Setting the Stage:
Technology White Paper

Access Ohio
2045
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Executive Summary

The Ohio Department of Transportation (ODOT) is updating Ohio’s long range transportation plan, Access Ohio 2045 (AO45). AO45 will build on ODOT’s long established foundation of strategic transportation investment which links to broader state economic, societal, and environmental goals and promotes public resource stewardship consistent with ODOT’s Mission, Vision, and Guiding Principles. AO45 is an opportunity to further ODOT’s reputation as a national leader, and prepare for the future in order to successfully navigate current and future challenges and to position the state for continued prosperity.

This white paper helps “set the stage” for AO45 by exploring the potential impacts of current and emerging technologies on transportation. The information and conclusions developed in this white paper will contribute to AO45 to ensure that technology is one of the several critical issues that is effectively and comprehensively addressed as Ohio sets a course for the future.

Based on existing conditions and trends, Ohio is positioned to play a key role in shaping how emerging technologies will impact transportation systems of the future. Partnerships with public and private stakeholders, research institutes, and upfront investments in smart infrastructure will enable Ohio to maintain and expand the use of automated and connected vehicles (ACV) and emerging technology. Recent Federal legislation aimed at streamlining ACV deployment may bring about changes to ODOT’s roles and responsibilities. The Federal government will issue guidance on safety, manufacturing standards, and testing, while States will govern matters of licensing, insurance, and liability. The potential impacts of a rapidly changing technological landscape based on trends identified in this paper are summarized as follows:

- Fully automated vehicles (AV) may not have wide penetration within the next 10 years; however, elements of automation will likely become mainstream in the near future. Anticipated impacts are subject to change based on the level of automation; therefore, a flexible and adaptable approach to planning and policy may help Ohio adjust to uncertain market trends.
- The most likely scenario for 2045 is one of a “mixed fleet” where fully AV share the roads with vehicles with low to nonexistent automated functions. ODOT will need to balance the opportunities that come with higher levels of automation and fleet penetration with the need to serve all transportation system users.
- Widespread successes of shared-use mobility systems have laid the groundwork for shared fleets of AV in urban areas. Key impacts include reduced demand for parking, improved safety, enhanced mobility for transit-dependent communities, and better first and last mile connectivity.
- Connected vehicle technology and Intelligent Transportation System (ITS) applications hold promise for more efficient use of existing roadway capacity, alleviating the need for roadway expansion projects.
- Emerging technologies could have an enormous impact on the freight sector by enabling more efficient goods movement, optimizing shipping and logistics patterns, and reducing labor costs (which would have significant implications for the economy). 3D printing and e-commerce may also impact freight operations by shifting demand for trucking and rail services.
• Big data can enable real-time, dynamic transportation networks and allow for better performance management and improved investment decision-making.
• Emerging pay-per-mile pilot programs and active traffic management strategies have the potential to transform revenue structures, creating more funding for transportation improvements.
• Existing and emerging technologies present opportunities for Ohio to enhance safety and security for all road users, reduce congestion and improve mobility, support a thriving economy and resilient transportation system, and foster environmental health and sustainability.

The future direction of transportation is at a crossroads where policy and technical guidance play an especially critical role in shaping change. Statewide policies that support shared electric AV could help expand mobility, reduce emissions, improve access to opportunity, and better utilize infrastructure to create more space for active transportation, public transport, and public space. On the contrary, incentivizing independent ownership of AV could compound the impacts of urban sprawl, as roadways become more congested and travel times increase. However, market forecasts show that (in response to public demand and industry regulations) auto manufacturers are developing more fuel efficient vehicles. Therefore, in the instance that AVs lead to an increase in vehicle miles traveled, it is possible that fuel efficiency could offset, or partially offset, vehicle emissions and associated externalities.

The implications of emerging technologies on public transit are also uncertain, and largely dependent on political and fiscal support. Public transportation could undergo a range of transformations with strategies like route and vehicle optimization, transit signal priority, and improved first-last mile connectivity. However, the growing convenience of personal and shared-mobility modes in the autonomous future could cause traditional fixed-route transit systems to become less competitive, especially cost-intensive dedicated route systems like Bus Rapid Transit (BRT). Alternately, rural areas with dispersed populations could benefit from flexible, on-demand transit service, especially areas with large concentrations of senior citizens and people with disabilities. Shifting mobility patterns could also impact active transportation, which may lose appeal as automated on-demand mobility becomes more affordable and convenient. These issues of multimodalism are important to consider as urban areas undergo changing development patterns and suffer from increasing congestion; especially in Ohio, which has a relatively large and dispersed network of urbanized areas for a state of its size.

The timing and magnitude of future technological advances are uncertain. There are numerous unanswered questions which will shape industry-wide outcomes. Technological hurdles, level of public acceptance, availability and cost of technologies all will make for an unpredictable future. In the face of this unpredictability, it will be essential for agencies to pursue robust strategies. Robustness can be strengthened by considering the many possible futures facing the State of Ohio, and developing strategies that help shape that future, that help hedge against undesirable futures, and that defer actions which can be taken later. Uncertainty is no excuse for inaction, but it argues for careful action with a clear understanding of the potential future landscape.

Impacts are not limited to transportation, but have widespread implications for land use, housing, urban design, economic development, equity, and environmental sustainability. With these uncertainties in mind, AO45 can be used as a tool to mitigate potential unwanted impacts of emerging technologies while leveraging opportunities. In both the short- and long-term, expanding research efforts and partnerships will be key, as well as establishing a robust set of goals, objectives, and priorities to guide Ohio’s transportation future.
**Introduction**

**HOW THIS PAPER LINKS TO AO45**

The Ohio Department of Transportation (ODOT) is updating Ohio’s long range transportation plan, Access Ohio 2045 (AO45). AO45 will build on Ohio’s long established foundation of strategic transportation investment which links to broader state economic, societal, and environmental goals and promotes public resource stewardship consistent with ODOT’s mission, vision, and guiding principles. AO45 is an opportunity to further Ohio’s reputation as a national leader, and prepare for the future in order to successfully navigate current and future challenges and to position the state for continued prosperity.

AO45 will provide ODOT with a strategic blueprint to manage the changes facing the transportation system and serve as a reference point to align Ohio’s ongoing policies, plans, and programs. The blueprint involves the support of partners and builds a strategy fueled by data driven, performance-based decisions—something Ohio has worked tirelessly to establish.

This white paper helps “set the stage” for AO45 by exploring the potential impacts of current and emerging technologies on transportation. The information and conclusions developed in this white paper will contribute to AO45 to ensure that technology is one of the several critical issues that is effectively and comprehensively addressed as ODOT sets a course for the future.

**THE IMPORTANCE OF EMERGING TECHNOLOGIES**

Several emerging technologies are expected to have short- and long-term impacts on Ohio’s transportation system, including automated and connected vehicles (ACV), shared-use mobility, data sharing and information, and alternative energy. One of the most transformative potential technologies is self-driving vehicles. Over the next 30 years, ACV have the potential to transform mobility throughout the United States. The emergence of these safer, more reliable vehicles, designed to perform all safety-critical driving functions and completely monitor roadway conditions, could fundamentally change the way Ohio’s residents, businesses, and visitors use all transportation modes. Combine the emergence of these vehicle systems with the other national trends of lower car ownership, enhanced car sharing, and improved mobility services and the future of how people move between home, work, and play could be dramatically altered.

Most of the transportation industry’s efforts today center on making sure evolving vehicle technologies safely operate on our transportation system while also trying to understand the impacts these vehicles will have on infrastructure. Transportation agencies are just beginning to explore the impacts of these systems on infrastructure, travel patterns, policies and
programs, and organizational structure. Most agencies are learning that the most dramatic impact of these vehicles and systems will be on mobility and safety.

These vehicles have the capability to usher in a world where impaired driving is nearly eliminated, where growing old does not automatically mean losing independence and mobility, and where the tragically high cost of traffic crashes is lowered to virtually nothing. These potential benefits could move from imagination to reality as the general fleet of vehicles becomes increasingly automated.

But the timing and magnitude of future technological advances are uncertain. In the area of advanced vehicle technologies, there are consumer reservations about ceding control along with privacy concerns. There are technical hurdles to replicating or exceeding human performance in certain conditions. In the sharing economy, the market remains unsettled. The success of Uber and Lyft in the ridesharing fields has already begun changing the urban mobility environments of major cities, but there are significant questions about how ridesharing will evolve and what the consumer appetite will be for additional services.

This era of change provides significant opportunities to harness emerging technology to improve the economic vitality and global competitiveness of Ohio. It is not without risk, however, as technology introduces volatility into the relatively stable transportation environment.

This paper includes discussion of where we are today, including a review of current policies and trends, existing Ohio activities in the technology area, and factors that have contributed to Ohio’s position as a transportation technology innovator and leader. The paper examines the anticipated evolution of major transportation technology areas and their likely impacts. Finally, the paper concludes with considerations for AO45 development.
Where Are We Today?

OVERVIEW

In the rapidly changing landscape of transportation, Ohio has already been identified as a national leader. The Smart City Challenge put Columbus, and the State of Ohio, in the spotlight as a region ready to embrace the numerous opportunities afforded by advanced technologies. Ohio has maintained this momentum through a diverse set of partnerships and research initiatives, including the Smart Belt Coalition and Transportation Research Centers. This section describes a key set of existing programs and projects in Ohio to ultimately assess how the state is poised for change. The following list of definitions/introductions provide some idea of the core technologies addressed.

- Automated Vehicles (AV): Driverless cars (and trucks) that are capable of sensing their environment and navigating without human input such as through use of global positioning system (GPS), radar, and light detection and ranging (LIDAR) technology.
- Connected Vehicles (CV): Cars and trucks that communicate with each other, with infrastructure, and with cloud-based platforms using mechatronics, telematics and artificial intelligence technologies, all of which can interact with the environment to provide greater safety, comfort, and entertainment.
- Shared Mobility: Shared transportation services such as ride-hailing (Lyft and Uber), public transit, bike-share, car-share, carpool, and vanpool that leverage spare capacity to transport people more efficiently. Technologies that enable on-demand trip booking, ride-matching, and integrated payment have played a key role in making shared-use mobility a large part of the transportation sector.
- Transportation Network Companies (TNCs): Companies that use on-line mobile applications to schedule a transportation service for payment, with drivers using their personal, noncommercial vehicle. Common examples of TNCs include Uber, Lyft, Via, and Chariot.
- Smart Infrastructure: Similar to CV, “smart” infrastructure relies on mechatronics, telematics and artificial intelligence technologies to interact with the environment. This most frequently refers to transportation network components (e.g., traffic signals) that communicate with vehicles and data platforms to send and receive data and optimize performance. The U.S. 33 Smart Mobility Corridor is an example of a smart infrastructure project.
- Alternative Energy: Renewable energy sources that are used in place of fossil fuels, intended to address concerns such as high carbon dioxide emissions, an important factor in climate change. Alternative energy also diversifies fuel sources, which can improve market stability.
- Intelligent Transportation Systems (ITS): The application of advanced technologies to increase safety, mobility, and efficiency of transportation systems through advanced data processing and wireless communication. ITS applications include dynamic traffic and weather management, traveler information, electronic payment and pricing, commercial vehicles operations, and transit...
management. ODOT has embraced transportation systems management and operations (TSMO) as an opportunity to increase the focus and execution of traffic operations (of which ITS are a core component) to better meet future system needs.

- **Big Data:** The explosion in data availability (both volume and velocity) can be leveraged to improve safety and operations, increase the accuracy of predictions, and provide approaches that drive sound decision-making. Growth in data availability is attributed to the Internet of things (IoT), which refers to the network of physical devices, vehicles, software, and electronics that enable rapid collection and exchange of data.

- **Unmanned Aircraft Systems (UAS):** Often referred to as “drones,” UAS are aircrafts without a human pilot on board, which are instead controlled by an operator on the ground. UAS are emerging as a strategy to increase roadway safety, optimize freight efficiency, and manage infrastructure assets.

### CURRENT LEGISLATIVE PROGRAMS AND TRENDS

The emergence of advanced technology in the transportation sector has prompted state and Federal regulatory action to guide implementation and ensure that new technologies are leveraged to their fullest potential.

#### Federal and State Legislation

At the Federal level, the Fixing America’s Surface Transportation Act (FAST Act), signed into law in December 2015, allocates over $300 billion to transportation infrastructure projects through 2020, emphasizing improved mobility, economic growth, and project delivery and innovation.

Under the FAST Act, the Federal Highway Administration (FHWA) established several rulemakings that outline regulations for performance-based planning, specifically with regard to highway safety, pavement and bridge condition, system performance, and freight. Integrated and collaborative data collection and management systems are fundamental to carrying out the performance-based planning process. Performance-based planning requirements will also put pressure on state departments of transportation (DOT) and metropolitan planning organizations (MPO) to invest in innovative technologies that support attainment of performance goals.

The FAST Act also authorized discretionary funding for advanced technology projects under the Technology and Innovation Deployment Program ($67.4 million per year), the Advanced Transportation and Congestion Management Technologies Deployment Program ($60 million per year), and the Intelligent Transportation Systems Program ($100 million per year). The Federal Transit Administration’s (FTA) Mobility on Demand (MOD) Sandbox Program, which funds transit projects that incorporate shared-mobility, also demonstrates a Federal commitment to investing in technology.

With growing controversy over the safe deployment of highly automated vehicles (HAV), the National Highway Traffic Safety Administration (NHTSA) issued policy guidance titled Accelerating the Next Revolution in Roadway Safety that addresses performance standards, levels of automation, regulatory tools and actions, and model statewide policy. While NHTSA is responsible for regulating vehicle safety, state governments are responsible for regulating use, including licensing, permitting, and registration. Future guidance will be issued as technology evolves, including NHTSA 3.0, which will establish Federal safety standards for AV.
Congress recently announced plans to develop Federal AV legislation to foster innovation and streamline deployment. While safety advocates and truck driver unions have expressed concerns regarding safety and economic impacts, legislators insist on the importance of national coordination at this phase in technological development. Federal regulation would pre-empt state regulation, which has implications for ODOT in terms of existing research, testing, and funding strategies.

Ohio Legislation

State-level AV policy varies considerably, with four states allowing deployment of fully AV on public roadways (Florida, Georgia, Tennessee, and Delaware) and 25 states taking no legal action. The remaining 22 states have either enacted piloting laws, issued executive orders, or established advisory committees.¹

In regards to AV policy, Ohio does not allow the general public to operate AV; however, House Bill 608, introduced in 2016, would permit licensed manufacturers to test AV on public roadways. This legislation, in conjunction with the Smart City grant and Transportation Research Center (TRC) testing facility,

demonstrates that Ohio is on the path to becoming a leader in ACV. The Ohio legislature also passed House Bill 237, which regulates increasingly popular (yet highly controversial) ride-hailing companies. House Bill 237 requires TNCs to obtain a $5,000 permit before operation, establishes insurance standards, and requires companies to conduct driver background checks and disclose fare receipts. House Bill 237 nullifies more stringent regulations adopted by Ohio cities, particularly Columbus, yet supports the expansion of ride-hailing by establishing statewide standards. Lastly, recent findings indicate that there is widespread support for increasing fuel economy standards to 40 miles per gallon by 2025, which would require auto manufacturers to develop more fuel-efficient vehicles.2 These three policy areas suggest that Ohio is moving towards a transportation future characterized by low-emissions, automated, and shared vehicles.

OHIO’S TRANSPORTATION TECHNOLOGY PROGRAMS

Ohio has a varied and engaged group of stakeholders involved in research, planning, and decision-making for emerging transportation technologies. ODOT plays a key role in setting the stage legislatively, identifying funding priorities, and facilitating collaboration between internal stakeholders and neighboring states. MPOs, municipalities, and transit agencies are at the forefront of local and regional planning efforts, which is where the bulk of investment decision-making occurs. Communication is especially critical at this level because technology must be compatible across geographies and infrastructure types to function properly, especially as regional connectivity becomes increasingly important. The Ohio Turnpike and Infrastructure Commission and Smart Belt Coalition are also key stakeholder, as the Ohio Turnpike will become a major testing ground for CV technology.

In the research sphere, the Ohio Smart Mobility Initiative (OMSI) is a partnership between ODOT, Ohio Department of Public Safety, Ohio Turnpike and Infrastructure Commission, the Ohio State University (OSU), and auto-industry stakeholders, with the purpose of sharing knowledge across transportation sectors and disciplines. OSU is home to the Center for Automotive Research (CAR), an independent research facility aimed at informing decision-makers and disseminating information to the public. Lastly, TRC plays an enormous role in conducting research and bringing together both public- and private-sectors stakeholders. The TRC Board is managed by the OSU School of Engineering.

ITS and Data-Sharing

Ohio has made significant advances in recent years to integrate ITS technologies into the existing transportation landscape. The ODOT managed Statewide Traffic Management Center (TMC) operates cameras, message boards, variable speed limit signs, dynamic message signs, highway advisory radio, and other

roadside traffic management devices. The Statewide TMC is also responsible for updating Ohgo.com, an interactive website that provides real-time updates on traffic conditions, travel times, work zones, and weather conditions.

Traffic data has historically been collected by loop detectors, which often return missing or fragmented data; however, the big data market and the onset of probe data has transformed how transportation agencies do business, as data are quickly becoming a commodity. Advancement in data collection will enable ODOT to implement better incident management systems and active traffic demand management strategies (ATDM) like the SmartLANE/Hard Shoulder Running project on I-670 that optimize system efficiency. Mobile devices and wireless sensors that collect massive amounts of data on travel times, speed, and weather conditions have enabled the shift towards these types of dynamic systems. The value of robust data cannot be understated, as it is not only fundamental to increasing efficiency, but planning for the future and measuring progress.

ODOT has advanced data sharing platforms in place, namely the Transportation Information Mapping System (TIMS). Historically, these platforms have been driven by ODOT’s commitment to maintaining inventory and condition data for asset management purposes. TIMS and related platforms have benefitted from an inclusive and standardized approach to data management which allows for sharing across different ODOT functional areas and with partner agencies. To implement real-time operations in the long-term, ODOT will need an Integrated Development Environment (IDE) that builds on the TIMS philosophy.

**TSMO Plan**

ODOT’s TSMO Plan identifies goals and objectives, resources, policy actions, performance measures, and an implementation plan to better integrate operations and maintenance into the existing transportation system. The Plan signifies a shift towards a more holistic approach to transportation planning, focusing on leveraging emerging technologies for real-time traffic operations and more efficient use of existing capacity. Overarching goals include safety, reliability, efficiency, access, coordination, integration, and security. Almost every TSMO strategy has a heavy technology component such as ITS, data analysis, and Road Weather Information Systems (RWIS), which ultimately amounts to more data and better decision-making.

One of the key recommendations in the TSMO Plan is to include TSMO in the long-range transportation planning process. This applies to MPOs, Regional Transportation Planning Organizations, and statewide planning efforts like AO45. Furthermore, many of the near-term strategies focus on integrating TSMO into ODOT’s organizational structure through additional staffing, councils, and communication systems.

**Smart City Challenge**

In 2016, the City of Columbus won the Smart City Challenge, receiving $40 million from U.S. DOT with an additional $100 million from private-sector matches. Columbus’ win (out of 78 total competitors) was attributed to their ability to leverage private-sector capital, as well as the emphasis on enhanced access to jobs, education, and services in low-income communities, particularly in the Linden neighborhood which has three times the city’s unemployment rate.\(^3\) Strong partnerships with business and academic stakeholders, like

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American Electric Power and OSU, also contributed to the win. The Smart City funding will go towards innovative projects that enhance communication between vehicles, people, and infrastructure to efficiently manage the flow of people and goods throughout the city.

Starting in 2018, Columbus will begin developing a smart corridor along Cleveland Avenue, which will use integrated, real-time data to manage traffic along the corridor, enhance BRT service, and enable ACV to operate through V2V and V2I communication technology. In the Easton Office/Shopping Park in northeast Columbus, electric ACVs will serve as a first-last mile connection to transit. Integrated, real-time data will also be used to optimize freight movement through truck platooning and dynamic routing. Lastly, a Smart Grid project is planned for northeast Columbus, which will provide the City with alternative energy to fuel electric vehicle charging stations.

**Transportation Research Center**

Ohio is home to the largest automotive testing center in North America, the Transportation Research Center (TRC), which is located 40 miles northwest of Columbus in East Liberty. NHTSA’s Vehicle Research and Test Center (VRTC) is also located on the premises. The 4,500 acre facility, which is one of the most recognized ACV testing grounds, is equipped with numerous outdoor testing facilities, impact laboratories, contract engineering, and an emissions laboratory. In January 2017, TRC was awarded a $45 million grant from OSU and the State of Ohio to expand the Smart Mobility Advanced Research and Test Center (SMART), enabling testing on urban, rural, and neighborhood street networks. The expansion will serve as a testing ground for technologies deployed as part of Columbus’ Smart City project. TRC’s location will provide for optimal coordination between key stakeholders including NHTSA, ODOT, auto manufacturers, and municipal agencies.

**Smart Belt Coalition**

The Smart Belt Coalition is a cross-state effort between Pennsylvania DOT, the Pennsylvania Turnpike Commission, Michigan DOT, Ohio DOT, and the Ohio Turnpike and Infrastructure Commission to collaborate on research, testing, policy, funding, and deployment of ACV technology. The Coalition envisions “an innovation network that fosters the advancement of connected vehicles while growing the knowledge and economy.” The Coalition consists of six affiliate members: the University of Michigan, American Center for Mobility, Kettering University, OSU, Transportation Research Center, and Carnegie Mellon University.

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4 Letter of Understanding among the Members of the Smart Belt Coalition, 2017.
Mellon University. The five state agencies are responsible for guiding research, development, and deployment of smart technologies, while the affiliate members are responsible for conducting research efforts.

The Smart Belt Coalition Strategic Plan focuses on three key areas: work zones, traffic incident management (TIM), and freight, with the overarching goal of using cutting-edge research to bring in Federal funding. Safety applications, integrated corridor management, and weather are prioritized as well. The plan compares software used by each partner for GIS, ITS data management, data processing, video management, and incident reporting, revealing quite a significant variation. Comparisons are also provided for fleet considerations, performance analytics, and workforce considerations in an effort to ensure compatibility upon deployment of smart technologies. Immediate project priorities include the Work Zone Reservation and Traveler Information System (WZRTIS) and Truck Platooning, while future priorities including the Response, Emergency Stating and Communications, Uniform Management, and Evacuation Program (R.E.S.C.U.M.E.), the Intelligent/Connected Work Zone Devices Project, and the Truck Parking Information and Management Project.

Ohio Smart Mobility Projects

ODOT is currently in progress, or planning, seven different smart mobility projects across the state. Most notably is the Smart Mobility Corridor, a 35-mile segment of U.S. Route 33 between Dublin and East Liberty that will be used as a testing ground for ACV. The highway will be equipped with fiber optic cables and wireless sensors that will enable V2I communication. The sensors will also collect data instantaneously, which will improve traffic management by providing more accurate travel flow data, weather conditions, and incident management data. The corridor will eventually be integrated with Columbus’ smart corridors. The Route 33 Smart Mobility Corridor is an important technological milestone in Ohio, as it demonstrates how technology can impact both urban and rural mobility as well as personal and goods movement. The project will also shed light on issues surrounding the integration of automated and human-operated vehicles, which has been cited as a major safety concern amongst the public and decision-makers.

Other in-progress Smart Mobility projects include the I-90 Lake Effect Corridor, which will consist of Dynamic Message Signs (DMS), traffic cameras, weather sensors, and networking and software devices along 65 miles of Cleveland’s heaviest snow incident corridor; the I-670 SmartLANE, which will proactively manage traffic and reduce congestion in downtown Columbus by installing Variable Speed Limits, Dynamic Hard Should Running, and DMS; and the Ohio Turnpike through Lorain, Cuyahoga, and Summit Counties which will include 30 Direct Short Range Communication (DSRC) units to test V2I and V2V capabilities. Smart Mobility projects in the planning phase include the I-270 Southwest Outerbelt, Smart Marysville, and the Buckeye Traffic Software Update.

Ohio/Indiana UAS Center

Unmanned aircraft systems (UAS) are a growing piece of the transportation puzzle. The UAS Center is a partnership between Ohio and Indiana aimed at advancing UAS technology to use for commercial purposes and flight operations support. The FAA is currently working on integrating UAS into the National Airspace System, and the research, deployment, and evaluation occurring at the UAS Center will surely factor into the conversation.
The broader impacts of UAS on Ohio’s transportation system are three-fold. First, the technology has potential to improve roadway safety by capturing images beyond the line of sight, thereby giving drivers more time to react to unforeseen obstacles. The technology can also be used to streamline incident management by surveying crash scenes from an aerial perspective. Second, UAS will impact freight and logistics networks by shifting goods delivery towards a more dispersed model, especially as on-demand delivery becomes increasingly prevalent. Third, UAS can be used for asset management by surveying infrastructure conditions from above. This would result in significant savings of time and resources used to manually inspect transportation assets.

**Exploration of Ride-Hailing Programs**

The explosive growth of TNCs over the last seven years has impacted urban transportation systems across the country, including Ohio. Ride-hailing’s on-demand nature, integrated payment system, and short wait times have allowed TNCs to become a highly competitive mode of transportation that has enhanced mobility and increased safety by reducing incidences of impaired driving. However, studies also show that TNCs have led to increased congestion in urban areas due to “deadhead” miles when drivers circle between drop-offs and pick-ups. There is also much controversy over whether TNCs serve as a first-last mile solution by connecting people to transit, or if they are contributing to the national decline in transit ridership by siphoning off riders.

Like many cities, Columbus and Cincinnati have both explored partnering with TNCs to fill gaps in the transit network. Although the Central Ohio Transit Authority (COTA) has plans to expand high-capacity transit, most areas in Columbus do not have the population density to support a built-out transit system. COTA’s partnership with Uber would provide riders who begin or end a trip at a transit facility with a partial subsidy, thereby incentivizing them to use transit. In 2016, Cincinnati Metro launched a similar program, offering riders discounted Uber rides by posting discount codes inside transit buses. As cities like Columbus and Cincinnati continue to densify, shifting to a shared-mobility framework will be critical to transporting a large number of people under limited capacity. TNCs also hold promise for rural areas that do not have the density to support fixed-route transit, especially for transit-dependent communities like seniors, people with disabilities, and low-income households. The Ohio Association of Regional Councils (OARC) has also demonstrated commitment to expanding shared mobility options through the Go Ohio Commute program, which connects residents to different commute options including carpoolsing, transit, walking, and biking.

**FACTORS DRIVING OHIO AS A LEADER**

Ohio’s investment into testing and deployment of ACV and smart infrastructure has allowed the State to become recognized as a national transportation leader. However, Ohio is not alone. Many states are vying to lead the charge into an autonomous future, with Michigan, Pennsylvania, and Nevada all working closely with auto-manufacturers and permitting AV testing on public roads. While Silicon Valley has made California a leader in innovation of technology itself, Ohio is positioned to become a leading player in the application of such technologies. The four key factors that contribute to Ohio’s emergence into this role include political climate, geographic location, development patterns, and research institutions.

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5 [http://usa.streetsblog.org/2015/08/13/study-uber-reduces-drunk-driving-deaths/](http://usa.streetsblog.org/2015/08/13/study-uber-reduces-drunk-driving-deaths/)
First, and most importantly, Ohio’s leadership is dedicated to investing resources and building partnerships that facilitate rapid technological growth, as demonstrated through the state’s 2018-2019 Transportation Budget Bill (Sub. H.B. 26). Ohio is one of a handful of states to assemble a cabinet-level working group on AV. They have also fostered partnerships with private-sector stakeholders, like Honda and Intel, to enhance communication and collaboration between key players.

Second, Ohio is a critical through state for freight traffic, ranking third in the value of truck goods shipped through any State. Ohio’s unique geographic location has forced decision-makers to think about ways to make freight movement more efficient, including truck platooning, electronic payment, weigh-in-motion, and other ITS technologies.

Third, auto-oriented development patterns and growth in traffic congestion have forced questions about how to optimize transportation systems in denser urban areas while enhancing mobility in rapidly expanding suburban and rural areas. Columbus’ Smart City investments into high-capacity transit as well as automated transit vehicles that operate in low-density areas exemplify how technology can be used to serve both urban and suburban populations.

Lastly, Ohio’s numerous research facilities have contributed to the State’s reputation as an information hub for ACV and smart infrastructure. The OSU, CAR, and TRC are all key assets that foster communication and streamline the deployment of advanced transportation technologies.

**How Ohio Is Poised for Change**

Ohio’s existing programs, policies, and stakeholders make it clear that the State is anticipating a drastic transformation in the coming years. As a leader in smart mobility, Ohio could also have the opportunity to lead in the policy sphere as new technologies bring up complex legal and moral questions. As Ohio grows as a national transportation role model, changes to existing policies and planning practices will require heightened attention. The rapid pace of technological change will also emphasize the importance of collaboration and coordination across agencies, especially in data and information-sharing. This may lead to a growing need for new types of partnerships, committees, and governance to oversee and guide such massive change.

The Smart Belt Coalition and U.S. Route 33 Smart Mobility Corridor demonstrate how Ohio is positioned to effectively leverage the changes offered by emerging technologies. ITS and Smart Infrastructure investments along the Ohio Turnpike and Route 33 will enhance both passenger and freight efficiency along these key corridors. Improved regional connectivity will provide residents with better access to jobs and services and will boost economic growth as freight operations become more efficient. Partnerships like the Smart Belt Coalition will allow Ohio to capitalize on a broad range of research efforts and expand the network of stakeholders interested in pursuing technologically innovative projects.
The technological revolution has potential to dramatically change land use and travel patterns. This change; however, is heavily dependent on whether AV are deployed individually and/or as a shared fleet. Individual deployment (i.e., every person owns their own autonomous car) may lead to increased congestion and travel times, as the convenience of not driving enables people to move further from jobs and services. Shared fleets, on the other hand, could increase vehicle occupancy, thereby reducing vehicle miles traveled and freeing up underutilized roadway capacity for other uses. However, is it also possible that AVs would lead to a rise in zero-occupancy vehicles, which could increase VMT and offset the anticipated capacity benefits. Smart City investments indicate that Columbus is headed towards a shared automated future where high-capacity transit serves dense areas and autonomous shuttles fill in service gaps in low-density areas. The shift to shared AV could not only enhance mobility, but bring street design issues such as capacity, curb space, multimodalism, and parking to the forefront of planning efforts.
Where Are We Going?

This section examines transportation technology evolution over the next 30 years.

AUTOMATED AND CONNECTED VEHICLES

AV technologies, in coordination with CV technologies, will have potentially transformative impacts on personal and freight mobility, safety, business models, land use, and quality of life. While there are many benefits expected, ushering in AV also will present challenges, especially during the transition period (potentially decades long), where both AV, CV, and more traditional vehicles without advanced technologies share Ohio’s roads. Transportation agencies need to address vehicles with varying capabilities from partly automated vehicles, such as those on the roadways today that provide functions (e.g., automated braking and lane assist), to HAV that do not require a driver.

Trends

The 2017 Gartner Hype Cycle, a valuable annually updated technology research resource, projects mainstream adoption of fully automated AVs (Society of Automotive Engineers (SAE) Level 5) to be more than 10 years out. In the interim (SAE Levels 2 through 4), drivers would need to assimilate to a new environment where at any moment, the responsibility of driving can be passed between the driver and the vehicle with just a few seconds notice. Automobile manufacturers are currently trying to design autonomous commercial vehicles (podcars, shuttles, buses, trucks, etc.), in addition to passenger vehicles. As the technology matures, costs to the public may decrease, either in terms of purchase price for privately owned ACV, or usage fees for fleets of shared AVs.
FIGURE 2 – SAE LEVELS OF AUTOMATION
Table 1 summarizes projected AV implementation rates without government mandates, which are based on the deployment pattern of automatic transmission technology. Victoria Transport Policy Institute predicts that fully AV will be commercially available and legal to drive on public roads by 2020, but will be costly and limited in performance and operability. Market shares are predicted to increase as AV performance improves, prices decline, and benefits are demonstrated.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Decade</th>
<th>Vehicle Sales</th>
<th>Veh. Fleet</th>
<th>Veh. Travel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available with large price premium</td>
<td>2020s</td>
<td>2-5%</td>
<td>1-2%</td>
<td>1-4%</td>
</tr>
<tr>
<td>Available with moderate price premium</td>
<td>2030s</td>
<td>20-40%</td>
<td>10-20%</td>
<td>10-30%</td>
</tr>
<tr>
<td>Available with minimal price premium</td>
<td>2040s</td>
<td>40-60%</td>
<td>20-40%</td>
<td>30-50%</td>
</tr>
<tr>
<td>Standard feature included on most new vehicles</td>
<td>2050s</td>
<td>80-100%</td>
<td>40-60%</td>
<td>50-80%</td>
</tr>
<tr>
<td>Saturation (everybody who wants it has it)</td>
<td>2060s</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Required for all new and operating vehicles</td>
<td>???</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>


**TABLE 1 - AUTONOMOUS VEHICLE IMPLEMENTATION PROJECTIONS**

There are ongoing debates regarding whether DSRC or 5G cellular networks should become the wireless technology standard for vehicular communication. On the downside, 5G is still very much in the development phase with no working prototypes or standards available yet and DSRC wouldn’t reach full functionality without widespread adoption of the technology. As 5G cellular technology standards are developed in the near future, in-vehicle infotainment may be realized, with the advent of interactive in-car surfaces for controlling these systems. It will become clearer which use cases are better served by DSRC or 5G, and from this experience, vehicular communication standards will be developed.

The connectivity necessary for providing CV features pose privacy, data security, and physical safety vulnerabilities of CV computer systems. If digital messages sent or received by CV and smart infrastructure are not authenticated or encrypted properly, they can be susceptible to remote hacking of vehicle controls, location data or payment card data through the vehicles’ wireless and phone components.

**Anticipated Impacts**

The greatest anticipated benefit of ACV is the potential for reduction of human driving errors, which currently result in thousands of avoidable collisions annually. Although there exists a fair amount of transportation data available from public agencies and private industry, the interval at which the data are collected currently does not support real-time decision-making. The advent of CV will greatly enhance the quantity, quality, and velocity of data available for enhanced collision warning systems. CV safety applications will enable drivers to have 360-degree awareness of hazards and situations outside their line of sight.

ACVs have potential to better utilize roadway capacity by reducing vehicle headways. This is possible through real-time communication that enables the following vehicle to predict the preceding vehicle’s intended movements. In a transportation network with dedicated AV lanes, or full market penetration, reduced headways and consequent capacity increases could alleviate the need to build additional capacity. Before full market penetration is achieved, some benefits (higher traffic speeds, reduced congestion, and automated intersections) will require dedicated AV lanes. This could raise debates about equity and cost-efficiency. In
addition, human drivers may be tempted to use these dedicated lanes, for example, by following a platoon of self-driving vehicles, which could introduce new risks, regulations, and enforcement requirements, most likely starting in the 2030s.⁶

ACV could significantly increase the demand for automobile travel by providing access to senior citizens, persons with disabilities, and youth, reducing crash risks, and making travel time more productive. Commuters may choose to live farther away from city centers and jobs in order to take advantage of lower costs of living. Driving jobs (taxi drivers, truck operators, etc.) may become obsolete, which could have significant economic impacts. While ACV have the potential to increase capacity and traffic speeds, they may also cause an increase in total trips due to induced demand and, if unregulated, the introduction of zero-occupancy trips.

While AV sensors, algorithms, and software hold promise for increasing roadway safety, accidents would still likely happen and instead of the driver being at fault, issues of liability would fall on manufacturers. This could impact the business model of traditional auto insurance policies, from underwriting to claims. Algorithm morality, the moral principles programmed into AV, control functions for situations of unavoidable harm, which could introduce additional complexity to insurance policies.

Opportunities for Ohio
Multimillion dollar investments in TRC, U.S. Route 33, the Ohio Turnpike and in the City of Columbus are priming the State to become a hub of ACV research and demonstrations. In preparation for ACV technology, Turnpike Commission officials are planning a new system of travel alert information for a section of the Ohio Turnpike located near Cleveland. They will link roadside sensors and other technology to the fiber optic cable infrastructure to produce traffic and weather alerts that could serve ACVs. This project is part of the new DriveOhio initiative, a campaign promoting vehicle communication technology.⁷

In June 2017, Wind River (a subsidiary of Intel Corporation) announced a partnership with TRC, Ohio State, and the City of Dublin to develop new self-driving and connected vehicle technologies. If Federal legislation to streamline deployment of ACV technologies is passed, there will likely be a greater need for more intensive monitoring and evaluation strategies to ensure that AVs are being safely operated on Ohio’s roadways.

**SHARED MOBILITY**

Shared transportation services have the potential to transport people more efficiently by getting more out of existing capacity and increasing vehicle productivity.

**Trends**

By 2020, the National League of Cities (NLC) predicts that TNCs will be mainstream modes of transportation in cities of all sizes worldwide, and their business models will expand to include freight and other services.

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⁶ https://www.vtpi.org/avip.pdf
TNCs will start to use AV for freight and delivery services. On-demand bus systems will expand their operations to larger service areas traditionally underserved by transit and public transportation will begin to use similar on-demand models.8

By 2030 or later, NLC sees increases in the number of citizens using bicycling, car sharing, TNC, and public transit modes resulting in a multimodal system that functions in a much more fluid manner due to improved connectivity between modes. Public agencies and private mobility service providers will integrate services, streamline payment methods, and coordinate first and last mile trips. Public transit is forecasted to begin its transition into driverless, electric vehicles with route optimization functionality. Its reduced operating costs and increased user-friendliness will attract additional riders and accelerate the current declines in auto-ownership. NLC envisions a future where driverless technology is initially mass deployed in fleet vehicles and buses, further reducing the need for privately owned vehicles.

Table 2 highlights several categories of innovative mobility services that have transformed the transportation landscape, providing on-demand services which are both convenient and economical.

<table>
<thead>
<tr>
<th>Service</th>
<th>Role of Technology</th>
<th>Problems Technology May Solve</th>
<th>Factors in Success</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carsharing (examples: Zipcar, car2go)</td>
<td>Reservations and tracking of vehicles; billing</td>
<td>Convenience in making/changing reservations and in locating/dropping off vehicles; national branding encourages use while traveling</td>
<td>Critical mass of users to support availability of vehicles at sufficient array of pickup/drop-off locations</td>
</tr>
<tr>
<td>Bikesharing (examples: Citi Bike, Divvy, Capital Bikeshare)</td>
<td>Reservations and tracking of bikes; billing</td>
<td>Convenience in finding bikeshare stations and information on bike availability; management of rebalancing</td>
<td>Critical mass of users to support a sufficient array of bike stations; rebalancing of bikes to ensure availability</td>
</tr>
<tr>
<td>Transportation network companies—sequential sharing (examples; Uber, Lyft)</td>
<td>Reservations and tracking of vehicles; billing; matching of riders for shared rides; quality control via online customer feedback</td>
<td>Convenience of arranging ride just prior to travel; customer tracking of vehicles and wait times reduces uncertainty; national branding encourages use while traveling</td>
<td>Critical mass of users to support widespread vehicle availability</td>
</tr>
</tbody>
</table>

8 [Link](http://www.nlc.org/Documents/Find%20City%20Solutions/Research%20Innovation/City%20of%20the%20Future/City%20of%20the%20Future%20FINAL%20WEB.pdf)
TABLE 2 – SELECTED TAXONOMY OF INNOVATIVE MOBILITY SERVICES

In the longer-term, the idea of shared mobility may encompass fractional ownership of passenger vehicles, shuttle services, and commercial trucks. Pay-per-mile insurance policies might become more commonplace and people may be able to lease vehicles for any period of time needed. This could lead to major cost savings and increase business opportunities for 10-15 passenger vanpools to fill the commute needs of rural residents. Eventually, when fleets of shared autonomous vehicles (SAVs) become available, private vehicle ownership may no longer be economically advantageous or even more convenient.

**Anticipated Impacts**

Statistics show that each Zipcar and car2go carshare vehicle removes up to 13 and 11 vehicles respectively from the road. A three-year study by scientists at the University of California, Berkeley, found that this results in each car2go vehicle removing between 5.5 to 12.7 metric tons of greenhouse gas emissions each year, which totals to larger CO2 reductions compared to government-mandated green policies.9

A study by Morgan Stanley states that the biggest beneficiary of ride-hailing services could be public transportation. Instead of competing with transit services, companies like Uber and Lyft can complement transit by 1) increasing first and last mile connections to and from rail stations, 2) increasing the number of people served by each station (which in turn decreases the number of stations per line and reduces the trip time as trains would need to make fewer stops), and 3) competing with car ownership.\(^\text{10}\)

The constant availability of on-demand vehicles has the potential to moderate the need for on-street parking and reduce the need for off-street parking. As transportation agencies begin to amend zoning ordinances to reduce the minimum automobile parking requirements, existing parking garages could be retrofitted into microhousing units or vertical urban farming in the metropolitan area, or demolished and used for other purposes.

**Opportunities for Ohio**

Several innovative shared mobility initiatives have sprung up around the State. While traditional forms of shared mobility such as urban ride-sharing (Uber, Lyft) and bike-sharing (CoGo) is prevalent in Ohio, Ohio State University has launched adaptive bikesharing programs from Zagster, which are geared towards people with disabilities. A new ride-sharing service called Liberty Mobility has formed to fill a need in Athens, Allen and Van Wert Counties\(^\text{11}\).

Most transportation agencies have embraced shared mobility as a mobility enhancement. A potential reduction in the inefficiencies associated with high individual and family vehicle ownership rates is a promising prospect. While shared mobility is largely evolving in response to private market forces, there will likely be opportunities for public agencies to encourage growth and innovation. By setting statewide standards through background checks and permitting, ODOT has exerted its role as a guiding force in the adoption of shared mobility options. Continuing to support and communicate with MPOs, local governments, and transit agencies will also help ensure that emerging forms of shared mobility are being used to meet the unique needs of each locality.

**FREIGHT AND URBAN GOODS MOVEMENT**

Innovations in freight and urban goods movement technology (3D printing, supply/demand matching mobile apps, connected and automated commercial vehicles, drones, etc.) have the potential to optimize and streamline logistics, particularly the process of manufacturing, scheduling, and transporting goods, services, and related information from point of origin to point of consumption.

**Nationwide trends**

Connected automated trucks hold promise for achieving new efficiencies in productivity of goods distribution that may trigger an economic boom in the industry. Logistics will no longer be restricted by drivers’ hours of service limit, while platooning trucks will experience significant fuel savings. While mainstream adoption of AV/CV trucks will not be seen in the near future, technological advances such as aerodynamic efficiencies

\(^{10}\) [http://www.huffingtonpost.com/entry/uber-lyft-public-transportation_us_574ef641e4b0af73af95ebff](http://www.huffingtonpost.com/entry/uber-lyft-public-transportation_us_574ef641e4b0af73af95ebff)
\(^{11}\) [http://libertymobilitynow.com/ohio/](http://libertymobilitynow.com/ohio/)
and semiautonomous features (e.g., automated braking systems, platooning) are already under way. A report by McKinsey & Company on the future of commercial transport predicts that trucking companies can expect revenues to increase by 50 percent over the next decade, with the bulk of that value created by new technologies.\(^\text{12}\) The research firm projects that by 2025, at least one third of new heavy trucks will be semiautonomous, eliminating the need for a full-time driver. Eliminating substantial costs such as drivers could reduce the total cost of ownership of a truck by as much as 35 to 50 percent. This will free up trucking company resources to invest in new trucks, further speeding up the pace of automation technology adoption. As consumers become accustomed to receiving deliveries more and more quickly (known as the “Amazon Effect”), this will increase demand for more trucks to be operating nonstop.

Drastic improvements in freight supply chain information across modes and across industry are expected in the future. There are already improved technologies, and an industry more open to information sharing, that is leading to more of an “appointment system” type of paradigm for freight deliveries and pickups. Moreover, large companies such as FedEx, UPS and Wal-Mart, have sophisticated software systems that optimize their truck movements, both for long-haul and local trips. For medium and smaller companies, application development companies such as Productivity Apex are developing freight movement optimization software which, when paired with a company’s fleet management/GPS tracking system, allows for sophisticated optimization of routing and order processing of pickups and deliveries for the companies trucks each day, resulting in over 10% improvements in energy use and driver time efficiency.\(^\text{13}\) Optimization areas can include route, forecasted traffic, real-time traffic, incident avoidance, freight/warehouse facility loading dock hours, driver schedule, driver hours of services, and more.

CBRE Group’s Industrial and Logistics Research team, who spearheads research initiatives on e-commerce fulfillment, automation, and development trends and supply chain strategies, anticipates autonomous trucks changing how warehouses, receiving docks, and logistics parks are designed.\(^\text{14}\) Battery loading stations will be needed for electric delivery vehicles. AV will allow trucks to travel farther, meaning more consumers can be serviced within a one-day range of a distribution center (critical because demand for distribution space outpaces supply). Drones, impervious to roadway traffic congestion may impact the way and speed at which packages or emergency supplies are delivered in urban areas. While the technology is available for delivery by drones to occur, concerns over safety and logistics remain unresolved.

3D printing will shorten delivery times by enabling more local and regional manufacturing near last-mile distribution points. This would greatly reduce port and air cargo traffic, as well as long haul shipping. Urban goods movement will shift from larger, heavy-duty trucks to smaller vans. In the long term future, mobile 3D printing will spawn autonomous manufacturing hubs, which have the potential to reduce storage costs and deliver items to customers even faster, eliminating the need to stock millions of products at warehouse hubs as close to their customers as possible.

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Adoption of robotics will replace workers in warehouses the same way autonomous trucks eliminates the need for truck drivers. CBRE predicts that logistics networks will become leaner, trading warehouses and distribution centers close to seaports fewer, but larger ones positioned farther from seaports with more local last-mile distribution points.

**Anticipated Impacts**

CBRE foresees the evolution of autonomous trucks, 3D printing, and supply chain robotics leading to:

- Lower transportation costs and a less dense warehouse network, with greater demand for cheaper land in remote locations for larger facilities and more diffuse, smaller, urban distribution points.
- More emphasis on last-mile distribution, with last-mile distribution points becoming production sites, thanks to 3D printing.
- More high-tech distribution centers, which could propel a new development cycle of more automated warehouses.\(^{15}\)

Government regulations can play a significant role in determining the direction of autonomous commercial vehicle technology and drones by supporting an environment which encourages the piloting of innovative freight management strategies. It is unclear whether the U.S. DOT or individual states will take the lead in issuing rules regarding the use of autonomous trucks in interstate commerce. Either scenario comes with its own set of complications. If states legalize regulations that are not consistent with other states, coordinating long haul trips will require additional complexity. If the U.S. DOT issues a Federal mandate (e.g., safety), this could lead to unwanted restrictions on cargo size and weight limits.

If future investments are made to further connected commercial vehicle technology, benefits such as transportation efficiency, lower operating costs, and improved safety, as shown in Figure 3, may also be realized.

FIGURE 3 - POTENTIAL IMPACT OF THE INTERNET OF THINGS ON THE FREIGHT INDUSTRY

Opportunities for Ohio

Ohio has demonstrated a commitment to self-driving and connected vehicle exploration through programs like the Smart Belt Coalition collaboration among transportation agencies and academic institutions in Ohio, Michigan and Pennsylvania. Coalition members want to work together to bring the region to the forefront of the development. That means sharing research, establishing standards and not duplicating efforts across state lines. Each state will work on different parts of the ACV puzzle. Ohio, which is focused on freight, likely will explore concepts like platooning.16

The Ohio Turnpike, equipped with 241 miles of fiber optic cable, will likely focus on ways to move freight more efficiently. The turnpike is a major freight corridor between the East Coast and the Midwest, with

16 http://www.govtech.com/fs/Ohio-Accelerates-Self-Driving-Vehicle-Effort-Through-Smart-Belt-Coalition.html
about 12 million trips and a billion miles of freight shipped annually. One way to move freight more efficiently may be realized through the modernization of the Ohio Turnpike’s current toll collection system. This project involves removing the gates and booths (which are due to be replaced), allowing vehicles to continue through without stopping. Options such as removing all entry toll lane gates and exit gates in E-Zpass Only lanes and installing new license plate image capture cameras are being considered.

TRC is planning a $45 million investment at their facilities which will include a six-lane, high-speed highway that will allow the center to test technologies like truck platooning, which consists of several commercial trucks following each other closely at a constant speed to provide better fuel efficiency and safety.

Recently, the Mid-Ohio Regional Planning Commission’s (MORPC) Midwest Connect proposal was one of the 10 winners of Hyperloop One’s Global Challenge. The proposed route would connect Chicago, Columbus, and Pittsburgh via high-speed transportation. Hyperloop One’s challenge winner announcement emphasizes the exceptional opportunity that linking these cities provides:

“A Hyperloop connecting Pittsburgh, Columbus, and Chicago would create a Midwest megaregion to rival the country’s coastal economic powerhouses. The proposal was chosen for the unique opportunity to realize this vision: there is currently no direct freight or passenger rail connection along the corridor, resulting in untapped economic potential; Hyperloop would transform the movement of goods and people in the Midwest, and leapfrog these communities into the next century.”

SMART INFRASTRUCTURE & DEVICES

The advent of connected smart infrastructure (connected roadside units, streetlights with wi-fi, transit bus stop warning system, DSRC-enabled signalized intersections, video-based parking detection system, point of service RFID readers, etc.) and smart devices (mobile phones, wearable technology, etc.) can greatly enhance the quantity, quality, and velocity of data available to provide traffic management centers, public agencies, and the public with a 360 degree view of the multimodal transportation network.

Nationwide Trends

Smart Cities of the future are envisioned to have digital technology embedded across all city functions. Big Data and the Internet of Things can help provide the information needed to make cities more interconnected. In the meantime, cities can aid in this effort by installing sensors and other intelligent transportation systems to monitor various aspects of the roadway network (e.g., movement of people, road conditions, energy consumption, etc.).

Several active transportation mobile apps such as Strava, MapMyRide, and Ride with GPS are already being used to track bicyclist and pedestrian activity (counts, intersection wait times, origins/destinations). In the

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near future, additional sensors will be integrated into the design of microscaled vehicles and smartphones. These sensors will capture information ranging from CO2 and noise levels to road condition and traffic data.

Wearable devices, or “wearables” may also become increasingly prevalent among the active transportation community. Measuring heart rate, distance traveled, and calories burned currently help people track their fitness progress.

Anticipated Impacts

It is said that connected cars will send 25 gigabytes of data to the cloud every hour. With increasing quantities of data available from connected infrastructure, vehicles and devices, it will be critical for transportation agencies to build and maintain a platform that supports connected transportation data collection and exchange from a wide variety of sources. This will streamline the effort for developers to access multimodal transportation data that can be used to build innovative applications and solutions for existing transportation issues. While real-time data generated from multimodal sources will fill many gaps in transportation planning and operations, data storage becomes a major issue for public agencies who are generally inexperienced on this front. Data also needs to be backed up on a regular basis, effectively doubling the storage size needed.

Opportunities for Ohio

Globally, data is becoming more of a commodity. ODOT has switched to purchasing data such as speed and weather data. This allows ODOT to forego the cost of installing and maintaining the roadside devices needed to collect this type of data.

The Ohio Turnpike (241-mile-long limited-access highway serving as a primary corridor to Chicago and Pittsburg; includes I-80, I-90, and I-76) is already outfitted with 241 miles of fiber optic cable and is now in the process of installing equipment that allows vehicles to communicate with transportation infrastructure. The fiber optic cable not only allows for information to be gathered on AV operation but also allows researchers to test connected vehicle technology.

Ohio is also investing $15 million in a Smart Mobility Corridor, a 35-mile stretch of U.S. 33 between Dublin and East Liberty (outside of Columbus) being lined with fiber optic cable that can collect data on ACV.

Columbus won the Smart City Challenge in 2016. The project is intended to turn Columbus into a testing ground for transportation technology. Future projects include making I-90 from I-271 to the Pennsylvania state line a smart highway as part of the state’s creation of an “expanding network of smart highways.”

INTEGRATED TRAFFIC MANAGEMENT

The explosion in data availability can be leveraged to create valuable intelligence regarding traffic management, increase prediction accuracy, and support real-time decision-making. With the Open Data Initiative spreading nationwide, opportunities arise for collaborative and innovative application development. Applications that integrate data from multiple systems have the most potential for optimizing traffic management.
Nationwide Trends

Due to Federal support by Federal Highway Administration (FHWA), Transportation Research Board (TRB), Strategic Highway Research Program (SHRP), and AASHTO, an increasing number of agencies are developing TSMO policies, goals, and objectives to increase travel choices and efficiency for all modes—including transit, bicycling, and walking—while reducing emissions and resource use. Emerging technologies will change the way incidents are managed, traveler information is disseminated, and multimodal payments are accepted.

Today, traveler information such as traffic conditions, traffic incidents, bridge/freeway/lane closures, transit disruptions, and transit departure times are provided in fragments based on mode or jurisdiction through apps hosted by 511, transit agencies, and private industry (e.g., Waze). Transportation agencies are looking to leverage Big Data from smart vehicles, infrastructure, and devices to add capacity to the existing roadway network, manage congestion, and reduce motor vehicle crashes. Private industry and the open source community can use this untapped resource to develop innovative applications, such as multimodal trip planners or crowd-sourced traveler information.

In the long-term future, full-scale multimodal integration (as shown in Source: Volpe National Transportation Systems Center, 2016.

Figure 4 will be achieved through 1) infrastructure and operational integration—different transport modes are connected physically as well as operationally, 2) information integration—information systems help service providers achieve operational integration in addition to providing real-time information to passengers on various modes regarding connectivity options, routes, schedules, and fares, and 3) fare integration—integrated payment solutions like smart cards allow seamless access and payment across different modes.20

Source: Volpe National Transportation Systems Center, 2016.

FIGURE 4 - THE FUTURE OF MULTIMODAL TRIP PLANNING APPS WITH SEAMLESS PAYMENT

Transportation operation and emergency response functions also need to be in constant communication with each other, so that when incidents do occur, the time it takes to coordinate and execute a response plan is minimized, reducing the impact of the disruption. Some agencies have chosen to co-locate highway patrol personnel within the same facility as the TMC for improved communication and coordination. In the future, the same effect can be accomplished through fiber/wireless backbone communications infrastructure.

**Anticipated Impacts**

As communication becomes less manual—for example, instead of calling to report an incident, the incident is automatically detected using vehicle-mounted sensors, while a drone surveys the incident from above and wirelessly transmits footage back to the TMC—the need to invest in and maintain certain infrastructure will decrease. Road signage, variable message signs, traffic signals, and others may become obsolete. Detection, verification, dispatch and response time of incidents such as vehicle collisions, terrorist attacks, evacuations and other emergencies will decrease, which can lead to reduced mortality and reduced nonrecurring congestion.

Connected wearables will become a resource for fitness gamification, using a social network to encourage increased levels of active transportation. In the long term, the development of wearable device features such as contactless payment sensors, connected traveler applications (e.g., bicyclist/pedestrian signal priority, transit smart stop), and traveler information alerts (e.g., additional crash risks to bicyclists/pedestrians due to high influx of traffic volumes on arterials, bicycle parking or bike share availability, etc.) will help integrate bicyclists and pedestrians into the increasingly multimodal future of transportation.

Developing universal transportation accounts comes with many challenges, such as issues of pricing between vendors, data exchange policies, and customer privacy. However, eliminating payment as a barrier to travel produces many benefits for customers as well as service providers. Customers will enjoy the convenience of having multiple travel options (and combinations of options) at their fingertips, which they will be able to prioritize based on the factors that matter to them the most (e.g., cost, travel time, amount of physical activity, available discounts or incentives, safety, etc.). Service providers, with access to traveler preference data, will be able to manage travel demand proactively and provide travel options that add more value, resulting in increased ridership and revenue.

Big Data can provide a deeper understanding of traveler route choices and modal preferences, giving transportation agencies insights on how to respond to the needs of the traveling public. Private industry companies are offering an increasing number of services that provide insights and enhanced visualization and tools to people without access to or experience with ArcGIS, machine learning/artificial intelligence, and other data processing platforms. While this reduces the need for public agencies to invest in Big Data storage and processing platforms, this also increases the dependency of public agencies to purchase these tools or services in order to gain the real-time decision-making functionality that they are after. Transportation agencies will be able to better leverage the value of Big Data if their workforce is able to unite domain expertise with data science.

**Opportunities for Ohio**

ODOT is currently in the process of finalizing their TSMO Plan\(^1\). One of the main findings of the study concludes that ODOT must shift to an approach that emphasizes the operation of the system in real-time,

allowing for the operation of the roadway to be responsive to constantly changing conditions. As technology advances rapidly, ODOT clearly recognizes the growing need to employ electrical and communications engineers, computer and data analysts, and GIS professionals so that the agency will be better prepared to respond to and support emerging technologies, such as data-driven performance measures, ACV, and Smart Cities. Below are several plan elements that signify a more integrated traffic management approach:

- Develop a Traffic Operations Assessment Systems Tool. New data sources (e.g., probe data subscriptions) developed in the last five years provide the capability to measure and assess traffic operations performance. This tool will provide a foundation that can be enhanced over time to include more data and assist other program areas with planning and prioritization of projects.

- Pursue interim Traffic Management Center upgrades and improvements. Develop control software that integrates the traffic signal system and ITS devices into one network to monitor device performance and for data collection. Create an Information Sharing Working Group to establish a list of offices within ODOT and partner agencies that need to exchange data and develop procedures for how the information is exchanged and how frequently.

The Smart Columbus Sandbox which currently contains 50 datasets from public sources and local and national companies will be made available to the public as a tool for developers to experiment with the data. It is part of the integrated data exchange, a cloud-based platform that holds the datasets. The city is looking for additional data to add to the sandbox.22

The State of Ohio is doing a major overhaul of its data repositories for its 26 various disciplines, such as education, transportation, public health and safety, waste, and abuse. The State’s Chief Information Officer (CIO) Stu Davis hopes to clean and consolidate more than 1,600 systems so that the data contained within them can be leveraged for use in predictive analytics. This is believed to be able to address some of Ohio’s biggest challenges, such as infant mortality, child welfare, opiate addiction, persistent poverty, and school dropout rates.23 An RFP calling to establish a pool of prequalified contractors that offer public/cloud based analytics platform processing capabilities and are capable of performing exploratory projects in a multitude of data analytics domains was released on January 5, 2017, resulting in the qualification of 50 companies to consider statement of work for data analytics projects with state agencies.24 25

**TRANSPORTATION PRICING STRATEGIES**

The advent of hybrid and electric vehicles has caused a loss of gasoline tax revenues, further widening the gap in funds needed to adequately maintain, operate, and improve the aging transportation network. Strategies to monetize transportation such as road usage charges, congestion pricing, cordon pricing, and vehicle emission fees have been explored with varying levels of success. ACV technology create new potential avenues for monetization.

Nationwide Trends

Adopting and Adapting: States and Automated Vehicle Policy\textsuperscript{26}, a report by Eno Center for Transportation recommends that states develop a per-mile AV fee in concert with the Federal government. The infrastructure costs associated with the operation of AVs presents a substantial funding need. Between the maintenance of public roadways and the potential loss of revenue (fuel taxes, parking, and traffic tickets) states and cities will have significant financial burden to address. Auspiciously, AV technology provides an opportunity to implement a straightforward Vehicle Miles Traveled (VMT) fee.

Eno’s 2017 Beyond Speculation: Automated Vehicles and Public Policy\textsuperscript{27} report details why and how the Federal government should develop a $0.01 per mile charge on automated driving. Companies are laying the groundwork to charge consumers by trip or by the mile, allowing for easy administration of such a fee at the government level. The next step is for state and local governments to take advantage of this to help fund their own public infrastructure investments. Further, states could design an AV VMT fee to account for differences in vehicle types, occupancy levels, congestion, and other variables.

The Federal government is also interested in encouraging VMT fees: the 2015 Fixing America’s Surface Transportation (FAST) Act set aside $95 million for VMT research.\textsuperscript{28} The United States Department of Transportation can use this money to begin testing a VMT fee system for AVs before they become more prevalent on the roadways.

TechCrunch states that after phones, cars will be the biggest category for mobile-data consumption.\textsuperscript{29} They predict that connectivity-driven revenue may come from the following sources:

- Interactive/informative surfaces. Inside a car, nearly every surface could be transformed into an interactive interface. Beyond the instrumentation panel, which has been gradually claiming more real estate on the steering wheel, there will be growth in backseat and rider-side infotainment screens. (Semi-) autonomous cars will present many more possibilities.
- Processing power. The cloud turned mobile phones into smart clients with all the heavy processing elsewhere, but each car can contain a portable data center all its own.
- Power management. The size and weight of phones were constrained for many years by the size of the battery required. Battery-intensive apps can run on car windows serving as augmented reality screens with practically no effect on the car battery.

\textit{McKinsey & Company’s Monetizing Car Data} report lists the following direct monetization options: features and services can be charged to end customers—by rolling their cost into the vehicle price, selling them as a

\textsuperscript{28} Federal Highway Administration, “Fixing America’s Surface Transportation Act or ‘FAST Act’ - Funding,” U.S. Department of Transportation, 2017.
\textsuperscript{29} https://techcrunch.com/2016/08/28/how-connected-cars-are-turning-into-revenue-generating-machines/.
one-time purchase after initial vehicle sale, or offering them via subscription or rechargeable credit - or
provided free of charge when customers agree to receiving advertising as part of the deal.30

Anticipated Impacts

Eno’s Adopting and Adapting: States and Automated Vehicle Policy report states that AV developers are not
necessarily against implementing a VMT fee on their vehicles. Policy-makers need to be mindful of market
distortions related to a VMT fee, and should consider using discounts or other incentives to encourage the
beneficial adoption of AV technology.31

According to McKinsey & Company’s Monetizing Car Data report, automotive suppliers, OEMs, high-tech
companies, start-ups, alternative mobility operators, data management services, insurers, roadside assistance
providers, and infrastructure operators will all be players in the connected car data monetization landscape.
Without policies in place, public transportation agencies may not take part in any of these new revenue streams.32

Opportunities for Ohio

The worst-case scenario for the future of AVs involves all roadway users (motorists, transit users, bicyclists,
pedestrians, etc.) switching to personal AVs for single-occupant trips, or worse—introducing zero-occupant
trips where AVs circle the block continuously waiting for their owner to return, thereby increasing VMT and
congestion and erasing all of the progress made to reduce single-occupant trips. Researchers, such as Eno,
have recommended researching different approaches to implementing and using a VMT fee on AVs as a way to
1) create a new revenue stream for state transportation investment and 2) encourage and incentivize the
responsible use of AVs on public roadways (i.e., shared AVs).

Ohio may find opportunities to address declines in traditional revenue sources through innovation in
transportation pricing. To date, the transportation industry’s experience in integrating AV and CV technology
with traditional transportation systems (e.g., traffic signals, advanced traffic management systems, etc.) is
limited. Nationwide pilot and demonstration sites are advancing research and developing implementation
frameworks. While more concrete (versus conceptual) information on how AV and CV technology works would
greatly benefit transportation pricing discussions, given the openness that the transportation industry has
displayed towards potential evolutions in pricing models, having this conversation at a statewide level may
add value. Real transition would take considerable time, effort, and political capital, but it may be
advantageous to at least open the conversation as soon as possible.

Findings and Future Direction

Based on existing conditions and trends, Ohio is positioned to play a key role in shaping how emerging technologies will impact transportation systems of the future. Partnerships with public and private stakeholders, research institutes, and upfront investments in smart infrastructure will enable ODOT to maintain and expand its role in conversations surrounding ACV and emerging technology. However, recent Federal legislation aimed at streamlining AV deployment may bring about changes to ODOT’s roles and responsibilities. The Federal government will issue guidance on safety, manufacturing standards, and testing, while States will govern matters of licensing, insurance, and liability. The potential impacts of a rapidly changing technological landscape based on trends identified in this paper are summarized as follows:

- Fully AV may not have widespread penetration within the next ten years; however, elements of vehicle automation will likely become mainstream in the near future. Anticipated impacts are subject to change based on the level of automation; therefore, a flexible and adaptable approach to planning and policy may help Ohio adjust to uncertain market trends.
- The most likely scenario for 2045 is one of a “mixed fleet” where fully AV share the roads with vehicles with low to nonexistent automated functions. ODOT will need to balance the opportunities that come with higher levels of automation and fleet penetration with the need to serve all transportation system users.
- Widespread success of shared-use mobility systems have laid the groundwork for shared fleets of AV in urban areas. Key impacts include reduced demand for parking, improved safety, enhanced mobility for transit-dependent communities, and better first-last mile connectivity.
- CV technology and ITS applications hold promise for more efficient use of existing roadway capacity, alleviating the need for much-debated roadway expansion projects.
- Emerging technologies could have an enormous impact on the freight sector by enabling efficient goods movement, optimizing shipping and logistics patterns, and eliminating labor costs (which will also have drastic implications for the economy). 3D printing and e-commerce may also impact freight operations by reducing demand for trucking and rail services.
- The big data market can enable real-time, dynamic transportation networks and allow for better performance management and improved investment decision-making.
- Emerging pay-per-mile pilot programs and active traffic management strategies may transform revenue structures, creating more funding for transportation improvements.
• Existing and emerging technologies present opportunities for Ohio to enhance safety and security for all road users, reduce congestion and improve mobility, support a thriving economy and resilient transportation system, and foster environmental health and sustainability.

The future direction of transportation is at a crossroads where policy and guidance play an especially critical role in shaping change. Statewide policies that support shared electric AV will help expand mobility, reduce emissions, improve access to opportunity, and better utilize infrastructure to create more space for active transportation, public transport, and public space. On the contrary, incentivizing independent ownership of ACV could compound the costly impacts of urban sprawl, as roadways become more congested and travel times increase. However, market forecasts show that (in response to public demand and industry regulations) auto manufacturers are developing more fuel efficient vehicles. Therefore, in the instance that independent ownership of AV leads to an increase in vehicle miles traveled, there would at minimum be a reduction in greenhouse gas emissions and associated externalities. Transportation agencies will have a role in educating the public about the benefits and risks associated with ACV.

The implications of emerging technologies on public transit are also uncertain, and largely dependent on political and fiscal support. Public transportation could undergo a range of transformations with strategies like route and vehicle optimization, transit signal priority, and improved first-last mile connectivity. However, the growing convenience of personal and shared-mobility modes of transportation in the autonomous future would likely cause public transit to become less competitive. This framework also applies to active transportation, which may lose appeal as on-demand mobility becomes more affordable and convenient. These issues of multimodalism are importance to consider as urban areas continue to densify and suffer from increasing congestion; especially in Ohio, which has a relatively large number of urbanized areas for a state of its size.

The timing and magnitude of future technological advances are uncertain. There are numerous unanswered questions which will shape industry-wide outcomes. Technological hurdles, level of public acceptance, availability and cost of technologies all will make for an unpredictable future. In the face of this unpredictability, it will be essential for agencies to pursue robust strategies. Robustness can be strengthened by considering the many possible futures facing the State of Ohio, and developing strategies that help shape that future, that help hedge against undesirable futures, and that defer actions which can be taken later. Uncertainty is no excuse for inaction, but it argues for careful action with a clear understanding of the potential future landscape.

Impacts are not limited to transportation, but have widespread implications for land use, housing, urban design, economic development, equity, and environmental sustainability. With these uncertainties in mind, AO 45 can be used as a tool to mitigate potential unwanted impacts of emerging technologies while leveraging opportunities. In both the short- and long-term, expanding research efforts and partnerships will be key, as well as establishing a robust set of goals, objectives, and priorities to guide Ohio’s transportation future.