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16. Abstract

Texas' 83rd Legislature charged TxDOT with examining and evaluating innovative transportation technologies for purposes of cost savings, reducing traffic congestion, enhancing safety, and increasing economic productivity. As a result, the Texas Transportation Task Force was formed encompassing a group of experts who discussed four groups of emerging transportation technologies including connected vehicles, autonomous vehicles, electric systems, and cloud computing/ crowdsourcing technologies.

A report of findings is provided from the Task Force's assessment of each of these technologies using a four-stage process. The first stage sought to understand technology development phases as each technology progressed from prototyping to public road testing to initial deployment and commercialization. The second stage assessed current and near-term (2018) technology maturity development from the perspective of both TxDOT and potential consumers. While the first two stages focused on these technologies as stand-alone technologies, the final two stages provided an assessment of them as standalone and combined technologies to discover synergistic effects and potential benefits and new systems that could be enabled. The third stage evaluated how individual joint technologies could serve Texas' statewide goals, and the fourth stage provided and evaluation of issues and concerns for each technology or joint technology as they progressed through development stages. Finally, the Task Force developed a preliminary short- and long-term vision for these technologies in Texas, which includes a menu of options for testing and implementation of new technologies.

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Developing Emerging Transportation Technologies in Texas

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About This Document

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. 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 Task Force 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. This document presents a synthesis of the TTTF's discussions and efforts between place from March and August 2103.

The purpose of this document is outlined below:

a. Provide an overview of emerging automotive, information, and communication technologies that are capable of transforming the transportation system,
b. Provide an overview of potential benefits to transportation agencies and drivers,
c. Inform readers of national and state efforts to research, develop, and encourage new transportation technologies,
d. Provide an overview of the TTTF, its creation, and its members,
e. Characterize technology development stages and their associated government, industry, and consumer activities,
f. Illustrate how the adoption and diffusion of new technology may further TxDOT's goals and other national transportation goals,
g. Identify public, societal, and technological barriers to new technology adoption and dispersion, and
h. Provide a vision for the future of the Texas transportation system and recommend steps for implementation.

This document conducts an evaluation of emerging transportation technologies, identifying key issues and concerns, from prototype testing to implementation, and presents a basis for developing a preliminary roadmap to implementation in order to best serve Texas' strategic transportation and economic development goals.

About the Committee

The Texas Technology Task Force, through TxDOT, was directed to oversee a study on transportation technology. Specifically, TxDOT was charged with examining and evaluating innovative transportation technologies to achieve cost savings, reduce traffic congestion, enhance safety, and increase economic productivity. As a result of this charge, the TTTF was created to complete the task.

The TTTF was formally created in February 2013 and began with an internal core group that sought experts in various transportation technologies to share knowledge and provide direction for the Task Force. The TTTF held three full-day workshops in Austin on April 29, June 12, and July 31, 2013. At each meeting, the internal core group and the panel of experts discussed various technologies and their development status, technology evaluation methods, and the short- and long-term vision for these technologies in Texas.

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Executive Summary

The Texas Department of Transportation (TxDOT) has been directed to examine and evaluate innovative transportation technologies for purposes of cost savings, reducing traffic congestion, enhancing safety, and increasing economic productivity. As a result, the Texas Transportation Task Force (TTTF) was formed, encompassing a group of experts who discussed emerging transportation technologies, their development status, evaluation methods, and the short- and long-term vision for these technologies in Texas. This report summarizes the Task Force findings.

In 2012 there were 3,399 fatalities on Texas roads, with total state crash costs reaching $26 billion. Five Texas cities ranked among the 56 worst nationally in terms of traffic delay, with annual commute-time delays in these cities ranging from 32 to 52 hours. Texas consumed over 15.6 billion gallons of gasoline and diesel fuels in 2009, ranking second nationally. The adoption and diffusion of emerging transportation technologies have the potential to limit crash frequency and severity, enhance mobility for Texas residents while spurring economic growth, and reduce wasted fuel for state residents stuck in traffic.

To these ends, four areas of emerging transportation technology were investigated in this report, including connected vehicles (vehicles able to communicate with other vehicles or roadway infrastructure), autonomous vehicles (also known as automated or self-driving vehicles), electric systems (such as DC fast charging and in-road inductive charging stations), and cloud computing/crowdsourcing technologies (allowing for travelers to access and provide road data, enabling better system management).

The Task Force developed an assessment methodology of each of these technologies using a four-stage process. First, an understanding of technology development phases was developed, as each technology progressed from prototyping to public road testing to initial deployment and commercialization. Next, current (2013) and near-term (2018) technology maturity perspectives were assessed, from the perspective of both TxDOT and potential consumers. While these technologies will likely remain stand-alone applications in the near future, as time progresses the technologies should become integrated—for example, combining increasing degrees of connectivity and automation to enable new joint technology safety and mobility systems. Therefore, an assessment of these joint technology synergies was conducted to understand the potential benefits and new systems that could be enabled.

After this groundwork was completed, two final assessments were conducted. The first evaluated how each technology (or joint technology systems) could serve Texas' statewide goals of economic development; TxDOT's goals of safety enhancement, congestion mitigation, connecting Texas communities, and becoming a best-in-class agency; and USDOT goals of maintaining infrastructure condition, ensuring system reliability, providing environmental sustainability, and reducing project delivery. Issues and concerns were evaluated for each technology or joint technology system as they progressed through development stages, including public agency concerns (institutional, infrastructure, regulatory, policy, and public cost); societal concerns (safety, energy, and other public concerns [e.g., privacy, disparate income impact, neighborhood concerns, etc.]); and technology-to-market concerns (private cost, time required for development and deployment, and technology concerns).

From this set of evaluations, several conclusions may be drawn. First, near-term benefit-cost ratios are likely the highest for connected vehicle and electric vehicle solutions, from both TxDOT and consumer standpoints. This observation stems from the fact that these technologies are the most advanced in terms of technological and application maturity. Second, autonomous vehicles and joint-technology systems using automation and connectivity have the potential for the greatest long-term benefits, although these technologies and systems also have the greatest costs. As such, future efforts may seek multiple paths in order to quickly take advantage of technologies and systems that are or will be ready within a short timeframe, while also planning for future developments in order to seize those truly large opportunities as they emerge.

The Task Force also identified five key enablers to help eliminate non-technical barriers and promote technology development. TxDOT could help provide a rich data environment to technology developers, allowing them to harness data in order to accelerate service delivery. A conducive testing environment should be fostered, including the potential temporary provision of infrastructure to technology developers for testing on closed systems, as well as consideration of measures for regulatory reform transportation and technology-based project streamlining. Public relations efforts would likely be necessary to attract new companies involved in emerging transportation technologies, as well as private capital to fund such efforts and public outreach to garner valuable public input. Limited funding for these efforts will also be necessary, although the Task Force anticipates that the majority of technology development and deployment will be funded and conducted by private entities. Finally, the Task Force envisions that these efforts will be spearheaded by a public-private partnership, involving government agency, research institute, and industry collaborations.

With this evaluation in hand, the Task Force developed a vision for moving forward, identifying four implementation strategies to be conducted over the next 5 years:

1) 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.
2) Public-Private Partnership – Utilize range of approaches to creating 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.
3) 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 regulations, or create innovative approaches to safety and ensure that the safety performance goals of the regulations are satisfied for a preselected technology.

4) Legislative and Regulatory Changes – Identify regulatory and legislative barriers to emerging transportation technologies, and provide support on how to address them.

If pursued, these actions should help make Texas a leader in the development and commercialization of emerging and ultimately disruptive transportation technologies. These actions should further the state's economic development, and ultimately lead to a safe, efficient, seamless, and enjoyable transportation system.

Texas Pride

Texans are privileged to have a dynamic economy, growing population, and vibrant culture. We also have increasing levels of congestion, a critical need to find more efficient ways to move commodities, and an obligation to find ways to make travel safer, all in an environment of stagnant-to-declining revenue streams and increasing costs. The TTTF was created to identify a path for Texas to follow so that it is strongly positioned to best implement, finance, or otherwise leverage emerging technologies in the near and mid-term with the objectives of addressing congestion, improving safety, and fostering economic development. This necessitates overcoming (1) a lack of awareness of those technologies and their interactions with the transportation system, (2) dated planning and financing mechanisms, and (3) conflicts between new technologies and existing enforcement frameworks. General Appropriations Bill, S.B. No. 1, Eighty-third Legislature, item 44, VII-31 (2013) was passed after the Task Force had been formed and directs TxDOT to oversee a study on transportation technology. Specifically, TxDOT was charged with examining and evaluating innovative transportation technologies for purposes of cost savings, reducing traffic congestion, enhancing safety, and increasing economic productivity.

Enabling Trends to Support Technology Adoption

Adoption of transportation technology, information technology (IT), and communication technology entails the use of new hardware, software, applications, and communications in all aspects of TxDOT's operations, including transactions that are inter- and intra-agency, and with consumers. Given the potential benefits of technology investment listed in Section 1.2, emerging technology adoption and diffusion in Texas should be encouraged.

At least four major external trends align to support this encouragement.

1. **Texas' role in the global marketplace should only grow over time, as the economy continues to move toward higher value-added production and services.** The transformation of Texas from a commodity producer to a center of knowledge and technology is virtually complete, notwithstanding the recent surge in energy production. Until recently, the structure of the Texas economy was similar in many ways to that of a developing nation: the state sold basic products such as food and energy, and tended to purchase more sophisticated manufactured goods. That trend has been turned upside down in recent years, as Texas has become a center of research, advanced technology, and high value-added services.
2. **Rapid population growth relative to the rest of the nation will likely characterize Texas over the next 30 years.** Three main factors influencing the Texas demographics landscape over the coming decades are relatively high birthrates, in-migration, and an

aging population—with each factor creating new challenges for the public sector. Strong overall population growth will place greater strain on an already overstressed road and highway network, as well as prompting continued interest in alternative forms of transportation.

3. **The physical character of Texas communities will continue to evolve**. The traditional model of community development is changing. Urban areas in Texas have long been characterized by relatively low density, as abundant land fostered spread-out cities that relied almost exclusively on the automobile. In recent years, the rate of population and traffic growth has outstripped the road system in many areas, leading to increased congestion. Partially as a result, many communities are now focusing on "traditional" neighborhood design. The defining characteristics of this development approach are walkability or pedestrian-oriented design; transportation options; a mix of land uses that integrate housing, shops, civic facilities, and work places; and maintenance or creation of green space.

4. **Providing adequate funding of basic infrastructure, including the transportation network, has become increasingly challenging**. As a result, the focus has shifted toward alternatives to traditional general obligation debt financing of basic infrastructure, with a greater emphasis on tolls, tax-increment financing, development fees, and other alternative financing structures.

Collectively, these factors will require Texas to leverage its existing transportation infrastructure as efficiently as possible, as continued growth runs head on into evolving development patterns and constrained resources. Meanwhile, the nature and scope of the state's infrastructure is changing. Much of the modern economy's development can be traced to the implementation of networks: highways, rail, telecommunications, and energy. The ability to efficiently move goods, people, capital, energy, and ideas continues to transform the way humans live, work, and play.

Throughout history, transportation was the first network system to be comprehensively deployed, with improvements in the movement of goods and people preceding every stage of urbanization. As outlined by Dr. John Kasarda of the University of North Carolina, transportation was a critical ingredient in the four major waves of industrialization that have occurred to date [1]:

- The first great cities developed around seaports and along trade routes.
- The second wave of development—and the beginning of the Industrial Revolution—occurred when factories used canals and rivers for power and shipping.
- The third wave of industrial development started with the railroad system, which opened up landlocked resources.
- The fourth wave of development began with massive investments in highway infrastructure that increased traffic, expanded personal mobility, and accelerated metropolitan growth.

According to the Federal Highway Administration, the current (fifth) wave of industrialization is based on innovations in logistics and manufacturing [2]. Increasingly, components are manufactured offshore, and are then assembled into finished products near the point of their final consumption or use. This business model depends strongly on a fast and reliable transportation network that minimizes the cost of production. Just as highway infrastructure made the fourth wave possible in the United States, the country's current performance depends heavily on a seamless, intermodal transportation system.

While the future is somewhat uncertain, the sixth wave might well entail the integration of different types of networks into a seamless and invisible underpinning for the movement of goods and people. In particular, the nascent efforts in developing connected and autonomous vehicles and smart grids, as well as a general orientation toward minimizing and ultimately removing human beings from a direct operational role in transportation, promises a range of social and economic benefits. It is the promise of these benefits, along with the economic gains associated with first-mover advantage and the pressures outlined above, that make the exploration of better integrating technology and transportation such a timely issue for Texas.

Chapter 1. Background and Context of Transportation Technology

This section provides a background of the current state of the Texas transportation system and illustrates how emerging automotive, information, and communication technology 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 of national and state efforts to research, develop, implement, and encourage emerging transportation technologies.

1.1 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 (VMT) in Texas increased by 1.34% from 2011 to 2012 (to roughly 240 billion miles). Comparatively, VMT in Texas has increased 1.1% on average annually since 2003. 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) [3]. A report by the Texas Transportation Institute compared urban congestion and delay in U.S. cities, ranking five Texas cities among the 56 worst nationally in terms of delay (Dallas 6th, Houston 9th, Austin 32nd, San Antonio 38th, and El Paso 56th). Annual delay per peak hour commuter rankings in these Texas cities ranged from 32 to 52 hours [4]. 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 [5]. In 2010, the U.S. Energy Information Administration (EIA) reported that Texas ranked number one 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 number two ranked state). When considering transportation-related carbon emissions only, Texas ranked number two (second to California) with 195 million metric tons [6].

1.2 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 the Texas Department of Transportation (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 [7]. 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.

1.3 National and State Actions

At the national and state levels, 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 (CV) technologies and their performance, international ITS standards, human factors, systems engineering, pilot programs, real-time data capture, dynamic mobility applications, and others. The ITS JPO updated its latest version of the National ITS Strategic Research Plan for 2010 through 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 CVs. See the full plan at http://www.its.dot.gov/strategicplan/.

The report highlights critical ITS areas that have seen advances in research and include the following:

- Safety enhancement capabilities of CVs, 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
- CV applications and technologies based on the existing Cellular network and smart in-vehicle and personal devices
- Other CVs 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 loss 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, which provides 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 partially AVs and will turn to fully AVs in future years. The NHTSA has been involved in research in a number of CV testbeds across the U.S. in collaboration with the USDOT, the ITS JPO, and university research centers [8].

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 [9]. 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 2 to 3 years. In states where vehicle performance standards, regulations, and licensing are being developed, the state Departments of Motor Vehicles have been directed to work the state Departments of Transportation to develop and enforce standards and regulations.

Chapter 2. Technology Classification and Technology Evaluation and Assessment

This chapter describes broad technology classifications and their subcomponents as well as various assessment and evaluation methods that the Task Force used to gain better understanding of various emerging technologies.

2.1 Technology Classification

Emerging transportation, information, and communication technologies have been grouped into four broad categories:

1. CVs, which can be further divided into the following:
   - Cellular-based technologies
   - DSRC-based technologies
2. AVs
3. Electric systems
4. Cloud computing and crowdsourcing

Figure 2.1 provides a general description for each category along with potential benefits of each. For more details on each of these technologies, see Appendix B.

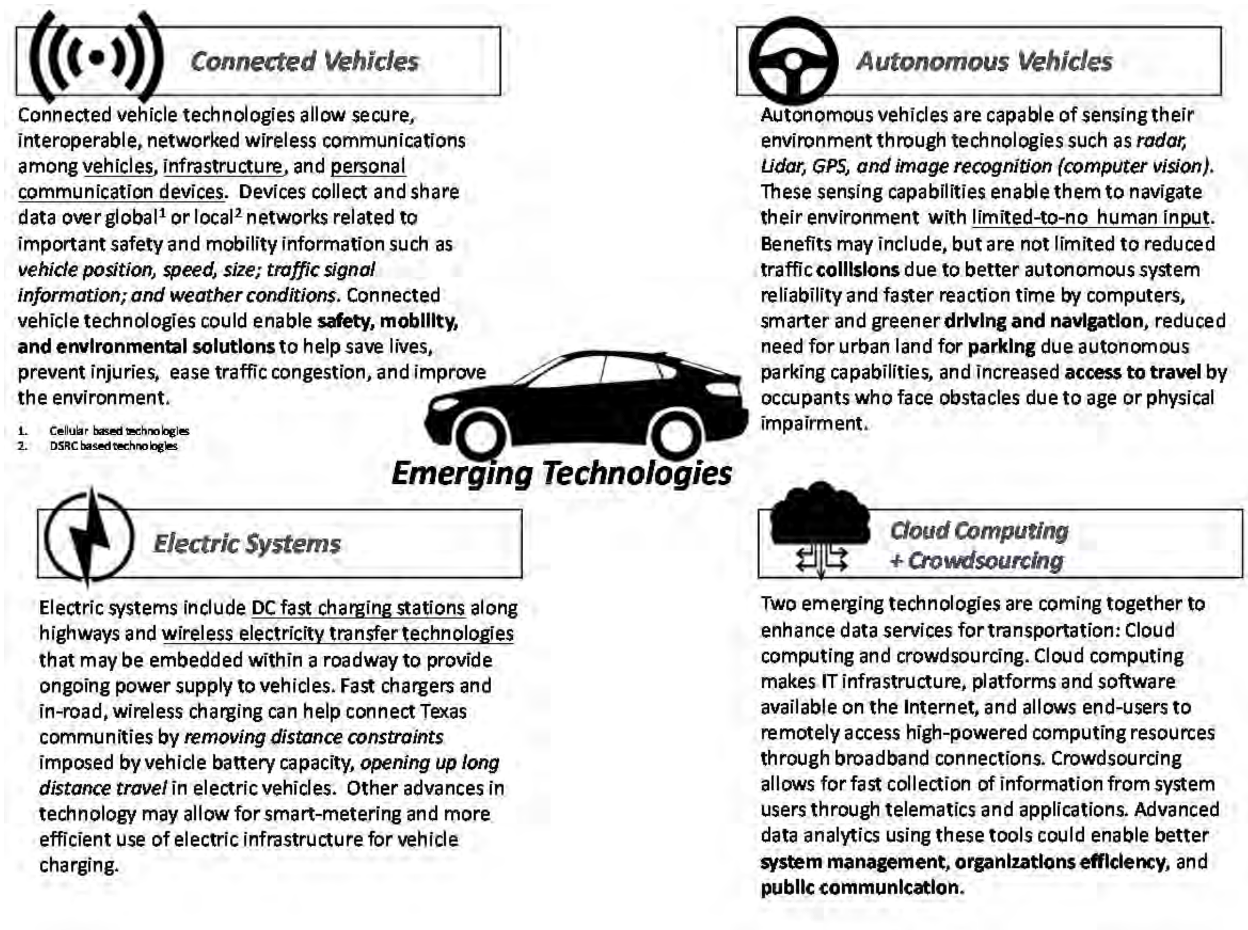


Figure 2.1: Technology Categories

2.2 Technology Evaluation and Assessment

Following this broad classification of technologies, the Task Force developed several evaluation frameworks to gain a better understanding of the technologies in terms of 1) their development stages, 2) current and expected near-term maturity, 3) joint-technology system synergies, and 4) the ability to meet transportation goals, and issues and concerns regarding their adoption.

2.2.1 Development Stages of Emerging Vehicular Technologies

Revolutions in automotive, information, and communication technologies over the last decade have significantly reshaped the landscape of transportation. With innovative technologies developing and becoming more sophisticated at a never-before-seen pace, the role of government agencies, such as TxDOT, are changing. Government agencies are becoming facilitators of new technology, rather than leaders in their development and deployment. A key mission of the Texas Technology Task Force (TTTF) is to identify critical concerns and issues that may occur during this role-changing process for TxDOT. However, such concerns and issues vary significantly by technology and by development stage.

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

TTTF has identified five key future technologies, which include AVs, CVs, electric vehicles (EVs), and cloud computing and crowdsourcing. The technology development process can be generally divided into two major phases: 1) research and development (R&D), and 2) deployment phases. Each phase can also be further divided. The R&D phase includes the initial idea and prototype testing stage on closed systems, and the large-scale field validation stage on public roadways. The deployment phases can generally be classified into 1) initial deployment stage, 2) transitional stage from legacy technologies to new technologies, and 3) the fully converted system under new technologies. Within the scope of the TTTF, the main focus is on R&D and initial deployment phases. Figure 2.2 provides a general roadmap of key milestones of each technology during different development stages. Tables 2.1 through 2.5 summarize the characteristics of the technologies and possible testing and deployment implementations as they progress through the development phases. Given the distinctive characteristics of DSRC-based and cellular-based CV technologies, each characteristic item is clearly indicated with its technology background. As illustrated, the key challenges in DSRC-based CV technologies are primarily in infrastructure and government policies; while the focus of cellular-based CV technology development is on the integration of regulations, safety, and security measures into the existing cellular application ecosystem.

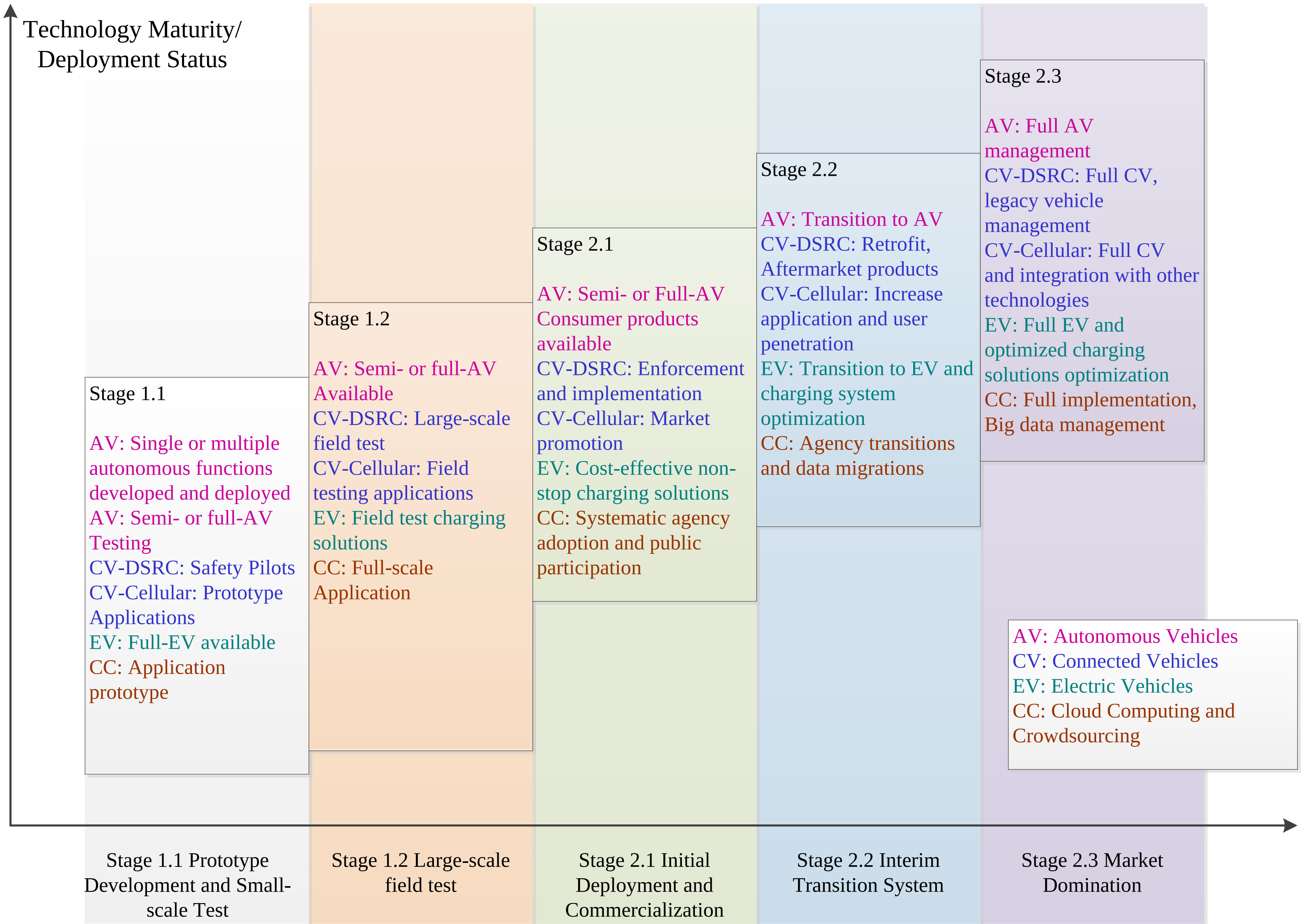


Figure 2.2: Technology Development Roadmap

Table 2.1: Technology Research and Development: Autonomous Vehicles

<table>
<tr>
<td rowspan="3">Stage 1: Technology Research and Development</td>
<td>Stage 1.1: Idea proposal, prototype testing on closed systems</td>
<td>Realized Functionalities
• Level 1 or 2 automation implementation
• Full level 3 and 4 prototype passenger vehicles
• Level 3 and 4 public transportation systems.

R&D Efforts
• Small-scale testing on test tracks or designated routes
• AV platoon testing
• Level 3/4 AV fleet interaction and coordination experiments
• Autonomous-conventional vehicle interaction testing
• Safety and mobility application development
• Human factor studies for Level 3 and 4</td>
<td rowspan="3">Stage 2: Technology Commercial-ization and Deployment</td>
<td>Stage 2.1: Initial deployment and commercial-ization</td>
<td>Realized Functionalities
• Commercially affordable Level 3/4 products become available
• Maturity of AV consumer market

Deployment Efforts
• Early-stage vehicle licensing and management system
• Early-stage infrastructure upgrading initiated
• After-market products and services emerged</td>
</tr>
<tr>
<td rowspan="2">Stage 1.2: Large-scale field testing on public roads</td>
<td rowspan="2">Realized Functionalities
• Prototype consumer products
• AV technology standardization

R&D Efforts
• Field safety and mobility application testing
• Large-scale AV individual vehicle testing with random route choices
• Large-scale AV fleet experiment in urban transportation network
• Special vehicle testing (e.g., car-sharing, freight, transit, patrol vehicles)</td>
<td>Stage 2.2: Interim transition system</td>
<td>Realized Functionalities
• After-market products and services mature and become popular
• Consumer acceptance of and adaption to the system increase

Deployment Efforts
• Fully operating licensing and management system
• Full infrastructure upgrading in progress</td>
</tr>
<tr>
<td>Stage 2.3: Market domination</td>
<td>Realized Functionalities
• AV domination
• Traffic management system fully compatible

Deployment Efforts
• Legacy vehicle management</td>
</tr>
</table>

Table 2.2: Technology Research and Development: Connected Vehicles (DSRC)

<table>
<tr>
<td rowspan="3">Stage 1: Technology Research and Develop-ment</td>
<td>Stage 1.1: Idea proposal, prototype testing on closed systems</td>
<td>Realized Functionalities
• Prototype hardware and communication systems
• Prototype safety and mobility applications
• Prototypes DSRC devices
• Security network architecture

R&D Efforts
• Test track/site testing
• Communication and data standards development
• System integrity and cyber security prototype solution development</td>
<td rowspan="3">Stage 2: Technology Commer-cialization and Deployment</td>
<td>Stage 2.1: Initial deployment and commercial-ization</td>
<td>Realized Functionalities
• Consumer applications in place, more early adopters
• Comprehensive cyber security solutions
• Emerging traveler information and traffic management solutions based on CV data

Deployment Efforts
• Federal enforcement and manufacturer deployment
• Coordination among different CV standards and with other wireless networks</td>
</tr>
<tr>
<td rowspan="2">Stage 1.2: Large-scale field testing on public roads</td>
<td rowspan="2">Realized Functionalities
• Commercial consumer products became available

R&D Efforts
• CV network testing
• Proof-of-concept testing on safety and mobility applications in a small scale
• Field evaluation of safety and mobility applications
• Large-scale DSRC security network testing.</td>
<td>Stage 2.2: Interim transition system</td>
<td>Realized Functionalities
• After-market products and services mature and become popular
• Consumer acceptance of and adaption to the system increase

Deployment Efforts
• Private companies are formed that provide third-party management and cyber protection services
• Integrated CV-based traveler information and traffic management</td>
</tr>
<tr>
<td>Stage 2.3: Market domination</td>
<td>Realized Functionalities
• Fully CV system
• Full standard and sophisticated cross-technology interface.

Deployment Efforts
• Big Data collection and dissemination
• Unconnected vehicle management
• Full CV-based traffic management</td>
</tr>
</table>

Table 2.3: Technology Research and Development: Connected Vehicles (Cellular)

<table>
<tr>
<td rowspan="3">Stage 1: Technology Research and Develop-ment</td>
<td>Stage 1.1: Idea proposal, prototype testing on closed systems</td>
<td>Realized Functionalities:
• Prototype safety and mobility applications
R&D Efforts:
• System integrity and cyber security prototype solution development</td>
<td rowspan="3">Stage 2: Technology Commer-cialization and Deployment</td>
<td>Stage 2.1: Initial deployment and commercial-ization</td>
<td>Realized Functionalities:
• Consumer applications in place, more early adopters
• Comprehensive cyber security solutions
• Emerging traveler information and traffic management solutions based on CV data

Deployment Efforts:
• Commercial products market promotion
• Coordination among different CV standards and with other wireless networks</td>
</tr>
<tr>
<td rowspan="2">Stage 1.2: Large-scale field testing on public roads</td>
<td rowspan="2">Realized Functionalities:
• Commercial consumer products became available

R&D Efforts:
• Marketing and ecosystem management and promotion
• Proof-of-concept testing on safety and mobility applications in a small scale
• Field evaluation of safety and mobility applications</td>
<td>Stage 2.2: Interim transition system</td>
<td>Realized Functionalities:
• Consumer acceptance of and adaption to the system increase
Deployment Efforts:
• Private companies are formed that provide third-party management and cyber protection services
• Integrated CV-based traveler information and traffic management</td>
</tr>
<tr>
<td>Stage 2.3: Market domination</td>
<td>Realized Functionalities:
• Fully CV system
• Full standard and sophisticated cross-technology interface.
Deployment Efforts
• Big Data collection and dissemination
• Unconnected vehicle management
• Full CV-based traffic management</td>
</tr>
</table>

Table 2.4: Technology Research and Development: Electric Vehicle Systems

<table>
<tr>
<td rowspan="3">Stage 1: Technology Research and Develop-ment</td>
<td>Stage 1.1: Idea proposal, prototype testing on closed systems</td>
<td>Realized Functionalities
• Hybrid EV
• Short-range EV
• Low-speed EV
• Prototype cell technologies
• High-cost consumer EV
• Prototype high-capacity battery technologies
• Prototype charging technologies
• Prototype full-EV standards

R&D Efforts
• Low-cost consumer EV testing
• Battery technology development
• Charging solutions experiment
• Field testing on special vehicles (public transit, car-sharing, etc.)</td>
<td rowspan="3">Stage 2: Technology Commer-cialization and Deployment</td>
<td>Stage 2.1: Initial deployment and commercial-ization</td>
<td>Realized Functionalities
• Competitive mass consumer products available
• Full-EV product standards
• Mass coverage of charging facilities in urban area

Deployment Efforts
• Charging system optimization
• On-road charging facilities deployment
• EV market promotion</td>
</tr>
<tr>
<td rowspan="2">Stage 1.2: Large-scale field testing on public roads</td>
<td rowspan="2">Realized Functionalities
• Consumer Full-EV products available
• Charging system provides basic coverage
• Non-stopping charging solutions emerging

R&D Efforts
• Cost reduction
• Full-EV and charging facility standard development
• Full-EV fleet testing
• Charging facility and technology testing on special vehicles (e.g., car-sharing, transit vehicles, freight vehicles)</td>
<td>Stage 2.2: Interim transition system</td>
<td>Realized Functionalities
• Hybrid charging/refueling facility for both EVs and non-EVs
• Increased consumer acceptance and adaption

Deployment Efforts
• Manufacture competition
• EV charging optimization</td>
</tr>
<tr>
<td>Stage 2.3: Market domination</td>
<td>Realized Functionalities
• Fully EV system
• Charging no longer a serious concern

Deployment Efforts
• Legacy vehicle management</td>
</tr>
</table>

Table 2.5: Technology Research and Development: Cloud Computing and Crowdsourcing

<table>
<tr>
<td rowspan="2">Stage 1: Technology Research and Develop-ment</td>
<td>Stage 1.1: Idea proposal, prototype testing on closed systems</td>
<td>Realized Functionalities
• Prototype systems
• Primarily in-lab simulation and small-scale offline testing
• Cyber security prototype solutions
• Crowdsourcing application prototypes

R&D Efforts
• Uplink applications: collecting and analyzing data.
• Downlink applications: data dissemination application development.
• Application-oriented technology development</td>
<td rowspan="3">Stage 2: Technology Commer-cialization and Deployment</td>
<td>Stage 2.1: Initial deployment and commercial-ization</td>
<td>Realized Functionalities
• Crowdsourcing large-scale user participation
• Systematic deployment in transportation agencies
• Intensive collaboration with cloud providers

Deployment Efforts
• System integration with the existing transportation agencies initiated
• Technology development on large-scale and high-input/output solutions</td>
</tr>
<tr>
<td rowspan="2">Stage 1.2: Large-scale field testing on public roads</td>
<td rowspan="2">Realized Functionalities
• Increased agency adoption
• Certified systems emerges

R&D Efforts
• Short-term offline testing of the applications
• Performance evaluation
• Standardization
• Large-scale traffic and travel demand monitoring based on crowdsourcing</td>
<td>Stage 2.2: Interim transition system</td>
<td>Realized Functionalities
• Increased integration with the system
• Full data sharing and collection services become available and operational
• Crowdsourcing in-loop solutions

Deployment Efforts
• Data and system migration</td>
</tr>
<tr>
<td></td>
<td>Stage 2.3: Market domination</td>
<td>Realized Functionalities
• Full system integration

Deployment Efforts
• Crowdsourcing big data processing, management, and applications</td>
</tr>
</table>

2.2.2 Technology Maturity Assessment Observations

To provide a clear picture of the current and future status of each technology, we assessed the maturity of the technologies with respect to five dimensions and two perspectives. With the goal of identifying trends in technology development, the TTTF assessed the current (2013) and future (2018) status of relative maturity ratings for each technology from the perspective of TxDOT and the consumer/driver perspective. The TxDOT perspective focuses on the feasibility and deployment of technologies, while consumer/driver perspective focuses on the provided services. The assessed 2018 technology statuses are based on the following three trends. First, the normal patterns of technology innovation in a 5-year period were considered. Second, the TTTF assumed that the expected 2013 and 2014 decision by the NHTSA would support the enforcement of DSRC-based CV devices [8]. Third, the TTTF assumed that Google's prediction of commercially available AVs within 5 years would be probable [10]. The five dimensions to assess the TxDOT perspectives include the following.

1. Technology maturity: The technology maturity rating indicates the development status of the supporting software and hardware technologies. The rating will also reflect whether the technology development faces significant barriers or challenges.
2. Application maturity: The application maturity rating complements the technology maturity rating by evaluating the sophistication and status of the applications developed for a particular technology. Some technologies such as cloud computing technologies may have been well-developed but their transportation applications may still be under-developed.
3. TxDOT Readiness: The TxDOT readiness rating indicates whether TxDOT has prepared or acquired policies, legislation, and funding for adopting a technology. Some technologies such as CV-DSRC and AV technologies require significant infrastructure, legislative management, and/or policy support; others, such as CV-cellular and EV technologies, will likely not require much extra effort from TxDOT to implement.
4. Public Readiness: This index indicates from the TxDOT perspective whether a technology is ready for the general public to accept. Major concerns such as privacy, equity, educational levels (for technology-intensive applications), community development, and affordability are considered in this readiness index.
5. Deployment Benefit/Cost: This index weights the social and financial benefits brought by a technology versus its deployment cost, including both public and private expenditures. The index is expected to vary with the maturing of the technology and applications.

From the consumer standpoint, those indexes are slightly changed as the following.

1. Availability/Ease of Adoption: This index reflects the availability and ease of adoption of a technology to consumers. This index is strongly related to the technology and application maturity rating from the TxDOT perspective but focused more on whether a consumer product is available rather than the detailed development status of a technology.

2. Ease of Use: Ease of use indicates the expected degree of user-friendliness for various technologies. This index shows the maturity of the application and human interfaces from a consumer's standpoint.
3. Level of Active Participation: The index depicts the degree of involvement needed for drivers to use certain technologies. Different applications require different level of user participation. Some applications such as on-road EV charging, full or partial vehicle automation/autonomy, and automated collision avoidance require minimal user participation. Other technologies such as crowdsourcing, CV-cellular, and safety warning systems rely on users to actively interact with the applications.
4. Privacy and Security: This index reflects privacy and security issue that may be crucial to consumers. It evaluates the level of privacy protection and whether comprehensive and reliable security solutions are available.
5. Personal Benefit/Cost: This index is similar to the deployment benefit/cost from TxDOT's perspective. The index compares consumers' anticipated personal gain versus their possible personal costs of purchasing the technology.

Maturity assessments by year and perspective are shown in Figure 2.3 (a through d).

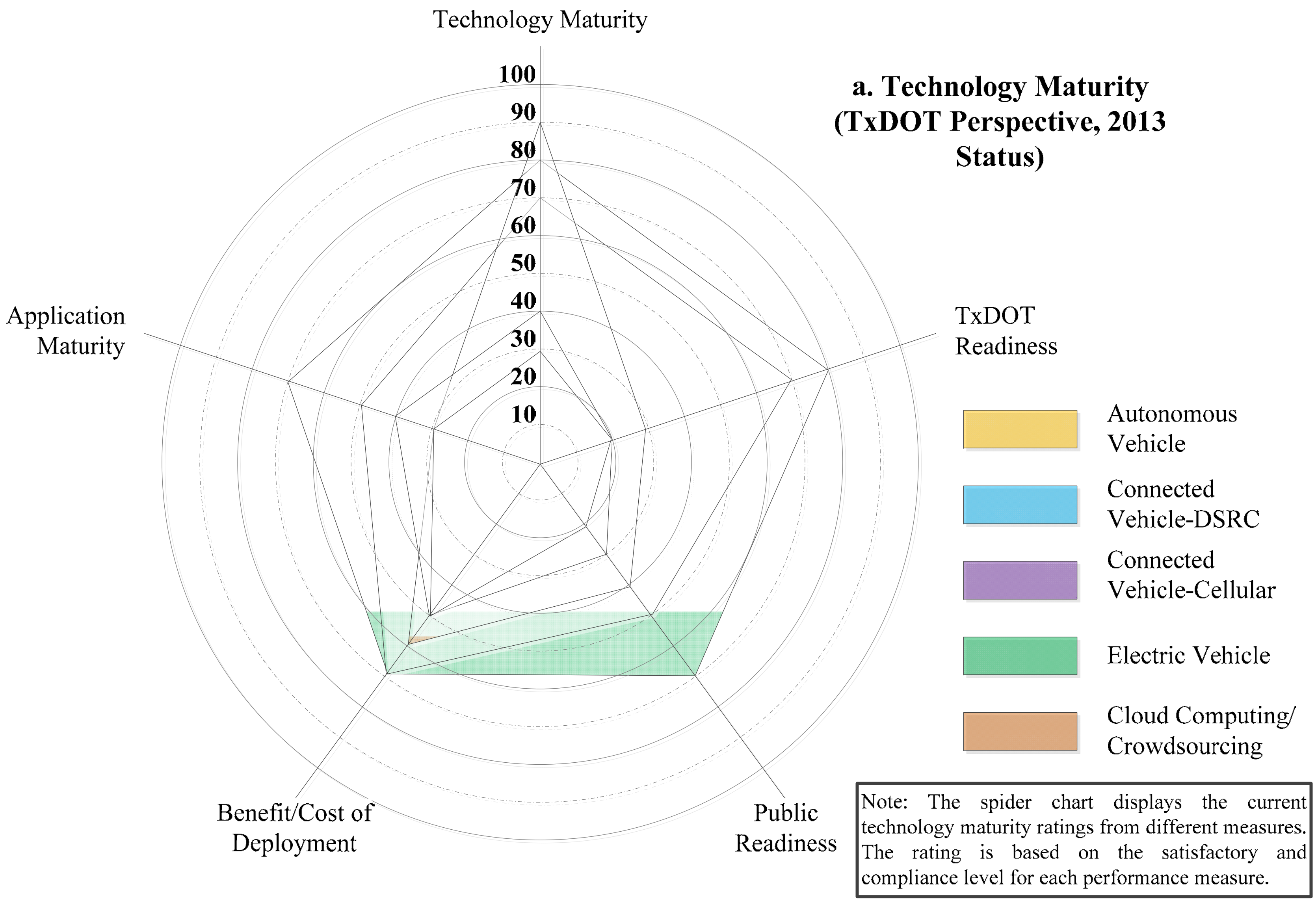
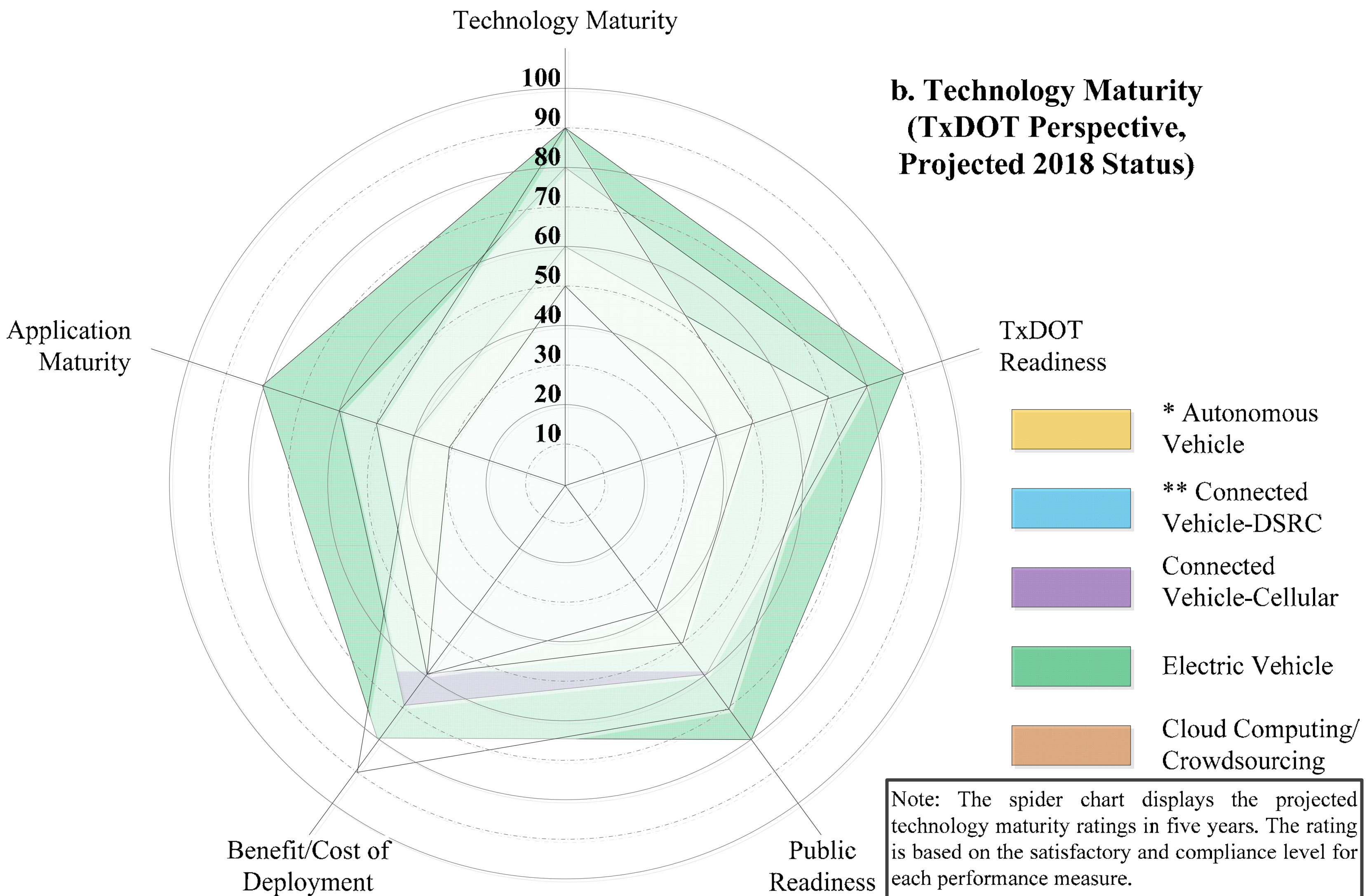
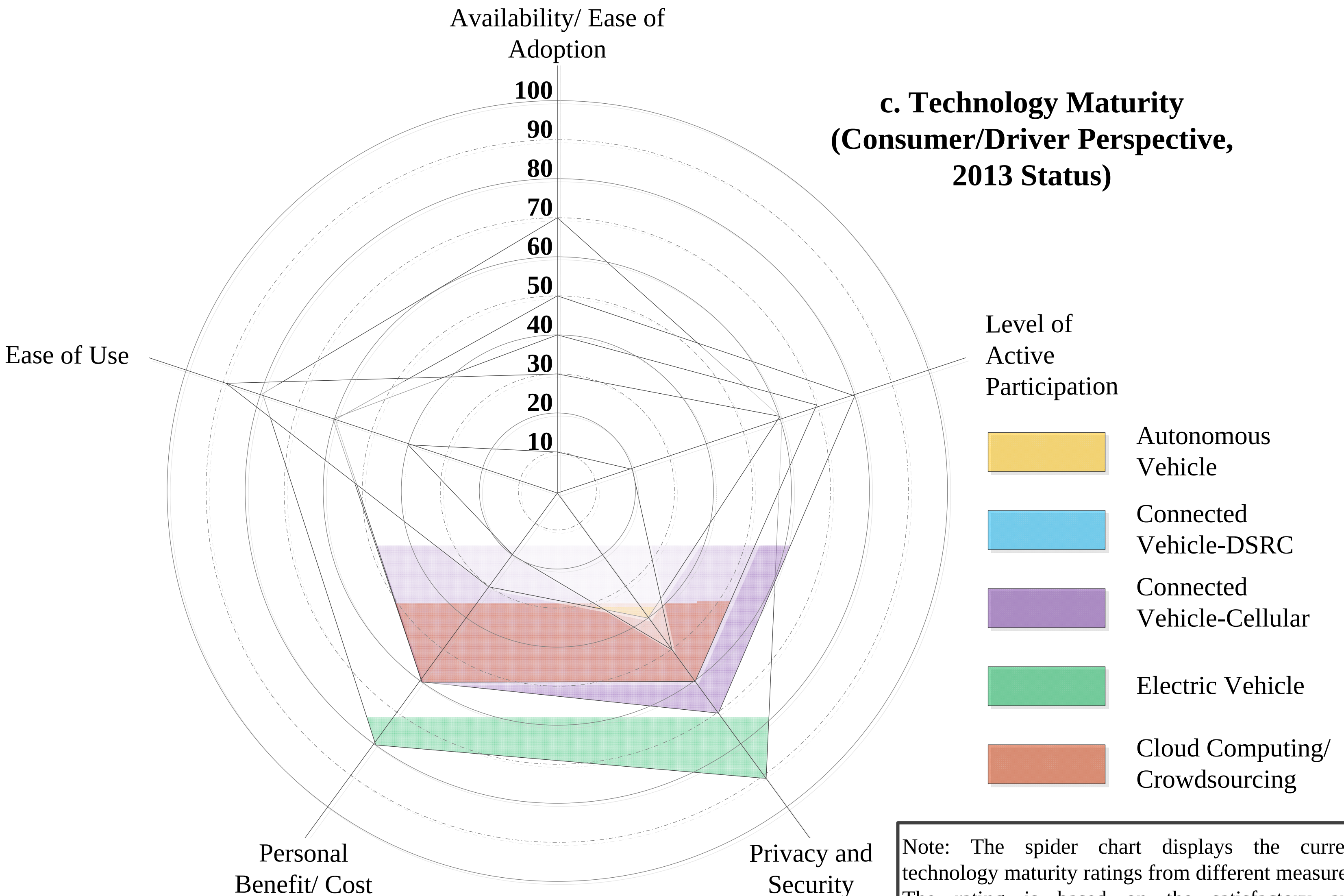


Figure 2.3: Technology Maturity Ratings



Note: The spider chart displays the projected technology maturity ratings in five years. The rating is based on the satisfactory and compliance level for each performance measure.
* Assume that Google autonomous car in market.
** Assume that NHTSA passes DSRC enforcement in 2013 and 2014.

Figure 2.3: Technology Maturity Ratings (continued)



Note: The spider chart displays the current technology maturity ratings from different measures. The rating is based on the satisfactory and compliance level for each performance measure.

Figure 2.3: Technology Maturity Ratings (continued)

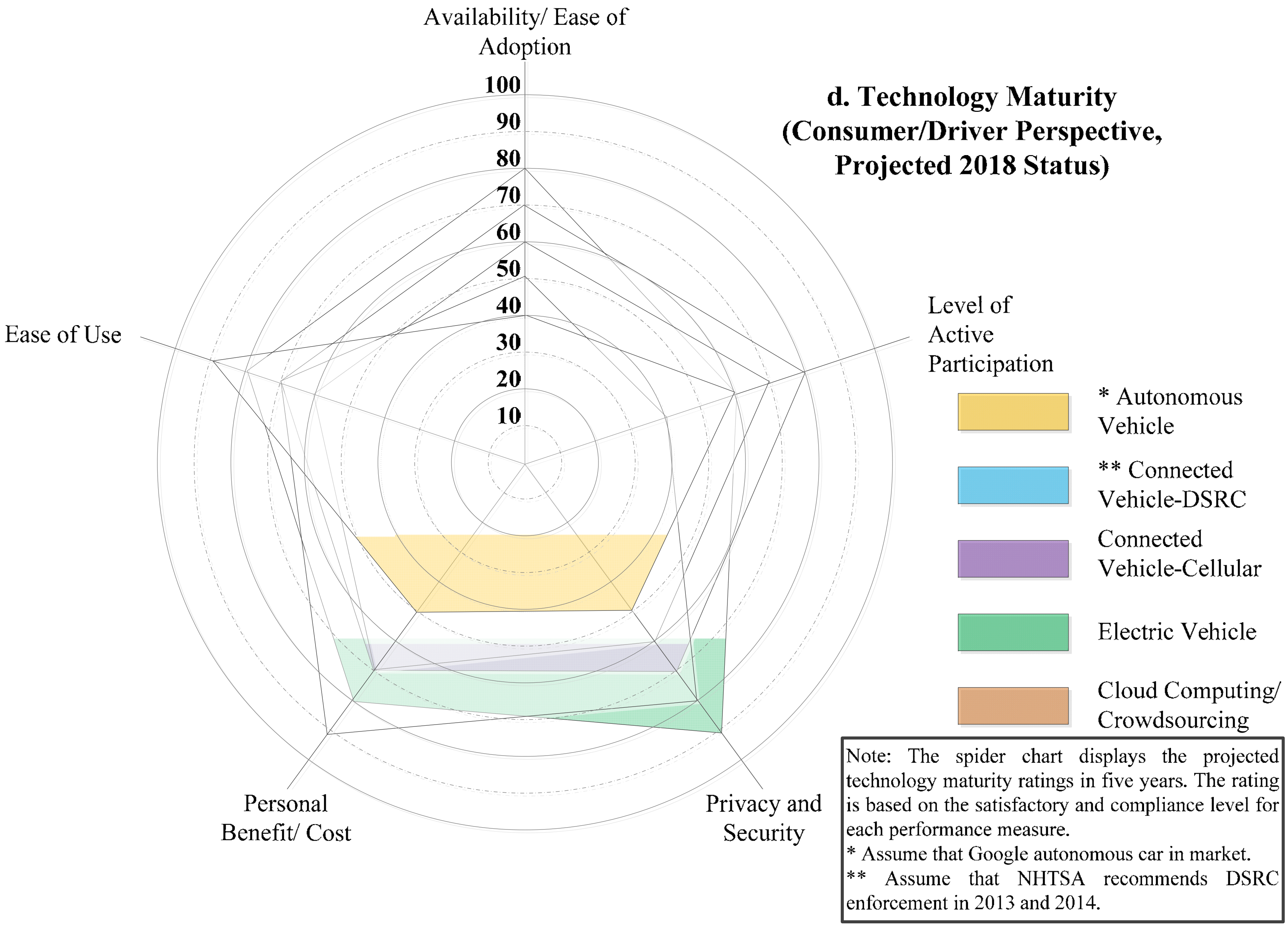


Figure 2.3: Technology Maturity Ratings (continued)

From these technology maturity assessments, key considerations and conclusions for each technology may be made as follows.

Between the two alternatives of the **CV technologies** (cellular versus DSRC), CV-cellular is a developed technology by the automobile industry and can be enhanced by the development of safety, mobility, and environmental applications. CV-DSRC faces a major crossroad with the NHTSA's decision in late 2013 and early 2014 regarding the enforcement of built-in DSRC devices in all vehicles. If the NHTSA enforces DSRC, CV-DSRC will become a cost-effective solution for a wide variety of traffic safety applications.

AVs today are still in the testing stage with extremely limited availability and under-developed applications. Deploying AVs will likely not require significant resources from government agencies other than policy development and license management; however, for consumers, the high cost of AVs may outweigh its benefits, as least within the near-term. This condition may change given Google's anticipated introduction of a commercially available product within 5 years, particularly if costs are able to fall substantially in subsequent years.

EV technology is a mature technology already, while the charging infrastructure for DC fast charging is more mature than wireless, in-road charging. Future development in this category will be incremental with expected advances in battery capacity, charging systems, and vehicle and charging infrastructure cost and performance. The current limitations of EVs and charging mean the technology is not fully accessible to a broad spectrum of consumers.

Cloud computing/crowdsourcing refers to the technology that collects, archives, shares, and disseminates traffic information among users and transportation agencies. The technology itself is well-developed in computer science, but its applications in transportation are still in the early development stage with much foreseeable potential. The development is expected to accelerate greatly within the next 5 years.

2.2.3 Joint Technology System Synergies

As noted earlier in this report, numerous technologies present the potential for dramatic improvements in travel in Texas. However, it is critical to understand that while stand-alone technological improvements have tremendous potential, their synergistic and collaborative impacts may be even greater. To these ends, the Task Force developed the graphic displayed in Figure 2.4 to highlight many (though by no means all) potential systems and applications that would be enabled as the degree of automation and connectivity increase.

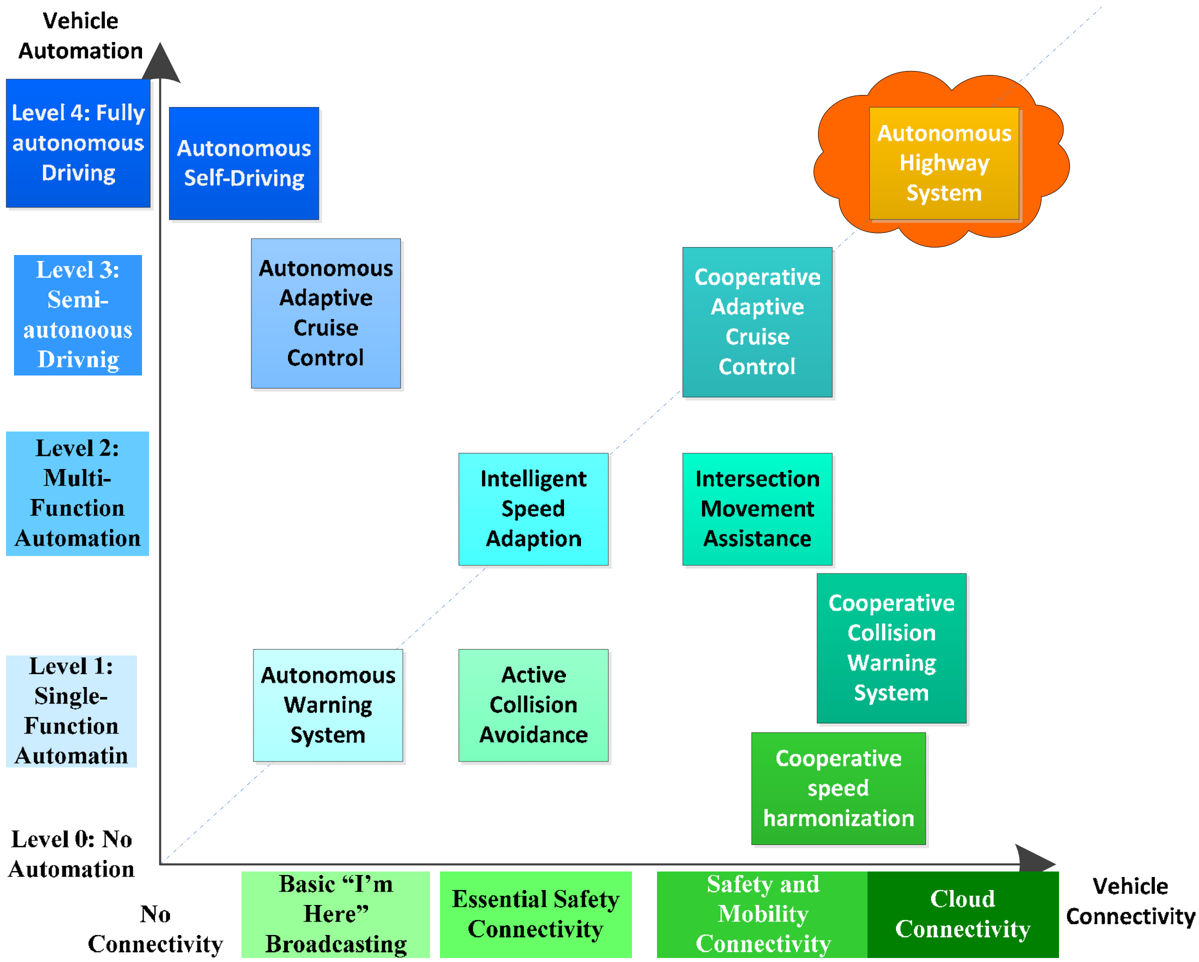


Figure 2.4: Safety and Mobility Systems by Technology Integration and Interaction

Additionally, a second view was examined within a framework of all four primary technologies discussed in this report (automation, connectivity, EVs, and cloud computing/crowdsourcing). This analysis inspected which technologies would provide the most desirable outcomes when combined, examining mobility-enhancing and safety-enhancing systems, with infrastructure- and vehicle-based sub-categories, as well as energy-focused joint technology systems. From this analysis, the compounding benefits of joint-technology systems become even more apparent. For further details, see Appendix B of this report.

2.2.4 Assessment of Transportation Technology Goals, Issues, and Concerns

With an understanding of the developmental stages of emerging transportation technologies, current and near-term technology maturity levels, and the potential synergistic effects of joint-technology systems, the last component of this assessment seeks to gain an understanding of which technologies and joint technology systems produce the most desirable outcomes, and what issues and concerns arise. To these ends, the Task Force developed a series of matrices designed to expose potential barriers to technology adoption and to reveal benefits that could be realized through their use; these matrices are found in Appendix C.

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 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 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 in Tables 1a through 1d: prototyping and closed testing, testing on public roadways, and initial deployment and commercialization. As with the proposed goals, issues and concerns are separated into these three categories:

- **Public Agency Concerns**: Institutional, Infrastructure, Regulatory, Policy, and Public Cost
- **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

2.3 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 vehicle-to-vehicle (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 the 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 vehicle-to-infrastructure systems. 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.

2.4 Enablers for Technology Development

In this section, based on the evaluation results, we identified several key technologies enablers that can help eliminate non-technical barriers and promote the technology development. Identifying these enablers will help further development of action plans for Texas.

2.4.1 Data Environment

Data is one of the most critical elements in the development of transportation applications. Transportation data can be classified into travel demand, dynamic traffic conditions, traffic events (such as work zones, incidents, and culture and sports events that significant affecting surrounding traffic), environment data such as road weather and air quality, and transportation infrastructure data including signage and signal timing, digital map, and infrastructure conditions etc. The innovative technologies investigated in this study all require data inputs and generate useful transportation data. However, in many cases, the necessary data inputs needed for developing and testing transportation applications are difficult or too costly to obtain (for example, digital maps and real-time traffic conditions); at the same time, the data generated from those applications, other than being consumed by application users, are not being fully utilized and exploited for their potential technical and business values.

From the TxDOT perspective, providing technology developers with a rich and healthy data environment requires significant coordination efforts among agencies in public sectors and data providers in the private sector. The data environment should not only streamline the provision of agency data such as infrastructure, incidents, construction, and detector data, but also establish agreements with data providers like GIS map and traveler information providers for sharing or obtaining their data at a discounted price. The environment should also provide data sharing and re-selling mechanism so that the data generated by any number of applications can be further utilized in other applications. Such a data environment can significantly reduce the resource and time requirements for application developers in negotiating and managing their data flow, which should accelerate technology development.

2.4.2 Test Environment

In order to further the state of emerging transportation technology within Texas, it is crucial that the state foster an environment that best facilitates and enables such technologies. To these ends, Texas has two primary environments that could be used to help develop such efforts: closed systems on which technology prototypes may be tested, and public roadways for advanced technology applications that are much closer to market readiness. The state of Texas may be able to utilize test tracks, portions of under-utilized roadways, or other available infrastructure, and make such facilities available to emerging transportation technology developers. Incentives like this could cut development costs and help attract technology firms to the already business-friendly state.

Additionally, the state could help improve the testing environment by providing mechanisms for technology developers who wish to transition from closed environments to testing on public roadways. While some technologies would likely need little or no added regulations, it would be a necessity for other technologies, like AVs. Also, regulatory reform for product liability, transportation technology-based project streamlining, public agency data sharing with technology developers (as noted above), and other efforts could also be examined, each of which could create a more conducive environment for testing on public roads.

2.4.3 Public Relations

A strong public relations effort is likely necessary to the success of this project. Numerous technology providers, manufacturers, and other firms must be made aware of these efforts in order to incentivize them to enter or expand their presence in the state with an emphasis on developing and deploying new transportation technologies. Such efforts may also appeal to new startups desiring to enter the market, and such companies must also be made aware of such efforts. A third target of public relations efforts could focus on angel investors, venture capital firms, and other funding sources that may be willing to fund new companies and projects within Texas. Moreover, outreach to these interested parties should help open lines of communication between technology developers and state officials, in order to help identify and address barriers to implementation. Finally, the general public should be made aware of these efforts in order to garner valuable public input.

2.4.4 Funding

While the activities described in this project may deliver substantial benefits to Texas, these efforts will carry some public agency costs. It is anticipated that the bulk of development and deployment costs will be funded by private corporations and financing, as companies seek to become market leaders and sell their products directly to the traveling public. However, public funds will likely be required in multiple ways. First, administrative and programmatic support must be provided in order start and run the project, including public relations efforts described above. Existing TxDOT and other state resources may be leveraged, including infrastructure and data availability, which should require agency staff time and effort. Other potential funded activities may include further research efforts, infrastructure deployment of new transportation technology applications, and other programmatic needs as they arise.

2.4.5 Public-Private Partnerships

Technology development, especially at the early stages of development, requires collaborations among government agencies, research institutes, and R&D forces in the industry. In transportation, the establishment of reliable partnership between public and private sectors is especially critical when dealing with the transportation system: a large-scale, 24/7, civilian system. Different parties present different resources, advantages, and disadvantages in technology development.

- **Transportation agencies**: Transportation agencies plan and manage the system. They can help provide policy and legislative support. They are also major sources for planning data, infrastructure data, construction information and data, incident data, and traffic detector data on major highways.
- **Research institutes**: Research institutes are a major R&D force during the initial development of many technologies. They can carry out innovative and fundamental research that appear not cost-effective to industry R&D departments. Meanwhile, research institutes can also conduct unbiased third-party evaluation studies for newly-developed technologies or products. Many research efforts and ideas have later been commercialized
- **Automobile industry**: The automobile industry has the capability of adopting and incorporating new technologies into vehicles, and marketing them to the public. They are major R&D forces in many vehicle-based technologies. Also, many manufacturers partner with companies from other industries like cellular providers, mobile device companies, and hardware and software companies regarding technology development and deployment. The business nature of the manufacturers makes them highly effective in developing, promoting, and implementing new technologies.
- **Traveler information and transportation service providers**: These companies have been a rising force over the last decade in the transportation industry. Many data and service providers have already replaced the traditional roles of transportation agencies in delivering ITS to travelers. With the rapid development in communication technologies, location technologies, and smartphones, theses providers should continue to significantly improve data quality and services in the near future. Meanwhile, these providers are still commercial entities ultimately pursuing profits. Many of their data sources come with licensing costs not affordable to ordinary developers especially during the initial prototyping and experimental stages.
- **Other technology companies**: One key observation in this study is that the new technologies are no longer simple transportation solutions that can be developed only by transportation engineers and car manufacturers. Technologies such as cloud

computing, crowdsourcing, and even CV-cellular technologies have been intensively studied or even implemented in other technology industries. Those parties, although not dedicated forces in the transportation solutions arena, can provide the needed technology and resources for the implementation of new technologies.

A healthy partnership among these technology development forces should significantly accelerate emerging transportation technology development and deployment in Texas. The strategies and business plans to fulfill such public-private partnership are the main tasks to be developed by the TTTF.

Chapter 3. Next Steps

The following sections provide an overview of the opportunities and implementation strategies that the TTTF has envisioned.

3.1 Vision

Texas has an opportunity to align the resources of the public and private sectors to become a center of economic development associated with the integration of technology into the transportation system of the state. However, this potential growth will not be fully realized without creating a set of tactics, policies, and actions that collectively form an economic development strategy for this emerging industry. This effort to go “narrower and deeper” forms the next phase of the TTTF work plans, and will yield a business plan that is expected include a four-pronged detailed implementation strategy: 1) create an incubator; 2) form a research consortium; 3) implement a pilot project that showcases a key technology (AVs); and 4) identify legislative and/or regulatory changes that are necessary to support transportation technology commercialization.

3.2 Implementation Strategies

The four implementation strategies identified in the vision are described in more detail below.

3.2.1 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. The ultimate goal is to seed and foster growth of a Texas-based industry cluster in this space, via both recruitment and development of firms. TxDOT and the University of Texas may be necessary partners with the TTTF in creating an incubator.

Incubator roles:

- Seek innovative companies across the world that are in the very early stages of creating a product or service focused on solving a problem related to transportation.
- Cultivate relationships with mentors, investors, and leaders to support and participate in incubator’s companies.
- Provide a location for chosen companies to reside in while growing from concept to commercialization. The ability to house multiple companies in the same location allows for the leveraging of mentors, collaboration, etc.
- Seek partnerships and sponsorships from large auto manufacturers and auto parts manufacturers while giving them access to the incubator companies and allowing them to invest and work with these companies.

TxDOT roles:

- As a public support organization, TxDOT will provide infrastructure/resources/ access to a network where incubator companies can test and develop their products or services. Public support will be the key differentiator in that it can provide a conduit to test and enhance solutions as they prepare to come to market.
- TxDOT will be a sounding board for the incubator, assisting the incubator in determining the best companies to include in its activities.
- TxDOT will give incubator companies regular feedback, helping them to become more efficient.

Summary

The combination of focused resources provided by the incubator, formal access to TxDOT, the innovative and entrepreneurial culture of Austin, and the highly competitive business climate provided by the State of Texas could result in the leading effort to develop disruptive transportation technology enterprises in the U.S. and potentially the world.

Examples of Analogous Efforts

<u>Transportation Technology Ventures (TTV)</u>

TTV is a seed venture capital fund and business accelerator focusing on innovation in the transportation industry [11]. Transportation is one of the oldest and largest businesses in the world and greatly in need of innovative solutions that improve safety; reduce congestion, energy usage, and pollution; increase efficiency and resource utilization; provide entertainment; and reduce costs.

A combination of recent technology shifts and emerging consumer trends—internet-connected cars, vehicle-to-vehicle communications, crowdsourcing, and resource sharing—have opened up a world of new opportunities for innovation in transportation. TTV aims to generate superior returns for its investors by providing the funding and resources needed to establish new, innovative businesses that capitalize on these new opportunities.

TTV provides two main value-added services to transportation-focused startup businesses:

Resources: TTV provides technical assistance with software development, including access to automotive software development kits, technical know-how, and testing and quality assurance validation with fleets. TTV also has substantial connections with automotive original equipment manufacturers, tier one suppliers, fleet management companies, academic and government institutions, and businesses participating in the transportation supply chain. These relationships are leveraged to help new companies commercialize their products and gain much needed early market traction.

Financing: TTV will help the selected new businesses raise seed level funding to develop and launch their new product and/or service. TTV has investment syndication experience and partners who will help fund a good opportunity.

TTV provides these value-added services to help launch new businesses that may originate from

- university researchers and scientists who have a new promising technology and desire to form a startup company;
- entrepreneurs in the field who need resources and money; and
- spin-offs from larger transportation-related businesses.

<u>Austin Technology Incubator (ATI)</u>

ATI harnesses business, government, and academic resources to provide strategic counsel, operational guidance, and infrastructure support to its member companies to help them transition into successful, high growth technology businesses [12].

Since its founding in 1989, ATI has worked with over 200 companies, helping them raise over $1 billion in investor capital. Over the past 5 years (a period including the recent recession), ATI has worked with over 100 companies, helping them to raise over $250 million in investor capital. During that same 5-year period, ATI alumni companies realized approximately $400 million in exit value. Roughly 75% of companies admitted into ATI receive external funding.

ATI is committed to working with the best founding teams in Austin. Out of an annual "pipeline" of 100–150 prospective companies, ATI typically admits only 5–10 into membership in the incubator. Investors, executive talent, and mentors recognize this selectivity.

ATI is a program of the IC² Institute of The University of Texas at Austin. It has a dual mission: promote economic development in Central Texas through entrepreneurial wealth and job creation, and provide a "teaching laboratory" in applied entrepreneurship for UT-Austin students. ATI works closely with other commercially focused and business-building programs at the university.

Although ATI is part of The University of Texas at Austin, there is no requirement that ATI companies need to be based on UT-Austin technology, or indeed have any formal connection to the university other than ATI membership.

ATI Focus Areas

ATI has over 20 years of experience adding value to technology start-ups. And, based on that experience, the incubation model has evolved as Austin's tech economy has grown and developed. Today, the belief is that the early stage community is best served by offering a broad business building platform, but complementing that with industry-specific capabilities. To that end, ATI has invested in developing domain expertise and market- and technology-specific networks of advisors and investors in four areas:

- Information technology (broadly defined to cover both software and silicon)
- Wireless telecommunications (again, covering both hardware infrastructure and software tools)
- Bioscience (with a human health focus, from device to therapeutics.)

- Clean energy/clean technology (with a strong sub-focus on electric power, although ATI welcomes applications from alternative fuels companies)

Each focus area has a dedicated ATI director, board of advisors, intern resources, and network of industry experts. In addition, ATI works with investors whose investment theses match their technologies: since implementing this model, over 75% of ATI members have attracted funding.

3.2.2 Research Consortia

There are a range of approaches to creating an organizational structure that facilitates economic development in emerging industries via collaboration and coordination among the public, private, and not-for-profit/academic sectors. In particular, most organizations will fall into one of two broad areas of emphasis: 1) research consortia, which collaborate to create intellectual capital and technology that can be shared to the common benefit; and 2) incubators/commercialization efforts, which focus on bringing new and evolving technologies to market. Texas has several examples of both.

SEMATECH and MCC were both created in response to concerns about the U.S. falling behind offshore competitors in technology manufacturing during the 1980s. Called a "technological catalyst," the SEMATECH government-academia-industry partnership was dedicated to "fundamental change in manufacturing technology and the domestic infrastructure to provide United States semiconductor companies the capability to be world-class suppliers" [13]. Among early participants were 31 universities in 14 states, along with private member companies including AT&T, IBM, Intel, Hewlett-Packard, NCR Corporation, Rockwell International, and Texas Instruments. Commitments included a program of "precompetitive" generic R&D to apply software solutions to the nation's manufacturing problems, efforts to design factories for the twenty-first century using modeling, simulation, and computer-integrated manufacturing, and reduction of the time between new generations of technology [13].

In late 1982, several major computer and semiconductor manufacturers in the United States banded together and founded MCC as an American answer to Japan's Fifth Generation Project, a large research project aimed at producing a new kind of computer by 1991. Many European and American computer companies saw this new initiative as an attempt to take full control of the world's high-end computer market, and MCC was created, in part, as a defensive move against that threat. Despite this purpose and the background of its senior staff, MCC accepted no government funding for many years. In the 1980s its major programs were packaging, software engineering, CAD, and advanced computer architectures. The latter comprised artificial intelligence, human interface, database, and parallel processing, with the latter two merging in the late 1980s. Many of the early shareholder companies were mainframe computer companies under stress in the 1980s. Over the years, MCC's membership diversified to include a broad range of high-profile corporations involved in information technology products, as well as government R&D agencies and leading universities. The organization was disbanded in 2000.[1]

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[1] Various online sources.

Prior to MCC, a research university typically did not play an active role in economic development, relying instead on external players to commercialize the intellectual capital created as part of its research and programs. For the University of Texas, MCC changed the equation, resulting in 30 endowed professorships and a major boost in the prestige of its engineering programs. It also created the momentum that led to UT's IC^2 Institute, which contributes to technology development and commercialization to this day.

3.2.3 Pilot Program Options

As part of the TTTF vision for encouraging and enabling new transportation technologies, an emerging technology pilot program may be adopted. The pilot program would collect specific data through testing for evaluating alternatives to the regulations, or create innovative approaches to safety and ensure that the safety performance goals of the regulations are satisfied. Partners in the pilot program would work with appropriate state agencies to develop a comprehensive plan for the pilot program that would be designed to achieve the intended goals. Considerations for pilot studies would include feasibility, time, cost, public safety and adverse events, etc. The program would provide valuable information and prediction of performance of full scale technology deployment.

3.2.4 Legislative and Regulatory Changes to Support 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.

The following may be necessary partners with the TTTF in addressing regulatory and legislative barriers: TxDOT, Texas Department of Public Safety, Texas Department of Insurance, Texas Commission on Environmental Quality, the NHTSA, and automobile manufacturers, technology and industry experts, and the public.

Appendix A: TTTF Biographies

Scott Belcher
President and CEO
Intelligent Transportation Society of America (ITSA)
Scott F. Belcher was appointed President and CEO of the ITSA in September 2007 after a successful legal and nonprofit management career. Prior to joining ITSA, Scott most recently served as Executive Vice President and General Counsel at the National Academy of Public Administration in Washington, D.C. Prior to that, Scott held senior management positions at a number of prominent trade associations, worked in private practice at the law firm of Beveridge & Diamond, PC, and at the Environmental Protection Agency.

Shannon Crum
Director
Research and Technology Implementation
Texas Department of Transportation
Shannon Crum serves as director of Research and Technology Implementation. She is responsible for the direction, coordination and oversight of TxDOT's research program, technology implementation program and new product evaluation program. She also oversees the Operational Excellence Office.

Crum joined TxDOT in 2004 and has served as the director of Data Management in the Transportation Planning and Programming Division since 2005. She provided direction and oversight for data collection and reporting on the agency's roadway asset inventory. She also oversaw development of TxDOT's annual "100-Most Congested Roadways" list and the Mobility Investment Priorities project, which is designed to advance development of high-impact projects on the most congested roads in the state.

Steven Dellenback
Director, Intelligent Systems Department
Southwest Research Institute
As director of the Intelligent Systems Department at Southwest Research Institute® (SwRI®), Dr. Steven Dellenback oversees more than 70 staff members performing design, development, deployment, and maintenance services for a number of clients, including military organizations, transportation agencies, vehicle manufacturers, and organizations that utilize enterprise-wide software applications.

Dr. Dellenback is a technical contributor to the TxDOT statewide integration project and the Florida Department of Transportation (FDOT) SunGuide® software project, which is developing an ITS application that is used at all major transportation centers throughout the state of Florida. He serves as the Project Manager for the SwRI research program that is developing advanced technologies for AVs, active safety systems, vehicle-to-vehicle communications, and vehicle-to roadside communications. He is the program lead for SwRI's efforts to develop the U.S. Army's unmanned vehicle program (Dismounted Soldier Autonomy Tools, or DSAT).

Dr. Dellenback was elected to the ITSA's Board of Directors in May 2012 and also serves as chairperson of the Coordinating Council. He is chairman of the National Transportation Communications for ITS Protocol (NTCIP) Test and Conformity Assessment Working Group, and is a voting member on the NTCIP Joint Committee and the Traffic Management Data Dictionary (TMDD) Steering Committee.

David Ferdman
Chief Strategy Officer
CyrusOne, Inc.

Mr. Ferdman is a serial entrepreneur. Mr. Ferdman co-founded CyrusOne (Nasdaq: CONE) in 2000 and served as its president and chief executive officer from 2000 to August 2011. He has been recognized as an industry leader in the outsourced data center services marketplace. In addition, Mr. Ferdman serves as a managing partner of Acalre Holdings, LP, a Texas-based private investment firm managing a portfolio of private investments, including technology infrastructure platforms, sports and entertainment venues, energy and commodity infrastructure, and commercial real estate.

Mr. Ferdman currently serves as a director of CyrusOne, Inc., a director of Circuit of the Americas in Austin, Texas (a premier international motorsports venue hosting the Formula 1 US Grand Prix), and a director of Serendipity Wine Imports, a Texas wine distributor.

Prior to CyrusOne, Mr. Ferdman co-founded and served as the chief operating officer of UWI Association Programs, a telecommunications platform. He has been published on the topic of entrepreneurship as well as a variety of data-center-related topics. He was a finalist in the 2004 Ernst and Young Entrepreneur of the Year Program.

Mike Heiligenstein
Executive Director
Central Texas Regional Mobility Authority

Mike Heiligenstein is the executive director of the Central Texas Regional Mobility Authority, a multimodal transportation agency. Mike has served the Mobility Authority since 2003, overseeing its growth from a startup transportation agency to a nationally recognized leader in toll road operations. During his tenure, the agency developed its first toll road (183A) and maximized its efficiency by implementing cutting-edge technologies, such as video billing and all-electronic tolling. Currently, Mike is overseeing construction of the $426 million, 6.2-mile Manor Expressway project east of Austin and development of state-of-the-art Express Lanes on the MoPac Expressway.

During his 30 years as a public official, first as a Round Rock City Council Member and later as a Williamson County Commissioner, Mike focused on infrastructure projects plus solutions to regional problems. Mike was a founding board member and two-time vice chair of the Austin-

San Antonio Corridor Council and a founding member and board member for the Envision Central Texas project. Mike currently serves on the boards of the Texas Transportation Institute and the International Bridge, Tunnel and Turnpike Association and will be President of this prestigious international group in 2014.

Jon Hockenyos
President
TXP, Inc.
Jon Hockenyos has had a life-long interest in economics and public policy. Mr. Hockenyos founded TXP while attending the LBJ School of Public Affairs at The University of Texas at Austin. Since then, TXP has successfully completed hundreds of projects for a wide variety of clients. In his role as president of the firm, Mr. Hockenyos is involved in managing the day-to-day operations of the organization, performing technical analysis, and developing strategies for clients.

He served on the Board of Directors for Capital Metro, the Board of the Arc of the Capital Area, and is a member of the Advisory Board of American Bank of Commerce.

Mike Krusee
Consultant
Mike Krusee was first elected as a member of the Texas House of Representatives from Austin, Texas, in 1992, serving until retirement in 2009. Subsequently, Mr. Krusee has served as a consultant to range of public and private sector clients on legislative and transportation issues.

Mr. Krusee served as Chairman of the House Transportation Committee from 2003 to 2009. His authorship of HB 3588 put Texas at the forefront of a national movement by states to employ innovative project delivery and financial tools to resolve mobility concerns.

Chairman Krusee served as the Transportation Chair of the National Conference of State Legislators from 2003 to 2005. In 2007, U.S. Secretary of Transportation Mary Peters appointed Mr. Krusee to the congressionally mandated National Surface Transportation Infrastructure Financing Commission.

Michael Morris
Director of Transportation
North Central Texas Council of Governments
Michael Morris has served in the Transportation Department of the North Central Texas Council of Governments (NCTCOG) since 1979.

After working as a transportation planner, senior transportation planner, and assistant director of transportation, Mr. Morris became director of transportation in 1990. His responsibilities as director include directing the overall transportation activities of NCTCOG, carrying out the transportation policies of the NCTCOG Executive Board and Regional Transportation Council, and managing the implementation of rules, regulations, and responsibilities of federal and state government.

Michael is a member of the Association of Metropolitan Planning Organizations, the Institute of Transportation Engineers (ITE), the American Society of Civil Engineers, and the Travel Model Improvement Program Review Panel of the Federal Highway Administration. Michael has served on the NRC Committee to Review EPA's Mobile Source Emissions Factor Model, the Committee for the Evaluation of the Congestion Mitigation and Air Quality Improvement Program, the Committee on Air Quality Management in the United States, and the Executive Committee of the Transportation Research Board. He is the recipient of numerous awards, including the 2004 National Award for Outstanding Achievement in the Metropolitan Planning Organization.

Shelley Row
President and CEO
Shelley Row Associates, LLC

Shelley Row is a world-known transportation professional and one of the most recognizable faces in the ITS industry. In 2000, Shelley was selected as the Office Director in the FHWA's Office of Transportation Operations where she oversaw the Manual on Uniform Traffic Control Devices, road weather management, and work zone programs.

Recently, she was a member of the Senior Executive Service where she served as the director of the USDOT's ITS JPO. In that position she managed a staff of highly skilled technical professionals and a $110 million annual budget. The development of connected vehicles (cars that exchange wireless data through DSRC) for safety, mobility, and the environment was the signature program.

She also served as the chief technical officer for the ITE, and started her career with TxDOT. She provided transportation expertise in volunteer service to city government, where she served on transportation transition teams for two mayors.

She is the president and CEO of Shelley Row Associates (SRA) LLC, a two-part company. SRA provides ITS consulting services specializing in ITS strategic planning, particularly for connected vehicle implementation.

Ron Schoon
Executive Manager, Partnership Development
National Renewable Energy Laboratory

As an Executive Manager of Partnership Development, Ron Schoon is responsible for lab-wide development of partnerships between NREL and industry. His current focus is in Fuels, Vehicles and Transportation.

He joined NREL in 2010 after 23 years in the transportation industry working in the heavy truck, automotive and commercial aircraft sectors. Prior to joining NREL, he spent six years at Navistar as the Chief Engineer responsible for aerodynamic and thermal performance of new truck and bus designs. He also managed a significant portion of the truck R&D and established partnerships that leveraged public and private funds for R&D projects. Previously, Mr. Schoon held management and senior engineering positions at General Motors and Boeing.

JD Stanley
Public Sector CTO
Internet Business Solutions Group Cisco

Mr. Stanley has over 19 years of experience in the ICT industry. Mr. Stanley the Public Sector Chief Technology Officer in Cisco's Internet Business Solutions Group, a process and technology innovation organization. Mr. Stanley while at Cisco for over 10 years he has provided management consulting, executive strategy, and transformation services to public and private sector organizations. Mr. Stanley's responsibilities include strategies and disruptive innovations associated with key programs: Connected Urban Development, Global Climate Change, Global System Integrators, Smart Grid & Energy Service Providers, Defense and Security, and 21st Century Workforce.

Mr. Stanley's expertise includes urbanization, climate change, public/private/citizen partnerships, global transportation; logistics/supply chain management and sustainment/MRO; life cycle program management; market/economic shaping/creating innovation models for private and public sectors; system of systems engineering and service oriented architectures.

In addition to 10 years with Cisco, Mr. Stanley has worked for FTP Software and Lotus. His background includes product line management and operations management. His technical experiences include over 17 years of IP Networking and Communications, along with Intelligent Agents, Swarming, Embedded Systems, IPv6, Mobility, and Systems Strategies.

Harry Voccola
Executive Advisor
Nokia Location & Commerce

Harry Voccola currently serves as executive advisor to Nokia Location & Commerce. Previously he was senior vice president for NAVTEQ, a subsidiary of Nokia. Mr. Voccola, who joined the company in 1995, has over 30 years of experience developing state and local marketplace transportation technology opportunities, including over twenty-five years in transportation technology services, mapping and dynamic content solutions, and ITS.

Mr. Voccola was instrumental in defining data requirements for the emerging vehicle and internet navigation markets. He directed the real time traffic deployment strategy in the U.S and led the NAVTEQ efforts to define the map database requirements for several federally sponsored field operational tests and regional deployments.

From 1980 to 1995, Voccola was senior vice president and general manager of Lockheed's Transportation Systems and Services. He designed and implemented HELP, Inc.—the first ITS public/private partnership that successfully evolved from a federally funded test to a self-funding service for the trucking industry and state DOTs. He also led the implementation of ETC systems, including service centers on the Southern California Transportation Corridor Agencies, the Georgia 400 Toll Road, and the New York State Thruway (EZ Pass).

Mr. Voccola served as past chairman of the board of the ITSA, where he served on its Board of Directors for its first 12 years. He also is a member of the Board of Directors of ITS California (chair for 2 years), the World Congress for Intelligent Transport Systems He has served as chair of the board of the Spatial Technologies Industry Association; and is currently serving as the chair of the Connected Vehicle Trade Association.

C. Michael Walton
Department of Civil, Architectural and Environmental Engineering
The University of Texas at Austin

Dr. C. Michael Walton is professor of Civil Engineering and holds the Ernest H. Cockrell Centennial Chair in Engineering at The University of Texas at Austin (UT). In addition, he holds a joint academic appointment in the Lyndon B. Johnson School of Public Affairs. For more than 40 years he has pursued a career in transport systems engineering and policy analysis.

Dr. Walton is a member of the National Academy of Engineering. In other professional society affairs he is a past chair of the board of the American Road and Transportation Builders Association (ARTBA), current president of the board of Governors of the Transportation and Development Institute of the American Society of Civil Engineers (ASCE), a founding member and past chair of the Board of Directors of the ITSA, a past chair of the Transportation Research Board Executive Committee, and a member of many other technical/professional organizations such as the ITE. He has served on or chaired a number of national study panels, including those mandated by Congress and others of the National Research Council.

Dr. Walton has received numerous honors and awards and has contributed to more than 500 publications in the areas of ITS; freight transport; and transportation engineering, planning, policy, and economics. Currently Dr. Walton has a research or consulting relationship with over 30 states and several engineering consulting firms, and serves as a member on several Boards of Directors of both public and privately held companies.

Elyse Yates
CEO
I&O Communications

Elyse Yates is the founder and CEO of Influence Opinions. She offers more than two decades of experience and expertise in arenas as diverse as politics, high-tech, public affairs, nonprofits and entertainment – not to mention amazing big-picture vision, incredible insight and strategies that work, all delivered with a zest for life that you wish you could bottle and sell.

Prior to launching the firm, Elyse was a Managing Director for Public Strategies, Inc., the recognized leader in public perception management for Fortune 500 companies. During her tenure there, Elyse built an interactive business unit and a media relations division, managed the marketing and branding of the company, and led teams consulting for a broad spectrum of clients including: Perot Systems, the San Antonio Spurs, Schering Plough, Seton Healthcare Family and Southwest Airlines. Earlier in her career, Elyse was a media relations specialist for IBM, where she helped found the IBM software Image Team and worked closely with media nationwide.

Among her earlier political credentials, Yates served as deputy spokesperson for then-Governor Ann Richards and as associate director of the Texas Consumer Association.

Elyse has volunteered in leadership positions for many years. She currently serves on the board for Ending Community Homelessness Coalition (ECHO) and for The University of Texas' School of Natural Science.

Appendix B: Technology Classifications and Joint Technology Impacts

Technologies used in the synergies, goals, and concerns analysis are described in this appendix.

Individual Technologies

Vehicle-to-Vehicle Technology (V2V) represents the components of the combination dynamic traffic data acquisition and distribution system. It is described as the communication infrastructure that enables message propagation among vehicles and generally includes the hardware component and communication enabling/information transmission technologies. Vehicle data and information can be derived from non-vehicle-embedded technologies, such as GPS, to identify vehicle speed and location. Alternatively, this information can be derived from vehicle-based sensor data, wherein the vehicle's computer provides speed and location, which is combined with other data such as latitude and longitude to produce more detailed situational awareness of the location of other vehicles.

Vehicle-to-Infrastructure Technology (V2I) represents the V2I architecture that allows vehicles to communicate with roadway infrastructure. In advanced implementations, vehicle speed and location may be transmitted to a central server. The central server could maintain the speed and location of all vehicles and aggregate this data for connected vehicle applications, such as route determination, incident location, and other safety and mobility applications. Hardware for V2I hardware includes components such as roadside sensors and DSRC antennas.

Cloud Computing and Crowdsourcing. Cloud computing makes IT infrastructure, platforms, and software available on the Internet, and allows end-users to remotely access high-powered computing resources through broadband connections. Crowdsourcing combines two ideas: wisdom of crowds and outsourcing of information. It represents a relatively new phenomenon in which an agency or company seeks the collective intelligence of the public to perform business-related tasks that it would ordinarily perform itself or outsource to a third party. The combination of cloud computing and crowdsourcing allows transportation service providers to more efficiently unify knowledge of a large crowd by removing obstacles to information sharing, data transmission, organization, and analysis. An individual driver's inputs, along with their available travel data, can be collected and communicated to a processing server using mobile communication technologies. *Note: these approaches are referenced in the Table 3 matrix under the Cl + CS headings.*

Vehicle Automation Levels 1 and 2 (A1 & A2). Level 1 (A1) and Level 2 (A2) vehicle automation follow definitions from the NHTSA.[2] Definitions are as follows.

A1 is described as function-specific automation and involves one or more specific control functions; if multiple functions are automated, they operate independently from each other.

[2] NHTSA Policy on Vehicle Automation

The driver may remain in control of the vehicle and is solely responsible for safe operation but can give limited authority over a primary control (such as 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). 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.

A2 is described as combined function automation and 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 may include adaptive cruise control in combination with lane centering.

Vehicle Automation Levels 3 and 4 (A3 & A4). Level 3 (A3) and Level 4 (A4) vehicle automation also follow definitions from the NHTSA.[3] Definitions are as follows.

A3 is described as limited self-driving automation; vehicles at this level of automation enable the driver to relinquish full control of all safety-critical functions under certain traffic or environmental conditions and in those conditions the driver relies 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.

A4 is described as full self-driving automation where 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.

A major distinction between A1 and A2 versus A3 and A4 lies in the requirement that the driver monitor the roadway at all times in the first two levels, whereas warning systems are designed to bring driver attention back to the roadway in levels 3 and 4.

Joint-Technology Systems

While the preceding descriptions define individual technologies, added benefits may be gained by merging technologies and applying them in novel ways to enhance safety, mobility, or energy usage. Infrastructure-focused systems tend to rely on a local or centralized operational manager

[3] NHTSA Policy on Vehicle Automation

or other infrastructure-centered component (e.g., roadside hazard or intersection warnings), while vehicle-focused systems may include communication between vehicles, but do not rely on external system control or guidance.

Infrastructure-Focused Safety Systems (S-F Safety Systems). These are associated with centralized computing, data storage, analysis and decision-making, and information sharing. S-F safety applications are designed to capture data, process and mine it for information on operational and environmental conditions, run safety algorithms, and share warnings and alerts with vehicles, for subsequent action. Examples may include wrong-way driver warnings, traffic signal violation warning, and communication to vehicles regarding upcoming hazards, which may trigger automated warnings or active countermeasures.

Vehicle-Focused Safety Systems (V-F Safety Systems). These applications are embedded within the vehicle (or possibly direct communication with other vehicles) and are designed to automatically alert or assist drivers to enhance safety and operation of the vehicle. Examples may include adaptive drivetrain management, pre-crash warning, left turn assistant, stop sign movement assistance, and others.

Infrastructure-Focused Mobility Systems (S-F Mobility Systems) These applications are made available to drivers through a centralized system capable of capturing and analyzing rich information about vehicles and transportation networks. They are designed to support intelligent management of transportation operations. Examples may include parking application for cities, origin and destination trip information, network traffic flow characterization, special event traffic management, lane or ramp metering, more efficient intersection management, strategies to smooth freeway traffic flow, shared AVs (driverless taxis), etc.

Vehicle-Focused Mobility Systems (V-F Mobility Systems). These applications are described as in-vehicle traveler information systems that automatically alert or assist drivers to enhance traveler mobility. Applications may include intelligent speed assistance or adaptation (including cooperative adaptive cruise control), and may automatically update the vehicle with speed-limit information, hazard warnings, etc.

Energy Applications are designed to support the monitoring and evaluation of energy use, with the goal of increased efficiency. Applications currently under evaluation focus on EV technologies, melded with other emerging transportation technologies. These strategies may better manage the vehicle fleet for charging, leading to more efficient charging station utilization and vehicle use.

Table B1 highlights many (though by no means all) potential applications that would be enabled by melding different technologies. Overall applications focus on safety, mobility, and energy applications, with subcategories for system and vehicle focuses.

Table B1: Transportation Technology Synergies and Collaborative Impacts

Added Benefits	V2V	V2I	Electr	CI + CS	Joint Technology Systems: A2	A3	A4	A3 or A4 + Comm.
V2V Communication		S1, M1		M2	S3	S3, M3, M4	S3, M3, M4	
V2I Communication	S1, M1		E1	S2, M2		S4, M4	S4, M4, M5	
Electric Vehicles		E1		E1		E2	E2	E3
Cloud & Crowd Source	M2	S2, M2	E1			S4	S4, M6	S4, M7
Automation 2	S3							
Automation 3	S3, M3, M4	S4, M4	E2	S4				
Automation 4	S3, M3, M4	S4, M4, M5	E2	S4, M6				
Autom. 3 or 4 + Comm.			E3	S4, M7				

Joint Technology Safety Systems	
Infrastructure-Focused	**Vehicle-Focused**
S1: Quick-response hazard warning	**S3:** Quick-response crash avoidance countermeasure
S2: Advance hazard warning	
S4: Advance hazard warning & countermeasure	

Joint Technology Mobility Systems	
Infrastructure-Focused	**Vehicle-Focused**
M1: Arterial/intersection traffic management	**M3:** Cooperative adaptive cruise control
M2: In-vehicle routing and traveler information	**M4*:** Freeway traffic control and harmonization
M4*: Freeway traffic control and harmonization	
M5: Parking applications	
M6: Driverless taxis and dynamic ride-sharing	
M7: Dynamic route guidance and traveler information	

* Freeway traffic control and harmonization is possible as both vehicle- and infrastructure-focused strategies, though the greatest benefits come when both are used in combination.

Energy Enhancement Applications
E1: Electric vehicless locate unoccupied charing stations
E2: Electric vehicles drive unoccupied to charging station, and leave once charged thereby freeing station
E3: E1 + E2 + autonomous electric vehicles wait for charging station to become free before approaching station

As the Table B1 matrix makes clear, new applications become available as each new technology is unlocked, providing enhanced mobility, safety, and energy efficiencies for travelers. However, not all technologies or collaborative applications will generate equivalent benefits, and it is not a simple task to simply go from automation level A1 to A4, or to quickly commercialize V2V and V2I and then deploy them on Texas streets.

Appendix C: Goals, Issues, and Concerns Facing Emerging Technologies

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 four matrices (presented as Table C3) are shown in Tables C1 and C2.

Table C1: 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 C2: 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 C3: 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)

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