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Technology Evaluation for the Technology Utilization Plan

Andrea Gold
Mark Werner
Mac Bruce
Kristie Chin
C. Michael Walton

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The Texas Technology Task Force is an external advisory board to the Texas Department of Transportation (TxDOT) that conducts technology discovery activities and delivers recommendations for advancing technology to prepare the future Texas transportation system. The Task Force is developing a Technology Utilization Plan that will serve as the fulcrum between technology discovery and implementation. The Technology Utilization Plan will be developed over three phases and completed in summer of 2020. This report provides information and results from phase one, which is focused on technology assessment. The assessment begins with the Emerging Technology Portfolio and covers alignment of transportation goals, identification of barriers to adoption, and determination of technology maturity. Ultimately, TxDOT and other public agency participants will benefit from insights into industry trends, partnership opportunities, potential areas for research, strategic deployments, and policy actions in order to help develop its innovative transportation innovation strategy.</td></tr>
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Andrea Gold
Mark Werner
Mac Bruce
Kristie Chin
C. Michael Walton

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Center for Transportation Research
The University of Texas at Austin
3925 W. Braker Lane, Stop D9300
Austin, TX 78759

http://ctr.utexas.edu/

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Project Engineer: C. Michael Walton
Professional Engineer License State and Number: Texas No. 46293
P.E. Designation: Research Supervisor

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Zeke Reyna, Strategic Research Analyst

Research and Technology Implementation

James Kuhr, Research Project Manager

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Preface

The transportation needs of Texas are evolving at a rapid pace with an expected doubling of population by 2050. When coupled with traditional transportation efforts, advanced and emerging technologies present the opportunity to enhance operations, achieve cost savings, reduce traffic congestion, promote safety, and increase economic activity. To ensure that TxDOT remains at the forefront of innovative transportation, the Task Force continue to evolve as a cross-functional body of transportation thought leaders and subject matter experts (SMEs), serving as an expert advisory body dedicated to transportation technology, to equip TxDOT with essential strategy, innovation, and communication tools.

Key activities of the Task Force include development of the Emerging & Advanced Technology Portfolio, development of white papers on critical technologies, a comprehensive communications strategy, and finally a Technology Utilization Plan that will serve as the fulcrum between technology discovery and implementation. TxDOT and other public agency participants will benefit from insights into industry trends, partnership opportunities, and potential areas for research, as well as strategic deployments, in order to help develop its innovative transportation innovation strategy.

This document provides information and results from Phase I of the Technology Utilization Plan.

1 Planning for Technology Utilization

The safe integration of transformational technologies into the transportation system and public agencies will require strategic planning efforts that align technologies and innovation with agency goals, assess deployment barriers, and analyze trade-offs and resource requirements. This report, which is Part I of III of the, Technology Utilization Plan will form a foundation for emerging technology identification and discovery. It will also form the basis for appraisal of technology use cases, transportation goal advancement, barriers to adoption, and maturity.

1.1 Texas at a Pivotal Moment

Texas is in a period of great change: in the midst of an economic uptick and drastic population growth, the State is making strides in technological advancement. Understanding the implications these technologies will have on the transportation system in Texas is pivotal for the State to continue supporting such multifaceted growth.

1.1.1 Population and Economy

Experiencing historic population growth, drawn by various job opportunities and pleasant climate, the Texas Office of the State Demographer estimates the state is to double its population by 2050. The fastest growing regions of the State are in urban and even more so in suburban counties of the large cities. As of 2019, two of the top-five fastest growing cities in the nation by number are in Texas, including Fort Worth and San Antonio. Trends show an urbanizing state, as between 2010 and 2050, 90% of the population growth is expected to be seen in urban areas. However, not all regions of the state are seeing such benefits, as 29 Texas counties are expected to lose population in this same time period, predominantly in rural areas of the state. Expanding economies in health, energy and tech sectors are only some of the drivers of the growth Texas is seeing. The Texas economy shows little sign of slowing, between 2005 and 2015 the state ranked second in percent GDP growth in the nation. With so much of this growth comes the increased demand in servicing this economy and the necessity for proper planning. Already, over $1.6 trillion and 1.2 billion tons of freight are moved on Texas highways annually, and freight traffic is expected to increase by 78% by 2040.

1.1.2 Technology

Technological advances in the areas of telecommunications, supply chain, and international movement are all changing the transportation landscape in Texas. The emerging technology of 5G communication is one that shows great potential for connected vehicle (CV) systems. CVs offer great benefits for safety and efficiency for drivers as the vehicles have the ability to communicate with each other and with roadside devices installed in roadway infrastructure. Currently many CV systems are set up to use DSRC radios, though the emergence of 5G offers benefits such as improved interoperability, a wider bandwidth, and increased security. Other technologies, such as 3D printing, have the potential to greatly alter the supply chain. 3D printing allows products and prototypes to be made much more easily, at a lower cost, and closer to the consumer. Rather than shipping parts from only a single manufacturer, parts can be created and shipped from various distribution centers. Freight-related improvements being made at the state level may impact Texas greatly, as efficiencies achieved at the Texas/Mexico border have the potential to generate both economic and environmental benefits. Already in use are weigh-in-motion and dimension-in-motion systems, which allow freight trucks to weigh in without stopping. As wait times continue to lag, further efficiencies are of great priority.

1.1.3 Consumer Preferences

Just as companies are capitalizing on these technologies, consumers are similarly demanding what is now possible and available to them. Shipping speeds have now greatly increased and many retailers have begun to offer same-day shipping, including Amazon, Target, Walmart, and others. Constant demand for faster and more efficient delivery is putting a significant strain on the supply chain. Some predictions describe the standard changing to a "demand chain," where production is localized and immediate rather than produced in one central facility. An emerging technology to meet this demand is being called X2C, or delivering "X" to customers. A significant undertaking already under way, companies are looking at X2C solutions such as autonomous ground vehicles or drones that can service the last-mile delivery.

1.1.4 Constraints on Public Resources

The State of Texas has an expansive road and infrastructure network that already requires continued updates; expanding the network to service the greatly increasing population requires substantial resources. One constraint that the state faces is the lowered return from the federal Highway Trust Fund. The Highway Trust Fund is the recipient of the federal fuel tax revenues, at 18.4¢ per gallon. This fund supports road construction and other surface transportation projects, including mass transit. Texas is technically the only "donor" state to the Fund at present, receiving only $0.95 for each dollar contributed. Additionally, the 18.4¢ tax has not been updated since 1993, even as the buying power of the dollar has fallen roughly 40% by 2016. According to the Texas Transportation Plan 2040, keeping Texas's various transportation modes in "a good state of repair" will require $547 billion in funding through 2040. Texas drivers drove about 100 million more miles in 2016 than in 2010, drastically increasing wear and tear of the roadways.

1.2 Strategic Planning for Technology

Strategic utilization of technology has the great potential to address many inefficiencies in our transportation system and create many other improvements. To properly implement emerging technology, however, it must be understood and planned for as comprehensively as possible. Such preparation calls for a three-pronged approach: awareness of investment trade-offs, understanding of potential unintended impacts of these technologies, and integration of these systems into daily life. These three components, which underlay creation of the Technology Utilization Plan, are outlined here.

1.2.1 Awareness & Education

Keeping abreast of technological developments benefits planners because even a baseline understanding may reveal potential applications of a new technology to an existing challenge. Additionally, an in-depth education in these technologies may point to unexpected applications, sparking additional benefits and potentially offshoots of further tech advancement and creativity.

1.2.2 Understanding Impacts & Tradeoffs

It is vital to understand a new technology holistically, by taking a deep dive to anticipate both beneficial and harmful impacts. Transportation in particular is a comprehensive and multifaceted area; mobility itself relies on interconnections, so changes in one mode would likely affect other modes as well.

1.2.3 Facilitate Safe & Appropriate Integration

Technology development is worth little without effective integration. Planners must understand the variety of impacts new technologies could have, such as how their implementation might reduce or increase the need for other services. To facilitate integration, the budget for investments may need to be adjusted.

2 Texas Technology Task Force

The Texas Technology Task Force is an external advisory body to the Texas Department of Transportation (TxDOT) that conducts technology discovery activities to monitor existing technologies and bring awareness about new ones. The following summarizes the Task Force's origins, mission, activities, and relationship to other innovation efforts within TxDOT.

2.1 Task Force Origin

The 83rd Texas Legislature (2013) issued a mandate to TxDOT to establish a technology task force to monitor and advise on emerging transportation technologies. The Texas Technology Task Force formed following this mandate with a deliberate composition of subject matter experts across industry, research institutions, and public agencies with extensive knowledge in vehicle automation, telecommunications, big data, innovative funding and partnerships, transit, freight, long-range and strategic planning, and additional areas of expertise. Task Force membership is dynamic; although it has remained relatively unchanged, it undergoes periodic review to ensure that the right mix of expertise is included to capture perspectives on new technologies and innovative processes.

2.2 Mission & Activities

The Task Force has designed its activities to advance the *mission of transformational technology discovery, stakeholder engagement, coordination and planning with other state agencies, and developing strategic recommendations for technology advancement*. The Task Force activities are planned around its organizing principles of *People, Portfolio, Plans, and Process.* Each of these principles and corresponding activities is described below.

2.2.1 People

The Task Force activities provide a platform to engage various stakeholder groups on technology awareness and planning. These stakeholder groups include the following:

Transportation leadership and policymakers - Texas Transportation Commission, TxDOT Administration, elected official and their staff, Governor's Office.

TxDOT staff - practitioners from across all TxDOT divisions, including but not limited to freight, traffic, strategic planning, information management, long-range planning, legislative affairs, fleet management, research & technology implementation.

Public agencies - other state agencies such as the Department of Motor Vehicles, Department of Public Safety, the Texas Department of Insurance, Texas Commission on Environmental Quality, Public Utilities Commission, local public agencies, metropolitan planning organizations, transit authorities, federal agencies, etc.

Industry experts - subject matter experts from automated driving systems, telecommunications, information & technology, data management and mining, transportation network companies (TNCs), freight and logistics, etc.

2.2.2 Portfolio

The Task Force developed and maintains the Emerging Technology Portfolio as a tool for tracking new and maturing technologies that are expected to be transformative to transportation. The Portfolio is a dynamic list that group technologies into the following technologies: next-generation vehicles, infrastructure & construction, materials & additive manufacturing, information & communications, service-based platforms, and other technologies. A full list of technologies in the portfolio is shown in Figure 1.

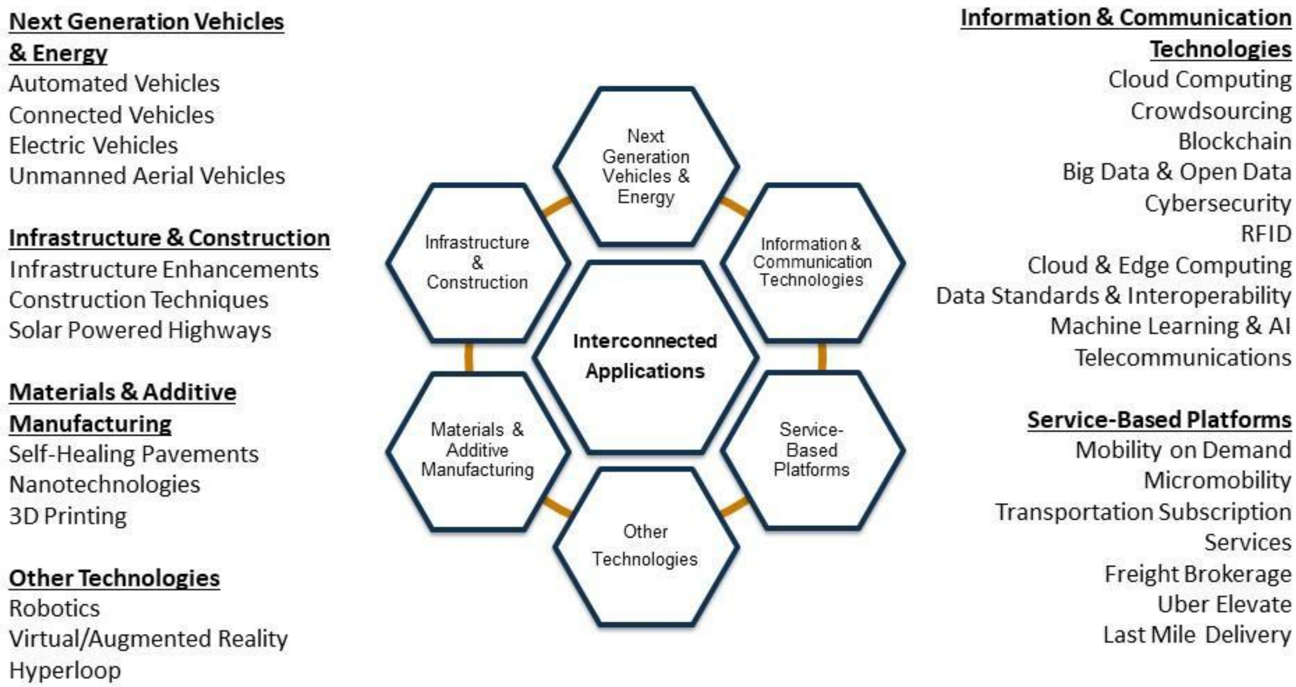

Figure 1: Emerging Technology Portfolio

For technologies in the Portfolio, the Task Force maps transportation applications and use cases, assesses alignment with transportation goals, identifies barriers to implementation, and determines maturity. The Portfolio informs the composition of the Task Force, meeting topics, and white papers. The Task Force considers which technologies may be competing, complementary, or evolving at different paces. The Task Force draws upon information from subject matter experts (individuals with experience and deep technical understanding of technology processes, implementation, and research and development), and industry reports to develop the list of technologies for the Portfolio. The Emerging Technology Portfolio serves as the basis for the technology discovery process, technology evaluation and prioritization, and major components of the Technology Utilization Plan.

2.2.3 Plan

The Task Force develops several documents that are intended to assist in TxDOT's planning activities. The first is the annual issuance of technology white papers on critical topics. Three to five white papers are developed each year in order to provide timely information on innovative technologies, policies, or programs. The Task Force selects white paper topics based on input from the Task Force activities with TxDOT staff and industry experts focusing on areas in which there is critical interest and a number of outstanding questions. The white papers are composed in a manner to serve as a mechanism to bring the most-up-to-date information to TxDOT and other stakeholders and inform strategies in the Technology Utilization Plan. Elements of the white papers contain, but are not limited to, information on technical details of technologies and their real-world applications, potential business models or markets, political and societal trends bearing an impact on technologies, identification of opportunities for utilization and adoption in Texas, and case studies on ongoing trials or pilots, when possible.

Next the Task Force develops and maintains a Communications & Stakeholder Engagement Plan that characterizes stakeholder groups, such as elected officials, other state agencies, TxDOT divisions, industry sectors, the public, etc., and defines, at a minimum, appropriate messages, informational materials, and communication channels. The plan outlines proposed methods of outreach and involvement of various stakeholders throughout the strategic planning process.

The final planning document is the Technology Utilization Plan, which will be composed in such a manner as to serve as a strategic guide on the anticipation and inclusion of advanced technologies for the Texas transportation system and within TxDOT. The Task Force works to continually familiarize itself with ongoing efforts within TxDOT to create an Emerging Technology in Transportation Plan. Where possible, the Task Force will develop the Technology Utilization Plan in a manner to supports the development of the Emerging Technology in Transportation Plan. Further, the Task Force will continue to work with TxDOT staff on an as-needed basis to support the development of the Emerging Technology in Transportation Plan. The Task Force is forming the Technology Utilization Plan through a multi-step process that draws from all of its activities and includes, but is not limited to, elements such as technology market forecasting, evaluation of benefits and barriers, technology maturation requirements and planning, lessons learned from early trials, and technology adoption strategies. The Technology Utilization Plan shall be developed to define a technical end-state enabled by technology adoption over time. The Technology Utilization Plan will identify opportunities for TxDOT to use advanced technology to reasonably meet existing and anticipated goals in the near and long term.

The Technology Utilization Plan will be developed over three phases: 1) evaluation of benefits and barriers to technology adoption, 2) synthesis of best practices and lessons learned, 3) delivery of technology utilization plan with recommendations. Figure 2 shows the successive phases with timelines for each.

Figure 2: Technology Utilization Plan Phases and Timeline

2.2.4 Process

The Task Force meets regularly with TxDOT staff to determine internal technology questions and priorities. The Task Force hosts meetings quarterly at TxDOT headquarters to engage industry subject matter experts through deep-dive presentations, panel discussions, and roundtables. These meetings also provide an opportunity for Task Force members and TxDOT staff to discuss technologies, address open questions, and formulate recommendations for additional research; implementation; or new policies, procedures, or programs to advance technology in Texas.

Figure 3 shows how *Process* drives the Task Force's *People, Portfolio, and Plan* activities.

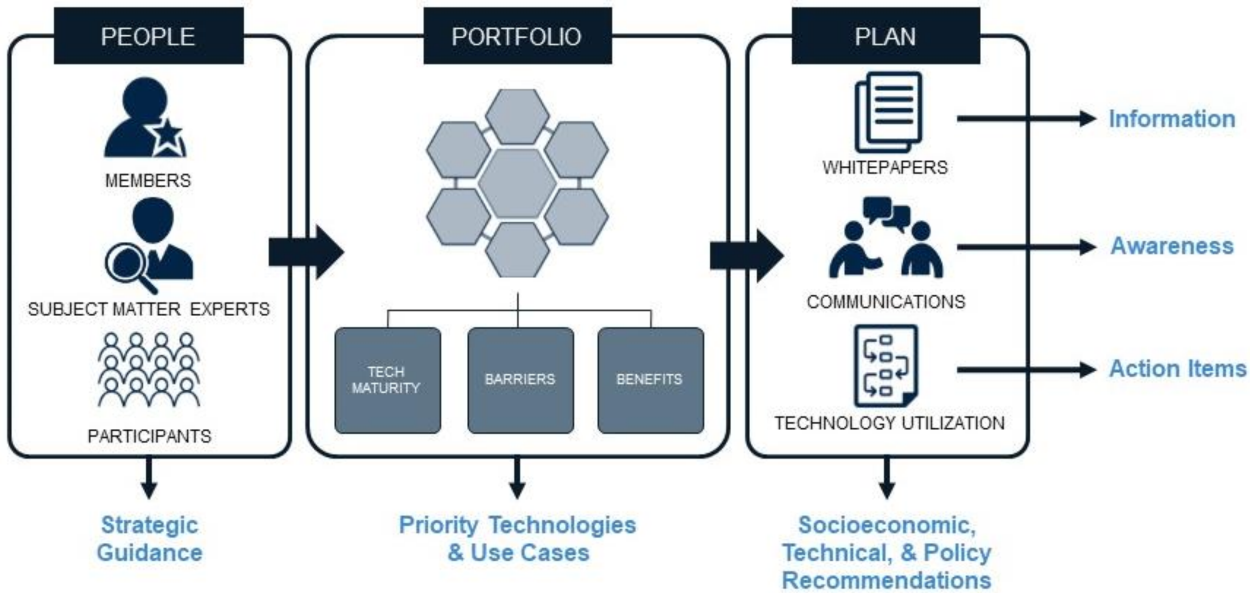

Figure 3:Task Force People, Portfolio, Plan, and Process

2.3 Relationship to Other TxDOT Innovative Activities

TxDOT has several strategic technology and innovation technology programs that coordinate with the Task Force. These include the following.

The Texas Innovation Alliance. The Texas Innovation Alliance is an action network of local, regional, and state agencies and research institutions who are committed to addressing community mobility challenges by creating a platform for innovation. Launched in 2016, the Texas Innovation Alliance empowers public agencies, research institutions, and industry partners to leverage collective resources, co-create solutions, and share results for improving mobility for all Texas communities. The Alliance is dedicated to improving the lives, safety, and economic prospects of Texans and enabled Texas to achieve the only statewide designation as a US Department of Transportation (USDOT) Automated Vehicle Proving Ground. The Alliance is focused in short-term planning and implementation of innovative transportation technologies and programs. The technology discovery activities of the Task

Force that result in identification of ready to deploy solutions are shared with the Alliance for further consideration and advancement.

The State Transportation Innovation Council (STIC). The State Transportation Innovation Council is a group whose mission is to facilitate the rapid implementation of innovative technology, tactics, and techniques among transportation program delivery professionals at all levels of state government and throughout the private and non-profit sector to ensure smart, efficient investment in Texas highway and transportation infrastructure. Their major goal is to provide a forum for transportation leadership to review and collaborate on specific initiatives that best align to the transportation goals of the State of Texas. STIC also responds to key issues and challenges that impact the local and regional transportation system. The technology discovery activities of the Task Force that result in identification of topics and technologies that need further research or are mature enough for scaling are shared with the STIC for further consideration.

The Connected and Automated Vehicle Task Force. Created by TxDOT, the Connected and Automated Vehicle (CAV) Task Force is a one-stop resource for information and coordination on all ongoing CAV projects, investments and initiatives in Texas. In addition to documenting public and private entity efforts and facilitating partnerships, the CAV Task Force hosts industry forums and reports lessons learned to facilitate progress and encourage greater collaboration. The technology discovery activities of the Task Force that identify policy and technology research needs for CAVs are shared with the CAV Task Force for further consideration.

3 Technology Utilization Plan & Development Methodology

The three major phases of the Technology Utilization Plan are described in more depth in this section.

3.1 Phase I: Evaluate Benefits and Barriers to Technology Adoption (January 2019–August 2019)

Phase I considers each technology in the Portfolio and completes an evaluation of impacts to TxDOT, the Texas transportation system, and the public stemming from the adoption of the emerging technologies identified. Through information gathered during the technology discovery activities, the Task Force conducts a high level assessment of benefits, such as expected safety improvements, reduced congestion, environmental impacts, cost savings, and increased accessibility. The Task Force also assesses barriers to adoption such as policy and regulatory challenges, funding, user acceptance, and security. The evaluation describes changes or uncertainty in the economic, political, and organizational spheres that need to be considered when planning for technology utilization.

3.2 Phase II: Synthesize Best Practices and Lessons Learned (September 2019–April 2020)

The Task Force will develop a synthesis of best practices, including, but not limited to, a compilation of technical information on the state of practice in developing or testing advanced technologies. The Task Force will provide examples of applications, techniques, tools, policies, and funding, reported and illustrated through specific case studies. In addition, the Task Force will develop a synthesis of lessons learned from ongoing pilot programs and/or model deployments. Information for this phase will be gathered through visits to model deployment sites and through key person interviews, technology demonstrations, and deep-dive sessions.

3.3 Phase III: Deliver Technology Utilization Plan (May 2020 – August 2020)

The Task Force will develop the Technology Utilization Plan to serve as a guide to the anticipation, adoption, and promotion of advanced technologies. Elements of the plan include, but are not limited to, the following:

- Define a desired results and technology vision
- Evaluate the innovative technologies
- Define the core technologies needed to meet the vision (prioritized from the portfolio)
- Identify elements of supportive environments to enable technology
- Assess the current state of the organization implementing the plan
- Form the Utilization Roadmap by identifying the phasing, insertion points, associated R&D investments, and work plans or packages for core technologies, and then sequence the activities within each functional and major program area in the tactical plan to form the roadmap
- Allocate resources and tasks and set priorities for action during the current year
- Assess the life-cycle costs of technology
- Educate the TxDOT and stakeholders on the plan and its implementation
- Deliver a recommended strategy for maximizing research and resource allocation
- Characterize a framework to measure progress toward implementation
- Where possible, provide research problem statements related to the innovative technologies and their application in Texas

3.3.1 Phase I Methodology

The process for informing the Phase I assessment consisted of three stages: online survey, subject matter expert interviews, and case study review. An online survey was designed to gauge the interest-level of the Task Force members and subject matter experts in various technologies. Survey questions are provided in Appendix A. The responses served as the basis to down-select priority technologies that respondents believe will be the most impactful for the Texas transportation system.

For each of these technologies, the Task Force identified industry leaders to conduct in-depth interviews to gain insights and lessons learned, and identify challenges and innovations. These leaders brought a diverse array of backgrounds and many years of experience, which contributed to our knowledge about the development or potential development of new technologies. Industry leaders were solicited from the private, public, and non-profit sectors in order to paint a full picture of the most relevant technologies, issues, and opportunities they may face now and in the future.

Finally, findings from the survey and interviews were synthesized with published scholarship and news sources to provide more context around each technology.

4 Priority Technologies & Applications

The survey results indicated that the following are the priority technologies:

1. CVs
2. Autonomous Vehicles (AVs)
3. Electric Vehicles (EVs)
4. Unmanned Aerial Vehicles (UAVs)
5. Big & Open Data and Artificial Intelligence
6. Mobility-as-a-Service

Each technology can be broken into applications that can then be grouped or categorized, as in the following section.

5 Applications

Each technology can be split into applications by user group. Each priority technology and application user group is described below.

5.1 Connected Vehicles

5.1.1 Passenger Travel

CVs offer safety benefits to both drivers and pedestrians with applications such as red-light violation warning and curve speed warnings. This technology enables improved traveller information, including notification of upcoming accidents or traffic slowdowns, as well as efficiency in traffic flow. One example is a red-light violation warning, the result of communication between personal cars and traffic signals. The signals can perceive the speed of a car approaching an intersection and its braking habits to determine if the car will stop in time for the light, and will delay the green for intersecting traffic accordingly. Curve speed warnings enhance safety for cars that have limited lines of sight (such as when view is obstructed by other vehicles or landscape features) by determining when a vehicle ahead of them is slowing. Speed harmonization applications can steady traffic flow and reduce stops and thus improve network efficiency. An example of such use cases is the $30 million research project in Ann Arbor, Michigan involving 2,800 vehicles and 73 lane-miles of roadway. This project proved a success in assessing the effectiveness of CV technology in terms of enhancing safety and reducing crashes.[i] [ii] CV technology is most beneficial with a higher density of vehicles and extensive infrastructure in place.

5.1.2 Transit

CVs in transit can employ vehicle-to-infrastructure technology between buses and other transit options, with infrastructure like traffic lights and other roadside units. By connecting mobile buses with static infrastructure, transit has the ability to improve network efficiency, such as through green light extensions, which allow buses that are behind schedule to make up time. Utah's DOT implemented this technology on a corridor of 35 signalized intersections with daily traffic ranging from 18,000 to 40,000 vehicles. The goal of this project was to improve the reliability of the bus service and optimize the use of available green time. An analysis of the completed application showed an improvement in on-time arrival for the equipped buses with minimal impact to intersecting traffic—in short, a success. Connected buses also offer the opportunity to relay timely arrival information to passengers on the bus and waiting at stops; live tracking is made possible through connection between traffic signals. CV infrastructure in transit is primarily useful in regions that have a comprehensive transit network, and often a larger budget. This technology will be less useful in smaller towns and rural communities.[iii]

5.1.3 Freight

Freight vehicles can greatly benefit from CV technology. These benefits include safety in the form of forward collision warning, notice of road slowdowns, and alerts of adverse weather ahead. These are all very important as these vehicles carrying substantial weight may need additional information and time to maintain safety. Traveler information is improved as these vehicles often collect and send information to central hubs that can disperse this safety and other information to drivers and app users, for example. The Wyoming DOT is currently running a pilot project along I-80 that involves 75 roadside units and 400 instrumented fleet vehicles. I-80 in Wyoming is one of the windiest portion of highway in the nation, and experiences severe weather as well. This pilot, initiated to prioritize safety in freight, provides drivers with forward collision warning and infrastructure-to-vehicle situational awareness, including notice of road closures and vehicle restrictions, as well as safety measures like work zone warnings.[iv] This infrastructure does in fact serve the rural community that frequents I-80. Having additional access to information on road and weather conditions is very useful to all users.

5.1.4 Infrastructure Owner and Operator

When implementing CV technology, a great deal of new and updated infrastructure is necessary, including roadside units or onboard units (OBUs). Widespread implementation of OBUs faces an economic hurdle, as in older vehicles the consumer must bear the cost to install the OBUs. While no additional road capacity is needed, there is not always a clear definition of who is responsible for the long-term costs for implementation and repair, as many of the projects were initiated under grant-based funding.

5.2 Autonomous Vehicles

5.2.1 Passenger Travel

AVs offer substantial benefits to passenger vehicles through applications that enhance safety and efficiency on the roadway. These applications are incorporated in both personal vehicles and shared fleets. Many accidents on US roadways are caused by distracted driving, AVs can help improve this.[v] Popular car manufacturers like Mercedes-Benz and BMW are beginning to establish their own automated technology as are technology companies like Waymo. Waymo has already launched AVs in Phoenix, AZ, emphasizing the mobility opportunity and safety benefits for the elderly and visually impaired, and the time savings while commuting.[vi] AVs have also been used in shared fleet technology; for example, Uber has already tested their AVs over many miles and transported thousands of passengers in various test cities across the nation, including Pittsburgh and Tempe, AZ. Using this technology, Uber will likely reduce the cost of rides or meals for their services.[vii]

5.2.2 Transit

AV technology provides transit systems a means to maintain safety and efficiency in route operations. Implementation of AV tech begins with the manufacturers that provide vehicles for transit. Volvo, for example, has made significant strides in AV technology by launching automated buses in Singapore, although the project is so new that results are not yet in.[viii] Another valuable application is low-speed transit shuttles, as are used in Arlington, TX. Arlington is host to many events that bring in large crowds, so offering innovative transport solutions for such large groups is pivotal.[ix] Arlington established the Milo pilot program, which is a shuttle service for events at its Globe Life Park and AT&T Stadium. This pilot concluded and served over 110 events with 98% of surveyed riders claiming they felt safe during the ride.

5.2.3 Freight

Freight truck operators have been in shortage for years now, and it is increasingly difficult to attract drivers despite respectable wages.[x] AVs offer companies the opportunity for cost saving and the ability to establish routes without a driver present. In one example, UPS has partnered with TuSimple, an organization that works to implement AV technology in long-haul trucking.[xi] UPS has been transporting packages between Phoenix and Tucson with the goal of cutting the cost of shipping. TuSimple has been helping UPS reach Level 4 autonomous driving, meaning that the vehicle is fully autonomous and able to reach a particular location. At Level 4 there will not need to be a driver behind the wheel.[xii] Another benefit brought through AV technology is the ability for truck platooning, where a "leader" automated truck can steer the following trucks, all of which are communicating their acceleration, braking, and steering, ultimately improving safety, aerodynamics, and fuel efficiency of the fleet.[xiii]

5.2.4 Infrastructure Owner and Operator

Common questions regarding the adoption of AVs as it relates to state transportation agencies include the following: How will they affect vehicle miles travelled (VMT) and how will they affect highway capacity? While there are many variables and some unknowns regarding how AVs are introduced and adapted to highways, most respected simulations predict that "at 50% market penetration AVs are likely to produce increases in VMT ranging from 5% to 20% depending on facility class." With regard to highway capacity, if we assume that the vehicle fleet is 100% AV and that vehicles have the ability to communicate with one another to negotiate merging and interstate right-of-way, some estimates conclude that "per-lane freeway capacities could increase to 4,000 vehicles per hour or more." [xiv] However, a more near-term, realistic estimate is a traffic flow benefit of 25 to 35% percent if AVs are 75% of the vehicle fleet mix. Truck platooning is another opportunity offered by AV technology for freight, offering CO_2 reductions, safety, and efficiency. Linking two or more trucks in a convoy reduces wind resistance on following vehicles. Safety is improved as the following trucks receive direction from the lead truck, improving reaction times. Lastly is efficiency, as platooning trucks can follow each other more closely, allowing more space for other vehicles to use the road.[xv]

5.3 Electric Vehicles

5.3.1 Passenger Travel

EV technology has been reenergized in personal vehicles within the last 10 years, particularly with advances in battery technology and efforts to improve air quality. These vehicles require charging stations, often placed at sites where the cars will remain parked for some time, such as malls. Popular personal EVs are made by Nissan, BMW, and Tesla. The Natural Resources Defense Council's study of EV adoption in Illinois acknowledged that switching to EVs from gasoline-powered vehicles decreases the total costs to consumers.[xvi]

5.3.2 Transit

In an effort for cities to reach environmental CO_2 goals, some transit organizations have invested in electric buses systems.[xvii] For example, the City of Austin purchased four electric buses from

Proterra, the fifth city in Texas to do so. Use of electric buses improves system sustainability and decrease vehicle noise.[xviii]

5.3.3 Freight

Players in the freight industry have begun to evaluate the possibility of freight EVs, though many hurdles still exist. Companies such as Tesla Volvo, Renault, and Daimler are some of the organizations working to make EV trucks a reality. These trucks present a significant opportunity to reduce CO_2 emission, though the extent of these reductions is largely determined by how the electricity is created. Tesla claims the their semi is able to charge in 30 minutes and last up to 640 km (397 miles). EVs powered by renewable energy sources run at an efficiency between 80 and 90%. However, EVs that are powered by fossil fuels run with similar efficiency levels to that of traditional diesel powered trucks, roughly 40% in long-haul journeys.[xix]

5.3.4 Infrastructure Owner and Operator

Electric buses offer significant improvements in CO_2 release, which is important because buses disproportionately emit CO_2 (meaning that there is a smaller share of buses in the scheme of all transportation modes, including passenger and freight, but they emit CO_2 a higher per unit rate). This is of particular concern as buses are typically found in densely populated areas, thus negatively affecting the health of more people at once. Despite the multiple benefits of these buses, their adoption has been slow, primarily due to capital and maintenance costs. Investing in electric buses includes upgrades to the whole system, well beyond simply purchasing the buses. The chargers are a significant cost on-site and on-route. An additional cost to these systems in maintenance. In total, investment and further maintenance of this infrastructure and its components are the stumbling blocks.[xx]

5.4 Unmanned Aerial Vehicles

UAVs, colloquially referred to as “drones,” are aircrafts that operate without human pilots or passengers. Some are autonomous, but most are controlled remotely by a human operator.

In May 2018, the USDOT announced that 10 state, local, and tribal governments would participate in the Unmanned Aircraft Systems Integration Pilot Program, a federal program designed to determine how drones could be used for commercial purposes in the United States. During the pilot, the selected entities will collect drone data through various scenarios that include: night operations, flights above residents, flights beyond the pilot’s line of sight, during package delivery, and while using detect-and-avoid technologies. Operations will test reliability and security of data links between pilot and aircraft. This indicates that the federal government is interested in moving towards creating a regulatory framework for UAVs, which may be a boon for innovation in this area in the near future. There are a number of relevant use cases for UAVs, including package delivery in both urban and rural environments, monitoring/inspection, and emergency response.

5.4.1 Package Delivery

Urban. While most of the last-mile package delivery drone pilot programs in the United States have occurred in rural or suburban areas under close supervision from the Federal Aviation Administration (FAA) and USDOT, some international pilots have been conducted in urban areas. For example, Flytrex, an Israeli start-up, is delivering goods by drone in Reykjavik, Iceland, in partnership with the Icelandic online retail company, AHA. This pilot, however, was not door to door; the drone flew a fixed route over a bay and delivered the goods to a designated landing pointed staffed by an AHA courier, which then transported the goods via automobile to the customer.

Rural. Holly Springs is a rural community outside Raleigh, North Carolina, which has grown from a population of 1,000 to 30,000 in less than three decades. This growth caused strains on infrastructure and created traffic congestion. In an effort to mitigate the effects of rapid population growth, the town of Holly Springs has partnered with Flytrex and Causey Aviation to begin a food delivery program using UAVs. Initially the program will deliver meals from the town center to residential neighborhood drop-off zones and would only fly in pre-approved, surveyed flight routes and authorized flying zones. This pilot is part of the FAA's Unmanned Aircraft Systems Integration Pilot Program. Initial reporting suggests that residents are wary of the program, but more testing is needed to determine the viability of using drones for delivery in a rural context such as Holly Springs.

5.4.2 Monitoring & Inspection

Many state DOTs are using UAVs to assist with bridge inspections, accident clearance, surveying, and identifying, monitoring and mitigating risks posed by landslides, rockslides, and flooding. According to the American Road and Transportation Builders Association, more than 55,000 bridges are in need of repair or replacement in the United States.[xxi] Some state DOTs are looking to maximize efficiency and improve their bridge inspection processes by using drones to monitor bridges. For instance, the Minnesota DOT began using drones to inspect bridges in 2015. Drones have the ability to hover close to aging trusses, piers, and bearings, snapping thousands of high-resolution images. Special software then stitches these images into 3D models, which engineers can examine and analyze.[xxii]

There are several benefits to using UAVs for infrastructure inspections, such as improved safety, time and money savings, and reduced congestion. Drone use increases safety for DOT workers by eliminating the need for the usual human-conducted inspection process, which traditionally involves setting up work zones along busy roadways, detouring traffic, and using heavy equipment. Drones save time by eliminating the need to create road detours and lane closures before an inspection, and cost savings are achieved because less manual labor is needed to complete an inspection. A typical manual inspection costs around $4,600 whereas a typical drone inspection costs approximately $250.[xxiii] Using drones to inspect bridges cuts down congestion, which in turn decreases the "user delay cost." For instance, the Michigan DOT estimates that the user delay cost of shutting down one lane of a four-lane, two-way highway bridge in a metropolitan area totals to $14,600 during the 10-hour period typically required to complete a bridge inspection.

5.4.3 Emergency Response

Many state agencies have used UAVs for flood response situations since 2005. The use cases can be categorized by three different flood event phases:

1. Prevention & preparedness (before the flood crests)
2. Response & mitigation (during the flood event)
3. Reconstruction & recovery (after evacuation orders are lifted)

The primary use cases for prevention/preparedness include strategic situation awareness, survey, and reconnaissance; and detailed or structural inspection.

The primary use cases for response and mitigation include strategic situation awareness, survey, and reconnaissance; detailed or structural inspection; debris, flood estimation, and damage assessment; water search and rescue; ground search and rescue; tactical situation awareness; and delivery. For example, during Hurricane Harvey, drones provided surveys and insights into of the extent of flooding and its impact. Additionally, "A UAS [unmanned aerial system] assisted in determining the fastest route to cut a bypass channel to relieve flooding from the Oso, Washington, mudslide."[xxiv]

The primary use cases for reconstruction and recovery include strategic situation awareness, survey, and reconnaissance; detailed or structural inspection; and ground search and rescue.

5.5 Big & Open Data + Machine Learning & Artificial Intelligence

Advances in computing techniques, processing capacity, and data collection are enabling artificial intelligence applications in myriad real-world settings. Algorithms at the heart of artificial intelligence can provide decision support, ease labor-intensive operations, perform predictive analysis, and inform targeted outreach. In the transportation sector such applications could reduce the administrative burden at public agencies such as TxDOT, the Department of Motor Vehicles, and other state agencies with oversight of infrastructure, vehicles, and transportation services. The combination of improved hardware engineering and manufacturing and machine learning methods for image processing has enabled the collection of higher resolution traffic data with less infrastructure, thus enabling more detailed transportation planning models and improved traffic incident management. Artificial intelligence is also being used in a new wave of traffic control devices, and preliminary deployments have been promising. However, with the advent of advanced models and the significantly higher quantity of data they typically consume and produce, key challenges for stewards of data and technology will include managing complex data sources, ensuring their ethical application in decision-making, protecting the privacy of the public, and reducing cybersecurity risks.

5.5.1 Levels of Automation

Levels of automation range from complete human control to complete computer control. The degree to which a task is automated can be characterized by the levels defined below. Lower levels of automation enhance value by optimizing workforce productivity, while higher levels of automation reduce costs by reducing labor.

1. **No Automation:** People-powered public services without automated applications
2. **Task Augmentation:** Limited assistance in services, e.g., data entry, identifying clusters of activity, creating accounts, etc.
3. **Close Supervision:** Routine administration of system monitoring with difficult decisions deferred to human discretion.
4. **Highly Automated:** automated services except for edge cases where human intervention is required.
5. **Fully Automated:** Fully automated system with no human intervention.

5.5.2 Application Areas

AI can provide benefits in many areas relevant to existing and emerging transportation and public agency tasks. Five applications are described below.

System & Service Planning
Comprehensive consideration of service and infrastructure development scenarios and strategies such as determining transit routes, added capacity needs, signal phasing and timing plans, funding allocation, etc. Application examples include using sensors and telecommunications to determine route choice, travel behavior, origins and destinations, transit wait times, etc.

Asset Management
Using sensors and data analytics to gather and predict insights about infrastructure and vehicle assets, their management and utilization strategies, long-term expenditure forecasts, and business management processes. Application examples include automated systems to identify pavement conditions—such as cracks, ruts, and potholes—and signage and striping conditions. Other applications include automated fleet vehicle diagnostics and predicative maintenance.

System Operations
Using technology and data to inform and automate strategies that optimize the safe, efficient, and reliable use of infrastructure for all modes. Application examples include intersection monitoring via camera, sensors, and telecommunications for conflict warning, pedestrian detection and notification, level-of-service monitoring, dynamic signal timing, and emergency response.

Communications & Information
Using machine learning and natural language processing to detect or respond to routine and exceptional scenarios which threaten public safety. Application examples include scanning Twitter feeds to target disaster and hurricane response efforts, identifying traffic patterns associated with dangerous road conditions or incidents, and forecasting dangerous levels of air pollution.

Business Administration
Using machine learning, data mining, and natural language processing and generation to optimize typical administrative functions such as sorting, formatting, cleaning data, populating forms, scheduling appointments, and responding to routine public inquiries. Application examples include machine vision that reads handwriting and automates sorting, software that can manage complex scheduling tasks, and chat bots that can engage in and respond to simple requests and questions from the public.

5.6 Mobility-as-a-Service

Since the mobility-as-a-service (MaaS) concept is relatively new, there is not a full consensus from academics or industry leaders about how to define this idea, but generally speaking the concept includes an emphasis on multimodal transportation that can be purchased on a single platform. The term *Mobility as a Service* represents the idea of a platform for buying mobility services based on consumer needs instead of buying the means of mobility (i.e., the vehicle). In other words, MaaS describes a platform through which users may purchase or access many different modes of transportation, such as bus service, light rail, TNC services, bike share, and e-scooter.

This idea has become prevalent with the recent disruption of the transportation industry by TNCs such as Uber and Lyft as well as by docked and dockless bikeshare companies and electric scooter providers. The following describes critical components and elements that support MaaS.

5.6.1 Integrated Trip Planning

The integration communication technologies in advanced digital transportation support systems have led to the provision of integrated trip planning services directly to the users. Most such systems provide alternative travel plans for both urban or interurban trips and focus on presenting various combinations of modes that serve the same origin and destination.

Dallas Area Rapid Transit (DART) has facilitated a partnership with Uber, Lyft, and Yellow Taxi wherein DART GoPass app users are able to plan trips while seeing private options as routing options. DART transit services can be paid for from within the app, but to pay for the other services the user must open the TNC service from a button within the GoPass app and pay for the TNC service separately in its own app.

Alternatively, in Denver, CO, the Denver Regional Transportation District (RTD) partnered with Uber and Masabi, a ticketing software provider, to provide an option to purchase transit tickets from RTD through the Uber app. While Uber hosts the transit ticketing option within its app, there is no formal data sharing agreement between Uber and RTD. They each have a separate contract with Masabi. Early results show that after about six months of the partnership over 1,200 transit tickets had been sold and Uber saw a 12% increase in Uber trips that start or end at an RTD station.

5.6.2 Single Payment Platform

Single payment platforms provide a common payment solution for users to have a single-account, single-payment system that allows both public and private mobility services to be paid using a single account-based payment system.

In Helsinki, Denmark residents are able to use the mobile app Whim to plan trips and pay for trips across multiple modes of transportation, including train, taxi, bus, carshare, or bikeshare. Whim aims to prove the right MaaS model can beat the service level of a passenger car or at least be comparable to it. It is important to note that multimodal trip planning does not simply mean that the user can select one of many different modes to reach a destination; rather, that they could employ a variety of modes within the same trip.

5.6.3 Travel Behavior Incentives

In the future, as MaaS progresses and becomes a feasible reality worldwide, the use of MaaS platforms as a mobility management tool could help reduce congestion and the environmental impact of the transportation system. Mobility management philosophy and programs aims to change the way people perceive travel alternatives as opposed to physically altering the options themselves. In this scenario, transit authorities could use the "carrot and stick" approach to incentivize users to take alternative transportation modes by offering discounted ticketing for those modes that cause less congestion or by offering the option to bundle services for a discounted rate. Surge pricing could also be implemented through the use of the MaaS platform. Using MaaS to incentivize travel behavior is highly theoretical at this point as a MaaS platform with payment integration and integrated trip planning has not yet been adopted by any US city.

5.6.4 Transportation Network Companies (TNCs), Shared & Dockless

In July 2019, Uber partnered with Lime, a dockless e-scooter company, and JUMP, a dockless e-bike company, to show the location of these dockless devices within the Uber app. This was the first time Uber has prominently displayed a third-party's services within its own app. These partnerships display a willingness to collaborate between private mobility companies, who are not in direct competition with each other, which is a good start towards MaaS. However, it remains to be seen if big private players such as Uber would allow their services to be included in a third-party app alongside direct competitors such as Lyft and public transit services. This is the big challenge when it comes to MaaS being adopted at scale in the United States.

In conclusion, MaaS adoption in Texas could decrease car ownership by connecting users with multimodal options, which would reduce VMT (thus reducing injury, congestion, and emissions), and increase accessibility by giving users more options to meet their specific transportation needs. While the technology exists to implement MaaS, the private and public players need to work out agreements about such a system would work. This is the slow work of compromise and it is unclear if departments of transportation or any other state agency or transit authority have the leverage or the tools to entice the private sector players to collaborate.

6 Assessment of Goal Alignment

To understand how the adoption of priority technologies would align with national and state transportation goals, a survey was conducted. For each goal alignment assessment, each survey respondent was asked to rank technologies in a matrix of technologies across rows against each evaluation dimension (columns) on a scale from one to five. Each integer on the ordinal scale corresponded to each individual's belief about how each dimension represents each technology, with lower values indicating less relevance in a dimension and higher values indicating more relevance. The identified goals are described in the next section.

6.1 Introduction to Goals

Five broad transportation related goals were identified for assessment:

- ***Transportation System Safety*** including consideration of the frequency and severity of incidents.
- ***Transportation System Congestion*** including considerations for improved congestion and travel time reliability.
- ***Environmental Sustainability*** including considerations for reduced fuel consumption, emissions and air quality, and VMT.
- ***Access to Options & Opportunities*** including considerations for increased access to education, jobs, and healthcare; increased travel options across modes; and enhanced flow of goods on the system.
- ***System Maintenance & Preservation*** including considerations for more efficient use of resources such as funding and personnel; optimal use of existing infrastructure; and reduction in the need for costly future public infrastructure investments.

6.2 Goal Assessment Results

Aggregated results of the goal assessment are displayed in Figure 4.

Figure 4: Priority Technology Goal Alignment Assessment

7 Assessment of Barriers

The same survey was used to assess potential implementation barriers to the adoption of priority technologies. For each barrier assessment, each survey respondent was asked to rank technologies in a matrix of technologies across rows against each evaluation dimension (columns) on a scale from one to five. Each integer on the ordinal scale corresponded to each individual's belief about how each dimension represents each technology, with lower values indicating less relevance in a dimension and higher values indicating more relevance. The identified barriers are described in the next section.

7.1 Intro to Barriers

Six implementation barriers were identified for assessment:

- ***Institutional & Regulatory Barriers*** including considerations for needed cross-public agency and industry collaboration; legislative and regulatory impediments; and internal changes to programs and procedures at public agencies.
- ***Public Concern or Cultural Barriers*** including considerations for disparate impacts across income groups or communities; concerns about user safety; and concerns about reliability or value of technology to end user.
- ***Lack of Existing Infrastructure and Public Investment*** including considerations for needed investment from public agencies; readiness of public infrastructure to accommodate technology; and interoperability.

- ***Industry Readiness & Technology Maturity*** including considerations for technology reliability; industry accepted and adopted standards; and ability for private sector to manage and support new products and services.
- ***Cost to Consumer*** including product and service affordability to end user.
- ***Security & Privacy*** including preventing unauthorized access of data; digital network intrusion; ethical use of data; and identity protection.

7.2 Results of Barriers Assessment

The results of the barrier assessment are shown in Figure 5.

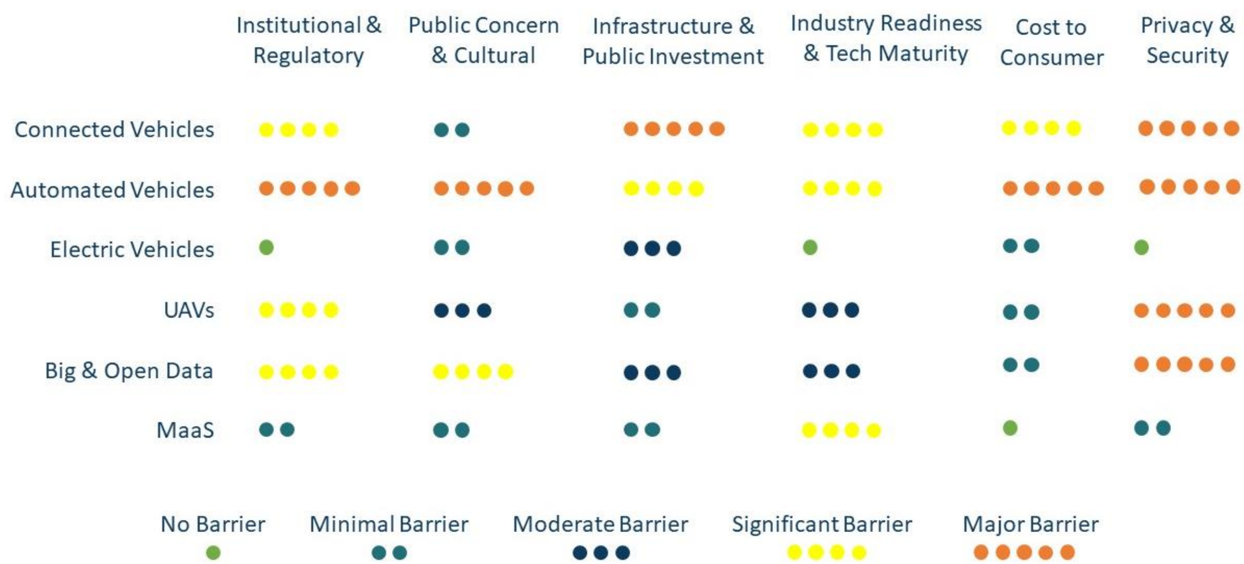

Figure 5: Priority Technology Barrier Assessment Results

8 Assessment of Maturity

Technology maturity assessment helps to make strategic planning decisions by providing an indication of timelines and progression toward market readiness. The technology maturity assessment scale and results are described in this section.

8.1 Maturity Assessment Scale

A five-point scale was developed to assess technology maturity. The five maturity classifications are described below.

- **Concept**—basic scientific principles addressed; early use cases identified; hardware or software system or not created; analytical validation.
- **Experimental**—early hardware or software developed and unrefined; potential application validated.

- **Prototype/Demonstration—**refined product based on early experiment; simulated validation; some components mature while other in need of further development.
- **System Testing—**limited implementation in real-world setting; limited production of technology; intentional user feedback and product refinement.
- **Operational—**proliferation of technology; commercial introduction of products; economically feasible cost.

8.2 Results of Maturity Assessment

The results of the maturity assessment are shown in Figure 6.

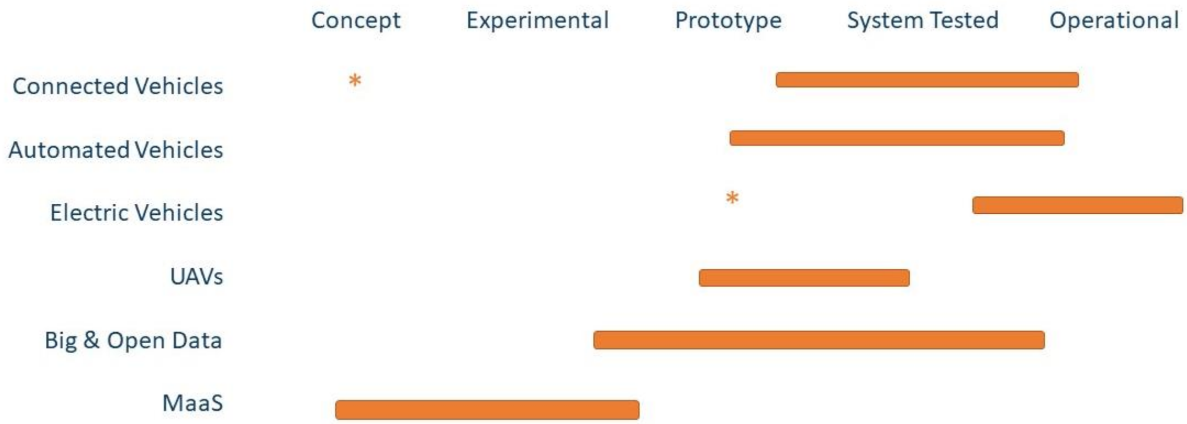

Figure 6: Priority Technology Maturity Assessment

9 Conclusions and Next Steps

The survey revealed that Task Force members and other respondents believe that CV infrastructure is mostly still in testing and beginning to be operational. This is truly the case, although there are scenarios in Utah where buses equipped with CV technology are already running. However, this technology still has a long way to come as it is not commonplace yet and policy considerations have kept this technology at a standstill. This is why there is an asterisk between the concept and experimental phase because there is no certainty whether DSRC or 5G will prevail—5G is still highly experimental and if this option prevails many more years of development and infrastructure would be needed.[xxv]

It was also observed through the survey that AVs are largely in testing some activities are still in the prototype phase. AV operation is in testing in some cities, such as with Uber in Pittsburgh or as shuttle services in Arlington. These technologies have not been expanded to wide-scale use for cities yet, as many barriers prevent this technology's full application for public use. AV applications range from farm work to taxi delivery, all of which are in varying degrees of evolution. Some are fully operational, and others are still being tested and evolving.[xxvi]

In contrast, EV infrastructure is almost entirely operational, with some applications still in testing and limited operation (primarily regarding battery technology, operational range, and charging infrastructure). EVs are operational on roads all over the country, though development of charging stations is still under development. EV sales have drastically increased and are predicted to potentially represent 5% of the global light-vehicle market share in 2020.[xxvii]

There are significant challenges to overcome in using drones to deliver packages. Large buildings cause unpredictable air patterns and wind corridors, which render most current drones useless in delivering packages to rooftops, as is often proposed in this environment. Additionally, because rooftops are different heights, drones would be forced to change altitudes often, which requires so much energy that it would not be economical to use current drones in this scenario because they would require near-constant recharging and refuelling.

Another challenge is public perception of drones. Most residents are concerned about drones flying near their houses and the possibility of unwanted surveillance. Furthermore, delivery companies must ensure that the approach they use is practical and economical; they are not as inclined to consider the external and indirect costs that the population at large faces from the use of such drones. Early pilots with drones have revealed significant externalities such as increased sound levels, aerial congestion, privacy violations, and energy consumption.

The next phase of work will focus on delving deeper into each priority technology to learn more about goals, barriers, and technology readiness. The Task Force will work with TxDOT to identify subject matter experts for additional deep-dive interviews, technology demonstrations, and pilot programs from which to collect lessons learned and best practices.

Appendix A: Survey Questions

Writeup of Questions Survey

Part 1
Part 1a.
This was accompanied by a list of 18 technologies

> Please prioritize the five technologies that you believe will be the most impactful to the Texas Transportation System?

Part 1b.

> Why did you prioritize these technologies (Which use cases, benefits, and applications are the most compelling)?

Part 2.
Part a.
This question is accompanied by five options ranging from negative impact - somewhat negative impact - no impact - somewhat positive impact - positive impact

> Please assess the impact that these technologies will have on transportation system safety?
>
> Please assess the impact that these technologies will have on transportation system congestion?
>
> Please assess the impact that these technologies will have on environmental sustainability?
>
> Please assess the impact that these technologies will have on access to options and opportunities?
>
> Please assess the impact that these technologies will have on system maintenance and preservation?
>
> Please provide any additional comments on impacts of these technologies that may have not been covered previously.

Part b.
This question is accompanied by five options ranging from no impact - minimal impact - moderate impact - significant impact - high impact

> To what extent is implementation of these technologies limited by institutional and regulatory barriers?
>
> To what extent is implementation of these technologies limited by public concern or cultural barriers?

To what extent is implementation of these technologies limited by lack of existing infrastructure and public investment?

To what extent is implementation of these technologies limited by industry readiness and technology maturity?

To what extent is implementation of these technologies limited by cost to consumer?

To what extent is implementation of these technologies limited by concerns in data security and privacy?

Please provide any additional comments on barriers to these technologies that may not have been covered previously?

Part 3.
This question is accompanied by five options ranging from concept - experimental - prototype demonstrated - system completed and tested - operational

Please describe what you believe to be the current maturity status of each technology

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[i] University of Michigan Transportation Research Institute: http://www.aacvte.org/get-connected/586-2/
[ii] USDOT ITSJPO: https://www.its.dot.gov/factsheets/pdf/ConnectedVehicleBenefits.pdf
[iii] Western States Rural Transportation Technology Implementers Forum: http://www.westernstatesforum.org/Documents/2017/Presentations/UDOT_Leonard_FINALc_DSRC.pdf
[iv] Wyoming DOT: https://wydotcvp.wyoroad.info/
[v] NHTSA: https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812517
[vi] Waymo: https://waymo.com/mission/
[vii] VentureBeat: https://venturebeat.com/2019/04/11/ubers-250-autonomous-cars-have-driven-millions-of-miles-and-transported-tens-of-thousands-of-passengers/
[viii] Volvo: https://www.volvobuses.com/en-en/news/2019/mar/volvo-and-singapore-university-ntu-unveil-world-first-full-size-autonomous-electric-bus.html
[ix] City of Arlington, Texas: https://www.arlingtontx.gov/visitors/transportation/autonomous_vehicles
[x] Washington Post: https://www.washingtonpost.com/news/wonk/wp/2018/05/28/america-has-a-massive-truck-driver-shortage-heres-why-few-want-an-80000-job/
[xi] TuSimple: https://www.tusimple.com/
[xii] Gizmodo: https://gizmodo.com/ups-has-been-delivering-cargo-in-self-driving-trucks-fo-1837272680
[xiii] FreightWaves: https://www.freightwaves.com/news/peloton-unveils-level-4-platooning-technology-with-autonomous-following-truck
[xiv] FP Think: https://orfe.princeton.edu/~alaink/Papers/FP_NextGenVehicleWhitePaper012414.pdf
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[xvi] M.J. Bradley & Associates, LLC (MJB&A): https://www.nrdc.org/sites/default/files/electric-vehicle-cost-benefit-analysis_2017-09-27.pdf
[xvii] Wired: https://www.wired.com/story/electric-buses-havent-taken-over-world/
[xviii] Proterra: https://www.proterra.com/press-release/austin-becomes-fifth-city-in-texas-to-purchase-proterra-battery-electric-buses/
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[xx] Wired: https://www.wired.com/story/electric-buses-havent-taken-over-world/
[xxi] AASHTO: http://asphaltmagazine.com/wp-content/uploads/2016/05/Dronesss.pdf
[xxii] CityLab: https://www.citylab.com/transportation/2018/01/to-care-for-aging-bridges-minnesota-taps-the-power-of-drones/551339/
[xxiii] AASHTO: http://asphaltmagazine.com/wp-content/uploads/2016/05/Dronesss.pdf
[xxiv] USDOT FHWA: https://www.fhwa.dot.gov/uas/resources/hif19019.pdf
[xxv] Automotive News: https://www.autonews.com/mobility-report/new-connected-car-battle-cellular-vs-dsrc
[xxvi] Wired: https://www.wired.com/story/future-of-transportation-self-driving-cars-reality-check/
[xxvii] McKinsey & Company: https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/the-global-electric-vehicle-market-is-amped-up-and-on-the-rise