Self-Driving Vehicles:
Current Status of Autonomous Vehicle Development
and Minnesota Policy Implications

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Abstract

Whether you call them self-driving, driverless, automated, or autonomous, these vehicles are on the move. Recent announcements by Google (which drove over 500,000 miles on its original prototype vehicles*) and other major automakers indicate the potential for development in this area. Driverless cars are often discussed as “disruptive technology” with the ability to transform transportation infrastructure, expand access, and deliver benefits to a variety of users. Some observers estimate limited availability of driverless cars by 2020 with wide availability to the public by 2040.

This report includes examination of the current status of this technology, the implications for road safety, capacity, travel behavior and cost. This report also considers the regulatory framework and policy challenges this technology may face. In particular, this research presents a Minnesota perspective. As the Minnesota Department of Transit (MnDOT) implements the 20-Year Minnesota State Highway Investment Plan and establishes priorities for the next several decades, state officials need information about the potential for this technology to transform Minnesota’s transportation system. The Metropolitan Council also needs to pay serious attention as self-driving cars can potentially change the way we live and travel within the Council’s planning horizon. Additionally, Minnesota policymakers will need to consider whether current policy accommodates the deployment of this driverless technology. Finally, this report summarizes the current consensus about self-driving vehicles, considers the implications for Minnesota, and suggests steps that policymakers in Minnesota can take to prepare for such technology.

* Google has since launched a fully autonomous prototype that does not allow human driving: it has no steering wheel, brake or accelerator pedals. http://googleblog.blogspot.com/2014/05/just-press-go-designing-self-driving.html
Introduction

The story is often told in this way: The year is 2035 and you have just woken up and it is time to go to work. You prepare for the day; take a shower, eat breakfast, grab the notes for this morning’s meeting, and head for the car. You slip inside, set the destination, and sit back to do some light reading in the 20-minute ride to work. Your car will drive for you, no problem. Not only can you daydream and read on your way, your commute has gotten faster and gridlock is relatively rare. In addition, “driving” has become much safer than the millions of crashes and thousands of fatalities of several decades ago (U.S. Census Bureau, 2014). That reduction was part of a trend that culminated with autonomous and connected vehicles. Driver error was the cause of most of those crashes and after years of technology improvement that provided more assistance to the driver, the driver was taken out of the equation altogether. In the most advanced examples of this story, after dropping you off at work, the car is instructed to gather another family member such as an elderly parent or child who could not normally navigate the roadways. In some truly transformational examples, the car is not owned by the user, instead a municipality or a private company owns a fleet of vehicles that can be summoned at a moment’s notice.

In consumer technology, the self-driving vehicle is often called disruptive and transformational (KPMG CAR, 2012; Bilger, 2013; ENO, 2013). Observers have noted that self-driving vehicles (SDVs) may change not only the way we drive but also how we use time and how urban landscapes are developed, and people are starting to take notice.

The story goes that at the 1997 COMDEX computer conference Bill Gates made a stark comparison between the transformational and cost saving ability of the PC industry and the relative costs of the consumer automobile, due to lack of innovation. Detroit reportedly responded with comparisons of its own including: “Yes, but would you want your car to crash twice a day?” (Hafner, 1998) Despite these invectives, car manufacturers have found a way to incorporate more computer technology into their vehicles over the last several decades to enhance vehicle offerings. Now, back-up cameras, assisted braking, GPS, and stability control systems come standard in many models and have improved performance and safety. These lower level forays into computerized or smart vehicles signal the potential for a more cooperative relationship. With technology companies like Google developing their own self-driving technology for use in existing vehicle models, it appears that technology and car manufacturers may work together on SDV development. Whatever the reluctance in the past for innovative technology, some Detroit automakers appear ready to adopt a more computer-like driving machine. The thought is that another analogy can be submitted here: traditional vehicles will go the way of the horse and buggy of centuries past; a marker of the passage of time and the transformational ability of technology to change the way people move.

2013 turned into the year of the self-driving car. Manufacturers from Bosch to Mercedes to Tesla gave updates on their self-driving car plans. Government regulators, such as NHTSA, issued rules and recommendations for the potential self-driving car market. 2020 is the most often quoted time frame for the availability of the next level of self-driving vehicles, with wider adoption in 2040-2050 (U.S. Congress, 2013; KPMG CAR, 2012; Litman, 2013). However, there are many obstacles to overcome to make this technology viable, widely available, and permissible. These include developing technology affordable enough for the consumer market, creating a framework to deal with legal and insurance challenges, adapting roadways to vehicle
use if necessary, and addressing issues of driver trust and adoption of the new technology. There is even some question as to who will be considered the ‘driver’ in the self-driving realm.

For Minnesota, there are unique challenges and opportunities to be addressed. In addition to building upon the national discussion above, this report will consider Minnesota’s driving statutes, road and driving conditions, and how current highway development plans might interact with driverless technology.

**History & Terminology**

It was only a few decades after the introduction of the first Model T Ford that people began to think about an automated version of the passenger vehicle (Technologizer, 2010). Throughout the ensuing decades, automotive and technology magazines documented the possibilities and those working to create “the car that drives itself” (Popular Science, 1958). In the 1950’s researchers from the major car brands worked on a system of roadway and car modifications they hoped would result in such a development. TV shows such as the 1980’s Knight Rider portrayed the self-driving cars movement in the American imagination. Universities and governments worked on projects to deliver the real thing. During this same time cars were advancing with new transmissions, more powerful engines, and sleeker makes. The most ambitious claimed that self-driving vehicles were just around the corner (Technologizer, 2010).

In the 1960’s, a grant from the U.S. federal government set a goal of 1985 for a self-driving prototype (Popular Science, 1967). Later, in 1991, the US Congress instructed the Department of Transportation to engage in research to develop “more intelligent vehicle-highway systems” as a part of the surface transportation infrastructure (H.R. 2950, 1991). This included transferring federal technology to state and local governments and investing funds in research around the country. One of the most high profile developments in federal support for the industry was in the form of the Defense Research Advanced Projects Agency (DARPA) Grand Challenge in 2004, 2005, and 2007, which provided a lead prize of $1 million for a driverless vehicle (DARPA, 2007). This project brought together teams from around the world in the US, but work was also completed and technology advanced by governments, universities, and car makers in countries from Japan to Europe. Indeed, those who participated in these challenges still form some of the core researchers and engineers seeking to make self-driving cars a reality in their lifetimes (Bilger, 2013). For decades, people claimed the breakthrough was imminent. Now, it appears, it finally has arrived.

Given the variously dispersed actors working on self-driving technology, it is no wonder that while the goals are similar, the name is not. From self-driving, which will be the choice of this text, to driverless, autonomous, auto-pilot, or connected cars all imply the idea that the car is digesting data from the environment and taking over a great share of the driving.

**Defining the Self-Driving Car**

Aside from the DARPA grants, much of the federal government’s involvement in the industry has been about safety. As of May 2013 the National Highway Transportation Safety Administration has defined 5 levels of automation for the auto industry and required level 1 automation on all new model vehicles after 2011. These levels are summarized as:
<table>
<thead>
<tr>
<th>NAME</th>
<th>Level 0</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
<th>Level 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NAME</strong></td>
<td>“No-Automation”</td>
<td>“Function-specific”</td>
<td>“Combined Function”</td>
<td>“Limited Self-Driving”</td>
<td>“Full Self-Driving”</td>
</tr>
<tr>
<td><strong>CONTROL</strong></td>
<td>Driver is in complete control at all times</td>
<td>One or more control function are automated</td>
<td>At least two primary control functions are automated and work in unison to relieve driver of control in certain situations</td>
<td>Driver can cede full control of all safety critical functions under certain conditions</td>
<td>Vehicle performs all safety-critical driving functions</td>
</tr>
<tr>
<td><strong>OPERATION</strong></td>
<td>Driver is solely responsible for safe operation and monitoring the roadway</td>
<td>Driver is solely responsible for safe operation and for monitoring roadway but can cede primary control or be assisted in certain situations</td>
<td>Driver is responsible for safe operation and for monitoring roadway and is expected to be available to take control at short notice</td>
<td>Driver can rely heavily on vehicle to monitor for changes in roadway that require driver control. Driver is expected to be available for occasional control</td>
<td>Vehicle monitors roadway conditions for an entire trip</td>
</tr>
</tbody>
</table>
Technological Development

The majority of self-driving car technologies under development focus on the car as the self-contained primary technology and not on developing external infrastructure. While the vehicle might gather information from the cars surrounding it in a “connected” manner, the technology to self-drive is under development to come almost entirely from within (or on) the car. While the focus appears to be on self-contained vehicles, it is likely that the complete self-driving vehicle will include some vehicle-to-vehicle communication (V2V) and some vehicle-to-infrastructure communication (V2I). Examples of V2V might include vehicles that set speed or traveling distance based on information from surrounding vehicles, and examples of V2I might include interaction with traffic lights to manage road congestion. In February 2014, NHTSA stated that it would focus on the development of V2V communication to allow for the deployment of safety technologies that help drivers monitor other cars to prevent crashes (NHTSA, 2014). The discussion around enhanced roads lags behind that of enhanced vehicles due to cost and scalability (Bilger, 2013). From a cost perspective, the ability to attach or incorporate an apparatus into an existing vehicle that can be utilized wherever the vehicle travels, beats the necessary dual technologies that would be needed within the car and on the road for a system than relies on enhanced roads. Additionally, while road and infrastructure development in the U.S. would depend on federal, state, and sometimes local cooperation and involvement in construction, vehicle enhancements can be developed independently by manufacturers and subjected to more limited regulation.

Focusing on the vehicle, a number of technological enhancements combine to make the self-driving car possible:

*Current Vehicle Adaptations*: Assist technologies include GPS, park assist, and adaptive cruise control. Crash avoidance technologies relying on sensors within the car for operation include back-up cameras and warnings, lane departure warnings, and blind spot detectors.

*Other Sensors*: These provide greater breadth and depth of information to the vehicle about the surrounding environment that may allow the vehicle to perform more functions for the driver. For instance, Google’s car relies on Light Detection and Ranging (LIDAR) to provide a picture of the area around the car. Other manufacturers use a combination of less powerful sensors and cameras to provide data needed for self-driving.

*V2V and V2I communication*: The most advanced enhancement is Dedicated Short-Range Communication (DSRC), which operates on a short-range wireless system. Notably only vehicles with this technology can communicate with each other (KPMG CAR, 2012).
**Current Events:** This table summarizes the 2013/2014 status of the various self-driving car projects and how is the technology currently being brought to market.

<table>
<thead>
<tr>
<th>Car Manufacturer</th>
<th>Current Products</th>
<th>Developments</th>
<th>Public Statements</th>
</tr>
</thead>
</table>
| Audi             | "Piloted Driving" | 1) Research with Volkswagen Group Electronics Research Lab and Stanford University  
2) 2010 Autonomous Audi TTS Pikes Peak Research Car  
3) Smaller laser sensor (about the size of a fist)  
4) Received only 2nd license to test in Nevada in 2013 | At Consumer Electronics Show 2013: "Today, Audi defines autonomous driving capabilities in terms of piloted parking and piloted driving" |
| BMW              | "Electronic co-pilot system" | 1) Partnership with automotive supplier Continental 2013-2014  
2) 2011 research prototype with 10,000+ driverless miles  
3) BMW TrackTrainer - digital map, GPS, video data to navigate racing circuit autonomously | BMW Europe Press Release 2013: "The main goal of the research partnership is to have highly automated driving functions ready for implementation until 2020 and thereafter" |
| Ford             | "Automated Fusion Hybrid" | 1) Automated Fusion Hybrid is a research platform for future fully automated vehicles.  
2) Blueprint for Mobility, which envisions a future of autonomous functionality and advanced technologies after 2025  
3) Partnership with University of Michigan and State Farm |Automated Fusion Hybrid Press Release December 2013: "We see a future of connected cars that communicate with each other and the world around them to make driving safer, ease traffic congestion and sustain the environment" |
<table>
<thead>
<tr>
<th><strong>GM</strong></th>
<th><strong>“Super Cruise” “Chevy EN-V”</strong></th>
<th>1) GM-Carnegie Mellon University Autonomous Driving Collaborative Research Lap -partnership won DARPA in 2007  2) Super Cruise in Cadillac semi-automated driving system  3) Chevy EN-V autonomous, electric vehicle combines GPS with vehicle-to-vehicle communications and distance-sensing technologies to enable autonomous driving</th>
<th>GM Innovation: Design and Technology: &quot;In fact, we expect semi-autonomous vehicles to be available to customers before the end of this decade and the technology for fully autonomous vehicles capable of navigating the roadways ready during the next decade.&quot;  Super Cruise Press Release April 2013: Super Cruise is designed to give the driver the ability of hands-free driving when the system determines it is safe to do so.&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lexus</strong></td>
<td><strong>“Advanced Active Safety Research Vehicle”</strong></td>
<td>Research Vehicle, Lexus LS460 with LIDAR</td>
<td>At Consumer Electronics Show 2013: &quot;Our goal is a system that constantly perceives, processes, and responds to its surroundings&quot;  &quot;For Toyota and Lexus, a driverless car is just part of the story. Our vision is a car equipped with an intelligent, always-attentive co-pilot whose skills contribute to safer driving.&quot;</td>
</tr>
<tr>
<td><strong>Mercedes-Benz</strong></td>
<td><strong>“Mercedes-Benz Intelligent Drive”</strong></td>
<td>1) Intelligent Drive autonomous features use GPS technology and rear-facing camera with a pre-programmed route  2) Intelligent Drive has completed 100 km drive on real roads in Germany</td>
<td>“Our approach is, let’s not do it with a special car with a lot of antennas, let’s do it with a standard car,”</td>
</tr>
<tr>
<td><strong>Nissan</strong></td>
<td><strong>“Autonomous Drive”</strong></td>
<td>Nissan 360 - test drive of Nissan Leaf with laser scanners, cameras, and advanced artificial intelligence actuators</td>
<td>&quot;Nissan will be ready with revolutionary commercially-viable Autonomous Drive in multiple vehicles by the year 2020&quot;</td>
</tr>
<tr>
<td><strong>Tesla</strong></td>
<td>&quot;Auto Pilot&quot;</td>
<td>Mid 2013: Early development phase to introduce a lower cost sensor system</td>
<td>“Intense effort under way at Tesla to develop a practical autopilot system for Model S. Engineers interested in working on autonomous driving, pls email <a href="mailto:autopilot@teslamotors.com">autopilot@teslamotors.com</a>. Team will report directly to me.” “We should be able to do 90 per cent of miles driven within three years,”</td>
</tr>
<tr>
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<tr>
<td><strong>Volkswagen</strong></td>
<td>&quot;Temporary Auto Pilot&quot;</td>
<td>1) Partnership with Stanford and ERL 2) Demonstrated temporary auto pilot system in 2011</td>
<td>&quot;Volkswagen Electronics Research Laboratory, autonomous driving research is exploring the necessary systems and infrastructure to enable truly driverless vehicles&quot;</td>
</tr>
<tr>
<td><strong>Volvo</strong></td>
<td>&quot;Drive Me&quot;</td>
<td>&quot;Drive Me&quot; public pilot project - partnership with Volvo Car group and Swedish Transport Administration to pinpoint benefits of autonomous driving by using 100 test cars</td>
<td></td>
</tr>
<tr>
<td><strong>Technology/Other</strong></td>
<td><strong>Product</strong></td>
<td><strong>Developments</strong></td>
<td><strong>Public Statements</strong></td>
</tr>
<tr>
<td><strong>Google</strong></td>
<td>&quot;Driverless Car Project&quot;</td>
<td>1) Driven 500,000+ Miles 2) Prototypes in operation using retrofitted LIDAR (Lexus and Prius models) 3) Developing own prototypes without steering wheels, brake or accelerator pedals.</td>
<td>Many, including <a href="http://googleblog.blogspot.com/2014/05/just-press-go-designing-self-driving.html">http://googleblog.blogspot.com/2014/05/just-press-go-designing-self-driving.html</a></td>
</tr>
</tbody>
</table>
| Bosch | Autonomous vehicle | 1) Provides technology for driver assistance functions like adaptive cruise control and high performance assistance systems  
2) Partner with Stanford Center for Automotive Research and Stanford Law | FT interview: “Driver assistance functions will require many more electronics and sensors in the car. Suppliers are better able [than carmakers] to build the necessary economics of scale,” |
Implications

Safety

By far the greatest implication referenced by those in the field is related to safety and convenience. Individuals, car manufacturers, and governments have always been concerned about safety. It is not surprising that the chance to improve safety is one of the most popular propositions for SDVs. While many of the convenience benefits of SDVs are somewhat intangible and accrue to the user, safety benefits can be referenced in number of lives saved and accidents prevented and accrue to other roadway users—drivers, pedestrians, and society as a whole.

NHTSA’s 2008 Crash Causation survey found that close to 90% of crashes are caused by driver mistakes (NHTSA, 2008). These mistakes, which include distractions, excessive speed, disobedience of traffic rules or norms, and misjudgment of road conditions, are factors within control of the driver (WHO, 2014). Volvo refers to these driver mistakes the 4Ds: distraction, drowsiness, drunkenness, and driver error (Bilger, 2013). The leading perspective is that, because SDVs would not be vulnerable to these weaknesses, they could reduce or eliminate human error in the driving process and work towards preventing the 1.24 million deaths globally and 34,000 deaths in the U.S. from car accidents (WHO, 2014). Few attempts have been made to analyze the value to individuals and society from accident reduction due to SDVs. One estimate from the Eno Center for Transportation Studies, a DC-based industry research group, put cost savings in the range of $17 billion to over $350 billion, depending largely on the percentage of the population adopting the technology. Other key assumptions contained in this and other analyses include the level of in-car automation reached, the cost of these technologies, capacity benefit (parking and congestion), injury and crash cost savings, and fuel savings.

The opportunity for increased safety in SDVs is a good and probable one, and car manufacturers have often traded on the safety features of their vehicles. The story for human drivers is not all bad, though. As a former NHTSA official noted, humans are surprisingly good at driving and cause far fewer accidents than we would expect (Bilger, 2013). The bar has been set particularly high for SDVs given the amount of decision-making and reaction to changing circumstances that human drivers complete. Drivers have to recognize and classify objects (i.e., moving car vs. stationary car), resolve conflicting messages (i.e., green light but yield to a pedestrian), complete the mechanics of driving in various conditions (i.e., pumping brakes on ice), and conduct trip planning on a real time basis (i.e., road closure rerouting). To make it onto the roadways, SDVs must meet and surpass this standard. The millions of accidents that occur in the U.S. each year also represent millions that were likely prevented by split-second driver decisions.

While the consensus appears to be that SDVs will improve driving safety, several steps remain to realize these benefits. NHTSA has noted that how humans interact with SDV systems, such as responding to warning signals, and how well the systems mesh with a broad range of human thought processes, will be key factors (United States Congress, 2013). While NHTSA has issued statements on preliminary policy for automated driving vehicles, it appears to be staying out of the development of full SDVs and focusing on what it considers “next generation of auto safety improvements.” As noted above, NHTSA has indicated that it will focus on V2V in the short term given its possible impact on safety. V2V certainly has safety implications. However, full SDVs are expected to do more than assist the driver, therefore SDVs may have a greater impact on safety improvements.
Capacity

Capacity improvements are the next most often mentioned benefit from those in the field. Roadway capacity improvement often means improvements in throughput, the maximum number of cars per hour per lane on a roadway, but can extend to other capacity concerns. Other hypothesized improvements include fewer necessary lanes due to increased throughput, narrower lanes because of accuracy and driving control of SDVs, and a reduction in infrastructure wear and tear through fewer crashes (KPMG CAR, 2012; United States Congress, 2013b). The theory is cars that can communicate with one another can follow each other at a much reduced distance, can maintain and adjust speed more efficiently, change lanes and merge into traffic more effectively, and can even benefit from drafting other vehicles. In the area of traffic management, Dresner and Stone of the University of Texas at Austin note that SDVs could allow for changes in intersection use. They model a “reservation based” approach to intersection management enabled by SDV and infrastructure technology rather than a system of stoplights (Dresner and Stone, 2008). Increases in capacity ultimately mean more convenient travel and reductions in congestion that currently cost Americans $100 billion in lost time, according to some reports (KPMG CAR, 2012).

Mobility and Access

Access to car transportation is currently limited to those who own a vehicle and can physically drive or those who can find someone to drive for them. While supplemental transportation programs and senior shuttles have provided needed services in recent decades, SDVs have the ability to expand the user base of cars to those who would normally be unable to physically drive. The elderly, disabled, and even children may be beneficiaries (ENO, 2013; RAND, 2014). Benefits might include increased independence and reduced cost of travel for those new users. Expansion of the user base would not just mean increased mobility for new users but also flexibility for those who previously acted as drivers. Drop offs at the airport or the mall might become a thing of the past and with these changes would come more time to be productive, active, or restful.

Vehicle Diversity

The question of whether SDVs would look like the cars of today remains open. For example, Personal Rapid Transit cars, autonomous vehicles that use some infrastructure modification to navigate city streets and that are already in operation in Masdar City, Abu Dhabi, look more pod-like than car-like. At the highest levels of automation, a steering wheel may no longer be necessary, freeing up valuable space to be redesigned. As well, if safety benefits at the highest level are achieved, existing safety features such as airbags may be unnecessary, changing the space needs of the modern automobile. Additionally, the types of material like steel and aluminum cages and frames may change if the types and nature of automobile accidents change (RAND, 2014). Narrow and specialized cars
would potentially be more feasible in this case. Vehicle type could also change with the advent of SDVs. For decades car manufacturers have marketed and sold cars based on factors like handling, control, and ultimately the connection between car and driver. With that connection unnecessary, the kinds of vehicles demanded by consumers may change.

Lastly, in terms of the diversity of vehicles on the road, certain types of vehicles could be eliminated from our roadways, such as taxis. Mass transportation vehicles and freight transit could change in type of function in response to SDVs or by incorporating SDV technology (ENO, 2013).

Cost of Ownership

The cost of car ownership is currently calculated on the basis of six costs: depreciation, fuel, interest, insurance, maintenance and repair, and sales tax. SDVs will likely affect the costs in each of these areas in different ways (Consumer Reports, 2012). The potential ownership cost implications for SDVs are varied but can broadly be grouped into those related to changes in the ownership model for vehicles and changes in the operating costs of owning a car.

Ownership model: The current car ownership model focuses on individual or family ownership. Based on United States DOT data, this amounts to more than one car per household. People own cars to get them to and from work and school and everywhere in between on their own schedule. However, as noted in the 2013 KPMG CAR report, cars often sit idle for many hours of the day in parking lots and garages, on side streets, and in driveways. With the SDV’s ability to direct itself to different locations, those idle hours could become useful to others. These others might be within the family, reducing the number of cars per household. Others in a community may communally own a vehicle. This change in the vehicle ownership model is one often mentioned by those in the field. Car sharing services in the late 2000s and early 2010s have already demonstrated the market for communal vehicles; transferring the concept to self-driving vehicles hardly seems a stretch. There are several forms ownership could take: private entities that rent per mile, car sharing co-ops, or publicly-owned fleets; but the potential to reduce the use of owner-operated vehicles is still remarkable one. SDVs could provide a way to use the idle hours. If the SDV is not owned by an individual or family, then costs of ownership such as depreciation, car loan interest, and sales tax would obviously not be accrued by them and would be shifted to the entity owning the vehicle. It is unclear whether any of these costs would change, however, given that depreciation is in part affected by the appeal and durability of the model. It is possible that SDVs could depreciate at a slower rate because of their desirability, the reduction in crashes, and reduced wear and tear associated with their use.

Operating Costs: SDVs could also have important implications for the operating costs of vehicles. Most notably, car repairs and maintenance costs may go down as a result of fewer accidents and more appropriate and efficient vehicle operation. Safer vehicles and a safer U.S. fleet overall could put downward pressure on insurance prices if policies continue to be bought and sold as they are now. Lastly, a few in the field have made connections between more efficient driving habits and fuel savings. Simply driving the speed limit and drafting other vehicles, as SDVs could potentially do, could result in fuel cost savings. In addition, to the extent that SDVs result in lighter vehicles, baseline MPGs could increase as well (RAND, 2014; KPMG CAR, 2013).
Travel behavior

Second order implications of SDVs could include an individual’s changes in destinations and journey behavior. As noted above, the costs associated with car ownership could change dramatically and the availability of car travel could expand to new groups. These changes affect the real and perceived cost of travel. With less effort required to execute a trip, individuals may choose to take more trips (KPMG CAR, 2013; RAND 2014; ENO, 2013). Todd Litman of the Victoria Transportation Institute has reviewed the literature on transport elasticity values; how changes in cost elements of the driving experience affect vehicle ownership or transport behavior. Overall increases in operating expenses decrease vehicle use, so reductions in operating costs by SDVs would seem to indicate an increase in vehicle use and travel. Of particular note is that greater parking fees reduce the amount of vehicle travel and increased travel speed or reduced delay tends to increase travel distance (Litman, 2007). If SDVs reduce the need for parking, as discussed next, there could be an increase in trips taken. Other second-order implications could involve the places in which people choose to live. In recent decades the world-wide movement of individuals has been from rural areas to urban centers. While this trend is expected to continue, the decreased travel costs in time and energy allowed by SDVs could result in people living further from urban centers and, in the most extreme cases, could create urban sprawl (WHO, 2014b). However, the change in ownership model may have an opposite effect. Currently most of the vehicle ownership costs are fixed (purchase, insurance, license, etc.), which creates an incentive to drive more (i.e., costs per mile go down as miles driven go up). If the ownership model changed into that of a fleet, then most of the trip cost becomes variable and visible. According to the IRS, current cost of car ownership is 56.5 cents per mile. This may have a downward impact on VMT. Lastly, SDVs could be programmed to adhere to traffic rules resulting in perhaps a much more desirable change, that of fewer driving violations and more compliant travel behavior.

Land use, Parking and City Planning

Volvo recently released a video on the potential for SDVs over the next few decades. One of the main selling points remains the increased productivity during commuting time (Volvo, 2014). Changing commuting time to productive or even restful time in a vehicle could result in less pressure for workers to live near the city center. Clearly urban sprawl or a decreased need to live close to urban centers will impact city and regional planning. Commuter trains and rapid bus routes have enabled exurban living for some time and SDVs have the potential to do the same. The extent to which this technology might affect trends towards urbanization remains to be seen, but the length of commuting distances could increase.

On the other hand, several reports and studies note the percentage of time that vehicles spend parked and the percentage of urban landscapes taken up by parking spaces, lots, and ramps (KPMG CAR, 2013; RAND 2014; ENO, 2013). If SDVs can use the idle time or park themselves away from city centers, there might be less need for parking spaces in urban areas. An increase in available space due to a reduction in parking could free up space for other purposes like housing or commerce. In this case, SDVs would combat urban sprawl and provide more useful land for living spaces.
Technology Cost

Most of our discussion on implications has focused on public and private benefits due to SDVs but embedded therein are public and private costs as well. SDVs are an expensive technology at current rates. LIDAR and related vehicle adaptations would cost in the tens of thousands for each car today. While developers and manufacturers expect the costs of technology to decrease rapidly as it often does with mass production, the needed technology adaptations are still an added cost that will likely be reflected in the purchase price of such vehicles (Bilger, 2013). Additionally, there is an ambiguous impact when capacity, mobility, and travel behavior implications are considered together. While existing roadways may support increased throughput with SDVs, the increased use from an expanded user base and reduced travel costs could eliminate the congestion benefits of this increased capacity. Another cost could be jobs eliminated, possibly including taxi drivers, parking attendants, valet parkers, car mechanics, meter attendants, traffic officers, and potentially bus and freight drivers.

Legal and Policy Issues

SDVs will transform not only the way people travel and commute but also the implications in the legal and policy arena. From state and national statutes to liability, privacy, and insurance rules, policymakers and rule makers will need to carefully consider and modify current law to accommodate contemporary issues.

A fair amount has been written and continues to be written on the legal context in which SDVs will operate, including one by an author of this work (Santa Clara Law Review, 2012). These interesting questions can become complex as the current legal system can apparently accommodate SDVs, but will need additional clarity from law makers or courts to address many areas of uncertainty.

Legality

There appears to be emerging agreement that self-driving vehicles are likely legal to operate in the United States, but current state statutes do not address the specific challenges presented. Law modification and regulatory action are likely necessary for the safety of SDV manufacturers, operators, and others on the road. Bryant Walker Smith (2012) of the Center for Internet and Society at Stanford Law School notes that state codes appear to assume the presence of a human driver at all times and the codes create laws on words such as “following distance” with that in mind.

Insurance and Liability

A main area of inquiry is the anticipated impact of SDVs on legal liability and insurance policies. Will insurance cover SDV accidents? Will the operator, the owner, or the manufacturer be held liable? Liability rules applying to SDVs will need to define roles, determine fault, and fix compensation for harm, as current law does for non-automated vehicles. Automobile accident liability cases are most often decided on theories of negligence or strict liability, which include no-fault statutes employed by some states. Negligence attempts to assign fault based on the specific conditions of the case and a series of criteria that define the relationship between the involved actors. Strict liability assigns fault based primarily on the existence of a violation under the law. However, in strict liability automobile accident cases, the courts have often employed...
some kind of reasonableness standard that moves them more towards a negligence framework. As such, it is likely that the legal framework under which SDVs will operate will be one of negligence. The theory of negligence is constructed from five elements: 1) Duty of Care, 2) Breach of the Duty of Care, 3) Cause of Harm, 4) Physical Harm, and 5) Proximate Cause. For SDVs the main question under this framework appears to be who has the duty of care (responsibility) and what are the consequences of breaching that duty. Depending upon how these questions are answered by the courts or addressed by legislators, SDVs could take on a product liability bent where manufacturers are held liable or liability might be transferred to a corporate entity owning or providing SDVs for rent or to the operator or private owner at the time of the accident.

**Operator Responsibility**

These legal questions are sure to be influenced by the level of automation under consideration. For instance, in those where the driver remains substantially in control of the vehicle, it is less likely that the new legal precedent will be created. Current precedent may even apply to models in which the driver receives warnings and is expected to take over if the SDV system needs to disengage, although it is questionable whether a human “fail safe” can be reasonably expected. Full automation, however, creates the potential for operators who are not physically able to drive. In those cases responsibility, negligence, and liability may be less clear.

**Data and Privacy**

A lot of data is generated in our 21st century interconnected, internet-enabled, media- and information-rich lives. A key business and policy consideration worldwide concerns “big data” or very large data sets generated by the content and information shared by the use of technology in a broad range of industries. SDVs will likely generate a great deal of data on operators’ travel habits, including information on GPS location, speed, traffic, weather conditions, and road conditions, as well as information about other road users around the operator. How to protect or use that data is an open question being debated.

Important context on privacy within vehicles was set by the 1983 Supreme Court decision in the case United States v. Knotts. This case determined that those traveling on a public road have no reasonable expectation of privacy in their movement (United States v. Knotts, 1983). State laws may add privacy protection but these rules differ by state and therefore provide a patchwork of protection across the U.S. SDVs bring a new element in their ability to collect, act upon, and store much more data than was the case for vehicles in 1983. Questions of use of data have often focused on the ability of law enforcement to use new types of data and whether a warrant is required. Supreme Court cases in 2012 and 2013 have held that attaching a GPS tracking unit to a vehicle and searching a cell phone’s content require a warrant (U.S. v. Jones, 2012, and Riley v. California, 2014).

As policymakers consider how to include privacy protections for the data requirements of SDVs, they will need to weigh the costs of protection on manufacturers and business owners against the benefits to operators or individuals. Policymakers might consider avenues such as setting limits on secondary uses of SDV data or setting time limits for the retention of that data. Until policymakers act, industry means of privacy protection and information will be used. A possible model could be the provision of privacy policies with opt-in mechanisms or information for consumers on how data will be gathered and used.
Federal Regulation

As mentioned above, NHTSA issued a 2013 policy statement outlining its definition of SDVs and related technology, its thoughts on the implications for highway safety, and recommendations for state policymakers. NHTSA recommended that state policymakers only issue rules governing testing within their respective states. Considerations included in the policy statement are included below and broadly cover who should be considered a qualified operator, where vehicle testing should be permitted, and the essential features of a safe SDV.

1) Ensure that the driver understands how to operate a self-driving vehicle safely through a driver-licensing program.

2) Ensure that on-road testing of self-driving vehicles minimizes risks to other road users. This includes certifying that the vehicle has already operated for a certain number of miles in self-driving mode without incident prior to testing the vehicle on public roads.

3) Limit testing operations to roadway, traffic, and environmental conditions suitable for the capabilities of the test self-driving vehicles. We encourage states to consider appropriate limitations on the conditions in which a vehicle may be operated in self-driving mode.

4) Establish reporting requirements to monitor the performance of self-driving technology during testing.

5) Ensure that the process for transitioning from self-driving mode to driver control is safe, simple, and timely.

6) Ensure that test vehicles have the capability to detect, record, and inform the driver that the automated systems have malfunctioned.

7) Ensure that installation and operation of any self-driving vehicle technology does not disable any Federally required safety features or systems. Federal law prohibits making inoperative any Federally required safety system and the installation of self-driving technologies should not degrade the performance of any of those Federally required systems or the overall safety of the vehicle.

8) Ensure that self-driving vehicles record information about the status of the automated control technologies in the event of a crash or loss of vehicle control.

Additionally, NHTSA more recently issued a statement on the directions of its research and its focus in the vehicle automation field. In this action, NHTSA may have wished to focus on short-term safety objectives or it may have wished to leave manufacturers and developers to focus on SDV technology, or it may not consider SDVs viable enough at the present time to warrant its efforts. No matter the objective, time will tell if the correct determination was made in this policy decision.
**States Action**

Several state legislatures and the District of Columbia have taken action to address SDVs specifically in their statutes. Washington, D.C., and Nevada, California, Florida, and Michigan now allow the operation of SDVs within the state or district for testing purposes. As NHTSA recommended, these states are providing rules on who can operate these vehicles; rules that might include considerations on manufacturer size and insurance requirements.

California, the state where Google is based, is taking the most comprehensive approach in its SDV regulatory activities. In October 2012, California passed SB1298, which allowed the testing of SDVs on its highways. The law addressed how the state would define autonomous vehicles, set broad rules for testing, and instructed state agencies to write further rules related to testing and SDV operation beyond testing. The law requires a person, defined as an “operator,” be in the vehicle and ready to take over should the autonomous technology disengage. In California’s case, the Department of Motor Vehicles (DMV), rather than a transportation agency or safety agency, is the one writing regulations on testing SDVs in the state. The CA DMV can call on another agency with expertise, however. To complete this task the CA DMV has been holding several public hearings for comment as well as holding workshops with manufacturers, academics, and public advocates to inform their rulemaking. As of the beginning of 2014, CA DMV had issued proposed regulatory language on testing permits that would be required to test within the state. Rulemaking for activities beyond testing has not currently been addressed. However, given the size of California and its early lead in developing rulemaking it is presumed that its experiences will be a model for ongoing state action.

**Minnesota Perspectives**

**Legacy of Transportation Innovation**

Minnesota is known around the country for innovative transportation systems including its use of HOT lanes rather than toll highways. As it relates to SDVs, Minnesota DOT has partnered with University of Minnesota researchers to attach driver assist technology to snow plows to study the benefits to snow removal (ITS, 2013). How might Minnesota be able to carry that reputation to self-driving vehicles? Other states like California have looked to address self-driving vehicles in their rulemaking by codifying rules that specifically address the testing and operation of SDVs. One clear option is to regulate testing within the state as NHTSA has suggested. Additionally, here, we will take a look at current Minnesota statutes that may need to be modified or changed to address SDVs. Our brainstorming also extended to local and agency activities and the unique conditions in Minnesota. For instance, the presence of snow and inclement weather conditions in Minnesota present a challenge to self-driving technology. Google has noted that their self-driving prototypes have trouble interpreting data in a number of road conditions, one of which is snow-covered roads (Official Google Blog, 2012). SDVs operating in the state would likely have to address this issue for year-round, fully autonomous operation. Limited use during inclement weather could be an option much in the way that motorcycles are not typically in use during winter months, but limiting use during bad weather would reduce scope and impact of potential safety benefits noted earlier. This issue could be addressed by future innovations of manufacturers. If Minnesota were to adopt statutes addressing testing within the state, it is possible that it could become a testing ground for innovations that seek to address inclement weather issues with SDVs.
Existing MN Statutes

An initial examination of Minnesota driving rules indicates that they will likely need to be modified to accommodate the operation of self-driving vehicles. MN driving rules are in statute in section MN 169.18. It is clear that these statutes were created with the expectation and assumption of a human driver present at all times. As an example Chapter 169, Section 011, Subdivision 24 states:

"Driver" means every person who drives or is in actual physical control of a vehicle.

Section 13 of the same chapter goes on to define reckless and careless driving that includes “a person driving a vehicle with disregard for the safety and rights of others.” Whether this chapter would need to be modified or new sections added to address SDVs is a decision for policy officials, however some determinations would likely need to be made for SDVs to be covered under these statutes.

Another key provision for SDVs is legal liability in the same section of MN law. First, in the same chapter, rules for liability for damage to highway and highway structures are addressed. An excerpt is included below as another example of rules that assume a single driver or owner that may need to be modified to address SDVs.

MN Statute 169.88 DAMAGEs; LIABILITY

(b) When such driver is not the owner of such vehicle, object, or contrivance, but is so operating, driving, or moving the same with the express or implied permission of the owner, then the owner and driver shall be jointly and severally liable for any such damage.

(c) Any person who by willful acts or failure to exercise due care, damages any road, street, or highway or highway structure shall be liable for the amount thereof.

(d) Damages under this section may be recovered in a civil action brought by the authorities in control of such highway or highway structure.

MN is a no-fault insurance state. Enacted into law to mitigate the economic effects of automobile accidents and speed up claims processing, the section starting at 65B.41 was passed in 1974. This statute allows for compensation of damages in automobile accidents by the insured insurance company regardless of fault. The presence of this statute certainly might make the resolution of claims involving SDVs less complex as the insurance market may price premiums based on the relative risk of SDVs (and other vehicles on the road) and insureds would receive compensation from their own insurer. However, two restrictions are worth noting that may affect SDVs. Insurers typically cap claims at some level within an insurance policy. In this case, above the cap, fault determination would matter. Additionally, the no-fault statute only extends to bodily injury and does not include property damage. In this case fault determination would also matter. With that in mind, rules governing who has or shares fault in the case of SDVs (manufacturer, operators or owner) will be essential in adjudicating these cases.

Other Policymaking

Other policy areas that might be need to be addressed for SDVs include environmental regulations, transportation planning and zoning. Minnesota does not currently have emissions rules for vehicles on its roadways so there are no implications for SDVs on that front. Minnesota has set clean energy goals in the past to encourage the development and use of energy sources
that are more renewable. To the extent that SDVs allow more effective use of fossil fuels, they could contribute to this goal.

Transportation planning and management are a key policy area related to SDVs and many of the benefits of this technology accrue in this area. State statutes governing the Minnesota Department of Transportation (MnDOT), MN Chapter 174, cite goals that may align with the benefits of SDVs use such as minimizing fatalities and injuries, providing a reasonable travel time for commuters, maintaining infrastructure in good repair, promoting the use of low-emission vehicles, and reducing greenhouse gas emissions. Therefore, embracing SDVs may help MnDOT to reach these goals. Additionally, planning for the development of SDV technology may be necessary. Currently MnDOT plans highway improvements and investments as much as 20-50 years ahead. These planning efforts certainly cover the period in which we expect SDVs to be more widely adopted. Planning for the impact of these vehicles on increased capacity, at least initially, could allow MnDOT to more accurately predict transportation needs in the upcoming decades.

Lastly, one key implication noted earlier was in the use of land in urban areas. SDVs could eventually free up parking areas for alternate investment and development. Local governments should be ready to recapture these spaces for economic and social benefit. Certainly cities and counties in Minnesota have already shown their willingness to let transit influence how their new construction and development decisions are made in a “transit-oriented” design process. These considerations can be applied in the SDV context as well to ensure that needed infrastructure is available for their use (Hennepin County, 2014).

SDVs could have diverse impacts on more than just driving rules and statutes. As the technology is refined, testing becomes more widespread, and models become available for consumer use, policymakers will need modify or enact rules to address and influence these broad implications.
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