Autonomous Vehicles Issues and Trends

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OFFICE OF PERFORMANCE AND ANALYSIS

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INTRODUCTION

The following contains a series of issue papers written loosely in white paper format on autonomous vehicle technology and the potential impacts to the transportation system at large and within Dakota County. These are not intended to be exhaustive research pieces, but instead condensed overviews on topics of import to County planning. Autonomous vehicle technology is one of the fastest growing industries in the world with a potential for range of impact arguably unmatched in modern times; the following papers represent potential starting points, references and recommendations for future study for a hugely expansive and constantly changing technology.

Autonomous vehicle technology is best described as a range of potential applications. Everything from cruise control to a completely driverless vehicle utilizes automated processes. Certain cars are now sold with “autopilot” which takes cruise control a step further by also automating lane changes, and providing limited steering and breaking while on the highway. All of these features are ostensibly incremental steps toward a fully or highly autonomous vehicle (HAV); a car that does not require any human interaction to operate.

The Society of Automotive Engineers (SAE) has developed a commonly used list of levels that describe the range of vehicle autonomy, available in Appendix A. These levels provide perhaps the best overview for someone unfamiliar with the topic. For the purposes of the following papers, Autonomous Vehicle(s) or AV(s) will refer to a vehicle or vehicles that require limited human interaction, described by the SAE as Levels 3 through 5. These vehicles are not yet in mass production and represent the largest shift in development of vehicle automation. Occasionally the term Highly Automated Vehicle or HAV will be used; this will be to make a point or comment that specifically relates to a vehicle that does not require a human in the driver’s seat. Certain other acronyms and topical terms will also be used throughout; for reference, please see the glossary available in Appendix B.

The information presented here represents a current state analysis and understanding of the technology; the industry is advancing quickly and some information may be proven incomplete in the future.

FORECASTING DEVELOPMENT AND THE IMPACTS ON RESIDENCY AND EMPLOYMENT

RESEARCH QUESTION: *How will driverless vehicles impact where people live and work? When do we currently expect these impacts to play out in terms of personal use and for transit? Consider in terms of Capital Improvement Program (CIP), and long term transportation plans.*

STATEMENT OF PURPOSE: According to some researchers, we are still about decade from seeing a full HAV on the road. Many have already started conversations about how AVs will impact where people live and work. Some believe that the technology will completely reverse current population trends; instead of further concentration in urban centers, AVs may encourage people to spread out by easing commutes and eliminating associated opportunity costs. The purpose of this paper is to provide an overview of how AVs will impact where people live and work, and when we could expect these changes to occur.

BACKGROUND: The question of how these impacts will exactly play out is certainly up for debate. Some might argue that AVs will make car trips faster, safer and more enjoyable, and make other activities such as reading or working feasible during trips. This may make longer commutes between suburban to urban areas more acceptable to many people. If people were to adopt longer commutes, AVs could contribute to increasing city sprawl.[1] Others might contend that regardless of who is driving, being in a car for 30 to 60 minutes, two times a day for a commute is not a pleasurable experience. In addition, only some people can read or look at a monitor in the car and not get car sick. The impact on urban centers themselves is also uncertain. AVs could theoretically free up the vast amount of space currently used in cities for parking by reducing the space between vehicles. In addition, one AV could be used by multiple people in a household (e.g., drop one person off at work and return home to take someone else to school, grocery store, or shopping) and this could certainly reduce the number of parking spots. A study from M.I.T. once estimated that in some U.S. cities, more than one third of space was covered by parking lots.[2] If unused, this space could be repurposed to satisfy the growing demand for green space, and urban gardening. Alternatively, however, if less parking means that there are more cars constantly in use, this could have implications for energy use and road capacity.[3] Road capacity especially is an issue of concern, and is addressed in more detail in the paper on highway operations.

If the impact on urban design and where people live is more unclear, agreement is certain that automation will significantly alter America's work force. Taxi and ride-booking services drivers, truck drivers, and transit drivers are all ostensibly at risk. These fields represent a combined five million jobs or 3 percent of the country's workforce.[4] Loss to these sectors would compound the already five million jobs lost in manufacturing since the 2000s, and is especially troubling considering that many of these workers migrated to transportation as a result.[5] What's more worrying is that this only includes direct impact on employment. The transportation industry also relies on a host of administrative support workers, and entire small town economies exist to support transitory workers and survive on the passed income. A loss or reduction in the amount of truckers passing through these areas would impact these jobs as well. These contingent effects are part of a wider trend that puts transportation, administrative support and service positions at odds with advancing technology. A widely cited study from the University of Oxford concluded that 47 percent of American workers are at high risk of losing their jobs to automation.[6] The only question is when.

[1] Autonomous Vehicles will change land use planning. What you should be thinking about now. *Stantec*. 25 Jan 2017
[2] Paved, but still alive. *New York Times*. 6 Jan 2012.
[3] Here's how self-driving cars will transform your city. *Wired*. 21 Oct 2016.
[4] The Rise and Nature of Alternative Work Arrangements in the United States, 1995-2015. *National Bureau of Economic Research*. 29 Mar 2016.
[5] Autonomous vehicles could cost America 5 million jobs. What should we do about it? *LA Times*. 22 Sep 2016.
[6] The Future of Employment. *University of Oxford*. 17 Sep 2013.

In order for passengers to utilize drive time differently, and for transportation workers to be replaced, a Level-5 AV is required to completely eliminate human interaction with the vehicle while in transit. Having an attentive driver behind the wheel, even for a car that can largely run on autopilot, may continue to be the standard for some time simply due to safety concerns; regulators will want to know that the driver can assume control at any time to respond to emergencies. The timeline to roll out the fully autonomous, Level-5 HAVs varies by manufacturer. Tesla CEO Elon Musk has said the company will have a fully self-driving car road ready in 2018. While others such as the CEO of the Toyota Research Institute, said none of the automakers or tech industries are close to achieving true Level-5 autonomy. In addition, Nissan's head of research and development said that fully self-driving cars aren't going to happen in the next five to ten years.[7]

CURRENT STATUS: In trying to anticipate the full impact of Level-5 AV, besides the time it takes the automakers to deliver, the most optimistic estimate being 2018 - according to Tesla CEO Elon Musk, it will take more time for people to accept and be comfortable riding in the vehicle or driving next to it. Given that innovation related to AVs is overtaking the ability for the government to regulate, it will take an additional time beyond technical feasibility before full AVs are widespread on the road.

It is still early in Uber's testing, but currently, a number of Uber's self-driving cars (these vehicles still had a driver at the wheel to take over if needed) are roaming the streets in Pennsylvania, Arizona and California. The data show that there have been regular instances where safety drivers take over the vehicle due to software failure, error, or to avoid harmful events; this is known as disengagements, the software disengaging from driving. On average, as of March 2017 disengagements occurred about every 196 miles driven. Test data provided by the company show that while Uber AVs still have long way to go, this number represents an improvement.[8] In California, several companies that conduct AV tests on public roads in 2016 were required to submit their disengagement reports; the summary is available in Table 1. The results are varied, but seem to indicate that the software improves exponentially; as more miles are driven, the less disengagements. This is, in fact, the original concept behind Google's technology as the software learns by example.[9] The average miles per disengagement for all companies increased from 183 to 250 in one year alone, a 36.6 percent increase.[10] While these trends are impressive, it is difficult to tell exactly when standards that satisfy both manufacturers and regulators will be reached.

FUTURE PLANNING: If predictions are correct, Level-3 and Level-4 vehicles will start to be available within the next decade. Autopilot features will be common on highways, and trucks will be some of the first to utilize this technology on a large scale.[11] However, this does not mean the worst employment predictions will be realized at this time, and the most pessimistic predictions may never come to pass. While these jobs and the dependent economies are at risk, previous industries have been automated without feeling the worst effects. ATMs were thought to eliminate teller positions, but instead changed the nature of the work; tellers were able to focus on different customer services and increased demand.[12] Trucks will continue to need drivers to operate the vehicle in tight urban areas, and while the truck is on highway autopilot the driver would be available for other business tasks.

AV development continues its rapid growth, however, and the constant state of change in the technology makes projecting future implementation timelines a challenge. The Institute of Electrical and Electronics Engineers (IEEE) predicts Level-3 to become standard by 2020, prompting highways to begin catering to cars on autopilot mode, and Level-4 and Level-5 AVs to be ready by 2030. Shortly after, the IEEE predicts that half of all cars will be at least Level-3. Fifteen years later, the time usually stated for vehicle fleet turnover, all cars could be mandated

[7] Automakers are slowing their self-driving car plans — and that could be a good thing. *Business Insider*. 8 Jan 2017.
[8] Uber's autonomous cars drove 20,354 miles and had to be taken over at every mile, according to documents. *Recode*. 16 Mar 2017.
[9] The trick that makes Google's self-driving cars work. *The Atlantic*. 15 May 2014.
[10] Data shows promise for autonomous vehicles' progress. *GovTech*. 3 Feb 2017.
[11] The complete timeline to self-driving cars. *Recode*. 16 Mar 2016.
[12] Automation and Anxiety. *The Economist*. 25 Jun 2016.

driverless.[13] Another forecast by the Victoria Transport Policy Institute (VTPI) predicts that Level-4 and Level-5 HAVs will become legal by 2025, start to be used in limited capacities (such as ride-booking services and freight) in the 2040s, and by 2060-80s HAVs will be mandated and there will be some restrictions on human-driven vehicles.[14] The VTPI forecast was developed three years after the IEEE, and has later rollout dates, indicating the technology may not be moving as fast as originally thought.

While it seems as though AV technology has emerged recently, and is advancing exponentially, it is older than most people realize. In 1995, the Carnegie Mellon University Robotics Institute designed a vehicle that drove across the country with 98 percent of miles driven autonomously.[15] This rate is comparable to vehicles currently in testing. While the technology has become more affordable, and the interest more widespread, the actual levels of tested autonomy have not increased. The final missing percentage points encompass making AVs completely safe and predictable on complex city streets and complex driving conditions, and this standard has still not been met.[16] This does not mean it is impossible, but planners should keep this in mind when faced with predictions of imminent vehicle autonomy.

Despite variable projections, planners need to start thinking about the possibilities of the inevitable changes to roadways. Today, the design of roads and traffic are built around the needs and behavior of human drivers, but changes will need to be made to accommodate variable levels of autonomy, especially on highways. There will be demand for more road signs, lane markers, and the need to keep them clear from obstruction. Intersections can be planned and reworked with the confidence that all AVs will obey the rules to obtain optimal traffic flow.[17] The potential for AVs to change the way people travel and their behavior while doing so is very significant. Understanding the direct and indirect consequences of adopting this technology is crucial when planning for the future of the state transportation system, and in writing legislation to ensure its safety.[18]

[13] Driverless Cars: Optional by 2024, Mandatory by 2044. *IEEE*. 29 Mar 2014.
[14] Autonomous Vehicle Implementation Predictions: Implications for Transportation Planning. *Victoria Transport Policy Institute*. 1 May 2017.
[15] No Hands Across America. *Carnegie Mellon University*. 1995.
[16] Two Million Miles Closer to a Fully Autonomous Future. NewCo Shift. 5 October 2016.
[17] 17 Ways Driverless Cars Could Change America. *The Federalist*. 16 July 2014.
[18] Autonomous Vehicles. *MinnesotaGO*. 5 Jan 2016.

Table 1: Disengagement Reports and Miles Driven by Company[19]

Company	Miles Driven	Disengagements	Miles per Disengagement
Google Auto/Waymo	635,868	124	5128
GM Cruise	9,623	262	36.7
Nissan	4,099	28	146.4
Delphi Automotive Systems	3,125	277	11.3
Bosch	983	1,442	0.7
Mercedes-Benz	673	336	2
BMW	638	1	638
Ford	590	3	196.7
Tesla Motors	550	182	3

[19] Autonomous Vehicle Disengagement Reports 2016. *CA DMV*. 1 Feb 2017.

LEGISLATIVE ISSUES

RESEARCH QUESTION: *What state and federal legislative issues (currently proposed or potential) should the County monitor?*

STATEMENT OF PURPOSE: Automakers and technology companies are investing a lot of resources in developing AVs, and are running real world pilot programs around the country. At this point, many believe that the technology is outpacing the ability of government to regulate it. The purpose of this paper is to examine what has been done legislatively to ensure the safe development and deployment of AVs.

BACKGROUND: The first legislative challenge is firmly establishing what constitutes an AV. Any regulatory actions will need to be clear about what they cover considering the technology is somewhat varied in concept. Will this new technology fall under a different class of laws from existing vehicles, and will manufacturers be held accountable for errors in judgement as people would be currently? It is impossible to convict a piece of software of legal misconduct, but the manufacturer may point to misuse or human error in many cases. Even if the system is particularly "smart" and the car is being trained by observing human drivers, it may be difficult to pin down exactly who is at fault. Of course, legislating AV liability is only a part of what will be needed going forward.

Nearly all states have considered legislation related to AV within the past five years, and thirteen states have passed legislation. The majority of these bills are related to testing; states with less weather hazards and areas where technology companies are located are most common.[1] However, North Dakota is a standout northern state that just this year passed a bill directing the Department of Transportation to work with AV companies to study the use of the technology on state highways. The study will review laws on licensing, registration, data ownership and inspection; the result will basically act as a blueprint for rollout of consumer AV in the state.[2] Since states with harsh winter conditions are expected to be late adopters of the technology, and North Dakota doesn't have an AV testing site or facility, the passage of this bill is a bit of an outlier. Neighboring states would benefit from monitoring the results of this study.

Minnesota legislators have introduced several bills related to automated driving, but all failed in committee. In the 2013 session, a first bill (HF 1580) sought to direct the commissioner of transportation to "evaluate policies and develop a proposal for legislation governing regulation of AV by January 31, 2014." No companion bill was taken up by the Senate, and the issue has not been addressed since in this capacity. Lacking any regulation in the state, AV testing and operation is likely legal here without oversight under current vehicle safety requirements and case law.[3]

There was further discussion in the 2016 session, however, when companion bills (SF 2569, HF 3325) sought to create an "autonomous vehicles task force" to "serve mobility needs of people with disabilities." While not addressing the topic from a general regulatory aspect, the initiative would have explored possibilities in improving these specific services using the technology. In April 2016, committees in both houses recommend passage as amended, but both bills died before a vote. There has been no AV related legislation introduced in the state of Minnesota in 2017.[4]

BEST CURRENT PRACTICES: Each year, the number of states considering legislation related to autonomous vehicles has gradually increased. The National Conference of State Legislatures (NCSL) created a link to an **autonomous vehicles legislative database**, which provides up-to-date, real-time information about state level AV legislation.

[1] Autonomous Vehicles: Self-Driving Vehicles Enacted Legislation. *NCSL*. 1 May 2017.
[2] Senate passes autonomous vehicle study. *Bismarck Tribune*. 28 Mar 2017.
[3] The SDVs Are Coming! An Examination of Minnesota Laws in Preparation for SelfDriving Vehicles. *Minnesota Journal of Law, Science & Technology*. 2015.
[4] Car Minus Driver: Autonomous vehicles driving regulation, liability, and policy. Part I. *Bench & Bar of Minnesota*. 4 Oct 2016

Currently, 84 Bills related to AVs have been introduced in 31 states.[5] Seeking clear definitions of AVs, testing provisions, and insurance and liability related to AVs received the most attention in state legislatures. Below are a few examples of the types of Bills most commonly seen so far. A listing of all bills introduced by topic is available in Table 2.

- **Definition:** change the definition of AV to mean any vehicle equipped with autonomous technology that has been integrated into that vehicle or a vehicle that meets specified levels of driving automation. As an example, California notes that the specified levels are those set by the SAE to be Level 3-5.

- **AV testing:** California submitted a Bill to allow the County of Merced to conduct a pilot project for the testing of autonomous vehicles. Requires the county to obtain an instrument of insurance, surety bond, or proof of self-insurance prior to the start of testing. The Bill also monitors progress of the technology by requiring disengagement reports submitted to the DMV.

- **Insurance and liability**: New York submitted a Bill that imposes strict liability on all actors - manufacturers, owners, and operators of unmanned vehicles. As vehicles become more autonomous, crashes that result from software failure will likely result in the manufacturer or software company being held liable. Insurance companies could see a shift in this market from personal to commercial or product liability.[6] Many states may take an approach to New York where it's clearly stated that liability can be shared based on the situation; assigning too strict a liability to manufacturers may stymy innovation.

Legislation moves much slower than the development of AV technology, and the State of Washington is no longer waiting for regulatory law to match speeds. Governor Inslee signed an executive order allowing HAVs without a human operator or monitor in the car to be tested on public roads. While several states have loosened regulations on testing HAVs, Washington is the first state to allow such testing without a human present behind the wheel.[7] While this makes the technology seem right around the corner, many experts still caution the step is a bit premature. They point to issues such as disengagements, noted on page five of this report, and Elon Musk has stated that Tesla is still several years away from producing an HAV that needs zero human input.[8] Despite these issues, Washington is ensuring that the technology will not outpace government, and other states may soon follow suit.

FUTURE PLANNING: AVs are certainly poised to become a significant part of the future of the automotive industry. As the technology for AVs continues to develop, it will be necessary for state and municipal governments to monitor Legislative action to anticipate appropriate future actions. Dakota County may want to monitor the study being conducted in North Dakota to better understand how that state approaches AV operations on highways. Minnesota may likely adopt similar measures; the lack of action in the legislature indicates that lawmakers are perhaps waiting for additional best practices to emerge.

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[5] As of 4/3/2017. For more updated information, see autonomous vehicles legislative database
[6] Marketplace of Change: Automobile Insurance in the Era of Autonomous Vehicles. *KPMG*. 2 May 2016.
[7] No driver? No problem: Self-driving cars could soon be tested on Washington roads. *Seattle Times*. 7 June 2017.
[8] Ibid.

Table 2: AV Bills Introduced by Topic

Topics	States	# of Bills
Commercial	9	11
Cybersecurity of Vehicle	2	4
Definitions	19	40
Infrastructure and Connected Vehicles	4	6
Insurance and Liability	13	26
Licensing and Registration	9	14
Operation on Public Roads	12	16
Operator Requirements	13	18
Other*	14	24
Privacy of Collected Vehicle Data	6	9
Request for Study	7	8
Vehicle Inspection Requirements	1	1
Vehicle Testing	14	28

* Topics related to driving and handheld communication devices, pilot project, accident report, driver's license endorsement, and more.

A majority of Bills are pending, but a smaller numbers have made it to the Governor's office.

Status	States	# of Bills
To Governor	1	1
Pending	28	78
Failed	4	5

INTERACTIONS WITH EXSISTING INFRASTRUCTURE

RESEARCH QUESTION: *How will driverless vehicles interact with traffic lights, or other existing systems?*

STATEMENT OF PURPOSE: AVs may need to communicate not only with other vehicles on the road, but with infrastructure in order to operate safely and efficiently. Networks of connected vehicles could improve the system at large by sharing information on road and traffic conditions. This paper aims to understand how and when this interaction may occur, and identify other potential systems that could assist AV travel.

BACKGROUND: Many personal devices are now sold with internet connectivity as standard. Whether for cross-functionality with your smartphone, or real-time updates to settings or displays, connectivity increases product marketability, functionality and in many cases, safety. Vehicles are no exception. Many cars are already connected for roadside assistance, directions, and entertainment purposes, among others. The goal of manufacturers and planners alike is to not simply connect cars to everyday internet resources, but to connect them to each other and with infrastructure continuously. This network of cars and roadside infrastructure could provide continuous real-time data on road conditions, and improve operational efficiency around hazards and construction zones. GM will become the first company to release cars in 2017 with DSRC functionality.[1] DSRC is currently the most promising technology that can deliver V2X communication. In late 2016, the US DOT through the NHTSA issued a Notice of Proposed Rulemaking that would enable DSRC on all light duty vehicles sold; this rule may take a year to approve and would most likely take affect sometime after 2020.[2] DSRC is most promising in terms of its ability to function in severe weather, resistance to interference, and it's extremely low latency, only a few milliseconds. There is currently a debate, however, on whether 5G cellular technology could offer these benefits alongside traditional internet resources.[3] 5G may well be available for widespread use by 2020, but planners should focus on preparing for DSRC infrastructure systems as this will likely continue to be the standard.

The most apparent application of V2I specifically may be traffic lights and advanced traffic management systems. Many transportation agencies, including Dakota County, are beginning to utilize internet-connected traffic lights to improve highway operations. Incorporating DSRC would further improve these strategies once more V2X enabled cars are on the road. DSRC equipped traffic lights could directly communicate "time-to-green" information to cars allowing the vehicle to effectively utilize green time at signals. These communications will also allow AVs to calculate appropriate headway when approaching intersections.[4] More importantly, V2I enabled traffic lights can warn approaching cars of pedestrians or obstacles in the street. In emergency situations, cars could communicate speed and break status to traffic lights, managing traffic to avoid collisions.[5] Traffic Light Information, a feature on new Audis, shows what this system might look like. The car displays the time remaining until a connected signal changes; in the future, it could optimize routing by maximizing the number of green lights one can make in sequence.[6]

V2I technology perhaps has the most direct safety applications for construction, weather and road hazards. Construction workers would not have to rely on signs alone, and instead could employ beacons or apps that directly warn the driver of specific hazards or workers ahead. Whole construction plans could be transmitted to AVs or CVs allowing them to suggest whole new routes to minimize interference.[7] Incorporating DSRC into DMSs would greatly increase a transportation department's ability to communicate construction, weather or other hazards to approaching cars, and cars communicating back to the DMS could improve estimated traffic delay

[1] V2V Safety Technology Now Standard on Cadillac CTS Sedans. *Cadillac Pressroom*. 9 Mar 2017.
[2] U.S. DOT advances deployment of Connected Vehicle Technology to prevent hundreds of thousands of crashes. *NHTSA*. 13 Dec 2016.
[3] New Cars Could Be Required To 'Talk' To Each Other As Soon As 2020. *Forbes*. 13 Dec 2016.
[4] Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations. *Eno Center for Transportation*. Oct 2013.
[5] Connected Vehicle Impacts on Transportation Planning. *FHWA*. Jun 2016.
[6] Audi launches first Vehicle-to-Infrastructure (V2I) technology in the U.S. starting in Las Vegas. *Audi USA*. 6 Dec 2016.
[7] Self-driving cars won't work until we change our roads-and attitudes. *Wired*. 15 Mar 2016.

times.[8] While road safety, construction zones and traffic management are the three most talked about areas in V2I applications, other opportunities will most likely present themselves as the technology becomes more commonplace

BEST CURRENT PRACTICES: The NHTSA estimates that the safety applications of enabled V2X, such as those described above, could eliminate or mitigate the severity of up to 80 percent of crashes not involving driver impairment.[9] With the technology being so new there are currently no working systems to use as examples, but as evident from the endorsement from the US DOT, the benefits are clear. Transportation planners may want to consider focusing on making small areas "autonomy enabled" with working DSRC systems, study what works best, and expand from there.[10]

FUTURE PLANNING: The level of DSRC system functionality largely depends on whether there is a critical mass of V2X capable vehicles on the road. As mentioned earlier, this may happen as early as the 2020s, and more certainly in the decades after the NHTSA proposed rule takes place. Important to note, however, that the deployment of V2I technologies in local infrastructure is not mandated by the NHTSA proposed rule.[11] Each transportation agency should evaluate the benefits and implement on their own as appropriate. The NHTSA is simply ensuring that the vehicle fleet will be enabled to do so.

To make deployment of V2X technology successful, therefore, there must be vehicles to exchange information with. The FHWA suggests that transportation agencies consider deploying DSRC technology on-board units in their fleet or to offer incentives for residents to install the units themselves.[12] This initial combined fleet can then act as a trial for the system, and can help introduce the technology to the public. Piloting the system using these onboard units and a few enabled roadside DMSs may make the most sense. Cost estimates for a pilot program of 10 intersections is available in Table 3. These include not just roadside units, but also the costs to incorporate traffic signals to work in conjunction to operationalize traffic flow.

[8] Op. cit. 5
[9] Op. cit. 2
[10] Op. cit. 7
[11] Vehicles to Infrastructure (V2I) Deployments. US DOT.
[12] Op. cit. 5

Table 3 – High Level Cost Estimate of the Capital Costs to Deploy Connected/Automated Vehicle Infrastructure, Equipment, and the Transit Signal Priority Application[13]

Item	Quantity	Per Unit Cost	Total Costs
Dedicated short-range communications roadside units	10 intersections	$13,100 to $21,200	$131,000 to $212,000
Signal controller upgrade	10 intersections	$3,200	$32,000
Backhaul communications	1 system (10 intersections)	$30,000 to $40,000	$300,000 to $400,000
Transit vehicle aftermarket on-board unit	5 vehicles	$10,000	$50,000
Connected/Automated Vehicles Project Total		$513,000 to $695,000	

[13] Op. cit. 5

HIGHWAY OPERATIONS AND DESIGN STANDARDS

RESEARCH QUESTION: *How will highway operations and design standards change to accommodate driverless cars, and how will the County be involved in shaping and ultimately implementing these changes?*

STATEMENT OF PURPOSE: AVs have the potential to drastically reshape traffic patterns on our highways. The way that roadways are designed, maintained and regulated may need to change as well. This paper addresses the potentials impacts of AVs on highway use and industry standards.

BACKGROUND: The primary areas of concern for roadway standards are in capacity planning, operational design, and maintenance. Communications technology will undoubtedly be a significant related issue as well, and is addressed in a separate paper on AVs interacting with infrastructure. Perhaps the most direct impact that AVs will have on highways is on capacity. AVs operate safely on highways with shorter headways (less distance between cars), and can employ “platooning” where a string of AVs travel in a tightly coordinated group. This is not simply limited to HAVs either. Cars are already on the road with autonomous cruise control systems which produce these benefits on a smaller scale. In addition, AVs utilize more efficient routes, and will reduce highway accidents caused by human error, easing congestion even further.[1] These features, especially when realized on a larger scale, may increase the carrying capacity of our existing highways.[2] However, other trends may offset these gains as described later in this paper. Lane widths could eventually be reduced as well, with variable lane widths used for various vehicle sizes. As AVs platoon in accordance with their size, they would be programmed to utilize these variable lanes.[3]

Roadway design itself will be a significant and evolving issue as AV technology and usage moves forward. As AVs are slowly acclimated to operating on today’s roads, predictability is key. On-board computers must be able to read and interpret lane markings and road striping. Poorly maintained roads will make AVs less accurate in predicting traffic flow and the actions of human operated vehicles.[4] However, when HAVs have saturated the market, it is possible that street signage, striping and traffic signals will become obsolete and all but disappear.[5] Operating Instructions, alerts, and commands could be communicated to vehicles instantly and change on the fly depending on variables such as construction issues or inclement weather. The issue in the immediate future is how to best facilitate the transition.[6]

BEST CURRENT PRACTICES: AVs have not yet impacted highway planning in a significant way, but a few initiatives point toward ideas for the future. A partnership between Dutch design and civil engineering firms led to a 500 meter stretch of highway in the Netherlands that glows in the dark. The paint is temperature sensitive to alert drivers when road conditions might be icy, and “induction priority lanes” use induction coils to charge electric cars in motion.[7] Ideas for improving the visibility of road design make take forms such as this. Brighter striping allows AVs to “read” the road far more accurately, even taking in account information on surface temperature. The program manager for automated vehicles at the North Central Texas Council of Governments suggests transportation authorities need to consider that projects which facilitate the deployment of AVs are better investments than lane widening and new highways.[8]

Highway operations will need to eventually incorporate software considerations to properly manage AVs. Amazon was recently awarded a patent that will assist in the development of such a network. Specifically, this

[1] Highway Capacity Impacts of Autonomous Vehicles: An Assessment. *Center for Urban Transportation Research*. Nov 2013
[2] Drivers of Change. *Transportation Management & Engineering*. 2013.
[3] Staying in Control: Bridging the Gaps in Autonomous Vehicle Safety. *Transportation Research Associates, Inc*. Sep 2016.
[4] Self-driving cars won’t work until we change our roads-and attitudes. *Wired*. 15 Mar 2016.
[5] Planning for the Autonomous Vehicle Revolution. *American Planning Association*. 15 Jun 2016
[6] Ibid.
[7] The Netherlands debuts a futuristic highway that glows in the dark. *GlobalPost*. 15 Apr 2014.
[8] Op. cit. 2

network manages how AVs navigate reversible lanes.[9] These components may become a necessary aspect of operational standards in the future. Unfortunately, much of the planning and work around these issues is speculative and depends on exactly how AVs are integrated into our transportation networks. While not many established best practices exist, there is more discussion on what planning may be required based on increasingly likely AV rollout scenarios.

FUTURE PLANNING: There is apparent potential that AV technology will allow more cars to use the same amount of road. Reducing headway and platooning offer clear gains. However, the changing nature of the market, as well as the average growth rate of the vehicle fleet may offset these gains. The Center for Urban Transportation at the University of South Florida estimates that at 50 percent market penetration, highway capacity will increase by 22 percent from today's 2,200 vehicles per hour per lane (vphpl) to 2,685 vphpl. The Victoria Transport Policy Institute (VTPI), a non-partisan think tank, estimates that the U.S. vehicle fleet will reach the 50 percent AV mark by the 2050s. The sale of new vehicles increases about 2-4 percent each year[10], and the average annual growth rate of vehicle miles travelled (VMT) in Minnesota is 1.5 percent (1.4 percent nationally).[11] Unfortunately, this suggests that any gain in highway capacity will be outpaced by the average increase in vehicles on the road. Some research, however, points to decreased ownership levels due to a potential increase in accessibility of ride-booking services that may be provided by AVs. Unfortunately, this may not suggest a decrease in VMT; more AVs circulating roadways looking for passengers could offset any gains or even cause an increase.

Reasonably priced AVs may also make purchasing a new car more appealing, and the projected growth of ride-booking services may increase overall cars on the road as well. These factors collectively could increase VMT by 35 percent for personal vehicles and as high as 90 percent for ride-booking vehicles and taxis.[12] Therefore, instead of planning for promised increases in highway capacity, transportation agencies may have to consider that highways will become even more congested. This congestion could theoretically be offset by a fully autonomous vehicle fleet, a scenario the VTPI predicts won't happen until late into this century, or a comprehensive mass transit and ridesharing system that depends on platooning AV buses or vans with arterial routes. The latter, although more technically feasible on a short time scale, is far more difficult from a planning and political standpoint. However, mass transit needs to be the ongoing focus of transportation departments, using whatever technology is available and feasible. Bus Rapid Transit with dedicated lanes, and light rail will continue to be the most reasonable systems to provide scalable transit into the foreseeable future. The conflicting forecasts as described here suggest that congestion will not be solved by AV use alone, at least not until a nearly driverless future can be reasonably predicted.

More short term design standards will assist in the AV transition. Transportation planners may consider reevaluating preventative maintenance plans and seasonal maintenance activities to ensure that roadway designs are clear and readable. In addition, highway signage will need to change as well. Typeface that is most readable for human drivers may become secondary. Highway signs may adopt barcodes or QR patterns (Quick Response, the matrix like optical label used most commonly with smartphones) that can be read by AVs.[13] 3M recently released signage that incorporates nearly invisible coding that can be read by autonomous vehicles. This would accomplish the same exchange of information without confusing human operators.[14] The county may want to plan for funding that utilizes machine-readable signage, highway designs that promote visibility, and maintenance plans with emphasis on visibility upkeep. Another option in this case is using LEDs as overhead lighting or for highway striping itself. Any method that makes lane markings clear and easily readable is encouraged so an AV can use them without the context and experience employed by a human driver.

[9] Amazon patented a highway network that controls self-driving cars and trucks. *Recode*. 17 Jan 2017.
[10] 2005-2016 Sales Statistics. *OICA*.
[11] Vehicle Miles of Travel Trends. *MNDOT*. Nov 2015.
[12] Urban Mobility System Upgrade How shared self-driving cars could change city traffic. *International Transport Forum*. 2015.
[13] How autonomous cars will change our highways. *Quartz Media*.
[14] The company that invented Post-It notes is hiding invisible messages in signs to help self-driving cars see the world. *Business Insider*. 13 Aug 2017.

TRANSITIONING WITH MANUAL VEHICLES

RESEARCH QUESTION: *How will driverless vehicles connect and transition with manual vehicles?*

STATEMENT OF PURPOSE: The integration of AVs into the transportation system will occur slowly, and in stages as various models are released with different degrees of consumer accessibility. It is very likely that human drivers will share the road for some time. This will create unique challenges for drivers unfamiliar with the behavior of AVs, and planners who want to mitigate potential risks. The following examines the possible interactions between human and automated drivers, how best to anticipate difficulties, and how to plan for possible solutions.

BACKGROUND: Human-operated vehicles already have a number of autonomous features such as lane departure warning, self-parking, automatic emergency brakes, and cruise control. Human-operated vehicles also have some capacities to communicate with one another via Wi-Fi and satellite connections – for example, it is very common to utilize the Global Positioning System to alert the driver of traffic conditions ahead. In addition, Audi is working on a system that would allow driver to use smartphone to instruct the vehicle to park itself.[1]

AVs, and HAVs especially, will be equipped with much more advanced equipment including several cameras, radar, laser sensors and a complex computing system. The extra equipment serves as the "eyes" and "ears" of the vehicle to keep it running smoothly. The computer system in the vehicle is constantly sending and receiving information about the surrounding environment.

Current efforts are devoted to testing and improving the technology - software companies and automakers are racing to introduce the first full consumer ready HAV. There is not much focus, however, on the communication or interaction between AVs and human-operated vehicles. Possible ways that AV could communicate with human-operated vehicles is to expand on and utilize existing technologies of Wi-Fi, Bluetooth, and satellite connections. While some of today's vehicles have these capabilities, it might require additional resources and cost for certain human-operated vehicles to be able to communicate back. DSRC may be another option, but is far less common than the aforementioned systems; the implementation of this technology is discussed in greater detail in the paper on infrastructure.

CURRENT STATUS: There have been a few accidents between AVs in testing and human-operated vehicles. The first fatality involving an AV happened last year when a collision was caused by a Tesla in autopilot mode; in this case, the car could not identify an impeding truck against the sky behind it and did not stop.[2] Some companies have been transparent about these incidents by voluntarily logging accidents caused by vehicles in their pilot programs. In the past two years, twelve such accidents have been reported; only one involved the AV being at fault. In this case, the AV expected the human driver to follow signage and yield.[3] That incident is an example of the impending difficulties of the AV transition. Human drivers expect human behavior, and not the calculated behavior of a program.

This unfamiliarity may contribute to a lack of trust of this new technology - a recent AAA survey found that more than half (54%) of U.S. drivers feel less safe at the prospect of sharing the road with a self-driving car.[4] Important to note, however, that AVs are still in the testing phase and it will be some time before they are able to widely operate on American roads. The models that are being tested now may not resemble the vehicles that are finally used on roads. AAA urges the gradual and safe introduction of AVs to ensure that American drivers are informed, prepared, and comfortable with the shift in mobility.[5] According to surveys conducted by Kelly Blue Book, State Farm, the University of Michigan and Vox, the public is generally unenthusiastic about AVs and doubt that AVs would improve safety, especially during the transition period, where there is a mix of traditional and AVs on the same road at the same time.[6]

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[1] Smartphones on wheels. *The Economist*. 6 September 2016.
[2] Tesla driver dies in first fatal autonomous car crash in US. *New Scientist*. 1 Jul 2016.
[3] Autonomous Vehicles: Disengagements, Accidents and Reaction Times. *PLoS ONE*. 20 Dec 2016.
[4] American Feel Unsafe Sharing the Road with Fully Self-Driving Cars. *AAA NewsRoom*. 7 Mar 2017.
[5] Ibid.
[6] How Limiting Autonomous Vehicle Rollout Can Ease Driver Transition. *Govtech*. 13 Feb 2017.

FUTURE PLANNING: Until we have 100 percent of AVs on the road, it is important to minimize the transitional impacts with human-operated vehicles.[7] There are a few suggestions as how to handle the situation. Planners might want to monitor these suggestions as they plan for future transportation system in their jurisdiction.

- The development of dedicated lanes for AVs on highways, similar to today's high-occupancy vehicle lanes. As the number of AVs on the road increases the number of dedicated lanes should increase as well. A Seattle-based venture capital firm is proposing one of the county's first dedicated lanes for AVs running along I-5 between Seattle and Vancouver, British Columbia.[8]
- Equip human-operated vehicles with appropriate technologies (DSRC, Bluetooth, Wi-Fi connections) so that they can communicate with AVs.
- Deploy AVs incrementally. This way the public will become more familiar with the technology and hence create a more seamless transition. Deploying AVs incrementally would help strike a balance between encouraging innovations while ensuring safety for the public.[9]

[7] Proposed highway lane for self-driving cars would link Seattle and Vancouver. *Curbed*. 3 Oct 2016.
[8] Ibid.
[9] Op. cit. 6

INTERACTION WITH BICYCLES AND PEDESTRIAN MODES

RESEARCH QUESTION: *How will driverless vehicles interact with bicycle and pedestrian modes?*

STATEMENT OF PURPOSE: Roads in the U.S. are designed primarily for cars, making navigation inconvenient and in some cases dangerous for pedestrians and cyclists. According to a study from the NHTSA, pedestrian and cyclist fatalities are surging nationwide. With more and more vehicles on the roads, it is difficult to imagine that these fatalities will go down without appropriate intervention. AVs certainly have the potential to reverse this trend with increased spatial awareness, and programmed adherence to traffic laws. The following examines how, especially in urban environments with high concentrations of pedestrian and cyclists, AVs can contribute to creating a safer environment.

BACKGROUND: According to the co-founder and president of Drive.ai "Most people's first interaction with AVs will not be as a rider, but more likely as a pedestrian crossing the street."[1] Interactions between AVs and pedestrians and cyclists are purely theorized in existing literature, and, at this point, there are probably more questions than answers. Most research suggests, however, that AVs will create a safer environment for pedestrians and cyclists. In most instances, AVs would be programmed to stop and yield for pedestrians and cyclists whether they have a right to make a move or not. While this poses some inconvenience to passengers inside the AV, it does eliminate the risk for pedestrian accidents caused by right-of-way misunderstandings.[2]

Despite the risk of accidents associated with confusing interactions, pedestrians are used to communicating at least visually with drivers before they make a decision. Communication between a pedestrian and a machine poses an entire new challenge. There are tech companies working on a communication device that would attempt to solve this problem (smartphone with a simple App download). Google was granted a patent on a system that utilizes mounted electronic screens on the outside of vehicles that could display large text and road signs along with a speaker that could call out "coming through" or "safe to cross".[3] Displaying large text and signs to signal pedestrians is a good first step. Researchers point to a more fundamental issue of communication between a human and a machine - humans may rely on old habits such as eyeballing an approaching car's speed to determine if it is safe to cross the street rather than relying on external displays.[4] Pedestrians and cyclists will need to learn how to recognize AVs, and be prepared for their different behaviors and communication methods.

CURRENT STATUS: According to data from the NHTSA, about 5,000 pedestrians were killed by cars in 2014. About half of deaths occurred because the pedestrian ran into the road, failed to yield to a vehicle with the right of way, or otherwise crossed the street improperly. It is nearly impossible for AVs to prevent every pedestrian death unless the technology can incorporate ways to prompt safer pedestrian behaviors.[5]

While there has been a lot of focus on the technology behind AV operations, there has been limited discussion on how AVs affect human behavior. If AVs are programmed to consistently defer to pedestrians, people may begin to take advantage of these predictable behaviors and ignore the car's right of way. [6] This may mean that AVs are simply not efficient in an urban setting, and it may require infrastructure improvements in order to isolate the vehicles from pedestrians entirely.

One of the ethical questions that manufacturers are working on answering is how AVs would make a split second decision between two bad situations - for example, hitting a group of pedestrians to save their passengers or sacrificing the vehicle to save the pedestrians and potentially hurting the passengers inside the vehicle. Due to the complicated liability issues surrounding these questions, AV manufacturers and software engineers are working very hard for the vehicle to avoid those situations in the first place. However, Mercedes' manager of driver assistant systems and active safety recently told *Car & Driver* that its level 4 and 5 self-driving vehicles will

[1] How Driverless Cars May Interact With People. *The New York Times*. 20 Aug 2016.
[2] Ibid.
[3] How a raised hand from a pedestrian could stop driverless cars. *New Scientist*. 9 Feb 2017.
[4] Will Pedestrians Be Able to Tell What a Driverless Car is About to Do? *The Atlantic*. 30 Aug 2016.
[5] Ibid.
[6] Self-driving cars doomed to be bullied by pedestrians. *The Register*. 27 Oct 2016.

prioritize the safety of passengers over the safety of pedestrians.[7] They argue that if you know you can save at least one person, at least save the one in the car.

FUTURE PLANNING: AVs of the future will need to be transparent about what their intentions are, how they make decisions and what they see, and how they communicate externally beyond turn signals. Pedestrians will also need to be informed about how AVs will operate on the roads. Efforts from both sides will make interactions between AVs and pedestrians safer.

The County may want to consider a designing an AV public information campaign. This could include information on when AVs may start to appear on County roads and in neighborhoods, and what to expect in terms of their programmed behaviors toward cyclists and pedestrians.

[7] Self-Driving Mercedes-Benzes Will Prioritize Occupant Safety over Pedestrians. *Car and Driver*. 7 Oct 2016.

AUTONOMOUS MASS TRANSIT MODES AND SYSTEMS

RESEARCH QUESTION: *How might driverless vehicles impact public transit, paratransit, ridesharing, and ride-booking services?*

STATEMENT OF PURPOSE: Public transit and other mass transportation networks are some of the largest potential applications of AV technology. Taxi services, ride-booking, and transportation networks for individuals with disabilities will be affected, among others. AV application could change the price, availability, and delivery models for these systems, including potential linkages. This paper examines these topics as well as the potential impact to ridership.

BACKGROUND: The application of AVs in the mass transit system and taxi services depends on the ongoing development of the technology, and is therefore largely speculative. The exact technical limitations, costs, and regulations will influence not only the practical uses of the technology but its impacts as well. The adoption of AVs by ride booking services is a foregone conclusion, and this is where widespread use will first appear. Uber and Lyft have always been at the forefront of AV development, with the eventual goal of completely eliminating their labor costs. This will significantly drive down prices and could make ride booking services a reasonable alternative to those without a car. Additionally, personal AVs could make dense urban commuting by car more attractive; those using mass transit systems to avoid parking or traffic considerations may utilize these self-parking, private cars instead.

The question becomes whether AVs will ever replace public transit modes, or make them underused. Ride booking services have already reduced the price of personal transportation considerably and have grown exponentially because of it. However, while these services seem to be taking customers away from traditional taxi services, they do not appear able to satisfy the increasing demands for transit. As an example, Uber services are 15 percent cheaper than taxis in the Twin Cities metro area, and nearly double that when tips are included,[1] but public transit ridership continues to increase despite these cost savings.[2] It is important to note, however, that ride booking services still remain more costly overall than transit. Ride booking services cost approximately $2.50 per mile,[3] while using bus or light rail in the metro costs on average approximately 25 cents per mile.[4] Would AVs lead to closer competition from the customer's perspective? One model developed by Columbia University estimates that an HAV ride booking service (fully autonomous with zero labor cost) may cost merely 41 cents per mile.[5] However, industry analysts note that these costs will be based on demand; whereas transit is a known quantity, the price of HAV ride booking would fluctuate and most certainly increase to maximize profitability.[6] Unfortunately, it is simply too early to predict exactly how this will impact ridership specifically. Since cars and taxi services continue to get cheaper, and public transit ridership continues to increase, planners should be cautious in thinking the demand for transit will decrease based on trends in these modes. Instead, it may make more sense to plan for how AV technology will improve public transit provision itself.

The incorporation of AV into existing transportation networks could take shape in a few ways. One is the adoption of HAVs by private ride-booking service companies to eliminate labor costs, as mentioned above. The next is the automation of buses and paratransit vehicles, and finally, a hypothetical public or private system of SAVs or what some refer to as "TaxiBots". SAVs especially have the most potential in this regard; one automated vehicle servicing multiple passengers simultaneously could do the work of 12 vehicles and eliminate 11 parking spaces for a mid-sized city.[7] The operational costs for these services could also be reduced by incorporating AV technology.

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[1] These Animated Charts Tell You Everything About Uber Prices In 21 Cities. *Business Insider*. 16 Oct 2014.
[2] Metro Transit ridership tops 85.8 million in 2015. *Metro Transit*. 22 Jan 2016.
[3] Op. Cit. 1
[4] Saving big by trading the car for transit. *Metro Transit*. 28 May 2014.
[5] Transforming Personal Mobility. *Columbia University*. 27 Jan 2013.
[6] Driverless cars could cost 35 cents per mile for the Uber consumer. *MarketWatch*. 19 Sep 2016.
[7] Urban Mobility System Upgrade How shared self-driving cars could change city traffic. *International Transport Forum*. 2015.

The model may be more efficient for rural and suburban areas in Dakota County where there are fewer riders with longer trips, which increases rider subsidies. For example, the average subsidy per rider for Metro Mobility was last reported as $23.94, for Minnesota Valley Transit Authority suburban buses it was $9.21, and Transit Link reported a $19.92 subsidy per rider.[8]

AVs alone, however, will likely not become an alternative sustainable transportation mode for highways or other highly trafficked areas. As discussed in the paper on highway design standards, they are unlikely to reduce congestion, and do not appear to be scalable for growing populations. The most successful scenario is to supplement a mass transit system that runs along major corridors with private or shared AV serving arterials, either public or privately operated.[9] Major routes will need to be handled by trains or buses; one estimate noted that it would be impossible to manage corridors with more than 5,000 people moving per direction per hour by AVs alone.[10] For the metro, this includes the corridors covered by the Blue and Green light rail lines[11] and most major highways. If a region was able to combine high-capacity public transport with a system of SAVs, however, research suggests that it would be possible to achieve nearly the same mobility with 10 percent of the cars.[12]

Safety and efficiency are clearly top priorities for researchers and for those conducting pilot programs, but the development of this technology has implications beyond operational benefits. Public transit has historically been a source of dependable employment for the middle class. Metro Transit, for example, employs 1,601 bus and train operators.[13] There is uncertainty about the future of these positions if buses and trains become fully automated. However, MNDOT noted that driving is only one of their operators' responsibilities. Automated buses and trains may free employees to interact more comprehensively with passengers on routes, resources and safety issues.[14] Transit workers and labor advocates may not need to be skeptical of AV implementation. In fact, it may provide opportunities to improve the overall quality of the work, and improve the passenger experience as well.

BEST CURRENT PRACTICES: Transportation will continue to require a variety of modes, and mass transit will be critical in serving large urban areas. However, there are opportunities to automate these transit modes themselves. In fact many cities are already experimenting with automated public transportation in some form, and demonstrate what may be possible in the future on a larger scale.

AV public transit options are currently being tested in several cities, but challenges remain. Navigating construction and weather elements are two primary obstacles, and are even more disruptive for large buses or transit vehicles. That being said, cities with minimal weather interference have started promising pilot programs. Las Vegas is planning to go live with an electric autonomous shuttle that will navigate the city's public roads, primarily downtown and on the Strip. While the shuttle only travels 12 miles per hour, it does so completely without human assistance.[15] The City of Jacksonville also conducted a test of a similar shuttle.[16] The Transportation Commission of Wahoe County in Nevada, which includes Reno and Carson City, has committed to a full pilot of an autonomous bus route.[17] This will be the first of its kind that involves an autonomous bus and a route not tightly controlled or monitored by local authorities.

MNDOT will certainly follow the Wahoe County Transportation Commission's pilot as they conduct their own AV transit research project which began earlier this year. The primary challenge right now is finding a partner willing to test out their expensive technology in the Minnesota climate.[18] Taking note that smaller shuttles pose fewer challenges than city buses, Metro Mobility may be a logical starting point. AVs could considerably improve service

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[8] Regional Transit Route Performance Analysis Data. *Metro Transit*. 2017.
[9] Urban Mobility System Upgrade How shared self-driving cars could change city traffic. *International Transport Forum*. 2015.
[10] Will autonomous cars change the role and value of public transportation? *Transport Politic*. 23 Jun 2015.
[11] Op. cit. 2
[12] Op. cit. 9
[13] Facilities & People. *Metro Transit*. 2017.
[14] MnDOT digs into driverless bus technology. *Finance & Commerce*. 15 Feb 2017.
[15] Which city just launched a driverless shuttle on public streets? *GovTech*. 13 Jan 2017.
[16] Jacksonville hosts Easy Mile autonomous vehicle demonstration. *Metro Magazine*. 9 Mar 2017.
[17] Proterra launches first autonomous bus program in U.S. *Metro Magazine*. 2 May 2017.
[18] Op. Cit. 14

and availability for people who depend on this type of transportation. Operating costs could be reduced by offering subsidies for AV rides offered by a third party, or by managing the vehicles themselves. The benefits of increased accessibility would assist elderly residents during a time when the state's senior population is set to double in the next 15 years. [19] In 2016, the Minnesota legislature considered a set of bills that would have created a 19 person panel to look into driverless vehicle services for seniors or people with disabilities. Proponents of the bill noted that the benefit would be most felt in rural areas of greater Minnesota that have less alternative transportation resources.[20] The bills were not passed, however, and have not been taken up in the subsequent session. Despite this, there are other partnerships arising to meeting these challenges, and one of special note within Dakota County itself.

The Dakota County Transportation Coordinating Collaborative (DCTCC) is a county sponsored initiative funded in part by the Federal Transit Administration and MnDOT to work with local stakeholders to increase access to transportation for all residents, but particularly seniors and individuals with special needs. As an extension of this mission, the DCTCC is working on implementing a new mobility management model. This model leverages resources from existing transportation partners and contracted on-demand technology to make transportation options more affordable and convenient. A new proposal to the MN Department of Human Services would test this idea. The pilot phase would allow individuals to utilize Medicaid waiver dollars to access ride-booking services, such as Lyft, through a call center or on-demand through a phone or computer. Kansas City implemented a similar service this year, and advertised on-demand ride-booking at 20 percent of the price.[21] The service is not only affordable, but would also allow those aging in place or living with special needs to be more independent and flexible in their movements. In doing so, it would create the platform necessary to transition to autonomous vehicle services for this population as ride-booking companies will most likely be one of the first adopters. This creates opportunities for even more efficiency, affordability, and individualized services. The project also demonstrates the potential for County, State and Federal partnerships to make progress in leveraging these advancements.

FUTURE PLANNING: As discussed above, the very first transit pilot programs are just beginning, and research is ongoing. Dakota County would do best to monitor programs, such as that in Wahoe County, which will outline the difficulties of autonomous buses operating in real world conditions (e.g. interacting with smaller vehicles in city traffic, construction hazards, and other difficulties bus operators handle on a daily basis). Shuttles for denser tourist areas make sense as a logical starting point as they have limited routes and less demanding consumers. In addition, utilizing driverless shuttles for individuals with disabilities and the elderly should be a focus in the County. These services would greatly improve the experiences of this population, and would assist existing aging-in-place initiatives.

Dedicated lanes for BRT should be considered for major highways and corridors; this opens the possibility for future Automated Rapid Transit (ART) or fleets of autonomous buses, shuttles or minivans that could accommodate commuters without relying on mixed use lanes.[22] Personal use AVs would use these lanes as well, platooning with various ART, softening the inefficiencies of any transition period. The rollout of AVs will need to work hand in hand with transit to fulfill transportation demands in the future; automation is likely to improve, but not replace the public transit system.

[19] The disabled should have access to driverless cars, Minnesota lawmaker says. *Pioneer Press*. 29 Mar 2016.
[20] Ibid.
[21] KCATA's Uber-like app breaks down barriers. *The Kansas City Star*.
[22] Autonomous Vehicles: Hype and Potential. *Urban Land Institute*. 1 Mar 2017.

APPLICATION AND PRIVACY OF VEHICLE DATA

RESEARCH QUESTION: *What are the potential data and privacy considerations? How will car data be used and tracked?*

STATEMENT OF PURPOSE: AVs will collect many layers of data on trips and passengers themselves; in many cases, AVs will rely on this data to operate. The potential uses of this unprecedented level of data collection, and the security issues surrounding it are already being discussed. Anything from hacking car operations to determining gas taxes using travel data are current issues that demonstrate the range of potential considerations. The following paper summarizes predictions and proposals made to utilize AV data, as well as possible privacy concerns.

BACKGROUND: The use of connected consumer electronics often requires consent to collect and utilize certain types of personal information. In most instances, users are already accustomed to this. Passive data collection built into internet ready devices and applications logs browsing histories, purchases, and even the locations of users; the latter is updated every couple of minutes via smartphone in some cases. AVs will be the next platform to which this exchange applies, and may collect more types of data than previous technologies.

Intel CEO Brian Krzanich estimates that the average AV will use and collect 4,000 GB of data every day.[1] In comparison, the average smartphone uses about 0.05 GB per day.[2] The vast majority of this data will be operational. Spatial imaging, mapping updates, real-time routing, and maintenance analysis, among other types, will be required for AV travel. However, beyond simple operation, an array of personal information on the passenger may also be collected. This includes the identity of the driver, the identity of passengers, start and end points, travel route, time and date of travel, speed of travel, and payment method if applicable.[3] If a crash involving an AV occurs, all data about the crash will be stored, not dissimilar in some ways to an airplane's black box. If you are driving a vehicle with autonomous capabilities, and are involved in a crash, there is the potential that your car's data could be used against you in court.[4]

New models of BMWs have sensors that can tell if there is a child passenger. An AV with this type of information could potentially suggest that you stop at a nearby business that pays the car company to alert passengers of a child-friendly offer, or choose a route that directs you towards certain businesses.[5] These privacy and intrusion issues have yet to be substantially addressed from a regulatory standpoint. California's draft regulations require notice and consent before this type of use is allowed,[6] but as is the case with most smartphones, user consent is required in order to use the device in the first place. Currently, no discussions on a business practices standard for consumer privacy protections on the software level exist either – when top AV software company representatives were asked about this at a Congressional hearing, no clear answers emerged.[7]

Enforcement or public planning applications of personal data from AVs should be considered as well. For example, government agencies could use trip data to levy gas taxes. Especially if more cars become fully electric, this could be an efficient way to charge for road usage. Massachusetts has already introduced a bill to do exactly this for AVs and electric vehicles.[8] In a more hypothetical scenario, governments could limit the miles AVs drive each day to regulate traffic conditions or reduce sprawl[9].

[1] Just one autonomous car will use 4,000 GB of data/day. *Network world*. 7 Dec 2016.
[2] By 2021, the average smartphone user will plow through 8.9 GB of data per month. *BGR*. 2 Jun 2016.
[3] Autonomous Vehicles: A World of New Data and Analytics. *Upside*. 12 Jul 2016.
[4] Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations. *Eno Center for Transportation*. Oct 2013.
[5] Self-driving cars: overlooking data privacy is a car crash waiting to happen. *The Guardian*. 8 Jun 2016.
[6] Op. cit. 4
[7] How Self-Driving Cars Will Threaten Privacy. *The Atlantic*. 21 Mar 2016.
[8] Mass. law would tax autonomous vehicles by the mile. *The Boston Globe*. 19 Jan 2017.
[9] Self-driving cars will mean more traffic. *Bloomberg*. 21 Jul 2014.

While the legal application of personal data accounts for one area of study, the security of the data is another of equal importance. Researchers have worked to prove that AV operations can theoretically be hacked; forcing them to brake or crash for example. However, experts maintain the difficulty for someone to actually accomplish this makes the reality of it happening in the real world nearly impossible.[10] A similar scenario is hacking major television networks. While technically possible, the work required and risks are so great that they far outweigh any benefits; this explains why this has only happened once or twice in the history of television. The more practical issue is ensuring the security of the data itself. AV data will be owned and stored by the software proprietor. The company's metadata, a de-identified set of summary information on all drivers, could be put to use for regulatory or planning purposes. For example, Uber will be posting summary trip information to a public website called "Movement" in order for regulators to better understand commuting patterns.[11] Personal driver information could remain at risk, however. Alternatively in Uber's case, the story broke that executives could track customers in real time; while the company maintains that policies are in place to prohibit this practice, several Uber security employees have stated that the practice is still possible, and continues to this day.[12] The same type of data, and the same concerns, will apply to AVs on a larger scale. Data will be owned by the vehicle and software companies, and their use of it may be largely self-regulated. While Uber is a voluntary consumer service, AVs will be an individual's private vehicle. The process to ensure the privacy of this data must be much more robust in this case.

BEST CURRENT PRACTICES: While AV software companies have yet to set an industry standard for data privacy, automobile manufacturers have developed a set of voluntary principles. The NHTSA is also working on their own set of guidelines that specifically address data privacy and cyber security.[13] These principles and guidelines should set a responsible foundation for future legislative requirements for the technology.

The Alliance of Automobile Manufacturers, Inc. and the Association of Global Automakers, Inc., jointly drafted the "Consumer Privacy Protection Principles for Vehicle Technologies and Services." The following principles were approved by membership and submitted to the US Federal Trade Commission in 2014.[14]

i. **Transparency:** Participating Members commit to providing Owners and Registered Users with ready access to clear, meaningful notices about the Participating Member's collection, use, and sharing of Covered Information.
ii. **Choice:** Participating Members commit to offering Owners and Registered Users with certain choices regarding the collection, use, and sharing of Covered Information.
iii. **Respect for Context:** Participating Members commit to using and sharing Covered Information in ways that are consistent with the context in which the Covered Information was collected, taking account of the likely impact on Owners and Registered Users.
iv. **Data Minimization, De-Identification & Retention:** Participating Members commit to collecting Covered Information only as needed for legitimate business purposes. Participating Members commit to retaining Covered Information no longer than they determine necessary for legitimate business purposes.
v. **Data Security:** Participating Members commit to implementing reasonable measures to protect Covered Information against unauthorized access or use.
vi. **Integrity & Access:** Participating Members commit to implementing reasonable measures to maintain the accuracy of Covered Information and commit to offering Owners and Registered Users reasonable means to review and correct Personal Subscription Information that they provide during the subscription or registration process for Vehicle Technologies and Services.
vii. **Accountability:** Participating Members commit to taking reasonable steps to ensure that they and other entities that receive Covered Information adhere to the Principles.

[10] Why Car Hacking Is Nearly Impossible. *Scientific American.* 28 Oct 2016.
[11] Uber to share more travel data with city authorities. *Financial Times.* 8 Jan 2017.
[12] Uber said it protects you from spying. Security sources say otherwise. *Center for Investigative Reporting.* 12 Dec 2016.
[13] U.S. DOT issues Federal guidance to the automotive industry for improving motor vehicle cybersecurity. *NHTSA.* 24 Oct 2016.
[14] Consumer Privacy Protection Principles for Vehicle Technologies and Services. *Alliance of Automobile Manufacturers, Inc. and the Association of Global Automakers, Inc.* 12 Nov 2014.

FUTURE PLANNING: The data privacy risks associated with AVs are already known. Their impact will depend on the extent of AV use, and how well their rollout is regulated. Dakota County should monitor releases from the NHTSA, as well as legislation in states with pilot AV programs such as Pennsylvania, California, and Massachusetts. It is recommended that Dakota County write a white paper in support of regulations that follow the above principles when the issue comes to the Minnesota legislature.

APPENDIX A: VEHICLE AUTONOMY LEVELS[1]

Level 0	**No Automation** The driver is in complete control of the vehicle at all times.
Level 1	**Driver Assistance** The vehicle can assist the driver or take control of either the vehicle's speed, through cruise control, or its lane position, through lane guidance. The driver must monitor the vehicle and road at all times and must be ready to take control at any moment, with hands on the steering wheel and feet on or near the pedals.
Level 2	**Occasional Self-Driving** The vehicle can take control of both the vehicle's speed and lane position in some situations, for example on limited-access freeways. The driver may disengage, with hands off the steering wheel and feet away from the pedals, but must monitor the vehicle and road at all times and be ready to take control at any moment.
Level 3	**Limited Self-Driving** The vehicle is in full control in some situations, monitors the road and traffic, and will inform the driver when he or she must take control. When the vehicle is in control the driver need not monitor the vehicle, road, or traffic but must be ready to take control when required.
Level 4	**Full Self-Driving Under Certain Conditions** The vehicle is in full control for the entire trip in these conditions, such as urban ride-sharing. The vehicle can operate without a driver in these conditions; the driver's only role is to provide the destination.
Level 5	**Full Self-Driving Under All Conditions** The vehicle can operate without a human driver or occupants.

[1] SAE, 2016

APPENDIX B: GLOSSARY OF TERMS AND ACRONYMS[1]

CV	**Connected Vehicle** Vehicles able to "talk" to each other, to infrastructure (traffic signals), and with other road users (pedestrians with compatible smartphones, for example) using built-in or add-on devices that continuously share important safety and mobility information.
DMS	**Dynamic Message Sign** (aka Variable-Message Sign) Electronic traffic sign often used on roadways to give travelers information about special events such as traffic, accidents, or increased roadway enforcement.
DSRC	**Dedicated Short Range Communications** One or two-way short-range to medium-range wireless communication channels specifically designed for automotive use and a corresponding set of protocols and standards.
FHWA	**Federal Highway Administration**
HAV	**Highly Automated Vehicle** Vehicles that do not require constant monitoring by a driver. (Levels 3-5, see below).
NHTSA	**National Highway Traffic Safety Administration**
Platooning	Vehicles that travel in close proximity to one another, nose-to-tail, at highway speeds. Vehicles in a "platoon" are able to match maneuvers, acceleration, and deceleration, without the usual space and time needed for human reaction time.
Ride-Booking Service	A service that allows people use smartphone apps to book and pay for a private car. Most commonly Uber or Lyft.
Ride-Sharing Service	A service that would allow people to use smartphone apps to book and pay for a car shared with other passengers travelling a similar direction.
SAE	**Society of Automotive Engineers** Professional association and standards developing organization for engineering professionals in various industries, primarily transportation.
SAV	**Shared Autonomous Vehicle** Level 4-5 AV that is used by multiple passengers, sequentially or simultaneously, for ridesharing or a public transportation system.
V2I	**Vehicle-to-Infrastructure** An exchange of information between AVs and/or CAVs and infrastructure such as traffic lights and DMSs.
V2V	**Vehicle-to-Vehicle** An exchange of information between vehicles.
V2X	**Vehicle-to-everything** Systems utilizing a dedicated wireless technology, such as DSRC, to exchange information between vehicles and any entity that may affect the vehicle. Encompasses V2V and V2I.

[1] NHSTA, 2016; SAE, 2016; ITT, 2015; FHWA, 2016

APPENDIX C: DAKOTA COUNTY CONSIDERATIONS FOR FUTURE PLANNING

AV Technology Workgroup

- Create a workgroup of staff from relevant departments (e.g. OPA, IT, Transportation) to monitor developments in technology, policy and legislation, and the results of operational studies nationwide. This group could meet periodically to discuss the sources and topics described here, among others, and develop a forum for continually posting information as it is released.

Governmental Agencies and Trade Associations

- International Transport Forum: Automated and Autonomous Driving
- National Council of State Legislatures: Autonomous Vehicles Legislative Database
- NHTSA: Automated Vehicles
- FHWA: Federal Automated Vehicles Policy
- SAE: On-Road Automated Driving (ORAD) Committee
- Self-Driving Coalition for Safer Streets (formed by Ford, Lyft, Uber, Volvo Cars, and Waymo)
- MNDOT: MinnesotaGO

Ongoing Studies and Trials

- Seattle-based venture capital firm proposing one of the county's first dedicated lanes for AVs running along I-5 between Seattle and Vancouver, British Columbia.[1]
- The Transportation Commission of Wahoe County in Nevada, which includes Reno and Carson City, has committed to a full pilot of an autonomous bus route.[2]
- North Dakota Department of Transportation to work with AV companies to study the use of the technology on state highways.[3]
- State of Washington allowing HAVs without a human operator or monitor in the car to be tested on public roads.[4]
- Disengagement reports for ongoing AV testing in California.
- Pennsylvania Autonomous Vehicle Testing[5]
- MNDOT autonomous buses research project.[6]

Highway Design and Maintenance

- AVs operate best with clear and easily identifiable physical markers. Plan for more road signs, lane markers, and the need to keep them clear from obstruction. Intersections can be planned and reworked with the confidence that all AVs will obey the rules to obtain optimal traffic flow.
- Re-evaluate preventative maintenance plans and seasonal maintenance activities to ensure that roadway designs are clear and readable.
- Monitor signage standards for the adoption of barcodes or QR patterns (Quick Response, the matrix like optical label used most commonly with smartphones) that can be read by AVs.[7]
- Use LEDs as overhead lighting or for highway striping itself. Any method that makes lane markings clear and easily readable is encouraged so an AV can use them without the context and experience employed by a human driver.

[1] Proposed highway lane for self-driving cars would link Seattle and Vancouver. *Curbed*. 3 Oct 2016.
[2] Proterra launches first autonomous bus program in U.S. *Metro Magazine*. 2 May 2017.
[3] Senate passes autonomous vehicle study. *Bismarck Tribune*. 28 Mar 2017.
[4] No driver? No problem: Self-driving cars could soon be tested on Washington roads. *Seattle Times*. 7 June 2017.
[5] Pennsylvania Autonomous Vehicle Testing. *Pennsylvania DOT*.
[6] MnDOT digs into driverless bus technology. *Finance & Commerce*. 15 Feb 2017.
[7] How autonomous cars will change our highways. *Quartz Media*.

- Until we have 100 percent of AVs on the road, it is important to minimize the transitional impacts with human-operated vehicles. There are a few suggestions as how to handle the situation. Planners might want to monitor these suggestions as they plan for future transportation system in their jurisdiction.
    - The development of dedicated lanes for AVs on highways, similar to today's high-occupancy vehicle lanes. As the number of AVs on the road increases the number of dedicated lanes should increase as well. A
    - Equip human-operated vehicles with appropriate technologies (DSRC, Bluetooth, Wi-Fi connections) so that they can communicate with AVs.
    - Deploy AVs incrementally. This way the public will become more familiar with the technology and hence create a more seamless transition. Deploying AVs incrementally would help strike a balance between encouraging innovations while ensuring safety for the public.

V2X Technology

- Deploy DSRC technology on-board units in the County fleet or offer incentives for residents to install the units themselves. This initial combined fleet can then act as a trial for a V2X system, and can help introduce the technology to the public. Piloting the system using these onboard units and a few enabled roadside DMSs may make the most sense.

Communication to the Public

- AVs of the future will need to be transparent about what their intentions are, how they make decisions and what they see, and how they communicate externally beyond turn signals. Pedestrians will also need to be informed about how AVs will operate on the roads. Efforts from both sides will make interactions between AVs and pedestrians safer.
- Design an AV public information campaign. This could include information on when AVs may start to appear on County roads and in neighborhoods, and what to expect in terms of their programmed behaviors toward cyclists and pedestrians.

Public Transit Services

- Shuttles for denser tourist areas make sense as a logical starting point as they have limited routes and less demanding consumers.
- Utilizing driverless shuttles for individuals with disabilities and the elderly should be a focus in the County. These services would greatly improve the experiences of this population, and would assist existing aging-in-place initiatives.
- Support programs that leverage ride-booking services for the population mentioned above. This will ease the transition for participants to utilize AVs when they become available.
- Dedicated lanes for BRT should be considered for major highways and corridors; this opens the possibility for future Automated Rapid Transit or fleets of autonomous buses, shuttles or minivans that could accommodate commuters without suffering the inefficiencies of mixed use lanes.