	3	2	3	2	3	2	3	2
	Policy	3	2	3	2	3	2	2	3	3	3	3	3	2
	Regulatory	3	2	3	2	3	2	2	3	3	3	3	3	2
	Infrastructure	2		3	1	3	2	1	2	2	3	2	3	2
	Cost - Public	3	1	3	1	2	2	1	2	2	3	2	3	2
Societal	Safety	1		1		2	1	2	3	2	2	4	4	1
	Energy	1		1		1	1	1	1	1	1	2	2	1
	Public Concerns	2		2		2	2	1	3	3	3	3	3	2
Technology to Market	Time (Develop & Deploy)	2		2		3	1	1	3	4	4	3	3	2
	Technology	3		2		2	1	2	3	3	3	3	3	2
	Cost - Private	3		3		3	1	2	3	2	2	2	2	2

Stage 2.1: Initial Deployment & Commercialization

Issues & Concerns		V2V (DSRC/Cell)		V2I (DSRC/Cell)		Electr	CI + CS	A1 & A2	A3 & A4	Joint Technology Systems				
										V-F Safety	I-F Safety	V-F Mobility	S-F Mobility	Energy
Public Agency	Institutional	3		3	2	2	3	2	3	2	3	2	3	3
	Policy	3		3	1	2	2	2	3	3	3	3	3	3
	Regulatory	3	2	3	2	2	3	2	4	3	3	3	3	3
	Infrastructure	2		4	2	3	2	2	2	2	4	2	4	3
	Cost - Public	3	1	3	1	3	2	2	2	2	4	2	4	3
Societal	Safety	2		2		2	1	2	3	3	3	4	4	2
	Energy	1		1		1	1	1	1	1	2	1	2	2
	Public Concerns	3		2		2	2	1	4	3	3	3	4	2
Technology to Market	Time (Develop & Deploy)	3		3		2	1	1	3	3	3	3	3	3
	Technology	2		2		2	1	2	4	3	3	3	4	2
	Cost - Private	2		3		3	1	2	4	2	3	3	3	3

Matrix Ratings and Rankings Assessments	
Proposal Goals: anticipated benefits	**Issues & Concerns: degree of concern**
0 = none	*0 = none*
1 = minor indirect	*1 = negligible*
2 = minor	*2 = minor*
3 = moderate	*3 = moderate*
4 = substantial	*4 = substantial*
5 = monumental	*5 = insurmountable in near future*

Notes

V2V: Vehicle to vehicle
V2I: Vehicle to infrastructure
Electr: Electric vehicles
CI + CS: Cloud & crowd source
A1 & A2; A3 & A4: Levels of automation
V-F: Vehicle-Focused joint technology systems
I-F: Infrastructure-Focused joint technology systems
The degree of some V2V and V2I issues differ depending on DSRC or cellular implementation, which is denoted by divisions.
Joint technology systems assume multiple base technologies (ex. V2V + A3)

3.2.1. Observations on Matrix Evaluations

From this series of matrices, several observations may be noted. First, the greatest stand-alone technology benefits clearly arrive from level A3 and A4 automation, with a substantial safety and congestion benefits also possible from V2V communication. However, when these individual technologies are combined, new safety and mobility systems may be produced, as noted earlier in this report. These new safety and mobility systems have the potential to produce benefits that compound the already monumental changes anticipated from stand-alone technologies. Safety and congestion in particular may experience seismic benefits through both vehicle- and infrastructure-focused systems, with the advent of new applications like advance collision warning and countermeasures, and cooperative adaptive cruise control.

Unfortunately, substantial issues and concerns remain, and appear to grow more worrisome as development progresses from prototyping and closed testing, to testing on public roadways, to initial deployment and commercialization. While there are no categories with substantial concerns in the prototyping and closed testing phase, there are four such areas when testing on public roads, and thirteen areas by the time the initial deployment and commercialization phase is reached.

Additionally, the technologies and applications that show the greatest promise also largely warrant greatest concern. In particular, automation levels A3 and A4 show many areas where there is a substantial degree of concern, and joint-technology infrastructure-focused safety and mobility systems appear to have more substantive barriers than joint-technology vehicle-focused systems. Joint-technology mobility systems present a key safety concern while testing on public roadways, as is the time required to develop and deploy joint-technology safety applications. During the initial deployment and commercialization phase, infrastructure and public costs represent substantial challenges for V2I. Infrastructure-focused safety and mobility systems are significant concerns during both public road testing and initial deployment phases. Once initial deployment and commercialization begins, additional concerns become more prominent, including public worries about privacy and increasing government control. Other technological concerns are substantial issues facing advanced vehicle automation (A3 and A4) and infrastructure-focused mobility systems. Finally, A3 and A4 face further significant regulatory

concerns like vehicle licensing and cost concerns, as early purchase prices will likely be unaffordable to the vast majority of Texans.

With this in mind, a potential path may be identified to achieving greatest impact among the proposal goals, while minimizing barriers encountered. That path relies on pursuing V2V communication, as well as automation levels A3 and A4, then developing vehicle-focused safety and mobility applications with these combined technologies. This pathway achieves 60% of the areas with potentially “monumental” benefits and 56% of those with “substantial” benefits, while only encountering 41% of areas with the most substantial issues and concerns. Readers should note that this is not to recommend that other technologies and applications should not be pursued, but rather to identify where greatest focus and efforts could be applied.

Chapter 4. Summary of Policy and Institutional Changes in Other States and Federal Agencies

The following sections provide an overview of various new and existing state, national, and international efforts to encourage emerging transportation technology development and adoption.

4.1 Existing Transportation Technology Strategic Plans and Efforts

Research and planning activities conducted or ongoing at the national level were reported in Phase I. The most notable federal planning efforts stemmed from partnerships with key agencies, which included the USDOT and its sub-organizations: the ITS JPO, NHTSA, FHWA (Federal Highway Administration), and RITA. Any known new developments from national efforts are reported in the next section. In addition, new developments from other states undertaking similar, coordinated efforts to develop an implementation plan for new transportation technologies are reported. And finally, new developments and activities from industry are provided.

4.2 New Emerging Transportation Technology Developments at the National Level

The NHTSA and the USDOT released a plan for V2V safety application in CVs in October 2011 [19]. Under this research plan, a pilot program in Ann Arbor, Michigan, was established that included nearly 3,000 vehicles communicating on public roads using DSRC technology, which was the key focus of the pilot program. At the end of the pilot program, which was planned to be at the end of 2013, the NHTSA stated that it would release a decision on whether or not to start putting DSRC technology into production cars, or to do more research. Recently the pilot program recently received a 6-month extension to continue research but the NHTSA has stated that this extension will not change the original plan to release a decision by the end of 2013. Testimony of The Honorable David L. Strickland, NHTSA Administrator, stated that a decision regarding DSRC would still be made in 2013 [20]. It was stated that the decision would come in two parts: the first would relate to DSRC for light-duty vehicles and the second will follow in 2014 and relate to DSRC for heavy-duty vehicles. In --- 2014 NHTSA released an ambitious mandate of CV technologies on-board all light-duty vehicles in future years. After analysis of findings and reporting of its pilot program results, the agency indicated it would still

move forward with drafting a regulatory proposal requiring V2V communication technology on new vehicles, to be consistent with relevant legal requirements, executive orders, and guidance. Such an announcement sends a strong message to automotive, communications, and other relevant industries to pursue R&D for CV applications [21]. Updates on DSRC for heavy-duty vehicles have not been made.

In December 2013, the ITS JPO stated that it has organized a new affiliation of DSRC infrastructure device makers, operators of V2I installations, and developers of applications that use V2I communications [22]. The newly announced affiliation will provide a common technical platform for CV technology and expand test bed options for users. Its establishment is intended to help ensure that all future CV applications are based on common implementations of the communications technology. Goals of the new affiliation include the following:

- Exchanging information,
- Sharing deployment lessons learned,
- Developing a common technical platform, and
- Expanding test bed options for users.

The following seven public, private, and academic institutions have entered into a memorandum of agreement with the RITA to be involved in the affiliation of test beds:

- Arada Systems
- Southwest Research Institute
- Detroit Department of Public Works
- Security Innovation
- Siemens Industry Inc.
- Cohda Wireless America LLC.
- University of Michigan

Finally, the Government Accounting Office (GAO) released a report in November 2013 titled *Intelligent Transportation Systems Vehicle-to-Vehicle Technologies Expected to Offer Safety Benefits but a Variety of Deployment Challenges Exist* [23]. This report investigated the benefits that could be realized with the adoption of CVs and identified five major areas where challenges exist and need to be addressed before adoption. Finally, the GAO revealed there is a current and

ongoing cost analysis being completed that will look at V2V costs in-vehicle and for the communication security system.

4.3 U.S. State Strategic Plans and R&D Activities

Two notable state efforts are underway: one in Michigan and the other in Florida. The Michigan Department of Transportation, in partnership with the Center for Automotive Research, completed the Michigan Connected and Automated Vehicle Technology Strategic Plan in July 2013 to leverage the testing and research that is ongoing in the state. The plan provides a motivation and overview of previous activities and research on emerging transportation technologies, and the State's mission, vision, and goals for AVs and CVs. The plan laid out measures and strategies, which are divided into the following themes or focus areas: leadership, safety, customer service, partnerships, system linkages, and efficiency. A description of how technologies further the goals of strategic plan and state goals has been provided. Appendices of technical information, and other useful and reference materials include the *Line of Business Strategy for Vehicle-Infrastructure Integration Part I: Strategic and Business Plan* and the *Line of Business Strategy for Vehicle-Infrastructure Integration Part II: Specific Goals and Activities* [24].

In Florida, the Department of Transportation, Tampa-Hillsborough Expressway Authority, and Center for Urban Transportation Research partnered to host the Florida Automated Vehicles Summit in November 2023. The summit explored issues related to AVs and facilitated discussions helpful for creating a framework for implementation of AVs in Florida that will ultimately save lives and enhance mobility. Key focus areas of the summit were AV technology and prediction of implementation roadmaps, engagement of public and private partners, key regulatory issues to enable the safe deployment of AVs, and the identification of a framework for multi-phased implementation of AV systems in the state. The summit brought together scholars, elected officials, automobile manufacturers, equipment manufacturers, transportation professionals, trade and industry organizations, and public agencies to create partnerships for moving forward [25].

4.4 Private Sector Technology Strategic Plans and Activities

No official plans from auto manufacturers have been made available, but information about company plans and involvement related to emerging technology has become available through conference proceedings, press releases, and interviews. The following provides an overview of new developments, activities, and announcements from private sector technology and automobile companies.

- Ford [26] [27]: Ford Motor Company revealed a glimpse of its newest research vehicle, a Fusion Hybrid designed to test out new autonomous driving technologies. The vehicles reportedly are using a combined lidar system and 360-degree cameras similar to Google's technology. Ford also revealed that it is part of the testing effort in Michigan along with State Farm insurance.
- Volvo [28]: Volvo announced a plan that is more aggressive than its competitors: a partnership with Swedish authorities to initiate trial runs of its self-driving cars, which Volvo is calling Drive Me. One hundred specially selected drivers will be given self-driving vehicles, and their commentary and diagnostic information will be fed back to the company for further development of AVs. The Drive Me project will be run on every type of roadway, from congested urban center streets to fast-moving freeways, in order to test the cars in all driving scenarios. For Volvo, 2014 will see the introduction of a new user interface and cloud functionality, and a projected rollout is set for 2017.
- Nissan [29]: Nissan announced that it will bring multiple self-driving cars to market by 2020. Nissan also announced the company is relying on partnerships between its own engineers and a number of universities, including Stanford, MIT, Oxford, Carnegie Mellon, and the University of Tokyo, to help create its autonomous driving technology.
- Mercedes and Nokia [30]: Nokia has teamed up with Mercedes-Benz to develop smart maps intended to spur the development of self-driving cars.
- IBM [31]: Continental, an automotive supply company, and IBM entered into a CV collaboration agreement to jointly develop fully connected mobile vehicle solutions for car manufacturers around the world.

Chapter 5. Implications for Texas

The review of the current state of the practice in emerging transportation technologies reveals several critical insights for the state of Texas. Table 4 summarizes the status of various technology development aspects, policies, legislation, R&D, standards, licensing, pilot studies, market and business developments, and testing environments.

Table 4. Summary of the Representative Efforts in Technology Development Aspects

	Autonomous Vehicles	**Connected Vehicles**	**Electric Systems**	**Crowdsourcing and Cloud Computing**
Policies	USDOT/NHTSA policy	Under development	Part of US government green energy/energy security policies [31]	U.S. Department of Commerce Policy [32]
Legislation	3 states passed; 8 states under consideration; 5 states failed	Upcoming USDOT legislative decisions (CV-DSRC)	State and federal promotion legislation	Under development
Technology R&D	Google cars; automobile industry	CV-cellular led by private sectors and academia; CV-DSRC led by USDOT and academia	Battery technologies; electric charging systems	Private industry
Standards	Under development	Safety message communication standards (CV-DSRC); no standards yet for CV-cellular	Under development by EVSP of ANSI [33]	Under development by IEEE, ITU, and NIST [34]
Licensing	Under development	Security network framework under development	Under development with User Fee charging strategies	Non-transportation licensing agency: FedRAMP [35] [36]
Pilot Studies	Google cars in CA, FL, and NV [37]	6 testbeds, 6 safety clinics [38]	Charging system pilot studies; highway electrifications pilots	Limited in planning and transportation agencies
Market Development	Private sector efforts	Joint private and public sector efforts	Established EV market	Efforts led by IT companies and private industry
Consumer Products	In 3 to 5 years from Google [39]	Full-CV products under development	Charging and electrification systems	IBM and Cisco system; WAZE mobile app

* EVSP: Electric Vehicles Standards Panel; ANSI: American National Standards Institute; IEEE: Institute of Electrical and Electronics Engineers; ITU: International Telecommunication Union; NIST: National Institute of Standards and Technology.

As indicated in Table 4, the development of emerging transportation technologies has attracted joint efforts from public, private, and academic sectors from many different aspects. Different technologies are currently at different development stages. In the meantime, not all aspects of the technologies have been intensively covered in the existing efforts, leaving opportunities and challenges for the state of Texas.

- **Policies and legislation**: The policy and legislation development for various emerging transportation technologies has been primarily lead by U.S. and state DOTs. Although the R&D of technology policies and legislation has been an ongoing process in federal and state government, developing a series of promotional policies and legislation for the state of Texas is still necessary and crucial to eliminate some of the existing institutional barriers facing the development of emerge transportation technologies. Regulatory and legislative barriers that may addressed to encourage and enable new technologies may include (but are not limited to) vehicle permitting and testing, insurance and liability, equipment certification, operation certification, requirements on accident reporting, licensing, driver requirements, performance standards and monitoring, data ownership, data security, data ownership, etc.
- **Standards and licensing**: Standards and licensing procedure developments are prerequisites for successfully implementing and managing new transportation technologies. Some of the technologies themselves are still in their development stages and there have been multiple efforts at federal and state levels to design standards and licensing procedures. For the state of Texas, it may not be necessary to initiate the development of a new set of standards and licensing procedures; instead, the State could track and monitor existing efforts and adopt "well-accepted" standards and procedures. Such a strategy can help prevent the potential compatibility issues seen in the existing electronic toll systems.
- **Technology development**: The promotion of technology development and implementation in the state of Texas is part of the TTTF's mission. The state of the Texas may not be the place where such technologies were originally invented or researched. Meanwhile, many states have deployed technology test sites or testbeds as a strategy to promote technology development in their state. For Texas to stand out among other states in promoting emerging transportation technologies, the real opportunity is to provide an

open and supportive environment for technology developers or industry R&D, addressing some of the key barriers that exist in other states such as lack of financial support or economic stability, legislative barriers to testing technologies, and the lack of data, infrastructure, and facility support.

- **Market and economic development**: Another component of the TTTF mission is continued support of the state's economic and market development, taking advantage of the state's vibrant economy, technology foundation, investment opportunities, and the consumer market. Most existing market and economic development strategic plans for emerging transportation technologies have been proposed and executed by private sector entities. Creating market development strategic plans will place Texas in a prime position, promoting and leading the effort in technology development. This approach requires that TxDOT and state government facilitate and collaborate with private sectors in creating a healthy, sustainable, and economically viable environment.

References

[1] TxDOT. (2013). *Comparison of Motor Vehicle Traffic Deaths, Vehicle Miles, Death Rates, and Economic Loss, 2003 - 2012*. Available: http://ftp.dot.state.tx.us/pub/txdot-info/trf/crash_statistics/2012/comparisons.pdf

[2] D. Schrank, B. Eisele, and T. Lomax, "TTI's 2012 Urban Mobility Report," *Texas A&M Transportation Institute. The Texas A&M University System*, 2012.

[3] FHWA, "Our Nation's Highways 2011," U. S. Department of Transportation, Federal Highway Administration (FHWA), Office of Highway Policy Information Publication FHWA-PL-10-023, 2010.

[4] USEIA, "State-Level Energy-Related Carbon Dioxide Emissions, 2000-2010," U.S. Energy Information Administration (EIA)2013.

[5] NHTSA. (2013). *Connected Vehicles - NHTSA (National Highway Traffic Safety Administration)*. Available: http://stnw.nhtsa.gov/safercar/ConnectedVehicles/pages/v2v.html

[6] B. Cronin. (2013). *Connected Vehicle Overview*. Available: http://www.its.dot.gov/presentations/trb_2013/pdf/Cronin%202013v2i.pdf

[7] CIS. (2013, August). *Automated Driving: Legislative and Regulatory Action - CIS (The Center for Internet and Society)* [Web].

[8] USDOT/RITA http://www.iteris.com/itsarch/index.htm

[9] NHTSA. (May 2012) "New DOT Research Shows Drivers Support Connected Vehicle Technology, Appreciate Potential Safety Benefits." Available online at http://www.nhtsa.gov/About+NHTSA/Press+Releases/2012/New+DOT+Research+Shows+Drivers+Support+Connected+Vehicle+Technology,+Appreciate+Potential+Safety+Benefits

[10] NHTSA. (February 2014) "U.S. Department of Transportation Announces Decision to Move Forward with Vehicle-to-Vehicle Communication Technology for Light Vehicles." Available online at http://www.nhtsa.gov/About+NHTSA/Press+Releases/2014/USDOT+to+Move+Forward+with+Vehicle-to-Vehicle+Communication+Technology+for+Light+Vehicles

[11] DARPA. “Urban Challenge.”Available online at: http://archive.darpa.mil/grandchallenge/

[12] Adam Fisher (September, 2013) ”Inside Google's Quest To Popularize Self-Driving Cars.” Popular Science. Available online at: http://www.popsci.com/cars/article/2013-09/google-self-driving-car

[13] John Markoff (May, 2014) “Google’s Next Phase in Driverless Cars: No Steering Wheel or Brake Pedals.” The New York Time. Available online at http://www.nytimes.com/2014/05/28/technology/googles-next-phase-in-driverless-cars-no-brakes-or-steering-wheel.html?_r=0

[14] NHTSA. (May, 2013) “Preliminary Statement of Policy Concerning Automated Vehicles.” Available online at: http://www.nhtsa.gov/About+NHTSA/Press+Releases/U.S.+Department+of+Transportation+Releases+Policy+on+Automated+Vehicle+Development

[15] Gabriel Weiner and Bryant Walker Smith. “Automated Driving: Legislative and Regulatory Action.” Available online at: cyberlaw.stanford.edu/wiki/index.php/Automated_Driving:_Legislative_and_Regulatory_Action

[16] Sebastian Blanco (May, 2012)” EVS: Utah State University quietly working on in-road wireless charging.” AutoblogGreen. Available online at:http://green.autoblog.com/2012/05/18/evs-utah-state-university-quietly-working-on-in-road-wireless-c/

[17] Mark Shwartz (February, 2012) “Wireless power could revolutionize highway transportation, Stanford researchers say.” Stanford News. Available online at: http://news.stanford.edu/news/2012/february/wireless-vehicle-charge-020112.html

[18] DiUS (May 2013) “Demand management of electric vehicle charging using Victoria’s Smart Grid Project report.” Available online at: http://www.smartgridnews.com/artman/uploads/2/Demand-management-of-EV-charging-using-Victorias-Smart-Grid_May-2013.jpg.pdf

[19] USDOT and NHTSA. Connected Vehicle Research Program Vehicle-to-Vehicle Safety Application Research Plan. U.S. Department of Transportation (USDOT), National Highway Traffic Safety Administration (NHTSA), 2011.

[20] Strickland, D. L. How Autonomous Vehicles Will Shape the Future of Surface Transportation. Testimony of The Honorable David L. Strickland Administrator National Highway Traffic Safety Administration House Committee on Transportation and Infrastructure Subcommittee on Highways and Transit, 2013.

[21] NHTSA. (February 2014) "U.S. Department of Transportation Announces Decision to Move Forward with Vehicle-to-Vehicle Communication Technology for Light Vehicles." Available online at http://www.nhtsa.gov/About+NHTSA/Press+Releases/2014/USDOT+to+Move+Forward+with+Vehicle-to-Vehicle+Communication+Technology+for+Light+Vehicles

[22] RITA. USDOT Announces New Connected Vehicle Test Bed Affiliation http://www.its.dot.gov/press/2013/cv_testbed_affiliation.htm, Accessed December 16th, 2013.

[23] GAO. Intelligent Transportation Systems: Vehicle-to-Vehicle Technologies Expected to Offer Safety Benefits, but a Variety of Deployment Challenges Exist, Government Accountability Office http://www.gao.gov/assets/660/658709.pdf, Accessed December 16th, 2013.

[24] MDOT and CARS. Connected and Automated Vehicle Technology Strategic Plan. Michigan Department of Transportation (MDOT), Center for Automotive Research (CARS), 2013.

[25] FES. Florida Automated Vehicles Summit, Florida Engineering Society(FES) http://www.fleng.org/seminars.cfm?event_id=598, Accessed December 16th, 2013.

[26] Fitchard, K. Ford Shows off its New Autonomous Driving Research Vehicle – It's Got Lasers http://gigaom.com/2013/12/12/ford-shows-off-its-new-autonomous-driving-research-vehicle-its-got-lasers/, Accessed December 16th, 2013.

[27] Lavrinc, D. Ford Unveils its First Autonomous Vehicle Prototype http://www.wired.com/autopia/2013/12/ford-fusion-hybrid-autonomous/, Accessed December 16th, 2013.

[28] Savov, V. Volvo Speeds Ahead with Autonomous Cars on Swedish Roads by 2017 http://www.theverge.com/2013/12/3/5169848/volvo-drive-me-autonomous-car-pilot-project, Accessed December 16th, 2013.

[29] Welch, C. Nissan Says It Will Bring Multiple Self-Driving Cars to Market by 2020 http://www.theverge.com/2013/8/27/4664272/nissan-will-bring-self-driving-cars-to-market-by-2020, Accessed December 16th, 2013.

[30] Albanesius, C. Mercedes, Nokia Partner on Maps for Self-Driving Cars http://www.pcmag.com/article2/0,2817,2424211,00.asp, Accessed December 16th, 2013.

[31] Continental and IBM. Continental and IBM Enter Connected Vehicle Collaboration http://online.wsj.com/article/PR-CO-20130910-905277.html, Accessed December 16th, 2013.

[32] DOE. One Million Electric Vehicles by 2015, February 2011 Status Report, Department of Energy. 2011.

[33] USDOC. Cloud Computing Policy. U.S. Department of Commerce (USDOC), Office of the Chief Information Officer, 2010.

[34] Bodson, D. Standardization Roadmap for Electric Vehicles [Standards]. Vehicular Technology Magazine, IEEE, Vol. 8, No. 3, 2013, pp. 114-116.

[35] IEEE. Standards in Cloud Computing http://cloudcomputing.ieee.org/standards, Accessed December 16th, 2013.

[36] USGSA. About Fedramp - U.S. General Services Administrtion(U.S.Gsa) http://www.gsa.gov/portal/category/102375, Accessed December 16th, 2013.

[37] USGSA. Fedramp Compliant Csps - U.S. General Services Administrtion(U.S.Gsa) http://www.gsa.gov/portal/category/105279, Accessed December 16th, 2013.

[38] Muller, J. With Driverless Cars, Once Again It Is California Leading the Way http://www.forbes.com/sites/joannmuller/2012/09/26/with-driverless-cars-once-again-it-is-california-leading-the-way/, Accessed December 16th, 2013.

[39] Fehr, W. Affiliated Connected Vehicle Test Bed Summit: Lessons Learned, Next Steps http://www.its.dot.gov/presentations/CV_Safety_sept2012/pdf/Day%202%20-%20Affiliated%20Test%20Bed.pdf, Accessed December 16th, 2013.

[40] Nichols, S. Google Wants Some Form of Self-Driving Cars on Roads by 2018 http://www.techradar.com/us/news/car-tech/google-wants-some-form-of-self-driving-cars-on-roads-by-2018-1130660, Accessed December 16th, 2013.